Athletic Clubeko jokalarien lesioak:
hazkundea eta heltzea arrisku faktore potentzial gisa

Injuries in Athletic Club players:
growth and maturation as potential risk factors

Doktorego tesia / PhD Thesis

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MEDIKUNTZA ETA ERIZAINTZA FAKULTATEA

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ESKER ONAK

Orain dela lau urte hasitako bidea bukatzear da, eta lau urte hauetan laguntza eskaini didazuen guztioi eskerrak ematea gustatuko litzaidake. Aldez aurretik barkamena eskatzea gustatuko litzaidake norbait aipatzea ahazten baldin badut.

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Lan honen irakurketa hasi aurretik, tesiaren egitura orokorra eta honen zergatia azaldu beharra dago.

Batetik, Bath-eko Unibertsitatean egindako egonaldiak, "Nazioarteko Doktorea" aipamena lortzeko bidea zabaldu zuen. Nazioarteko tesia egiteko baldintzak bete nahian, tesi honetako zenbait atal ingelesez idatzi ziren. Hurrengoak dira tesiaren atal nagusiak eta atal hauek idazteko erabili zen hizkuntza: Laburpena/*abstract* (euskaraz eta ingelesez), sarrera (euskaraz), helburuak (euskaraz), metodologia orokorra (euskaraz), emaitzak eta eztabaida (ingelesez), eztabaida orokorra eta aplikazio praktikoa (euskaraz), ondorioak (euskaraz eta ingelesez), erreferentziak (euskaraz) eta beste argitalpenak (euskaraz).

Bestetik, artikuluen bildumaren bidez egindako tesia izanda, tesia ikerketa artikuluz osatua dago. Artikulu hauetatik hiru Journal Citation Reports (JCR) datu baseen Sports Science ataleko zerrendetan lehenengo eta bigarren kuartiletan (Q1-Q2) argitaratuta daude eta gainerakoak azterketa prozesuan daude Q1 eta Q2-n dauden aldizkarietan. Tesi honetako ikerlan bakoitzak bere sarrera laburra, erabilitako metodologia zehatza, emaitzak eta eztabaida ditu, eta tesiaren "Emaitzak eta eztabaida" atalean ageri dira.

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LABURPENA

Sarrera: Lesioek harrobietako jokalarien progresioa eteten dute. Lesio horien inpaktua murrizteko, jokalarien disponibilitatean eragin handiena duten lesioak eta hauen arrisku-faktoreak identifikatzea ezinbestekoa da. Nerabe kirolarietan hazkundea eta heltzea lesioen arrisku-faktore ez-aldagarritzat hartzen dira. Hala ere, gai honen inguruan argitaratutako ikerketek lortutako emaitzak kontraesankorrak dira kasu askotan, muga metodologiko asko dituzte eta.

Helburua: Athletic Clubeko taldeen epidemiologia deskribatzea, hazkundea eta heltzea arrisku-faktoretzat aztertzea eta heltze-egoera estimatzeko metodoak konparatzea.

Metodologia: Tesi honetan biltzen diren ikerketa guztiak 1997-2022 denboraldietan Athletic Clubeko jokalarietan periodikoki jasotako datuetan (lesioak, antropometria eta hezur-adina) oinarritu ziren. Lesioen sailkapena Asoziazio Futbolaren Nazioarteko Federazioak (FIFA) emandako argibideetan eta klubeko medikuen esperientzian oinarritu zen, eta hazkunde-lesioak kategoria gehigarri bezala erregistratu ziren. 2011-2012 denboralditik aurrera jokalarien esposizio indibiduala jaso eta talde eta lesio-mota bakoitzaren intzidentzia (lesio kopurua/1000 h) eta *burden*a (baja egunak/1000 h) deskribatu ziren (*I. ikerlana*). Bestalde, 14 urtez azpiko (U14) kategorian egindako eskumuturreko erradiografiaren arabera jokalariak goiztiar, normal edo berantiar bezala sailkatu (hezurraren heltze-egoera erlatiboaren arabera) eta hiru taldeen *injury burden*a konparatu zen (*II. ikerlana*). Altueraren jarraipen longitudinalaz baliatuz, jokalari bakoitzaren *peak height velocity*a (PHV), PHV adina, helduaroko altuera eta hazkunde-abiadura kalkulatu ziren. Aldagai hauek kontuan izanda jokalariak heltze-egoeraren (*pre-*, *circa-*, *post-*PHV edo helduak), heltze-*timing*aren (goiztiarra, normala edo berantiarra) eta hazkunde-abiaduraren (bizkorra, normala, geldoa) arabera sailkatu ziren. Gainera, aipatutako aldagaiek lesioengan duten inpaktua aztertu zen (*III-VI ikerlanak*). Amaitzeko, altueraren jarraipen longitudinalaren bidez egindako heltze-egoeraren (*pre-*, *circa-*, *post-*PHV) sailkapena estimazio metodo ezberdinen bidez lortutako sailkapenarekin konparatu zen [osatu gabeko hazkunde-kurben ebaluazio bisuala, *maturity offset* ekuazioak, iragarritako helduaroko altueraren ehunekoa (PAH%)] (*VII. ikerlana*).

Emaitzak: Belauneko lotailuetako/giltzaduretako lesioek *burden* handia izan zuten emakumezkoen taldeetan. Gizonezkoen U15 taldean eta gazteagoetan, inpaktu

gehieneko lesioak hazkunde-lesioak izan ziren, *burden* handiena U14 kategorian izanik (*I. ikerlana*). U14 kategorian, jokalari goiztiarren *injury burden* orokorra 2,8 bider handiagoa izan zen berantiarrekin konparatuta. Bestalde, giharretako lesioen *burden*a 4 bider handiagoa izan zen goiztiarretan normal eta berantiarretan baino. Giltzadura/lotailuetako lesioen *burden*a, ordea, 7 eta 12 aldiz txikiagoa izan zen berantiarretan goiztiar eta normalekin konparatuta. Hazkunde-lesioek inpaktu handia izan zuten goiztiar, normal eta berantiarretan, baina hiru taldeen artean ez zen ezberdintasun adierazgarririk aurkitu (*II. ikerlana*). Lesio-mota espezifikoen inpaktua heltze-egoeraren arabera aldakorra izan zen; hazkunde-lesioek inpaktu handiagoa izan zuten *circa*-PHVn, eta giharretako eta giltzadura/lotailuetako lesioek, aldiz, *post*-PHVn eta helduetan (*III-VI. ikerlanak*). Hazkunde-lesioak *pre*-, *circa*- eta *post*-PHV periodoetan eman ziren. Hala ere, *pre*-PHVn lesio distalek (adibidez, Sever gaixotasunak) inpaktu handiagoa izan zuten; *post*-PHVn, ostera, lesio proximalek (adibidez, espondilolisiak) *(III-VI. ikerlanak*). Heltze-*timing*ari dagokionez, *pre*-PHVn zeuden jokalari berantiarretan hazkunde-lesio eta giltzadura/lotailuetako lesioen *burden*a txikiagoa izan zen heltze-*timing* normala zutenekin konparatuta. Bestalde, heldu berantiarretan *burden* orokorra eta giltzadura/lotailuetako lesioetako *burden*a handiagoa izan zen goiztiarrekin konparatuta (*IV. ikerlana*). Oro har, hazkunde-abiadura bizkorra zuten jokalariek hazkunde-lesioak izateko aukera gehiago izan zituzten *pre*-, *circa*- eta *post*-PHV periodoetan (*VI. ikerlana*). Bestetik, PHV bizkorra zuten jokalariek hazkunde-lesioen *injury burden* handiagoa izan zuten *circa*-PHVn. Heltze-egoera estimatzeko metodoei dagokionez, hazkunde-kurben ebaluazio bisuala metodorik egokiena izan zen. Bigarren aukera PAH% bidez egindako sailkapena izango litzateke, izan ere, *maturity offset* ekuazioek jokalarien erdia edo herena txarto sailkatu zituzten (*VII. ikerlana*).

Ondorioak: Lesio-mota bakoitzaren inpaktua jokalarien kategoriaren eta generoaren arabera aldatzen da. Hazkunde-lesioek baja egun asko eragiten dituzte U13, U14 eta U15 kategorietan, beraz, lesio hauen agerpenean eragina izan dezaketen arrisku-faktoreak identifikatzea beharrezkoa da. Bestetik, hazkundea, heltze-egoera eta heltze-*timing*a arrisku-faktore moduan identifikatu zituen tesi honek. Hortaz, lesioak murrizteko esku-hartzeetan kontuan hartu beharreko aldagaiak direla ondorioztatu da. Bestalde, jokalariak heltze-egoeraren arabera sailkatzeko metodorik egokiena hazkunde-kurben ebaluazio bisuala zela adierazi zuten emaitzek.

ABSTRACT

Introduction: Injuries interrupt the development of elite youth academy football players. To reduce the impact of injuries, it is necessary to detect the injuries that affect participation the most and which the risk factors are. Growth and maturation represent two potential non-modifiable intrinsic risk factors that are unique to adolescent players. However, findings in earlier studies are sometimes inconsistent and contradictory due to the methodological limitations in the literature published.

Aim: To describe the epidemiology of the teams in Athletic Club, to explore growth and maturation as risk factors in academy male players and to compare methods to estimate maturity status.

Methodology: All studies were based on injury, anthropometric and skeletal age data from routine monitoring of players at Athletic Club (1997-2022). Injury classification was based on the consensus of the International Federation of Association Football (FIFA) and practitioner's experience. Besides, an additional category for growth-related injuries was included. Individual exposure was recorded since 2011-2012 season, which allowed to study injury incidence (number of injuries/1000h) and injury burden (number of days lost/1000h) for each injury in each category (*Paper I*). Further, hand-wrist x-rays allowed to compare injury burden in U14 players according to their relative skeletal maturity status (early, on-time, late maturer) (*Paper II*). Longitudinal height data allowed to calculate peak height velocity (PHV), age at PHV, adult stature and growth-rated for each player. These metrics were used to classify players according to their maturity status (pre-, circa- and post-PHV), timing (early, on-time, late) and growth-rate (fast, average, slow) and study the effect of these variables on injury-risk (*Papers III-VI*). Besides, maturity status assessment based on longitudinal height recording was compared to classification by different estimation methods [visual assessment of incomplete growth curves, maturity offset equations, percentage of predicted adult height (PAH%)] (*Paper VII*).

Results: Knee/joint ligament injuries were especially burdensome in women's teams. Growth-related injuries were the most impactful injuries in men's U15 and younger, with the highest injury burden in U14 age-group (*Paper I*). In this category, overall injury burden was 2.8-times higher in early maturers compared with late maturers. Muscle injuries were 4-times more burdensome in early maturers compared with on-time and late maturers. Besides, joint/ligament injuries were 7- and 12- times less burdensome in late maturers than in on-time and late maturers, respectively. Growth-related injuries were the most burdensome injuries in all three groups, but significant differences were not found between groups (*Paper II*). The occurrence and impact of specific injuries varies according to maturity status; growth-related injuries had a higher impact in circa-PHV, while muscle and joint/ligament injuries were more common in post-PHV and specially, adult players (*Papers III-VI*). Growth-related injuries occurred in all pre-, circa- and post-PHV periods, but specific injuries followed the distal to proximal pattern: distal injuries (e.g., Sever's disease) peaked in pre-PHV, while proximal injuries (e.g., spondylolysis) peaked in post-PHV (*Papers III-VI*). Concerning to maturity timing, in PHV period, growth-related and knee joint/ligament injuries had lower burden in late maturers than on-time maturers. Adult late maturers had greater burden of overall and joint/ligament injuries than early maturers (*Paper IV*). Overall, players with more rapid growth-rates were at higher risk for growth-related injuries in all pre-, circa- and post-PHV periods (*Paper VI*). Further, players with a fast PHV have a higher growth-related injury burden in circa-PHV (*Paper VI*). Regarding methods to classify players as pre-, circa- or post-PHV, visual assessment of the individual growth curves by an experienced assessor provided the most accurate estimates. Maturity offset prediction equations misclassified most players, while PAH% provided a reasonably valid alternative (*Paper VII*).

Conclusions: Based on our findings, injuries patterns in elite academy football players differ according to age-group and genre. Growth-related injuries cause a large proportion of lost training and competition days in the youngest age-groups (U15 and younger); thus, a better understanding of risk factors affecting those injuries seems vital. This thesis identified risk factors related to maturity status, timing, and growth-rate, which should be monitored to design targeted injury reduction programmes. In this context, visual assessment of the individual growth curves by an experienced assessor provides the most accurate estimates to classify players as pre-, circa- or post-PHV, highlighting the importance of longitudinal recording of growth.

LABURDURAK

ACL: Aurreko lotailu gurutzatua/Anterior cruciate ligament

AIIS: Aurreko beheko arantza iliakoa /Anterior inferior iliac spine

ASIS: Aurreko goiko arantza iliakoa/Anterior superior iliac Spine

APHV: Altueraren hazkunde-abiadura gorenaren adina/Age at peak height velocity

CA: Adin kronologikoa/Chronological age

CEISH: Gizakiekin lotutako Ikerketetarako Etika Batzordea/Human Research Ethics Committee

CI: Konfidantza-tartea/Confidence interval

FIFA: Asoziazio Futbolaren Nazioarteko Federazioa/InternationalFederation of Association Football

GLMM: Generalized linear mixed-effects models

IOC: Nazioarteko Olinpiar Batzordea/ International Olympic Committee

IQR: Kuartil arteko tartea/ Interquartile range

ISAK: International Society for the Advancement of Kinanthropometry

KR: Khamis-Roche

LCAL: Alboko lotailu kolaterala/Lateral collateral ligament

PAH%: Iragarritako helduaroko altueraren ehunekoa/Percentage of predicted adult height

PHV: Altueraren hazkunde-abiadura gorena/Peak height velocity

RR: Rate ratio

SA: Hezur-adina/Skeletal age

SITAR: Super-Imposition by Translation and Rotation

SD: Desbideratze estandarra/Standard deviation

TW-2RUS: Tanner-Whitehouse-2 (radius, ulna, short bones)

U(XX): XX urtez azpiko kategoria/Under XX category

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1. SARRERA

1. SARRERA

Athletic Club Bilbon jolasten duen futbol klub profesional euskaldun bat da. Berezitasun modura, klubaren filosofia dela eta, harrobian garatutako edo euskaldunak diren jokalariek bakarrik jokatzen dute gizonezkoen eta emakumezkoen lehen taldeetan. Hori dela eta, harrobiak garrantzia handia du Athletic Cluben, eta munduko onenen artean dago Lezamako harrobia.

Lehenengo talderako jokalariak trebatu nahian, 11 urtetik aurrerako taldeak ditu Athletic Clubek: Bilbao Athletic (Bigarren B Maila), Basconia (Hirugarren maila), emakumezkoen B taldea (Bigarren maila), emakumezkoen C taldea, gazteen bi talde [19 eta 17 urtez azpiko taldeak (U19 eta U17)], hiru kadete talde (gizonezkoen U16 eta U15 emakumezkoen U16 taldea), hiru haurrenak (gizonezkoen U14 eta U13 taldeak eta emakumezkoen U14 taldea) eta bi kimu talde (gizonezkoen U12 eta U11 taldeak). Horiek dira Athleticen oinarria osatzen duten taldeak eta bertan prestatzen eta sortzen dira talde profesionaletara igarotzen diren futbol jokalariak. Ume eta nerabeak gazte-gaztetatik entrenatzen dira Lezaman, izan ere, entrenamenduak eta partidak goi-mailako futbolariak garatzeko ezinbestekoak dira.

Hala ere, entrenamenduak ere alde negatiboak izan ditzake, hala nola estresa, lesioak edota epe luzerako osasun-arazoak (1). Hau kontuan hartuta, kirolari osasuntsuak garatzea da Athletic Clubeko zerbitzu medikoen helburu nagusia (2). Izan ere, osasuna kaltetzeaz gain, lesioek jokalarien parte-hartzea, Lezaman jarraitzeko aukerak (3) eta errendimendua mugatzen dute.

Jokalari osasuntsuak garatzeko lehen urratsa jokalarietan inpaktu gehien duten lesioak ezagutzea, hau da, harrobiko jokalarien lesioen epidemiologia deskribatzea eta ulertzea da. Behin lesioak identifikatuta, inpaktu handieneko lesioen agerpena baldintzatzen duten arrisku-faktoreak identifikatzea izango litzateke hurrengo pausua. Horrela, arrisku-faktoreak identifikatuta izateak lesioen inpaktua murrizteko esku-hartzeak diseinatzea eta gauzatzea ahalbidetuko luke. Hain zuzen ere, doktorego-tesi honetan prozesu honen lehenengo bi pausuak landuko dira; izan ere, Athletic Clubeko harrobiko taldeen lesioak deskribatu (*I. ikerlana*) eta hazkundearekin eta heltzearekin harremana duten arrisku-faktoreak aztertuko dira (*II-VI. ikerlanak*). Gainera, lesioak prebenitzeko esku-hartzeak aurrera eraman ahal izateko heltzea estimatzeko metodoak aztertuko dira (*VII. ikerlana*).

1.1 FUTBOLARI GAZTEEN LESIOEN EPIDEMIOLOGIA

Orain dela gutxi argitaratutako metaanalisi baten arabera (4), lesioak oso ohikoak dira futbolari gazteetan. Gizonezkoetan intzidentzia (lesioen maiztasuna) 5,70 lesio/1000 h-koa da. Emakumezkoek, ordea, 6,77 lesio izaten dituzte 1000 h-ko. Kokapenari dagokionez, beheko gorputz-adarrean gertatzen dira lesio gehienak, bai gizonezkoetan eta bai emakumezkoetan ere. Hala ere, gizonezkoetan ohikoagoak dira giharretako eta tendoietako lesioak eta emakumezkoetan, ostera, giltzadura/lotailuetako lesioak. Dena dela, orain arte egindako ikerketa gehienak futbolari helduetan egindakoak dira eta gutxi dira gazte eta umeetan egindako ikerketak, batez ere emakumezkoetan.

Lesioen intzidentzia aztertzeaz gain, *injury burden*a aztertzea ezinbestekoa da futboleko lesioen epidemiologian (5). Haatik, *injury burden*a aztertu duten ikerketak gutxi dira eta are gutxiago emakumezko futbolariei buruz egindakoak (4). *Injury burden*ak lesioek eragindako baja-egunak aztertzen ditu (baja-egunak/1000 h) eta lesioek jokalarietan/taldean duten inpaktua adierazteko aldagairik egokiena da. Lesio batek eragindako *burden*a, lesio horren intzidentziaren (maiztasuna) eta larritasunaren (lesio bakoitzak batez beste eragindako baja-egunak) araberakoa da. Intzidentzia handiko eta larritasun txiki/ertaineko lesioek (adibidez, muskulu iskiotibialen lesioek) edota intzidentzia txikiko baina larritasun handiko lesioek (adibidez, belauneko aurreko lotailu gurutzatuaren lesioak) baja egun asko (*burden* handia) eragin dezakete. Bajan luze egoteak jokalarien parte-hartzea eta harrobian jarraitzeko aukerak murriztu (3) eta arazo psikologikoak (6) eragin ditzake, besteak beste. Beraz, *injury burden* handiena duten lesioak identifikatzea behar-beharrezkoa da futbol harrobietan inpaktu handiena duten lesioak ezagutzeko.

Bestalde, kategoriaren arabera lesioak aldatzen dira. Futbol-kategoriak jaiotze-urtearen arabera antolatzen dira (adibidez, 14 urtez azpiko kategoria edo U14), eta kategoria bakoitzean lesio ezberdinak gertatzen direla erakutsi dute hainbat ikerketek (7,8). Hala, muskuluetako eta giltzadura/lotailuetako lesioen intzidentzia eta *burden*a handiagoa da jokalari helduetan (17-19 urtez azpiko gizonezkoen kategorietan); nerabezaro inguruko kategorietan (13-15 urtez azpiko gizonezkoen kategorietan), aldiz, hazkunde-lesioak (adibidez, osteokondrosiak, apofisien abultsioak edota epifisiolisiak) dira nagusi (9). Lesio hauen inpaktua handia den arren (7,8,10,11), orain arte egindako ikerketa gehienek ez dituzte hazkunde-lesioak modu zehatzean jaso. Izan ere, 2006an Asoziazio Futbolaren Nazioarteko Federazioak (FIFA) (12) ez zuen eman lesio hauek sailkatzeko eta erregistratzeko argibiderik.

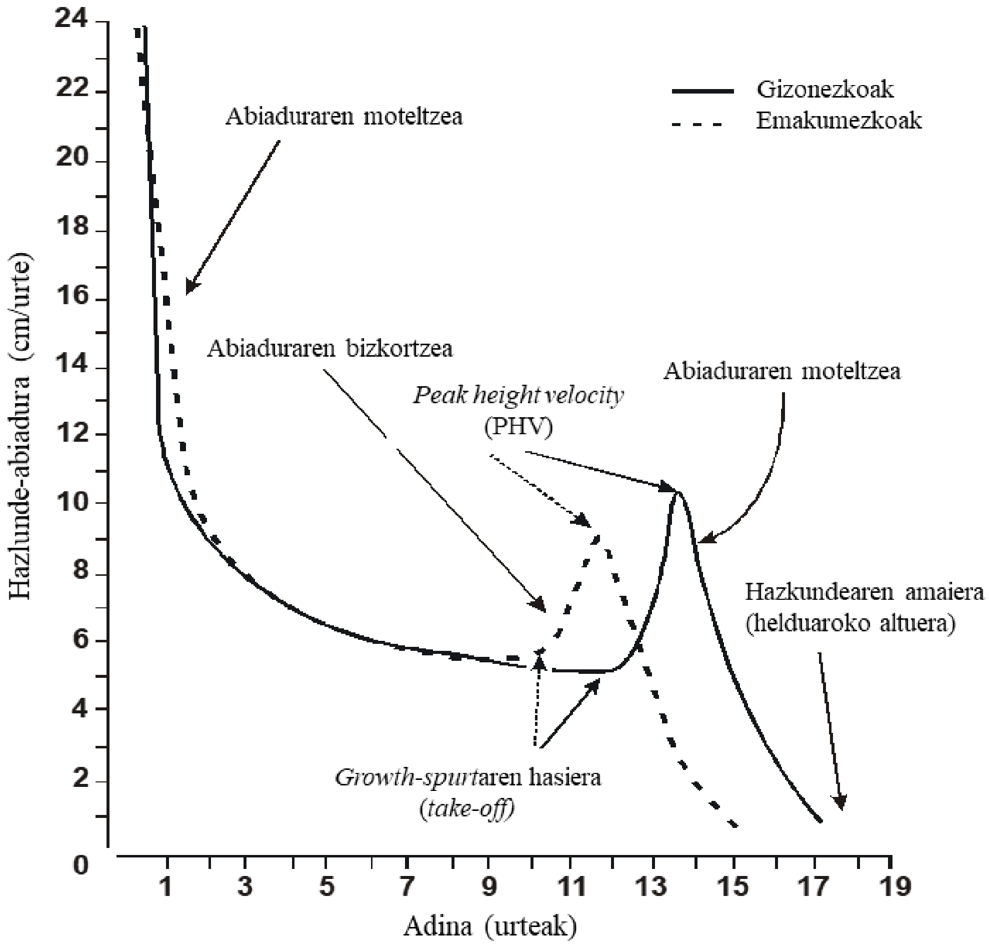
1.2 HAZKUNDEA, HELTZEA ETA LESIOAK FUTBOLEAN

1.2.1 Hazkundea

Hazkunde-prozesua gorputzeko dimentsioen handitzean datza, eta, eskuarki, aldagai antropometrikoen bidez neurtzen da, hala nola altuera, pisua edo gorputzeko segmentuen luzera (hanken luzera, enborraren altuera edo beso-zabalera) neurtuz (13). Hazkunde-abiadurak, ordea, aldagai horien aldaketa aztertzen du denbora tarte konkretu batean; esate baterako, altueraren aldaketa zentimetrotan urte batean (cm/urte).

1.1 Irudiko hazkunde-kurbetan jaiotzen garen unetik helduak izan arte hazkunde-abiadura zelan aldatzen den azter daiteke. Bizitzako lehen urteetan oso bizkorra izan ohi da hazkunde-abiadura eta apurka-apurka moteltzen doa haurtzaroan zehar. Ondoren, nerabezaroan, *growth-spurt* deritzon fenomenoa gertatzen da, zeinean hazkunde-abiadura bizkortzen den (13). *Growth-spurt*aren hasiera (*take-off* deritzona) 8-10 urte bitartean gertatzen da emakumezkoetan. Gizonezkoetan, ostera, geroago gertatzen da, 10-12 urte bitartean. Abiaduraren bizkortze horren ostean, altueraren hazkunde-abiadura gorena edo *peak height velocity*a (PHV) gertatzen da, hau da, hazkunde-abiadura bizkorreneko momentua. Oro har, 11-12 eta 13-14 urte bitartean gertatzen da emakumezkoetan eta gizonezkoetan, hurrenez hurren. Bestalde, PHVa bizkorragoa izaten da gizonezkoetan (8-10 cm/urtean) emakumezkoen aldean (7-9 cm/urtean). PHVaren ostean, hazkunde-abiadura moteldu ohi da helduaroko altuera lortu arte. Oro har, helduaroko altuera 16 urterekin lortzen da emakumezkoetan eta 18rekin gizonezkoetan; hala ere, pertsona batzuek 20-21 urtera arte hazten jarraitzen dute (13).

Bestalde, bitxia bada ere, hazkundea ez da gorputzeko atal edota segmentu guztietan aldi berean agertzen. Gorputz-hazkundea beheko gorputz-adarretako alde distaletatik hasi ohi da; ondoren, goiko gorputz-adarretatik jarraitzen du eta, azkenik, enborra hazten da. Ondorioz, beheko gorputz-adarren PHVa enborrarena baino lehenago gertatzen da (13).



1.1 Irudia: Hazkunde-abiaduraren progresioa adinaren arabera eta hazkunde-prozesuaren faseak (13).

1.2.2 Heltzea

Heltzea eta hazkundea lotuta dauden arren, heltzea hazkundea baino kontzeptu konplexuagoa da. Izan ere, heltzea, heldua izan arte gertatzen den trantsizio-prozesua deskribatzen duen terminoa dela esan daiteke (13). Heltzea hiru kontzepturen arabera azter daiteke: heltze-egoera, heltze-*timing*a eta heltze-erritmoa.

Heltze-egoerak momentu edo adin jakin batean norbanakoa heltze-prozesuaren zein momentutan edo fasetan dagoen aztertzen du. Hau da, heldu bilakatzeko “bidean” zein mailatan dagoen. Modu absolutuan edo erlatiboan neurtu daiteke heltze-egoera. Batetik, heltze-egoera absolutuak neurketa egiten den momentuan (adibidez, 13 urterekin) jokalariak duen heltze-maila absolutua edo zenbatekoa aztertuko luke (adibidez, 14 urteko hezur-adina). Bestetik, heltze-egoera erlatiboak neurketa egiten den momentuan (adibidez, 13 urterekin) jokalariak erreferentziazko datu batekin konparatuta duen heltze-maila aztertzen du. Adibidez, 13 urterekin 14 urteko hezur-adina badu (heltze-egoera absolutua), hezur-adina adin kronologikoa baino urte bete aurreratuagoa egongo litzateke, hau da, heltze-egoera erlatiboa +1 izango litzateke.

Heltze-*timing*ak, ostera, heltze-gertakari espezifikoak (adibidez, menarkia edota PHVa) zein adinetan (noiz) gertatzen diren aztertzen du. Ondoren, erreferentziazko balioekin konparatu (adibidez, menarkiaren bataz besteko adin kronologikoa) eta norbanakoak goiztiar (normala baino arinago), normal edo berantiar (normala baino beranduago) bezala sailkatzen ditu.

Hirugarrenik, heltze-erritmoak heltzearen progresioaren abiadura aztertzen du. Esate baterako, urte betean eman den hezur-adinaren aldaketa.

Hiru kontzeptu hauek hiru sistematan azter daitezke: sistema sexualan (karaktere sexualen garapena aztertzen duena), hezur-sisteman (hezurren garapena aztertzen duena) eta sistema somatikoan (gorputzaren eta aldagai antropometrikoen garapena aztertzen duena) (13). Hurrengo ataletan sistema bakoitzean heltze-egoera, heltze-*timing*a eta heltze-erritmoa aztertzeko argibideak emango dira.

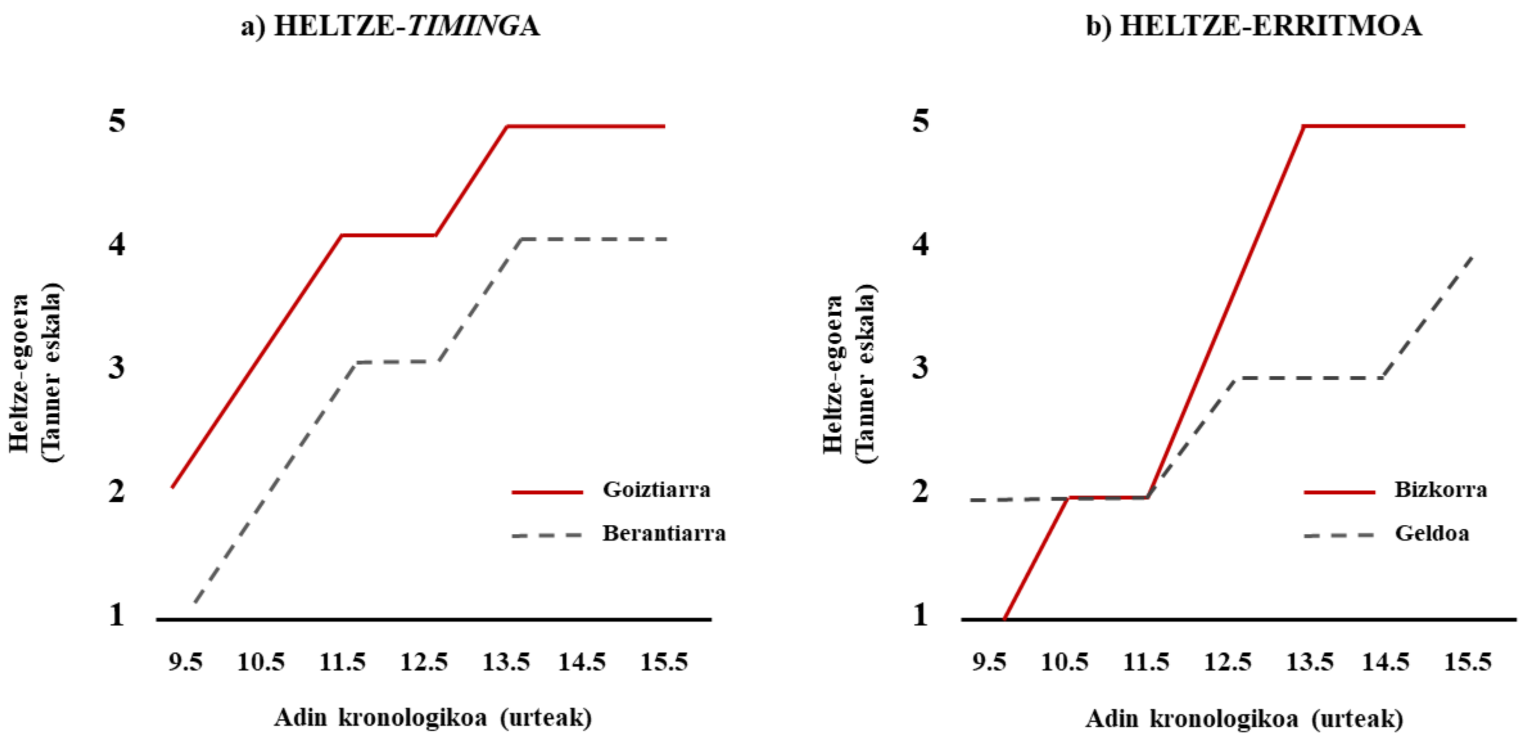
1.2.2.1 Heltze sexuala

Karaktere sexual sekundarioen garapena, hala nola, bularren, zakilaren eta testikuluen garapena edota menarkiaren (lehenengo hilerokoaren) eta espermakiaren (lehenengo eiakulazioaren) gertaera, aztertzen ditu heltze sexualak (13).

Heltze-egoera sexuala aztertzeko modurik erabiliena Tanner sailkapena erabiltzea da (13). Sailkapen honek gizonezkoen eta emakumezkoaren karaktere sexual sekundarioen garapen-maila 5 mailatan bereizten ditu (1.2 Irudia). Era berean, heltze-egoera sexuala aztertzeko bigarren aukera bat menarkia edota espermarkiaren gertaera eman den (*post*-menarkia/espermakia) edo ez (*pre*-menarkia/espermakia) aztertzea izango litzateke (13).

Aldiz, heltze-*timing* sexualak Tanner estadio edo fase bakoitza, menarkia edo espermakia zein adinetan gertatu den aztertzen du (1.2 Irudia). Horrek populazio orokorraren bataz besteko adinarekin konparatzea eta gizabanakoak goiztiar, normal edo berantiar bezala sailkatzea baimenduko luke (13).

Heltze-erritmo sexuala aztertzeko, ordea, gizabanako batek Tanner eskalaren estadio batetik bestera igarotzeko beharrezko denbora aztertuko genuke; hau da, karaktere sexualen garapena bizkorra edo geldoa izan den (1.2 Irudia) (13).



1.2 Irudia: Lau jokalariren karaktere sexual sekundarioen garapena Tanner eskalaren arabera (13).

(a) Heltze-*timing* goiztiarra *vs*. berantiarra.

(b) Heltze-erritmo bizkorra *vs*. geldoa.

1.2.2.2 Hezur-heltzea

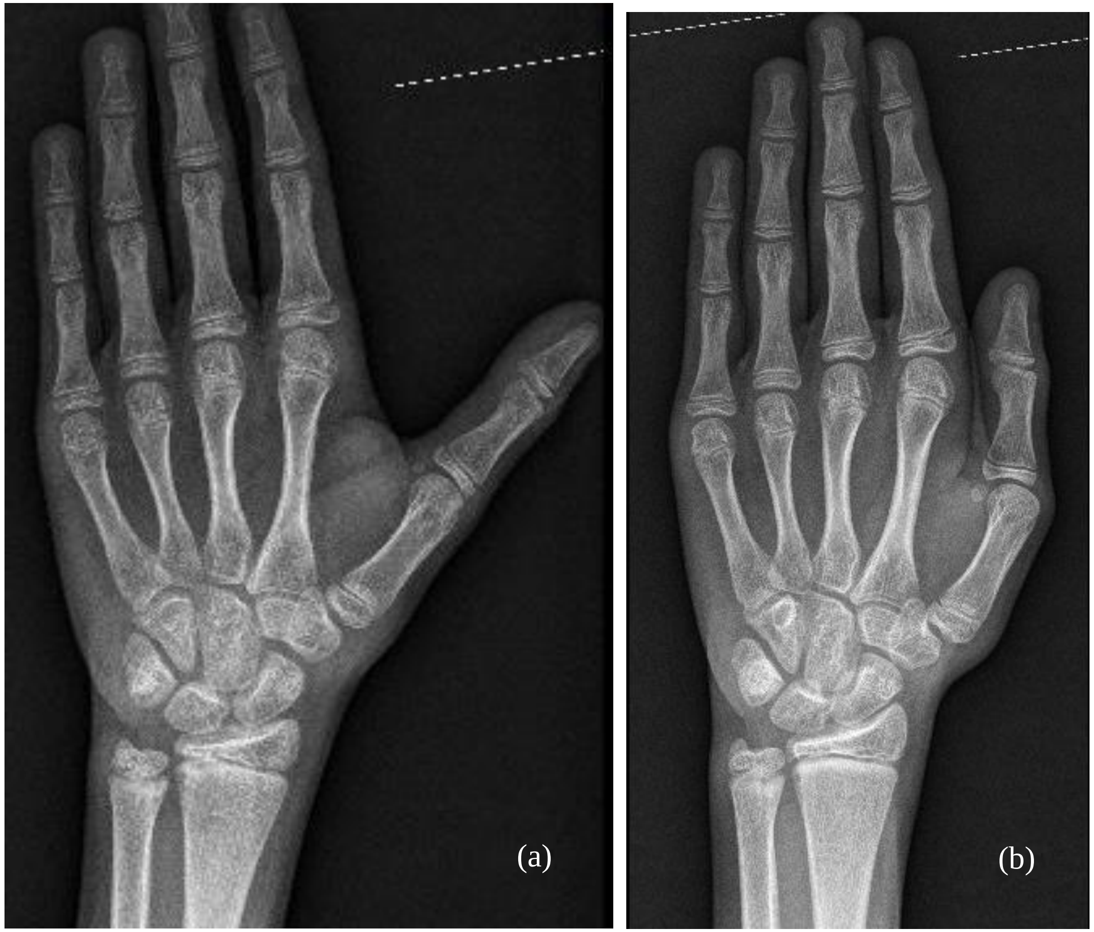
Heltze sexualaren balorazioak intimitatearen kontrako erasotzat har daitekeela kontuan hartuta, kirol munduan heltzea aztertzeko *gold-standard*a, alegia, metodo gomendagarriena, hezurraren heltzea aztertzea da. Fidagarritasun handiko metodoa den arren, alde txarrak ere baditu hezur-heltzea aztertzeak; hala nola, irradiazioa sortzen duen eskumutur eta eskuko erradiografia egin behar izatea, irudiak ebaluatzen aditua den aztertzaile baten beharra eta irudia bera aztertzeko beharrezkoa den denbora (13). Hori dela eta, eliteko futbol harrobi gutxi batzuetan erabiltzen da metodo hau.

Hezurraren heltze-egoera aztertzerakoan, heltze egoera absolutua (hezur adina urteetan) eta erlatiboa (hezur adina eta adin kronologikoaren arteko ezberdintasuna) azter daitezke. Hezur adinaren eta adin kronologikoaren arteko ezberdintasunaren arabera, jokalariak goiztiar (hezur adina adin kronologikoa baino handiagoa denean), normal (antzekoa denean) edo berantiar (hezur adina adin kronologikoa baino txikiagoa denean) bezala sailkatu daitezke. Sailkapen hori egiterako orduan banda edo tarte ezberdinak erabiltzen dira: ± 0,5 urteko desberdintasuna (goiztiarra >0,5 urte; normala 0,5 eta -0,5 urte bitartean; berantiarra <-0,5 urte) edo ± 1 urteko desberdintasuna (goiztiarra >1 urte; normala 1 eta -1 urte bitartean; berantiarra <-1 urte) (1.3 Irudia) (14)

Hezurraren heltze-*timing*ak, ordea, hezur-adin jakin bat (adibidez, 14 urte) zein adin kronologikorekin lortzen den aztertuko luke. Hala ere, hezurraren heltze-*timing*a ez da bat ere erabilia kirol munduan. Azkenik, hezurraren heltze-erritmoa aztertzeko, hezur adinaren aldaketa aztertuko genuke denbora tarte batean (adibidez, U14 denboraldi-aurretik U15 denboraldi-aurrera eman den hezur-adinaren aldaketa) (1.4 Irudia) (13).

1.3 Irudia: 14 urtez azpiko kategoriako 3 jokalariren hezur-heltzea denboraldiaren hasieran.

(a) Adin kronologikoa: 13,2; hezur-adina (heltze-egoera absolutua): 14,8 urte; hezur adina – adin kronologikoa (heltze-egoera erlatiboa): 1,6 urte.
(b) Adin kronologikoa: 13,6; hezur-adina (heltze-egoera absolutua): 13,7 urte; hezur adina – adin kronologikoa (heltze-egoera erlatiboa): 0,1 urte.
(c) Adin kronologikoa: 13,6; hezur-adina (heltze-egoera absolutua): 12,7 urte; hezur adina – adin kronologikoa (heltze-egoera erlatiboa): -0,9 urte.



1.4 Irudia: Jokalari baten esku eta eskumuturreko x izpien irudia (a) 14 eta (b) 15 urtez azpiko denboraldien hasieran, hurrenez hurren.

(a) Adin kronologikoa: 13,4; hezur-adina (heltze-egoera absolutua): 13,2 urte; hezur adina – adin kronologikoa (heltze-egoera erlatiboa): -0,2 urte;
(b) Adin kronologikoa: 14,3; hezur-adina (heltze-egoera absolutua): 14,4 urte; hezur adina – adin kronologikoa (heltze-egoera erlatiboa): 0,1 urte;

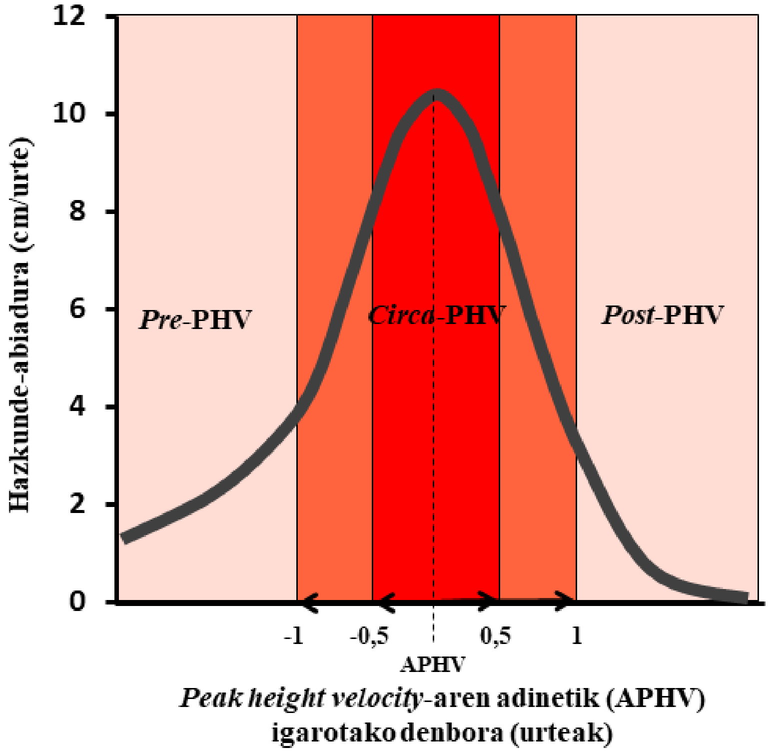
Hezur adinaren aldaketa/denbora (heltze-erritmoa): (14,4-13,2 hezur-urte) / 0,9 urte= 1,33 hezur-urte / urtean

1.2.2.3 Heltze somatikoa

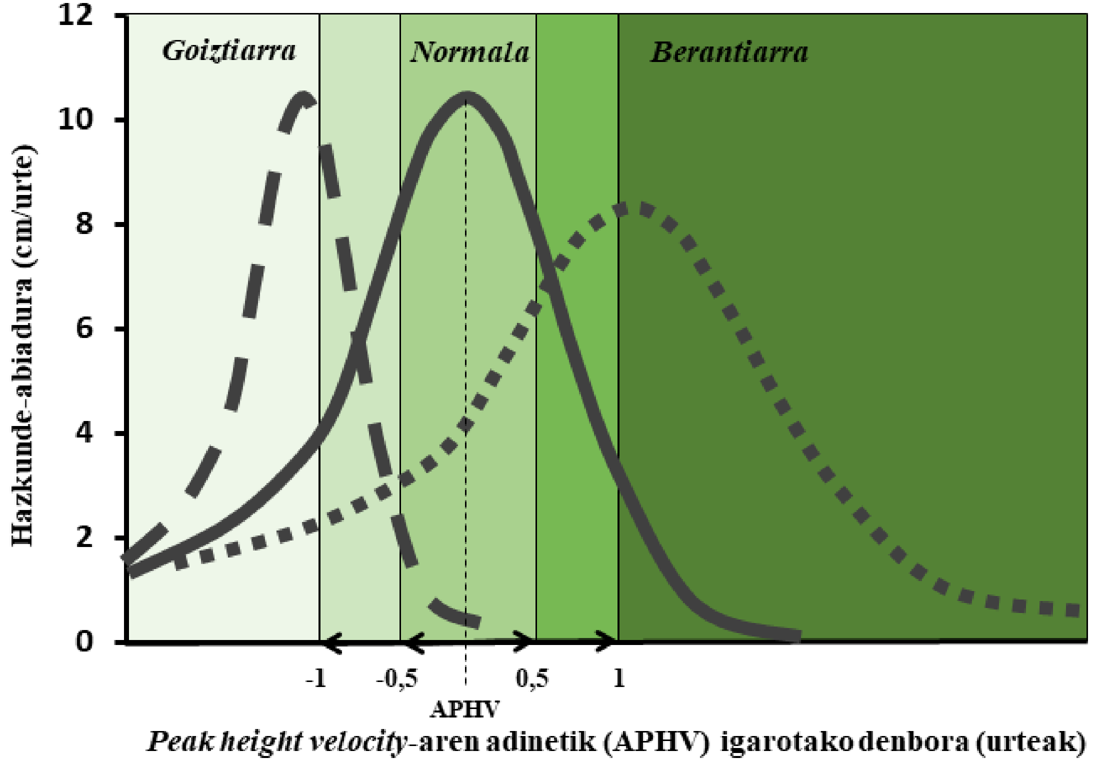
Hezurraren heltzea aztertzeko beharrezkoak diren baliabideak eliteko harrobietatik kanpo eskuragarri ez daudenez, azken urteotan heltze somatikoa aztertzeko metodoek indar handia hartu dute kirol munduan (15). Heltze-egoera somatikoa aztertzerako orduan bi dira erreferentziatzat hartzen diren indikatzaile nagusiak; batetik, PHV adina eta bestetik, helduaroko altuera.

Jokalari baten PHVa gertatzen den adina ezagututa, bai heltze-egoera eta bai heltze-*timing*a aztertu dezakegu. Norberaren PHV adina kontuan hartuta heltze-egoera somatikoak 3 fase bereizten ditu: PHV aurreko fasea (*pre*-PHV), PHV inguruko fasea (*circa*-PHV) edo PHV osteko fasea (*post*-PHV). Fase horiek bereizterakoan, *circa*-PHV fasea urtebeteko (norberaren PHV adina ± 0,5 urte) edo bi urteko (norberaren PHV adina ± 1 urte) periodo bezala hartu eta horren arabera *pre*-, *circa*- eta *post*-PHV periodoak definituko genituzke (1.5 Irudia) (13).

Era berean, heltze-*timing*ak jokalariak goiztiar, normal edo berantiar bezala sailkatzen ditu jokalari bakoitzaren PHV adina populazio orokorrarenarekin konparatuta. Heltze-egoerarekin gertatzen den bezala, ± 0,5 eta ± 1 urteko tarteak erabili daitezke jokalariak goiztiar (PHV adina erreferentziazko balioa baino goizago ematen denean), normal edo berantiar (PHV adina erreferentziazko balioa baino beranduago ematen denean) bezala definitzeko (1.6 Irudia) (13).



1.5 Irudia: Heltze-egoera somatikoaren faseak *peak height velocity*aren (PHV) adinaren arabera.



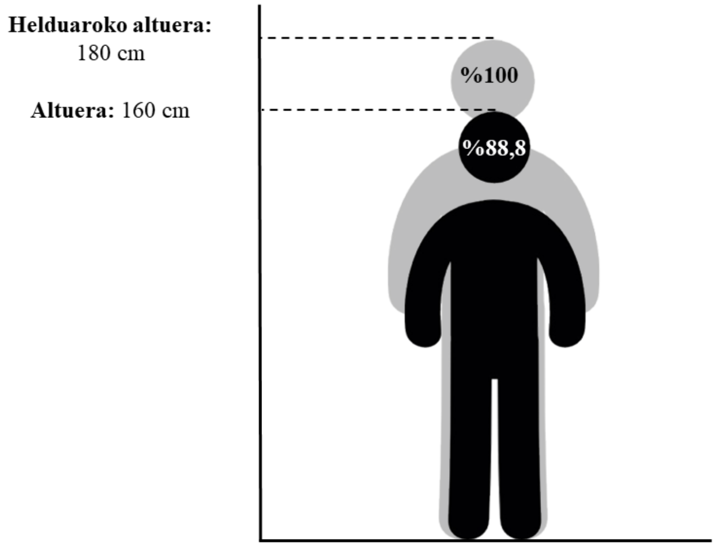
1.6 Irudia: Heltze-*timing* somatikoaren sailkapena *peak height velocity* (PHV) adinaren arabera.

PHV adina kalkulatzeko metodorik zehatzena hazkunde-abiadura longitudinalki erregistratzea da (13). Hala ere, metodo honek sailkapena erretrospektiboki egitea bakarrik ahalbidetzen du. Hau da, hazkunde-kurba osoa izan arte ezin dugu jokalariaren heltze-egoera aurretiaz iragarri, eta beraz, futbol harrobien testuinguruan praktikotasun eskasa du. Hori dela eta, PHVa adina aurresateko neurketa antropometrikoetan oinarritzen diren ekuazioek indar asko hartu dute azken urteotan (15,16). Horien artean bi dira gehien erabiltzen direnak: alde batetik, *maturity offset* ekuazioak [Mirwald (17) eta Moore-1 eta 2 (18)] eta bestetik, *maturity ratio*a [Fransen (19)] (1. Taula). *Maturity offset* ekuazioek *maturity offset*a bera, hau da, PHV gertatzeko geratzen diren urteak kalkulatzen dute. Horrela, jokalariaren *maturity offset*a eta adin kronologikoa gehituta, jokalari horren PHVa noiz gertatuko den (oraindik gertatu ez bada, *maturity offset* negatiboa) edo gertatu zen (jadanik gertatu bada, *maturity offset* positiboa) jakin daiteke. Bestalde, *maturity ratio* ekuazioaren bidez ere PHV adina kalkulatu daiteke. Ekuazio polinomiko honek hanken luzera eta enborraren altueraren arteko ratio bat kalkulatzen du (1. Taula). Ondoren, PHV adina kalkulatzeko jokalariaren adin kronologikoa *maturity ratio*agatik zatitu beharko litzateke. Behin PHV adina estimatuta, heltze-egoera eta heltze-*timing* somatikoa aztertu ahal izango ditugu (1.5 eta 1.6 Irudiak).

Bestetik, atal honetako lehenengo paragrafoan aipatu den bezala, helduaroko altuera ere heltze somatikoa aztertzeko erreferentzia moduan erabili daiteke. Helduaroko altuera jasotzeko modurik egokiena, hazkundea longitudinalki jaso eta hazteari uzten dionean jokalariak duen altuera jasotzea izango litzateke. Oro har, urtebetez hazkunde-abiadura 1 cm/urte baino txikiagoa denean helduaroko altuera lortu dela esaten da (13) eta 19 eta 21 urte inguruan ematen da emakumezko eta gizonezkoetan, hurrenez hurren (13). Hala ere, PHVarekin gertatzen zen bezala, informazio hau erretrospektiboki bakarrik erabili daiteke. Hori dela eta, kirol-arloan helduaroko altuera aurreikusteko ekuazioak erabiltzen dira helduaroko altueraren ehunekoa [ingelesez, *predicted adult height percentage* (PAH%)] kalkulatzeko. Alde batetik, hezur-adina eta hazkundea aztertuz egindako ikerketa longitudinalei esker, hezur-adinaren bidez helduaroko altuera kalkulatu daiteke (20). Hala ere, aurrerago aipatu den bezala, eliteko harrobi gutxi batzuek dute hezur-adina kalkulatzeko aukera eta beraz, neurketa antropometrikoetan oinarritutako Khamis-Roche ekuazioa (21) gero eta erabiliagoa da gaur egun (15).

Ekuazio honek jokalariaren altuera, pisua eta bere gurasoen altuera hartzen ditu kontuan jokalariaren helduaroko altuera aurreikusteko (1. Taula).

Pertsona baten helduaroko altuera erreferentziatzat hartuta, jokalari bat neurtu eta momentu horretan helduaroko altueraren zein ehunekotan zegoen kalkulatu dezakegu (adibidez, jokalari baten helduaroko altuera 180 cm bada, 160 cm neurtzen zuenean %88,88an zegoen: 160 cm *100/180 cm= %88,88) (1.7 Irudia) (22). Aldagai honek jokalariak heldutasunerako prozesu edo “bidean” (helduaroko altuera %100 izanda) jokalariak jadanik heldutako edo “betetako” ehunekoa adierazten du. Momentu jakin batean (adibidez, 13 urterekin) egindako neurketaren bidez (adibidez, 160 cm neurtzen zituenean) kalkulatutako aldagaia da helduaroko altueraren ehunekoa, eta heltze-egoera somatiko absolutua zenbatekoa den adierazten du.



1.7 Irudia: Jokalari baten heltze-egoera helduaroko altueraren ehunekoaren arabera.

Estimatutako helduaroko altuera (adibidez, Khamis-Roche ekuazioaren bidez): 180 cm

Jokalariaren momentuko altuera: 160 cm

Estimatutako helduaroko altueraren ehunekoa: 160*100/180=%88,8

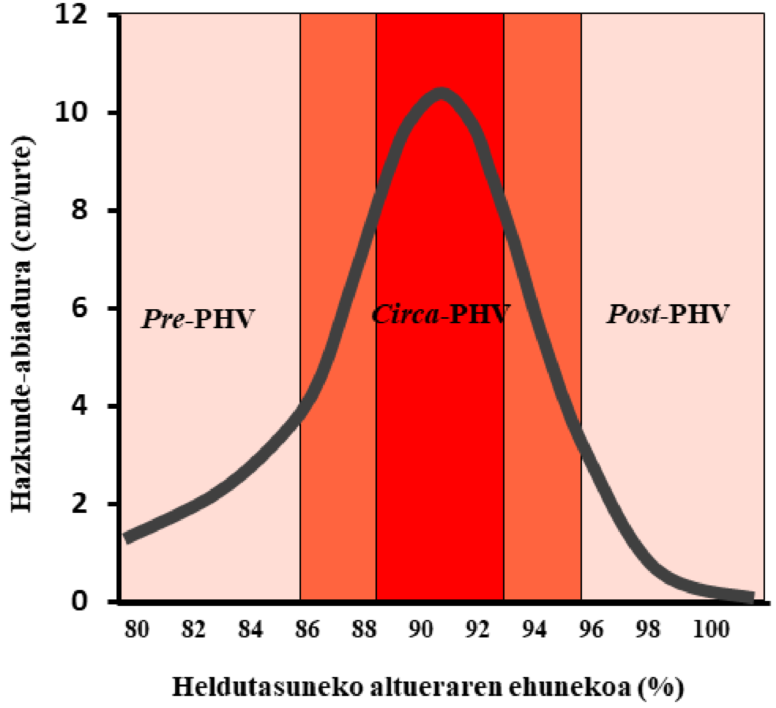
1. Taula: Heltze somatikoa estimatzeko ekuazioen laburpena.

Metodoa		Aldagaiak	Ekuazioa
Maturity offset	Mirwald (17)	Adin kronologikoa Altuera zutunik Altuera jesarrita Hanken luzera Pisua	♂: Maturity offset = - 9,236 + (0,0002708 * (hanken luzera * altuera jesarrita)) + (- 0,001663 * (adin kronologikoa * hanken luzera)) + (0,007216 * (adin kronologikoa * altuera jesarrita)) + (0,02292 * ((pisua / altuera zutunik) * 100)) ♀: Maturity offset = - 9,376 + (0,0001882 * (hanken luzera * altuera jesarrita)) + (0,0022 * (adin kronologikoa * hanken luzera)) + (0,005841 * (adin kronologikoa * altuera jesarrita)) -0.002658 * (adin kronologikoa * pisua) + (0,07693 * ((pisua / altuera zutunik) * 100))
	Moore-1 (18)	Adin kronologikoa Altuera jesarrita	♂: Maturity offset = -8,128741 + (0,0070346 * (adin kronologikoa* altuera jesarrita))
	Moore-2 (18)	Adin kronologikoa Altuera zutunik	♂: Maturity offset = -7,999994 + (0,0036124 * (adin kronologikoa * altuera zutunik)) ♀: Maturity offset = -7,709133 + (0,0042232 * (adin kronologikoa * altuera zutunik))
Maturity ratio	Fransen (19)	Adin kronologikoa Altuera zutunik Hanken luzera Pisua	♂: Maturity ratio = (6,986547255416 + 0,115802846632 * adin kronologikoa) + (0,001450825199 * adin kronologikoa^{2}) + (0,004518400406 * pisua) – (0,000034086447 * pisua^{2}) − 0,151951447289 * zutikako altuera + 0,000932836659 * zutikako altuera^{2} − 0,000001656585 ∗ zutikako altuera^{3} + 0,032198263733 ∗ hanken luzera − 0,000269025264 ∗ hanken luzera^{2} − 0,000760897942 ∗ (zutikako altuera ∗ adin kronologikoa)
Helduaroko altueraren ehunekoa	Khamis-Roche (21)	Adin kronologikoa Zutikako altuera Pisua Gurasoen altuera	Helduaroko altuera = βo + zutikako altuera * β1 + pisua *(β2) + zuzendutako gurasoen zutikako altuera *β3 Oharra: βo, β1, β2, eta β3 genero eta adin kronologikoaren araberako koefiziente espezifikoak dira ((21) Zuzendutako gurason zutikako altuera: ♂: [gurasoen bataz besteko altuera (cm)*0.955] + 2.316 ♀: [gurasoen bataz besteko altuera (cm)*0.953] + 2.803

Gainera, helduaroko altueraren ehunekoak jokalariak *pre*-, *circa*- edo *post*-PHV bezala sailkatzea ahalbidetzen du. Ikerketa longitudinalen arabera, PHVa helduaroko altueraren %88-%96 bitartean eman ohi da (gehienetan, %91-%92 inguruan) (23,24). Beraz, *circa*-PHV periodorako banda bat ezarri eta horren arabera jokalariaren heltze-egoera aztertu daiteke (1.8 Irudia). Hala ere, aipatu beharra dago, *circa*-PHVa definitzeko ± 0,5 eta ± 1 urteko bandak erabiltzen diren bezala, helduaroko altueraren bidez periodo hau definitzeko banda ezberdinak aurki ditzakegula literaturan (adibidez, %85-%96, %88-%93 edo %90-%93) (25).

Horrez gain, heltze-egoera erlatiboa aztertzea ahalbidetzen du helduaroko altueraren ehunekoak. Horretarako, jokalari baten helduaroko altueraren ehunekoa (adibidez, %88) momentu jakin batean (adibidez, 13 urterekin) kalkulatu, eta populazio orokorrak momentu horretan duen helduaroko altueraren ehunekoarekin konparatzen da. Horrela, adin espezifiko horretan jokalariak populazio orokorrak baino helduaroko altueraren ehuneko aurreratuagoa (heltze-egoera erlatibo goiztiarra), antzekoa (heltze-egoera erlatibo normala) edo atzeratuagoa (heltze-egoera erlatibo berantiarra) duen jakingo genuke (26).

Aurretik aipatutako *maturity offset*, *maturity ratio* eta PAH% metodoen praktikotasuna eta erabilgarritasuna handia den arren, ez dira guztiz fidagarriak PHVa estimatzeko orduan; izan ere, hazkunde-kurba osoen bidez kalkulatutako PHVarekin konparatuta errore handia erakutsi dute (25,27–29). Hazkunde-kurba osoa kontuan izanda PHVa kalkulatzea metodorik aproposena den arren, aurrerago aipatu den bezala, aukera honek jokalarien sailkapen erretrospektiboa besterik ez du ematen. Jokalaria sailkatzeko bere hazkunde-prozesua amaitu arte itxaroten bada, datu hauen praktikotasuna eskasa da. Hori dela eta, hazkunde-abiadura longitudinalki jaso eta oraindik hazten ari diren jokalarien “osatu gabeko” kurbak (adibidez, 13 urteko jokalari baten kurba) ebaluatzen dituzte futbol harrobi batzuetako profesionalek euren esperientzian oinarrituta (adibidez, hazkunde-abiadura eta kurbaren formari erreparatuz). Horrela, hazkunde-kurbak datu gehiagorekin “osatu” ahala, jokalarien heltze-egoera (*pre*-, *circa*- edo *post*-PHV) eta heltze-*timing*a (goiztiarra, normala, berantiarra) estimatzen dute (16). Kasu askotan, PAH% eta hazkunde-abiadura jaso eta bietaz baliatzen dira sailkapen zehatzagoak egin nahian.



1.8 Irudia: Heltze-egoera somatikoaren faseak helduaroko altueraren ehunekoaren arabera.

Kasu honetan %85-%95 eta %89-%93 bandak adierazten dira *circa*-PHV periodoa definitzeko.

1.2.3 Hazkundearen, heltzearen eta lesioen arteko harreman teorikoa

Kategoriaz kategoria egindako ikerketen arabera, lesioen intzidentzia eta *injury burden*a nerabezarotik aurrera (13-14 urtez azpiko kategoriatik aurrera gizonezkoetan) handiagotzen da (7,8,30,31). Lehen aipatu bezala, adin horretan gertatu ohi da PHVa eta ondorioz, hazkundea eta heltzea futbolari gazteen lesioen arrisku-faktoretzat aztertzea proposatu dute kirol epidemiologian adituek (2).

Oro har, hiru faktore nagusi aipatzen dituzte adituek hazkundearen, heltzearen eta lesioen arteko harremana azaltzerako orduan:

1.2.3.1 Hezurraren garapenaren eragina lesioetan

Gazteen hezurren epifisietako hazkunde-plakak zaurgarriak dira trakzio- eta zizaila-indarren aurrean (9,32). Hori dela eta, populazio honetan hazkunde-lesioak (adibidez, epifisiolisiak eta osteokondrosiak) ohikoak izaten dira (7,8).

1.2.3.2 Hazkunde bizkorraren eragina lesioetan

Biomekanikari dagokionez, hazkundeak giltzaduren palanka-besoen luzatzea eta pisuaren handitzea eragiten du (13). Ondorioz, inertzia-momentuak handitzen dira eta mugimendu bera egiteko indar handiagoaren beharra eragiten du. Hala ere, palankak handitu eta berehala, oraindik, muskulu eta tendoiek ezin dute indar handirik egin, izan ere, egitura hauen garapena hezurren garapenaren ostean gertatzen da (32). Beraz, hezurrak luzatu baina muskulu/tendoiak oraindik garatu gabe dauden tarte horretan, aldaketa neuromuskularrak, trakestasuna eta lesioak ager daitezke (33).

Bestalde, hezurren hazkunde bizkorrak apofisietan (muskulu eta hezurren arteko loturetan) trakzio handia eragiten du. Oraindik guztiz heldu gabe dauden gazteen apofisien zaurgarritasuna handia denez, hazkunde bizkorrak hazkunde-lesioak eragin ditzake (9).

Hirugarrenik, hezurren hazkunde bizkorra hezur-dentsitatea gutxitzearekin lotzen da eta beraz, hezur-hausturen arriskua handiagotzea ekar dezake (34).

1.2.3.3 Jokalarien arteko heltze-egoeraren ezberdintasunaren eragina lesioetan

Gizabanakoen heltze-*timing* eta -erritmo desberdintasunak direla eta, adin bereko taldekideen artean heltze-egoera oso ezberdina duten jokalariak topa daitezke (22). Hau da, adin bereko jokalariak gazteago/nagusiago izateak edota bizkorrago/geldoago heltzeak, ezaugarri antropometriko eta fisiko oso ezberdinak izatea eragin dezake. Alde batetik, jokalarien arteko ezberdintasun fisikoak kontaktu-egoeren ondorioz gertatzen diren lesio akutuetan eragina izan dezakeela proposatu dute hainbat ikertzailek (35). Hots, ahulagoak, txikiagoak eta argalagoak diren jokalari berantiarrek kontaktuaren ondoriozko lesio gehiago izan ditzaketela. Bestalde, entrenamendu mota eta karga jokalarien heltze-ezaugarrietarako egokia ez izatea lesioak eragin ditzake (15,16).

1.2.4 Hazkundea eta heltzea futbolarien lesioekin harremanean jarri dituzten ikerketak

Gai honen inguruko interesa gero eta handiagoa da eta hazkundearen, heltzearen eta futbol-lesioen inguruko hainbat ikerketa argitaratu dira azken urteotan. Atal honek, azken urteotan hazkunde-abiadura, hezur-heltzea eta heltze-somatikoa futbolarien lesioekin harremanean jarri dituzten ikerketen emaitza nagusiak biltzen ditu.

1.2.4.1 Hazkunde-abiadura eta lesioak

Oro har, hazkunde-abiadura bizkorra lesio gehiago izateko aukerarekin lotu izan da literatura zientifikoan. Kemper et al.-k (36) Herbehereetako futbolariekin egindako ikerketaren arabera, hilabete batean 0,6 cm baino gehiago hazten ziren futbolariek lesionatzeko aukera gehiago zituzten. Bestalde, Rommers et al.-k (37) Belgikan egindako ikerketak ere hazkunde-abiadura bizkorragoa lesioekin harremanetan zegoela erakutsi zuten. Hala ere, aipatutako ikerketek zenbait muga metodologiko dituzte. Batetik, oso denbora tarte txikian (maiztasun handia) jaso zen altuera eta horrek hazkundearen neurketaren errorea handiagotu dezake (13). Bestalde, ikerketek ez zuten hazkundea modu longitudinalean erregistratu. Hazkundea prozesu ez-lineala izanik (1.1 Irudia), jokalarien hazkunde-kurba osoa erregistratzea ezinbestekoa da hazkunde-abiaduraren eta lesioen artean dagoen harremana hobeto ezagutzeko (35). Gainera, orain arte aurrera eramandako ikerketek ez dituzte kontuan hartu lesio-motak ezta lesioek eragindako baja-egunak ere. Ez hori bakarrik, orain arteko ikerketek ez dute jokalarien heltze-egoera kontuan hartu hazkundeak lesioen agerpenean duen eragina aztertzean.

1.2.4.2 Hezur-heltzea eta lesioak

Hezur-adina eta futbolarien lesioak aztertu dituzten ikerketek jokalariak hezur-heltze erlatiboaren arabera sailkatu dituzte. Horrela, jokalariak goiztiar (hezur adina – adin kronologikoa > 1 urte), normal (hezur adina – adin kronologikoa 1 eta -1 urte bitartean) edo berantiar (hezur adina – adin kronologikoa < -1 urte) moduan sailkatu dituzte eta lesioen intzidentziak konparatu dituzte (35).

Alde batetik, Le Gall et al.-k (38) 14 urtez azpiko futbol jokalari frantziarrekin egindako ikerketan ez zuten intzidentzia orokorrean ezberdintasun adierazgarririk aurkitu jokalari goiztiar, normal eta berantiarren artean. Materne et al.-k (39), ordea, hezur-heltze goiztiarra zuten jokalariek heltze normala zutenak baino lesionatzeko aukera gehiago zituztela aurkitu zuten. Lesio espezifikoei dagokienez, 14 urtez azpiko jokalari goiztiarrek iztarteko lesio gehiago eta hazkunde-lesio gutxiago izan zituzten. Bestalde, heltze berantiarra zuten 14 urtez azpiko jokalariek lesio larri gehiago (28 baja-egun baino gehiagokoak) eta tendinopatia gutxiago izan zituzten (38).

Hala ere, ikerketa horiek zenbait muga dituzte. Lehenik, ez zuten kontuan hartu jokalarien esposizio indibiduala, alegia, jokalari bakoitzak jokatu/entrenatutako minutuak; hau da, jokalaria lesionatzeko arriskuan egon den denbora (40). Bigarrenik, intzidentzia bakarrik aztertu zuten eta ez *injury burden*a (lesioen maiztasuna eta larritasuna kontuan hartzen dituena) (5). Gainera, jokalariak hezur-heltze erlatiboaren arabera sailkatzerakoan ± 1 urteko tartea hartu zuten kontuan eta beraz, jokalari berantiarren kopurua txikia izan zen.

1.2.4.3 Heltze somatikoa eta lesioak

Heltze somatikoaren eta lesioen arteko harremana aztertu duten ikerketa gehienek erakutsi dute PHVaren inguruko periodoan lesio-arriskua handiagoa dela.

Van der Sluis et al.-k (41) Herbehereetako futbolarien lesioak konparatu zituzten *pre*-PHV (PHVa eta osteko 6-18 hilabeteen artean), *circa*-PHV (PHV ± 6 hilabete) eta *post*-PHV (PHV ostean 6-18 hilabete) periodoen artean. *Circa*-PHVn lesio traumatiko gehiago aurkitu zituzten *pre*-PHVaren aldean. Hala ere, ez zen desberdintasun adierazgarririk topatu gainkargak eragindako lesioetan, lesioen larritasunean ezta partidu/entrenamenduen intzidentzian ere. Bestalde, Bultek et al.-k (30) intzidentzia eta *burden* handiagoa aurkitu zuten PHV osteko 6 hilabeteetan. Johnson et al.-k (31), aldiz, Erresuma Batuko jokalariak helduaroko altueraren ehunekoa kontuan hartuta jokalariak banatu eta kontaktu gabeko lesioen intzidentzia eta *burden*a konparatu zuten. Euren emaitzek intzidentzia handiagoa erakutsi zuten *circa*-PHVn *pre*-PHVren aldean. Gainera *burden*a handiagoa izan zen *circa* eta *post*-PHV periodoetan *pre*-PHVren aldean.

Bestetik, heltze-egoeraren efektua aztertzeaz gain, heltze-*timing*aren efektua aztertu zuten Johnson et al.-k (31). Hain zuzen ere, heltze goiztiar eta normal/berantiarren arteko intzidentzia eta *burden*aren konparaketa egin zuten *pre*-, *circa*- eta *post*-PHV periodoetan. Hala ere, ez zuten emaitza adierazgarririk aurkitu. Era berean, Light et al.-k (42) ez zuten heltze goiztiarra, normala eta berantiarra zuten jokalarien intzidentzien artean ezberdintasun adierazgarririk topatu. Van der Sluis et al.-k (43), ostera, gainkargak eragindako lesioen intzidentzia handiagoa topatu zuten *pre* eta *circa*-PHVn zeuden jokalari berantiarragoetan (goiztiarragoekin konparatuta).

Aurretik aipatutako ikerketek hainbat muga dituzte. Alde batetik, muga nagusia PHVa estimatzeko erabili duten metodoa da (Mirwald eta Khamis-Roche). Izan ere, nahiz eta aipatutako metodoak praktikan erabilgarriak izan, zehaztasun eskasa dute (bereziki, heltze goiztiarra eta berantiarra duten nerabeetan PHV adina estimatzerakoan) (28,29,44). Bestetik, ez da heltze somatikoak lesio espezifikoetan duen eragina aztertu. Bukatzeko, periodo ezberdinetan izaten diren lesioak aztertzean ez dira *post*-PHVn dauden futbolariak eta helduak direnak desberdindu.

1.2.4.4 Hazkunde-abiadura, heltze somatikoa eta lesioak

Gaur egun, Johnsonek et al.-k (45) egindako ikerketa da hazkunde-abiadura eta heltze-egoeraren arteko interakzioak lesioekin duen harremana aztertu duen bakarra. Batetik, hazkunde-abiadura altua zuten eta *circa*-PHV inguruan zeuden jokalariek lesio gehiago jasan zituztela adierazi zuten euren emaitzek. Bestetik, hazkunde-abiadura geldoa zuten eta helduaroko altueratik hurbil zeuden jokalariek *injury burden* altuagoa zutela ikusi zuten. Hala ere, ikerketa honek hainbat muga ditu; hala nola, denboraldi bakarreko datuak aztertzea, Khamis-Roche metodoa erabiltzea edota lesio-motari buruzko informazio ez jasotzea. Ez hori bakarrik, heltze-egoera aztertzerakoan, helduaroko altueraren ehunekoa aldagai jarrai bezala aztertu zuten eta beraz, ez zuten hazkunde-abiaduraren eragina *pre*-, *circa*- eta *post*-PHV faseetan banan-banan aztertu.

Bestalde, PHVaren eta lesioen arteko harremana aztertu duen ikerketarik ez dago (35). Orain arte idatzitako ikerlanek hazkunde-abiadura bizkorraren eta lesioen arteko harremana erakutsi eta *circa* eta *post*-PHVn lesioen inpaktua handiagoa dela baieztatu dute (30,31). Hala ere, oraindik ez dakigu PHVak bi periodo hauetan lesioek duten inpaktuarekin zerikusia duten edo ez.

2. HELBURUAK

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Aurrerago aipatu dugun bezala, lesioen inpaktua oso handia da harrobiko futbol jokalarietan; izan ere, euren progresioa, errendimendua eta osasuna kaltetu dezakete. Gazteetan gertatzen diren hazkunde- eta heltze-prozesuek lesioen agerpenean eragina izan dezaketela proposatu dute hainbat ikertzailek. Hala ere, orain arte egindako ikerketek mugak dituzte eta beraz, kalitatezko ikerketa gehiago behar dira arlo honetan.

Hortaz, lan honen **helburu orokorra** Athletic Club taldeko jokalarien lesioak ezagutzea eta hazkundearekin eta heltzearekin duten erlazioa aztertzea izan zen.

Era berean, hainbat **helburu espezifiko** izan zituen tesi honek, ikerlan ezberdinetan garatu egin zirenak:

1. Athletic Clubeko gizonezkoen zein emakumezkoen lesioen epidemiologia kategoriaz kategoria deskribatzea (*I. ikerlana)*.
2. Athletic Clubeko jokalari gazte gizonezkoen hazkundearen, heltzearen eta lesioen arteko harremana aztertzea (*II-VI. ikerlanak*):
    - 2.1. Gizonezkoen U14 taldean *injury burden*a deskribatu eta konparatu jokalarien hezurraren heltze-egoera erlatiboaren arabera (goiztiarrak, normalak, berantiarrak) (*II. ikerlana*).
    - 2.2. Heltze-egoeraren (helduaroko altueraren ehunekoa) eta lesio-mota espezifikoen arteko harremana aztertzea. Zehazki, lesio bakoitza helduaroko altueraren zein ehunekotan ematen den deskribatzea (*III. ikerlana*).
    - 2.3. Lesio-mota espezifikoen *injury burden*a aztertzea heltze-egoeraren (*pre*-, *circa*-, *post*-PHV edo helduak) eta heltze-*timing*aren (goiztiarra, normala, berantiarra) arabera (*IV. ikerlana*).
    - 2.4. Hazkunde-abiaduraren eta lesio-mota espezifikoen (intzidentzia eta *burden*) arteko harremana aztertzea *pre*-, *circa*- eta *post*-PHV periodoetan (*V. ikerlana*).
    - 2.5. PHVaren abiaduraren (bizkorra, normala, geldoa) eta *circa*- eta *post*-PHV periodoetako *injury burden*aren arteko harremana aztertzea (*VI. ikerlana*).
3. Heltze-egoera somatikoa (*pre*-, *circa*-, *post*-PHV) estimatzeko metodoak aztertzea eta konparatzea (*VII. ikerlana*).

3. METODOLOGIA OROKORRA

3. METODOLOGIA OROKORRA

3.1 PARTE-HARTZAILEAK ETA IKERKETA PERIODOA

Tesi honetan parte hartu zuten subjektuak 1998-2022 denboraldietan Athletic Club taldeko jokalariak izan ziren. Denboraldi horietan zehar jokalari guztien lesioak eta datu antropometrikoak modu sistematikoan jaso zituzten zerbitzu medikoko kideek. Horrez gain, 2011-2012 denboralditik aurrera jokalarien esposizio indibiduala (jokatu eta entrenatutako minutuak) eta 14 urtez azpiko jokalarien hezur-adina jaso zituzten. Jokalariek eta gurasoek/tutoreek (adingabeen kasuan) klubean egindako froga eta testetan parte-hartzea onartzen zutela adierazten zuten kontratu bidez. Bestalde, Euskal Herriko Unibertsitateko (UPV/EHU) Etika Batzordeak ikerketa hau onartu zuen (CEISH/340/2015).

Ikerlan bakoitzaren helburuen arabera ikerketan parte-hartzeko inklusio-irizpide batzuk ezarri eta horiek betetzen zituzten subjektuak aztertu ziren. Ikerlan bakoitzaren parte-hartzaileen informazio zehatza ikerlan bakoitzaren metodologia atalean ikus daiteke (*Results and discussion* atalean).

3.2 LESIOEN DEFINIZIOAK ETA ERREGISTRO PROZEDURAK

Lesioak jokalari batek futbolean jasandako kexa fisiko baten ondorioz etorkizuneko entrenamendu edo partidu batean parte hartu ezin zuenean erregistratu ziren klubaren online datu-basean. Lesionatu ostean, futbolaria lesionatutzat hartzen zen zerbitzu medikoak entrenamendu eta partidetan guztiz parte-hartzeko baimena eman arte. Lesio bakoitzak eragindako baja egunak jaso ziren. Selekzioarekin jokatutako partiduetan eta entrenamenduetan jasandako lesioak ere kontuan hartu ziren. Gaixotasunak analisitik kanpo utzi ziren (12).

Lesioen sailkapena Asoziazio Futbolaren Nazioarteko Federazioak (FIFA) emandako argibideetan eta medikuen esperientzian oinarritu zen (12). Lau medikuetatik bik ikerketa osoan zehar jaso zituzten lesioak (1997-2020). Hazkunde-lesioak ez ziren FIFAk gomendatutako definizioen barruan sartu eta beraz, Caine et al.-k (9) emandako definizioa kontuan hartuta erregistratu ziren: “gorputza heldu ez zaien gazteetan soilik gertatzen diren lesio bereziak dira, helduek izaten ez dituztenak. Hala nola, hazkunde-plaken lesioak, apofisitisak, abultsioak edo zurtoin berde gisako hausturak”.

3.3 ESPOSIZIOA

Esposizioa kontuan hartzea ezinbestekoa da lesioen arriskua aztertzerako orduan. Oro har, lesionatzeko arriskuan dagoen denbora (adibidez, minutuak) aztertzen du esposizioak.

Talde-kiroletan, jokalari bakoitzak entrenatutako eta jokatutako minutuak jasotzea da egokiena eta jokalari bakoitza "arriskuan" egon den denborari buruzko informazio zehatzena ematen du. Bestalde, talde-mailan lesio arriskua aztertzeko analisiak egin nahi izatekotan, jokalari guztien esposizio indibiduala (minutuak) batuta, talde osoaren esposizio totala lortzen da. Horrela, esposizio indibiduala jasotzeak arriskua maila indibidualean eta taldean aztertzea baimentzen du. Bestalde, partidetan lesionatzeko arriskua entrenamenduetan baino handiagoa denez, partida eta entrenamenduetako esposizio indibiduala banatuta jasotzea gomendagarria izaten da; horrela, bi egoeratan arriskua aztertzeko aukera emanez (40).

Hala ere, askotan minututan jasotako informazioa ez dago eskuragarri eta beraz, esposizioa neurtzeko beste aukera batzuk erabiltzen dira (40). Adibidez, parte hartutako entrenamendu/partida kopurua, iraupena, partidetan zelaian dauden jokalari kopurua, eta taldekide kopurua jakinda, jokalari bakoitzak izandako esposizioa estimatuko daiteke (estimatutako minutuak). Beste aukera bat, jokalari bakoitzak jolastutako denboraldi kopurua (jokalari-denboraldiak) esposizio neurritzat hartzea da. Jokalariak ez entrenatzearen edo jokatzearen arrazoi nagusia lesioak izanda, estimatutako esposizio totalari (adibidez, 2,3 jokalari-denboraldi) lesionatuta egoteagatik galdutako esposizioa (20 egun lesionatuta /365 egun= 0,05 jokalari-denboraldi) kendu ohi zaio (2,3 jokalari-denboraldi – 0,05 jokalari-denboraldi lesionatuta= 2,25 jokalari-denboraldi).

Tesi honetako ikerlanetan aurretik aipatutako esposizioa neurtzeko hiru erak (espozio indibiduala, estimatutako esposizioa eta jokalari-denboraldiak) erabili ziren. Alde batetik, *I. eta II. ikerlanetan* intzidentzia (lesio kopurua/1000h) eta *burden*a (baja egun kopurua/1000h) esposizio indibiduala kontuan erabilita kalkulatu ziren. 2011-2012 denboralditik aurrera Athletic Clubeko jokalarien esposizio indibiduala minututan jaso da. Kategoria bakoitzeko lesioen epidemiologia aztertzeko azken 10 denboraldietako lagina nahikoa denez, esposizio indibiduala jaso zen azken 10 denboraldiak aztertu ziren *I. ikerlanean*. Horrez gain, denboraldi berean (2011-2012) U14 taldeko jokalarien x-izpi bidezko ebaluazio aztertzen hasi zen. Hau da, U14 kategorian hezur adinaren azterketa egin zitzaien jokalari guztien esposizio indibiduala ere jasota zegoen. Beraz, hezurraren heltze egoera erlatiboak (goiztiarra, normala, berantiarra) lesioetan duen eragina aztertzerako orduan esposizio indibiduala kontuan hartu zen. Hala ere, lesio-arriskua aztertu zuten gainerako ikerlanetan (*III.-VI. ikerlanak*) ez zen jokalarien esposizio indibiduala kontuan izan. 3.6 atalean azalduko den bezala, hazkundearen jarraipen luzea zuten jokalariak bakarrik parte hartu zuten ikerlan horietan. Inklusio-irizpide horrek lagina asko txikitzea eragin zuen eta parte-hartzaile kopurua are gehiago ez mugatzeko, esposizio indibiduala jasota ez zuten denboraldiak (2011-2012 baino arinago) ere aztertu ziren. Beraz, esposizio kontuan hartzeko, jokalari-denboraldiak (*IV. eta VI. ikerlanak*) eta estimatutako esposizio minutuak erabili ziren (*V. ikerlana)*.

3.4 NEURKETA ANTROPOMETRIKOAK

Antropometria neurketa guztiak ISAK-ek (*International Society for the Advancement of Kinanthropometry*) gomendatzen duen protokoloari jarraituz egin ziren (46).

Zutikako altuera hurbileko 0,1 cm-tan neurtu zen tallimetro eramangarri baten bitartez (Añó Sayol, Barcelona, Spain). Horretarako, *vertex*aren (buruaren punturik altuenaren) eta euste-planoaren arteko distantzia neurtu zen. Ondo neurtzeko, jokalariek oinak elkarren ondoan eta orpoak, ipurmasailak eta bizkarraren goiko aldea eskalarekin kontaktuan jarri zituzten. Bestalde, aurrera begiratzeko esan zitzaien *Frankfort*en planoari eutsita. Horretarako, tragusera doan irudizko lerro bat imajinatu behar da (lurrarekiko paralelo). Bukatzeko, altuera neurtu aurretik jokalariei arnasketa sakon bat egiteko esan zitzaien. Behatzaileen arteko eta norberak egindako neurketen arteko errorea, 0,29 eta 0,23 cm izan zen.

Pisua hurbileko 0.1 kg-tan neurtu zen baskula eramangarri baten bitartez (Seca, Bonn, Germany). Horretarako, jokalariak baskularen erdian jartzen ziren zutik eta aurrera begira, bi oinak elkarren parean zituztelarik eta, beti ere, pisua bi hanketan berdin banatuta.

Neurketen errorea murrizteko, neurketak arratsaldeko entrenamenduen aurretik egin ziren beti 3-4 hilabete inguruko maiztasunarekin. Gainera, neurketak egiten aritu ziren lau medikuetatik bik denboraldi guztietan parte hartu zuten neurketetan.

Bestetik, 2009-2010 eta 2015-2016 denboraldien bitartean Iraia Bidaurrazagaren tesia dela eta altuera jesarrita (cm) jaso zen bi taldetako jokalarietan. Jokalariak tallimetroaren eskalaren kontra zegoen 50 cm-tako banku batean jesartzen ziren aurrera begira eta bizkarra zuzen eskalaren kontra jarrita. Aurrekoan bezala, buruak *Frankfort*en planoan jartzen zen eta neurketa inspirazioa egitean burutzen zen. Aldagai honetarako neurketaren errorea 0,14 cm izan zen.

3.5 HEZUR-HELTZEA

Hezur-heltzea aztertzeko metodo erabilienak eskumuturreko eta eskuko erradiografien azterketan oinarritzen dira. Hezurren heltze-prozesua ezagunak diren patroi edo orden zehatz batzuk jarraituz ematen da eta hezur-heltzeari buruzko atlasetan aurki dezakegu. Horrela, atlas hauetako erreferentziazko laginak oinarritzat hartuta, eskumuturreko eta eskuko erradiografia aztertu eta gizabanako baten hezur-adina kalkulatu daiteke (13).

1978-1987 urteetan Bilbo inguruko gazteen hezur-heltzea aztertu zuen Basurtoko Ospitalean egindako ikerketa batek (47). Honi esker, Bizkaiko populazioaren atlas espezifikoa idatzi eta gure gizartean oinarritutako datu espezifikoetan oinarrituz hezur-heltzea estimatu daiteke gaur egun. Atlas honek hezur-heltzea aztertzeko bi metodo/aukera eman zituen: Greulich Pyle eta Tanner-Whitehouse II-RUS (*radius, ulna, short bones*) (TW2-RUS). Gaur egun Athletic Clubeko zerbitzu medikoek bi metodoetan oinarrituta aztertzen ditu erradiografiak; hala ere, bi hauen artean TW2-RUS metodoa da kirol eta futbol literaturan gehien erabiltzen dena (48). Beraz, ikerketa honetan TW2-RUS metodoaren bidez egindako estimazioak erabili ziren. Metodo honek aztertzen dituen hezurrak hurrengoak dira: erradioaren epifisi distala, kubituaren epifisi distala eta lehenengo hirugarren eta bosgarren metakarpo eta falangeen (distalak, tartekoak eta proximalak) epifisiak.

2011-2012 denboraldian hasi zen Athletic Club jokalarien hezur-adina aztertzen. Zehazki, denboraldiaurrean 14 urtez azpiko kategorian jokatzen duten jokalariei eskumutur eta karpoaren x izpi bidezko irudia egiten zaie (gaur egun, 15 urtez azpiko kategorian berriak diren jokalariei ere). Erradiografien azterketa adituak ziren bi mediku berberek egin zuten denboraldi guztietan zehar. Hezur-adina aztertzerakoan, behatzaile barne-errorea eta behatzaileen arteko hezur-adinaren errorea 0,10 eta 0,25 urtekoa izan zen, hurrenez hurren.

Behin hezur-adina estimatuta, jokalariak hezurraren heltze-egoera erlatiboaren arabera (hezur-adina – adin kronologikoa) sailkatu ziren: goiztiarrak (hezur-adina – adin kronologikoa > 0,5 urte), normalak (hezur-adina – adin kronologikoa 0,5 eta -0,5 urte bitartean) edo berantiarrak (hezur-adina – adin kronologikoa < -0,5 urte) (49). Bestalde, hezur-adina erabilita helduaroko altuera kalkulatu zen (47).

3.6 HAZKUNDEA ETA HELTZE-SOMATIKOA

Tesi honen sarreran aipatu den dezala, heltze-somatikoa aztertzeko kontuan hartzen diren erreferentzia nagusiak bi dira; batetik, altueraren abiadura gorena edo *peak height velocity*a (PHV) eta bestetik, helduaroko altuera.

PHV adina (urteak) eta PHVa (cm/urte) kalkulatzeko metodorik zehatzena altueraren jarraipen longitudinala egin eta hazkunde-abiadura modelizatzeko metodoak erabiltzea da. Tesi honetan metodo hauek erabiltzen adituak diren *Basque Center for Applied Mathematics* (BCAM) taldeko kideekin kolaboratu zen. Eurekin elkarlanean aritu eta gero, kurbak modelizatzeko *Super-Imposition by Translation And Rotation* (SITAR) metodoa (50) erabili zen. Aipatu beharra dago azken urteetan PHVa hazkunde-kurben modelizazio bidez kalkulatu duten ikerketa gehienetan (kirol eta futbol arloan barne) SITAR metodoa erabili dela. PHV eta PHV adinaren estimazio zehatzagoak egiteko asmoz, jokalariek bi inklusio-irizpide bete behar izan zituzten ikerketan parte-hartzeko. Batetik, jokalariaren 10 altuera neurketa edo gehiago izatea. Bestetik, neurketak bai PHV adinaren aurretik eta ostean izatea; izan ere, hazkunde-prozesu osoan zehar datuak izatea garrantzitsua omen da PHV eta PHV adinaren estimazio zehatzak egiteko (28). 3.1 Irudian inklusio-irizpideak bete zituzten jokalarien hazkunde-kurbak ageri dira.

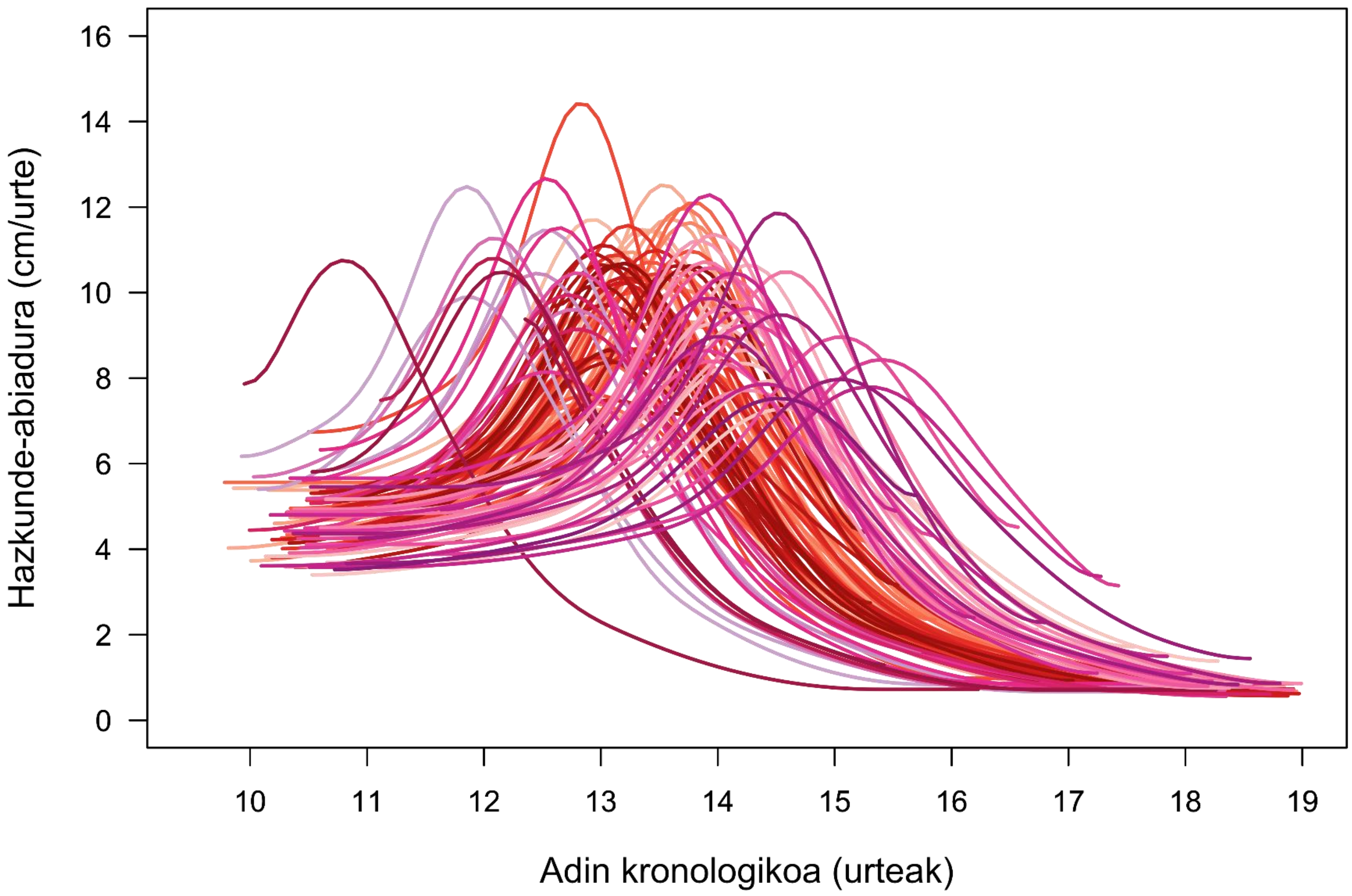
PHV adina kontuan hartuta, jokalarien heltze-egoera eta heltze-*timing*a aztertu ziren. Heltze-egoeraren arabera *pre*-, *circa*- eta *post*-PHV periodoak definitzeko, jokalari bakoitzaren PHV adina eta ± 0,5 urte tartea erabili ziren (1.5 Irudia). Bestalde, heltze-*timing*a definitzeko, Euskal Herriko gizonezkoen bataz besteko PHV adina (13,3 urte) ± 0,5 urte tartea erabili ziren: goiztiarra (PHV adina < 12,8 urte), normala (PHV adina 12,8 eta 13,8 urte bitartean) eta berantiarra (PHV adina >13,8 urte) (3.2 Irudia).

Bestalde, Lezamako jokalarien PHVaren (cm/urte) pertzentilen (P) arabera jokalariak hiru taldetan banatu ziren: PHV bizkorra (≥P75: ≥10,84 cm/urte), PHV normala (P25–P75: 8,98–10,84 cm/urte) eta PHV motela (≤ P25: ≤8,98 cm/urte) (3.3 Irudia).

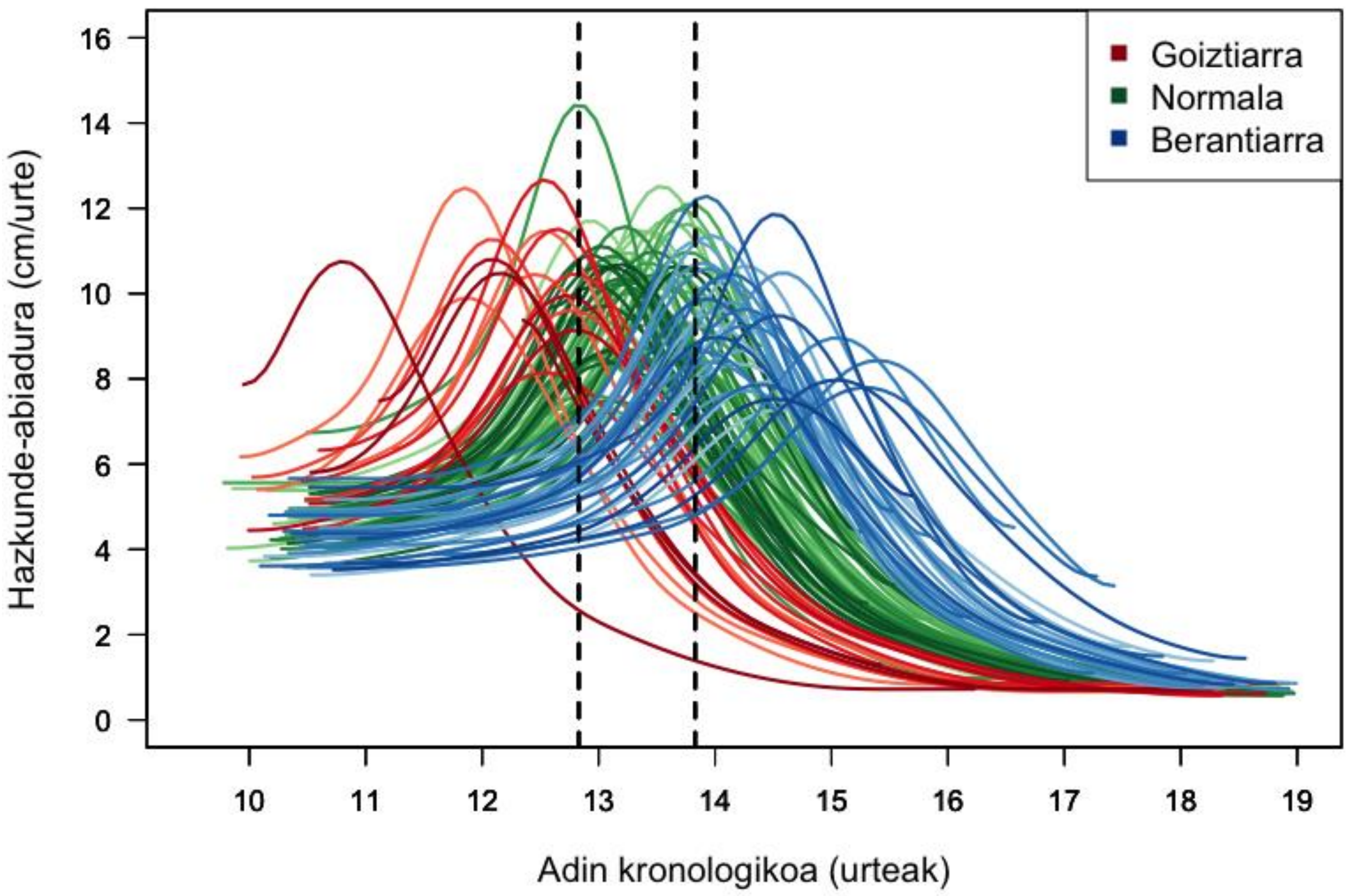
Jokalarien hazkunde-kurbak *cubic splines* izeneko bigarren modelizazio metodo batekin ere modelizatu ziren (51); izan ere, metodo honek hazkunde-kurbaren puntu bakoitzean (0,1 urtero) jokalariaren altuera eta hazkunde-abiadura (cm/urte) kalkulatzea baimentzen du.

Bestetik, helduaroko altuera ere heltze somatikoa aztertzeko erreferentzia gisa hartu zen. Helduaroko altuera jokalaria urtebetez hazkunde-abiadura 1 cm/urte baino abiadura txikiagoa zuenean ezarri zen. Behin helduaroko altuera jasota, modu erretrospektiboan, momentu konkretu batean jokalariaren helduaroko altueraren zein ehunekotan zegoen kalkulatu eta jokalariak *pre*-, *circa*-, *post*-PHV edo heldu bezala sailkatu ziren. Sailkapen hau egiteko, literaturan erabiliak izan diren *circa*-PHV periodorako banda ezberdinak erabili ziren (1.8 Irudia); horien artean, %85-%95, %85-%96, %88-%96, %88-%93 eta %90-%93 (20).

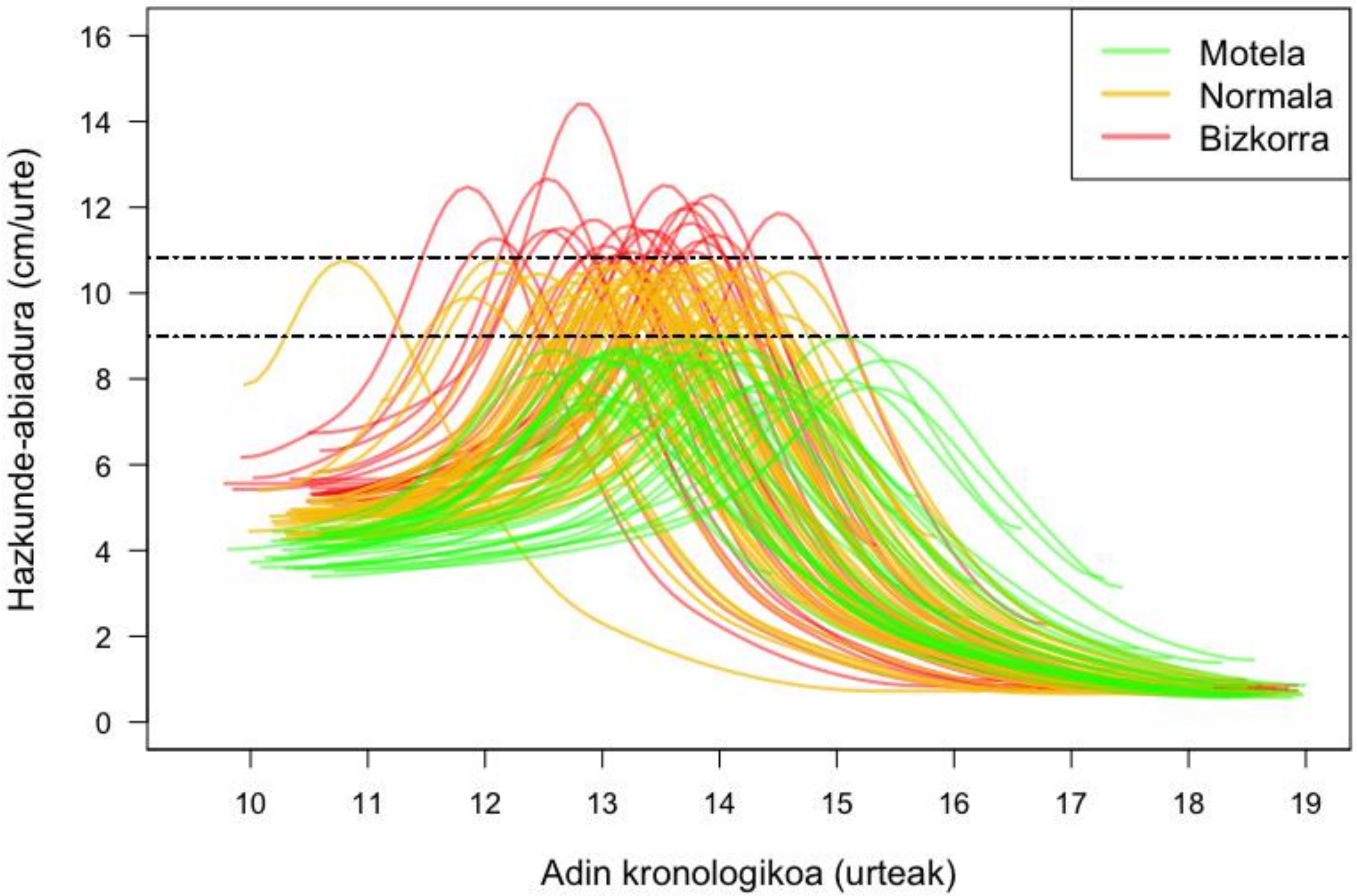
Bestetik, SITAR metodoa (50) erabilita (*gold standard*) PHV adina eta heltze-egoera (*pre*-, *circa*- eta *post*-PHV) aztertu ziren jokalarietan (n=124), estimazio ekuazio ezberdinen bidez heltze-egoera (*pre*-, *circa*- eta *post*-PHV) aztertu zen berriz. Horrela, *gold-standard*arekin egindako sailkapena eta metodo ezberdinen bidez egindakoa konparatzeko. Erabilitako estimazio ekuazioak hurrengoak izan ziren: *maturity offset* ekuazioak [Mirwald (17), Moore-1 eta 2 (18), *maturity ratio*a [Fransen (19)] eta Khamis-Roche ekuazioa (21). Horrez gain, hazkunde-kurbak ebaluatzen aditua zen aztertzaile baten heltze-egoera sailkatzeko gaitasuna aztertu zen. Horretarako, 124 jokalarien hazkunde-kurben datu antropometrikoak erabilita, osatu gabeko 2560 hazkunde-kurba (oraindik hazten ari ziren jokalarien kurbak) biltzen zituen galdetegia egin zen (https://sites.google.com/view/growthcurvessurvey). Hazkunde-kurbak aztertzen esperientzia duen profesional batek galdetegiko kurbak *pre*-, *circa*- edo *post*-PHV bezala sailkatu ziren. Ondoren, *gold-standard*arekin egindako sailkapenarekin konparatu zen. Erreferentziazko metodoarekin, estimazio ekuazioekin eta hazkunde-kurben obserbazioaren bidez egindako heltze-egoeraren sailkapenak (*pre*-, *circa*- eta *post*-PHV) egiterakoan aurreko bi paragrafoetan aipatutako irizpide berdinak erabili ziren. Hau da, PHV adina ± 0,5 eta 1 urteko tarteak (SITAR, maturity offset, maturity ratio eta hazkunde-kurben obserbazio bidez egindako sailkapenetan) eta helduaroko altueraren banda ezberdinak (PAH% bidez sailkatu zenean).



3.1 Irudia: Inklusio-irizpideak bete zituzten Athletic Clubeko jokalarien hazkunde-kurba modelizatuak (n=124) (BCAMeko ikerlariekin egindako grafika).



3.2 Irudia: Athletic Clubeko jokalarien heltze-*timing*aren araberako sailkapena Euskal Herriko *peak height velocity* adina erreferentziatzat hartuta (n=110). Lerro bertikal ez-jarraituek jokalariak goiztiar (peak-height velocity adina <12.8 urte), normal (12.8–13.8 urte) edo berantiar (>13.8 urte) bezala sailkatzeko adin kronologikoaren mugak adierazten dituzte. (BCAMeko ikerlariekin egindako grafika).



3.3 Irudia: Athletic Clubeko jokalarien *peak height velocity*aren (cm/urte) araberako sailkapena (n=124). Lerro horizontal ez-jarraituek jokalariak bizkor (*peak-height velocity* ≥10,84 cm/urte), normal (8,98–10,84 cm/urte) edo motel (≤8,98 cm/urte) bezala sailkatzeko mugak adierazten dituzte. (BCAMeko ikerlariekin egindako grafika).

3.7 DATUEN ANALISIA

Lesioen intzidentziak (lesio kopurua/esposizio denbora) eta *injury burden*ak (baja-egun kopurua/esposizio-denbora) kalkulatu ziren. Bestalde, taldeen arteko intzidentziak eta *burden*ak konparatzeko *Rate Ratio*ak erabili ziren. Fidagarritasun-tarteak % 95eko fidagarritasun-mailan kalkulatu ziren *bootstrap* prozedura parametrikoa erabiliz. Horrez gain, P balioak Benjamin & Hochberg metodoarekin egokitu ziren R programako *padjust* paketea erabilita. Emaitzak adierazgarritzat hartu ziren $p < 0{,}05$ zenean.

Estimazio-metodoak erabiliz kalkulatutako heltze-egoeraren sailkapena (*pre*-, *circa*- eta *post*-PHV) eta erreferentziazko sailkapenaren arteko konkordantzia aztertzeko, *Cohen´s Kappa* (52) kalkulatu zen.

4. RESULTS AND DISCUSSION

4. RESULTS AND DISCUSSION

PAPER I: AN INJURY BURDEN HEAT MAP OF ALL MEN'S AND WOMEN'S TEAMS OF A PROFESSIONAL FOOTBALL CLUB OVER A DECADE

Under review in *Journal of Science and Medicine in Sport*.

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ABSTRACT

Objectives: To provide a descriptive 10-season summary of injury data from all teams of a professional football club, presenting the incidence, median severity, and burden of specific injuries as a heat map.

Methods: All men's and women's teams from Athletic Club were prospectively followed from 2011 to 2021. Injuries and exposure time were registered according to the FIFA consensus. A team-by-injury table was created, showing the incidence, median severity, and burden in each cell. Cells were colored based on the injury burden value using a green–yellow–red gradient (lowest to highest).

Results: The highest overall injury burden was found in the women's 2nd and 1st teams and the men's U(under)17 team (>200 days lost/1000 h). Muscle injury burden demonstrated an increasing pattern with age, with hamstring and quadriceps injuries being the major muscle injury types. Knee joint/ligament injuries, particularly anterior cruciate ligament ruptures, had the highest impact on women's teams, followed by the men's 2nd team. Ankle joint/ligament injuries had a relatively low injury burden in most teams compared to both muscle and knee joint/ligament injuries. Growth-related injuries were the most impactful injuries in the men's U15 and younger teams, and the women's U14 team, with a predominance of anterior inferior iliac spine injuries and spondylolysis.

Conclusion: Epidemiological data on injuries can inform and guide injury management processes. New and improved visualization methods might be important assets for sports science and medicine departments when presenting injury data to key decision-makers.

Keywords: soccer, epidemiology, data visualization, prevention, rehabilitation.

INTRODUCTION

Understanding the injury profile of football players provides a foundation for football practitioners and researchers working in injury prevention and rehabilitation (53). Football clubs include both men's and women's teams and encompass all levels from the youngest academy age groups (~9–11 years old) to adult professional 1st teams. Establishing a continuous injury surveillance system in each team with detailed injury and exposure time registration is necessary to determine the objectives and evaluate the effectiveness of injury management plans (40).

While there is a considerable body of injury-related literature on adult men's football (54), there is a scarcity of studies evaluating youth and women's teams (4,55). Further, most studies focus on the number of injuries, though it is also necessary to account for injury severity and burden (5). A recent and powerful tool employed to assess these variables is the injury risk matrix (7,8,56–58), which presents a) injury incidence (number of injuries/1000 h), b) mean or median injury severity (number of days lost per injury), and c) injury burden (days lost/1000 h), calculated as the cross-product of incidence and severity (5). Despite being highly informative, risk matrices may be challenging to interpret for those unfamiliar with scientific figures, as may be the case for the key decision-makers in a football club (e.g., players, coaches, directors). In addition, analyzing individual figures for each team in a club with 10 to 20 teams is time-consuming, and more efficient presentation formats may facilitate improved communication with decision-makers and enhance their engagement in injury management strategies (59).

We propose a heat map approach that contains the incidence, median severity, and burden of specific injuries in all men's and women's teams of a football club and employs colors to guide the identification of the most burdensome (or hot) injuries as a quick overview. Moreover, sharing single-club injury data remains important, as it may serve as a reference for other clubs or researchers seeking to compare their data and inform prevention targets and hypotheses regarding potential risk factors. Thus, the aim of this study was to provide a descriptive summary of 10 seasons of injury data collected from all teams of a professional football club that presents the incidence, median severity, and burden of specific injuries as a heat map.

METHODS

Participants and study design

The study was approved by the Ethics Committee of the University of the Basque Country (CEISH/340/2015). All players from Athletic Club were prospectively followed over 10 consecutive seasons (from July 2011 to June 2021), except for men's U(under)12 (2013–2021), women's 2nd (2017–2021), women's U16 (2018–2021) and women's 3rd and U14 (2019–2021) teams. Athletic Club's men's and women's 1st teams play in the Spanish First Division. The academy has a team in each of the age-based levels or categories. In men, this includes U11, U12, U13, U14, U15, U16, U17, and U19 teams, in addition to 3rd and 2nd teams comprising 17–23-year-old players competing in the Spanish Fourth and Third Divisions, respectively. In women, this includes U14 and U16 teams as well as a 3rd team (15–21 years old, Spanish Third Division) and a 2nd team (17–23 years old, Spanish Second Division).

Injury and exposure time recording

The club's 4 doctors, who remained the same for all 10 seasons, diagnosed, treated, and recorded all time-loss injuries according to the consensus on definitions and data collection procedures outlined by the International Federation of Association Football (FIFA) (12). All teams had daily access to the medical staff, and consistent injury-recording procedures were employed. The specific injury diagnoses were recorded in the club's online database when a player was unable to participate in a future training session or match due to a physical complaint resulting from football training or match play, and the player was considered injured clearance from the medical staff for full participation was obtained.

Injuries were classified into the following 5 groups based on previous studies and practitioner experience (60): 1) muscular (quadriceps, hamstring, adductor, calf, gluteal, and psoas), 2) knee joint/ligament (anterior cruciate ligament [ACL], meniscal and medial collateral ligament), 3) ankle joint/ligament (lateral collateral ligament and syndesmosis), 4) growth-related (Sever's disease, Osgood-Schlatter disease, spondylolysis, and osteochondrosis of the anterior inferior iliac spine, ischial tuberosity, or anterior superior iliac spine), and 5) other diagnoses, including low back pain, groin pain (adductor-, iliopsoas-, inguinal- and pubic-related), contusion, bone injury, tendon injury, and concussion. Individual player exposure time in minutes in both training and matches was recorded daily by the medical and coaching staff (40).

Data analysis

Injury incidence is presented as the number of time-loss injuries/1000 hours and injury burden is presented as the number of days lost/1000 hours. Injury severity is expressed as the median number of days lost. A team-by-injury table was created, showing injury incidence, median severity, and burden in each cell. Cells were colored based on the injury burden value using a custom-developed green–yellow–red gradient, with an injury burden of 0 indicated by green and the highest burden value indicated by dark red. All analyses were performed using R version 4.1.2 (R Core Team 2021, R Foundation for Statistical Computing, Vienna, Austria).

RESULTS

The injury heat map is presented in Figure 4.I.1. The highest overall injury burden was observed in the women's 2nd and 1st and men's U17 teams, with values above 200 days lost/1000 h. Muscle injury burden had an increasing pattern with age, with overall high incidence values but low median severities. Muscle injury burden was highest in the women's 1st team, and muscle injuries carried the highest burden of all injuries in the men's 1st and 3rd teams. Hamstring injuries predominated in men's U19 and older teams, while quadriceps injuries had a similar or higher impact on most of the younger teams. In the women's 1st team, hamstring injuries had a similar burden to that observed in the men's teams, though this was not the case for the other women's teams. Meanwhile, the burden of quadriceps injuries peaked in the women's 2nd and U16 teams. In the women's 1st team, calf injuries had the same burden as hamstring injuries and were responsible for the highest median number of days lost of all muscle injuries.

Knee joint/ligament injuries demonstrated large injury burden values in the women's teams, with ACL ruptures being the injury with the highest impact in all women's teams. In men, knee joint/ligament injuries and ACL ruptures had the highest incidence and burden values in the men's 2nd team. Of all injury types, ACL rupture accounted for the highest median absence (192–372 median lost days). Ankle joint/ligament injuries had a relatively low injury burden in most teams compared to muscle and knee

	TOTAL	Muscular	Hamstrings	Quadriceps	Adductor	Calf	Gluteal	Psoas	Knee joint/lig.	ACL	Meniscal	Knee MCL	Ankle joint/lig.	Ankle LCL	Syndesmosis
Men's 1st	7.2-8 120	3.4-9 45	1.4-11 20	0.6-12 11	0.7-9 7	0.4-6 5	0.2-6 1	0.1-4 0	0.5-12 21	0.1-192 11	0.1-16 3	0.1-11 2	0.9-9 17	0.4-6 4	0-31 1
Men's 2nd	7.3-7 169	3.4-7 47	1.6-8 25	0.9-8 14	0.5-7 5	0.1-11 1	0.2-6 1	0.1-4 1	0.9-20 79	0.2-213 46	0.2-38 8	0.2-17 3	0.8-8 11	0.5-9 9	0-26 1
Men's 3rd	6.8-9 150	2.9-9 39	1.1-9 15	0.7-10 10	0.6-6 8	0.1-4 0	0.2-4 1	0.3-13 6	0.8-10 35	0-256 9	0.2-38 10	0.3-8 2	1-13 20	0.5-11 7	0.1-31 2
Men's U19	8.3-9 191	3.1-7 43	1.2-7 21	0.7-7 8	0.3-6 3	0.2-10 2	0.2-9 2	0.4-9 4	0.9-39 50	0-306 12	0.3-23 11	0.2-16 5	1-14 20	0.6-13 11	0.2-36 6
Men's U17	7.3-11 207	2.8-10 46	0.7-8 13	0.9-18 17	0.5-8 6	0.2-12 3	0.2-9 2	0.2-12 2	0.5-16 45	0.1-266 36	0.1-9 3	0.1-6 1	1.2-15 33	0.7-8 14	0.2-56 13
Men's U16	6.6-11 188	2.6-9 42	0.7-8 11	0.8-13 15	0.3-14 5	0.1-3 1	0.3-10 3	0.4-7 5	0.5-17 41	0.1-260 26	0.1-98 9	0.1-10 1	0.8-15 17	0.5-15 9	0.1-46 5
Men's U15	6.6-12 169	2.4-11 35	0.8-10 15	0.4-11 6	0.4-7 3	0.2-10 2	0.2-14 3	0.4-13 5	0.5-26 20	0-237 6	0.1-42 6	0.1-20 2	0.4-10 6	0.3-9 3	-
Men's U14	6.7-16 184	1.5-14 24	0.5-15 8	0.4-28 9	0.1-6 1	0.2-23 3	0.1-12 1	-	0.3-9 9	-	0-64 3	0.1-7 1	0.7-12 13	0.4-12 8	0-45 1
Men's U13	4.8-16 145	0.8-6 16	0.4-10 4	0.1-30 10	0.1-5 1	0.1-7 1	0-14 0	-	0.4-16 8	-	-	0.2-16 3	0.2-5 2	0.2-8 2	-
Men's U12	3.7-10 57	0.6-8 7	0.4-8 4	0.2-14 3	0-3 0	0-5 0	-	-	0.2-8 2	-	-	0.1-16 2	0.3-8 2	0.1-8 1	-
Men's U11	4-10 73	0.8-9 14	0.3-9 4	0.2-25 9	0.2-4 1	0.1-6 0	-	-	0.3-11 6	-	0.1-20 1	0.1-12 1	0.1-6 1	0.1-12 1	-
Women's 1st	7.1-12 224	3.8-12 66	1.2-13 20	1.1-12 17	0.7-9 8	0.6-18 20	0.1-6 1	0.1-5 0	1.3-18 119	0.2-254 68	0.2-51 11	0.2-17 5	0.7-11 16	0.4-4 4	0.1-45 6
Women's 2nd	5-15 241	2.7-14 48	0.3-9 2	1.6-18 33	0.5-12 8	0.2-20 3	0.1-4 0	0.1-15 1	1.1-41 133	0.3-372 90	0.3-6 7	0.1-7 0	0.5-16 18	0.3-12 4	-
Women's 3rd	4.3-11 154	1.3-10 15	0.2-20 5	0.5-9 4	0.2-14 3	0.1-9 1	0.1-5 1	0.1-3 0	0.9-34 96	0.4-248 90	0.1-2 0	0.1-34 4	0.9-11 15	0.7-10 9	0.1-47 6
Women's U16	5.7-23 191	2.2-18 46	0.8-8 8	0.8-32 28	0.3-6 2	0.3-26 7	-	-	1.7-32 102	0.1-362 50	0.1-24 3	0.4-44 21	0.6-14 9	0.4-9 5	-
Women's U14	3.6-17 174	0.9-14 16	0.4-13 6	0.4-24 10	-	-	-	-	0.4-142 61	0.2-222 47	-	-	0.4-77 33	0.2-10 2	-

	Growth-related	Sever	Osgood	AIIS	ASIS	Ischium	Spondylolysis	Low back pain	Groin pain	Contusion	Bone	Tendon	Concussion
Men's 1st	0-70 1	-	-	-	-	-	0-70 1	0.2-4 1	0.4-27 7	1.3-4 9	0.2-43 7	0.3-4 7	-
Men's 2nd	0-100 3	-	-	-	-	-	0-100 3	0.2-4 1	0.3-10 4	0.9-4 5	0.3-18 10	0.2-3 2	0-9 0
Men's 3rd	0.1-104 6	-	-	-	0-56 2	-	0-107 4	0.1-8 2	0.3-26 12	1-5 11	0.3-37 17	0.1-7 1	0-12 0
Men's U19	0.2-86 11	-	-	-	0-15 1	-	0.1-105 11	0.4-10 4	0.3-29 24	1.1-3 7	0.5-21 16	0.3-6 6	0.1-3 0
Men's U17	0.3-65 17	-	-	0-54 2	0.1-47 3	0.1-53 5	0.1-86 7	0.4-11 5	0.1-82 10	0.9-3 4	0.4-34 23	0.1-14 2	-
Men's U16	0.6-71 39	0-6 0	-	0.1-16 2	0.1-71 8	0.1-41 4	0.2-91 23	0.4-8 4	0.1-90 8	0.8-6 10	0.3-61 25	0.1-5 0	0.1-8 1
Men's U15	1.1-46 64	0.1-12 1	0.1-9 2	0.4-35 15	0-26 1	0.1-38 4	0.4-89 34	0.4-14 10	0.1-26 3	0.7-4 5	0.4-37 18	0.1-13 3	0-7 0
Men's U14	2.7-24 103	0.5-12 8	0.4-15 7	0.9-25 29	0-60 3	0.3-27 10	0.2-118 34	0.2-24 5	0-46 1	0.5-9 5	0.6-32 24	0-2 0	-
Men's U13	2.2-24 87	0.5-18 9	0.2-14 10	0.8-24 28	-	0.2-54 13	0.1-133 10	0.2-10 5	0-9 0	0.4-6 4	0.4-32 20	0-9 0	-
Men's U12	1.9-13 33	0.4-10 5	0.2-10 3	0.6-15 13	-	0.1-19 2	-	0.1-3 0	-	0.3-6 2	0.2-34 9	0-8 0	0-3 0
Men's U11	2.3-13 43	0.4-8 5	0.1-7 1	0.9-14 17	-	0.2-25 6	0-164 5	-	-	0.3-9 3	0.1-35 4	-	-
Women's 1st	-	-	-	-	-	-	-	0.1-8 1	0.1-20 2	0.4-4 2	0.2-12 4	0.3-6 7	-
Women's 2nd	-	-	-	-	-	-	-	-	0.1-9 1	0.4-12 28	0.1-66 7	-	-
Women's 3rd	0.2-68 16	-	0.2-68 16	-	-	-	-	0.4-4 3	-	0.4-8 3	-	-	-
Women's U16	0.4-17 7	-	0.1-28 4	0.1-6 1	-	-	-	0.1-23 3	-	0.1-14 2	0.7-33 27	-	-
Women's U14	1.7-18 63	0.2-4 1	0.4-6 2	0.9-23 35	-	-	0.2-119 25	0.2-8 2	-	-	-	-	-

Figure 4.I.1: Injury burden heat map of all teams of a professional football club over a decade.

Each cell shows the number of injuries/1000 h (top left), the median absence days per injury (top right), and the number of days lost/1000 h (bottom). Cells are colored based on the injury burden value using a green–yellow–red gradient, with an injury burden of 0 indicated by green and the highest burden value indicated by dark red. ACL: Anterior cruciate ligament, AIIS: Anterior inferior iliac spine, ASIS: Anterior superior iliac spine, LCL: Lateral collateral ligament, Lig.: Ligament, MCL: Medial collateral ligament, U: Under.

joint/ligament injuries, with men's U17 and women's U14 teams having the highest values.
Growth-related injuries were the most impactful injuries in men's U15 and younger and women's U14 teams. The highest growth-related injury burden was observed in the men's U14 team. Anterior inferior iliac spine injuries were the injuries with the highest burden in men's U13 and younger and women's U14 teams, while spondylolysis was the most burdensome injury in men's U14 and U15 teams and also had a high impact on men's U16 and women's U14 teams. Spondylolysis had the second highest median absence of all injuries, accounting for approximately 100 days of absence per injury. Regarding the remaining injury diagnoses, bone injuries (primarily fractures) had a relatively high burden and median absence in most academy teams, groin pain had a high impact on the men's U19 team, and contusions on the women's 2nd team. Additional detailed injury data for each team and the yearly evolution of injuries are provided in a Supplementary File.

DISCUSSION

This is the first study to describe the incidence, severity, and burden of injuries in all men's and women's teams of a professional football club. The results were synthesized using a heat map approach to ease the interpretation and guide the quick identification of injury-related hotspots. Our findings indicate that the overall injury burden was highest in the women's 2nd and 1st teams. Men's academy teams also had high injury burdens, which peaked at the U17 level and were in general higher than those observed in the 1st team. The pattern of injuries varied according to the team level, and the findings need to be discussed in relation to injury etiology and potential applications.

Hotspot of knee injuries in women's football

The substantial impact of knee joint/ligament injuries in women's football, which is 2 to 6 times higher than in men' football, is well known and appears to be related to biomechanics and neuromuscular control of the trunk, hip, and knee (61). ACL rupture specifically is one of the most concerning injuries for player development, as it results in greater than 200 days of absence and potential long-term consequences (62). These injuries had a large impact on all women's teams in this study, including the younger age groups (56). In men's football, the burden of knee joint/ligament injuries was very low in players younger than 15 years of age but had a similar impact to that of muscle injuries in older players who had surpassed the adolescent growth spurt period (33). A positive finding was that men's 1^{st} team players had a very low burden of knee and ACL injuries, which supports the notion that male players reaching the highest playing level are resilient to injury (3).

There was nonetheless a concerning result regarding the men's 2^{nd} team, where knee joint/ligament injuries and ACL ruptures were found to be particularly burdensome. The progression from the 2^{nd} to the 1^{st} team is the most challenging step for academy players (63). They are young (18–23 years old) and potentially not fully developed, they compete in a professional league under considerable pressure against high-level adult players, and they may encounter physical and psychosocial demands for which they are not prepared (3,64). Female 2^{nd} team players may experience similar challenges, as evidenced by the finding that they had the highest overall and ACL rupture burden of the entire club. These results are worrisome, as we have previously shown that high injury burden, low match availability, and an ACL rupture in 2^{nd} and 3^{rd} team male players decreased their chances of progressing to the 1^{st} team (3).

Muscle injury burden gradually increased with age

The progressive increase in the burden of muscle injuries from the youngest age groups to the adult teams is in agreement with previous studies (7,8,58). As we have previously shown, muscle injury burden increases after the adolescent growth spurt (60) and continues to rise as players face a larger volume of high-intensity demands with increasing age and playing level (7,58). Hamstring injuries remain the most impactful injuries in adult men's football (65); however, quadriceps injuries had a similar or higher burden in most academy teams.

The highest muscle injury burden was observed in the women's 1^{st} team. We previously reported a higher incidence of quadriceps injuries than hamstring injuries in our women's 1^{st} team based on data from the first 5 seasons included in this study (66). Nevertheless, the trend changed in the last 5 seasons, with a higher incidence and burden of hamstring injuries observed, similar to those seen in the men's teams (Supplementary File, page 63) (67,68). In the majority of the younger women's teams, however, quadriceps injuries continued to predominate. In the ongoing professionalization of women's football, clubs are likely to invest more in their 1^{st} teams, and we may expect to see substantial differences in the physical qualities, demands, and practices of 1^{st} team players compared to academy players (69). This may also extend to their injury patterns, and the quickly evolving nature of women's football calls for constant updates and special attention paid to academy players (56).

Growth-related injuries had a large impact on boys and girls

Growth-related injury burden peaked in the men's U14 team, with similar values to those of knee joint/ligament injuries in women. This age group generally coincides with peak height velocity (PHV; ~13.8 years in boys), the most rapid point of growth in stature during the adolescent growth spurt. This period is characterized by rapid skeletal growth, which causes neuromuscular alterations (33), a temporary decrease in bone mineral density (70), and weakness of the epiphyseal growth plates (32). However, not all boys experience PHV at the same age (13), which might explain why the growth-related injury burden was also high in men's U13 and U15 age groups. Thus, it is key to account for individual maturation status, which was not performed in the current study (60).

Growth-related injuries also appeared to be a problem in female U14 players, though the injury burden in this age group was lower compared to males of the same age group. An earlier occurrence of PHV (~12.1 years) and slower growth rates in girls might explain these results (13). It is possible that at younger ages (<U12), female players also suffer a high burden of growth-related injuries. However, little scientific and practical evidence is currently available regarding growth, maturation, and injuries in women (56).

The 2 major growth-related injury types in both males and females were anterior inferior iliac spine injuries and spondylolysis. The repetitive football actions of kicking and sprinting place the immature anterior inferior iliac spine, the proximal origin of the straight head of the rectus femoris, at risk (10,71). Similarly, repetitive and excessive lumbar extension and rotation is the primary mechanism of spondylolysis, which peaks post-PHV when neuromuscular control is impaired (33,60). Although occurring infrequently, spondylolysis causes prolonged absences (∼100 days) and may have long-term consequences (72).

Burden of other injury types

Ankle joint/ligament injuries are considered to have an important presence in the injury profile of football players (68,73). In our sample, despite being more frequent than knee joint/ligament injuries, they had approximately half the burden of both muscle and knee joint/ligament injuries. Among other injury types, the most relevant contributors to the overall injury burden were bone injuries, primarily fractures, which were particularly frequent and burdensome in young players (8). Nonetheless, it is worth noting that some injuries with relatively low injury burden, such as tendon injuries, low back pain, groin pain, or ankle injuries, tend to present as chronic overuse injuries that do not result in an absence from the pitch. Since non–time-loss injuries were not recorded in this study, the true impact of these injury types is expected to be higher than what we observed (74). This might be particularly relevant as players approach the professional-team levels. The pressure to be available is high, and players may continue playing in the presence of pain with the aid of medication or other relieving strategies (75). In this line, concussions have become a point of emphasis due to their potential long-term neurocognitive impact. Despite the frequency and median severity of concussions being low in our study, we acknowledge that their management and registration need to be improved (76). Finally, some injuries might not be frequent or burdensome at the team level but may have significant consequences at the individual level if they are not properly managed and complications arise, or the injury reoccurs.

Practical applications and limitations

The injury heat map provides a general overview of a club's injury situation over a given period in an easy-to-interpret format that is appropriate for directors, coaches, and sports science and medical staff. These key stakeholders can quickly identify the injuries with the highest impact, or hotspots, at the club level. While the current discussion considered the vertical analysis of the heat map (i.e., the discussion centered around the types of injuries), horizontal analysis by team enables the identification of the most relevant injury management targets for each team, irrespective of how the data compares with other teams. Comparison with previous or reference data may also facilitate the evaluation of the effectiveness of current strategies. Injury-related data may have additional applications, such as the inclusion of availability or injury burden objectives as contract incentives for players and staff. This type of visualization fits well in injury reports that clubs periodically produce (typically 2–4 times per season). These reports are important assets for sports science and medicine departments and may contain other data not included in this manuscript, such as yearly evolution graphs, availability, individual player data, comparisons with other periods, and suggested strategies.

This is, however, only a descriptive analysis that should be followed by efforts to understand injury mechanisms and risk factors and improve preventive strategies and return-to-play processes considering the individual characteristics of each player (55). Among other limitations, our data only pertain to a single club, and the injury profile of football teams appears to be affected by numerous contextual factors that were not accounted for and could have varied over the study period (e.g., coaching, playing style, resources, prevention and return-to-play strategies), which limits the generalizability of the results. The categorization of injuries might also be club-dependent, and the sample of injuries and team-seasons was small in some cases. All in all, consistent injury data recording, analysis, visualization, and communication are keystones of injury management systems and player development and performance programs. We would like to encourage clubs and organizations to share their data, as they might serve as references for other clubs and contribute to meta-analysis research.

Conclusions

This study described the incidence, severity, and burden of injuries in all men's and women's teams of a professional football club using a heat map format that provides a quick, color-based overview of injury impact. The highest overall injury burden was found in the women's 2nd and 1st and men's U17 teams. Muscle injury burden demonstrated an increasing pattern with age, while knee joint/ligament injuries, particularly ACL ruptures, had the highest impact on the women's teams. Growth-related injuries were the most impactful injuries in men's U15 and younger and women's U14 teams, with a predominance of anterior inferior iliac spine injuries and spondylolysis. Such information, when consistently collected in a club context, can be used to identify action points and evaluate the effectiveness of strategies as the first step in the management of injury prevention and return-to-play processes. New and improved visualization methods may be important assets for sports science and medicine departments when presenting injury data to key decision-makers.

PAPER II: RELATIVE SKELETAL MATURITY STATUS AFFECTS INJURY BURDEN IN U14 ELITE ACADEMY FOOTBALL PLAYERS

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ABSTRACT

Maturation progresses at different times and at different rates between individuals. Thus, differences in maturity status exist among players in the same chronological age-based category, especially in U14 players. The purpose of this prospective study was to describe injury burden according to the relative skeletal maturity status in U14 elite academy football players. From 2011 to 2020 injuries and individual exposure (training and match) were prospectively recorded in 183 male U14 players. Skeletal age (SA) was assessed using the Tanner-Whitehouse 2 method. Relative skeletal maturity status [SA minus chronological age (CA)] was classified as follows: early (SA-CA > 0.5), on-time (SA-CA ± 0.5) and late (SA-CA < -0.5). Overall and specific injury burden (days lost/1000h) and rate ratios for comparisons between groups were calculated. Overall injury burden was 2.8-times higher (3.6-times in training) in early maturers compared with late maturers. Growth-related injuries were the most burdensome injuries in all three groups, but significant differences were not found between groups. Muscle injuries were 4-times more burdensome in early maturers compared with on-time and late maturers. Besides, joint/ligament injuries were 7- and 12- times less burdensome in late maturers than in on-time and early maturers, respectively. Significant differences between groups in overall and specific injury burden were not found in matches. Our results showed different injury patterns in U14 early, on-time and late maturers. Hence, monitoring maturity seems crucial to detect potential injuries that cause the greatest disruption, and facilitate design of targeted injury prevention programs.

Keywords: epidemiology, football, injury, burden, maturation, growth and development, youth, adolescence.

INTRODUCTION

Professional football clubs invest many resources in their youth academies to develop young football players, with the aim of providing new players to the First team. Remaining free of injury is a key factor for progressing (3), not only that, injuries lead to increased susceptibility for future injuries and long-term health risks in adulthood (1). Thus, preventing injuries is a priority in football.

Injury incidence (injury frequency) and burden (the product of injury frequency and severity) peaks since early- (Under U12-U14) and mid- adolescence (Under U15-17) (8), when marked somatic growth and significant musculoskeletal and physiological development occur. U14 age group generally coincides with the peak height velocity (PHV) in males, which is the period of maximal growth during adolescence (13). However, due to individual variance in pubertal timing, not all boys will experience the growth spurt at the same age (13). Consequently, inter-individual differences in maturity status can be found among players of the same age-based category, especially in U14s (77,78). The large variations in maturity status within chronological age groups have been proposed as factors that may influence injury risk in young footballers. On the one hand, it is assumed that early maturers, whose maturation occurs in advance of the mean and are likely to be bigger, heavier and stronger (13), may be at higher risk due to greater engagement and involvement in competitive play. Besides, inappropriate training load in groups of players with mixed maturity and developmental status is another related worry (79). However, available data on growth, maturation and injury risk in football provide conflicting evidence due to methodological differences and limitations.

Skeletal maturation is considered the single best maturity indicator, as the start (skeleton of cartilage) and endpoints (skeleton of mature bone) are known and can be followed throughout the maturation process with precise and reliable estimates (13). Nevertheless, to date, most of the studies have used non-invasive methods with limited accuracy and only 3 studies have considered the effect of skeletal maturity on injuries in elite youth football players (38,39,80). Available research assessing skeletal age suggest that early maturers, who have advanced skeletal age compared to their chronological age (relative maturity status), have a higher injury incidence compared with on-time and late maturers (38,39,80). Regarding specific injury risk, early maturers seem to be more prone to muscle and tendon injuries, while on-time and late maturers have higher incidence for growth related injuries (38,39).

Available research which measured skeletal age also have inherent limitations. Firstly, they measured injury incidence, which does not account for injury severity. Identifying injuries with the highest injury burden is vital to detect potential injuries that cause the greatest disruption, and facilitate design of targeted injury prevention programs (5). Secondly, they did not account for individual exposure data. Recent research suggests that advanced maturity status in U11, U13 and U14 groups is associated with higher grades in coaches' evaluations of match performance (81). This may translate to more playing opportunities and therefore, research which includes individual training and match exposure is needed to allow for direct comparisons and more nuanced interpretation (40). This study aimed to build on these limitations by using 9-season injury, exposure (training and match) and skeletal maturation data to describe overall and specific injury burden in U14 early, on-time and late maturing elite academy football players.

MATERIALS AND METHODS

Study design and study population

A prospective observational study of 183 male U14 players of an elite Spanish football academy was carried out between the 2011-2012 and 2019-2020 playing seasons. The male professional team plays in the Spanish LaLiga, and the development of academy players is key to the club's success because only players developed in the academy or born in the Basque Country can play in this club. Players were single sports athletes, trained 4 times per week and played a game every weekend. This study was approved by the Ethics Committee of the University of the Basque Country (UPV/EHU) (CEISH/340/2015). Written informed consent to use regularly collected data for research purposes was obtained from the players guardians.

Recording of injuries and exposure

Players' training/match exposure in minutes (daily) and injuries were recorded. The club's medical staff diagnosed, treated, and recorded all time-loss injuries following the consensus on definitions and data collection procedures outlined by the International Federation of Association Football (FIFA) (12). Injuries were recorded when a player was unable to participate in a future training session or match due to a physical complaint. A player was considered injured until the medical staff cleared the player for full participation.

Growth-related injuries were not explicitly considered by the 2006 consensus statement on injury definitions (12). Thus, we included an additional category for "growth-related injuries", defined as unique injuries not seen in adults but common in skeletally immature athletes (e.g., growth plate fractures, apophysitis, apophyseal avulsion fractures, and greenstick fractures) (9). Injuries were classified into three groups based previous research (8,11,60,77) and practitioner experience: 1) growth-related injuries (Sever's disease, Osgood Schlatter disease, apophyseal injuries (osteochondrosis or avulsion) of the anterior inferior iliac spine, ischial tuberosity, or anterior superior iliac spine and spondylolysis), 2) muscle injuries (quadriceps, hamstring, and adductor), and 3) joint/ligament injuries (knee and ankle). The same doctor recorded injuries since the start of the study, thereby reducing the chance of bias, differences in injury interpretation, and changes in observation methods between doctors.

Anthropometric measurements

Standing height (±0.1 cm; Añó Sayol, Barcelona, Spain) and weight (±0.1 kg; Seca, Bonn, Germany) was measured by doctors before afternoon trainings. The same two doctors measured players during the entire study period, thereby reducing chance of bias.

Skeletal maturity status

Skeletal maturation was assessed at the beginning of the season, using x-ray images of the athlete's left hand and wrist complex. Skeletal age was determined using the Tanner–Whitehouse radius-ulna-short bone protocol (TW2-RUS) using sample data of the Basque Country (47). This allowed us to make better comparisons with reference to sample data as our academy only admits players born or developed in the Basque Country. TW2-RUS has been shown to be the method of choice for those using the Tanner–Whitehouse protocol with youth football players (48).

The images were interpreted by two experienced doctors who were based at the academy for over 20 years and were in place throughout the 9-season period of the present study. Doctors were trained in the use of this method and have a decade experience carrying out skeletal age assessments using TW2-RUS. To test the reproducibility of the assessments of the bone age, the investigators re-evaluated randomly selected hand–wrist radiographs from 10 subjects in 2021. The coefficients of intra-observer and inter-observer reliability were 0.99 (0.98-1) and 0.95 (0.84-0.99) with an error of 0.10 and 0.25 years, respectively.

Players were assigned into three categories according to their relative skeletal maturity status: early, on-time, or late. On-time maturers refer to players whose SA is within 0.5 years of the CA, early maturers refer to players whose SA is older than CA by more than 0.5 years and late maturers refer to players whose SA is younger than CA by more than 0.5 years. Mature players (SA > 18 years) with hand and wrist fully ossified were not found.

Adult height was estimated using bone age rates according to TW2-RUS method (47) and percentage of predicted adult height was calculated using players standing height.

Data analysis

Differences in exposure time were compared using Kruskal Wallis test. Injury burden was calculated to account for both frequency (incidence) and severity (mean absence) of injuries (5) and was presented as the number of days lost/ 1000 player hours (40). Injury burden of early *vs*. on-time *vs*. late maturers were compared by calculating rate ratios (RRs). Rate ratios of 1.2, 1.9, and 3.0 can be taken as small, medium, and large, respectively (82). Zero-inflated negative binomial models were fitted to account for the excess of zeros and overdispersion in the data (83) using the glmmTMB package in R (version 3.6.2).

Confidence intervals were calculated at the 95% confidence level for rates and RRs using a parametric bootstrap procedure. P-values were adjusted for multiple comparison with the Benjamini & Hochberg method using R function p.adjust on the package stats. The significance level was set at <0.05.

RESULTS

A total number of 277 injuries (157 during training and 120 in matches) were recorded which caused 7301 days lost (4405 in training and 2896 in matches). Descriptive data is presented in Table 4.II.1 Significant differences between groups were not found for average total, training and match exposure.

Overall injury burden was 2.8-times higher in early maturers compared with late maturers (Table 4.II.2). This difference was more pronounced during training sessions, as injury burden was 3.6-times higher in early maturers compared to late maturers (Table 4.II.3). Significant differences between groups were not found in the matches (Table 4.II.4).

Growth-related injuries were the most burdensome injuries in all maturity status groups. Despite not finding significant differences among maturity groups, Sever's disease and AIIS apophyseal injuries were more burdensome in late maturers while ASIS apophyseal injuries and spondylolysis were more burdensome in early maturers (Tables 4.II.1, 4.II.2, 4.II.3).

Muscle injuries in early maturers were 4-times more burdensome compared with on-time and late maturers (Table 4.II.2). Differences in injury burden were more pronounced during trainings [RR for early *vs*. on-time: 7.30 (1.78-89.98)] (Table 4.II.3). This trend remained similar for hamstring injuries, in which early maturers had 6-times higher (12-times in trainings) burden than on-time maturers (Table 4.II.2 and 4-II.3). Significant differences between maturity groups were not found in matches (Table 4.II.4).

Joint/ligament injuries in late maturers were 7- and 12- times less burdensome than in on-time and early maturers, respectively (Table 4.II.2). In training sessions, significant differences were only found in early *vs*. late maturers; with early maturers showing 6-times higher burden (Table 4.II.3). Concerning specific injuries, significant differences for ankle join/ligament injuries were also found, being injuries in early maturers 16-times more burdensome than in late maturers (Table 4.II.2).

Table 4.II.1 – Number of players, chronological age, skeletal age and average exposure (hours per season) according to skeletal maturity status.

	Early	**On-time**	**Late**	**All**
Number of players	74 (40.6%)	80 (44%)	28 (15.4%)	182
Height	169.79 ± 6.45	162.57 ± 6.42	158.92 ± 6.58	164.62 ± 7.68
Weight	55.84 ± 7.1	47.68 ± 6.45	43.36 ± 6.05	50.29 ± 8.18
Predicted adult height	181.2 ± 5.57	179.95 ± 4.92	181.46 ± 5.81	180.69 ± 5.33
Percentage of predicted adult height	93.72 ± 2.82	90.33 ± 1.98	87.64 ± 2.80	91.30 ± 3.30
Chronological age	13.5 ± 0.5	13.5 ± 0.4	13.7 ± 0.4	13.5 ± 0.5
Skeletal age	14.8 ± 0.8	13.7 ± 0.6	12.6 ± 0.9	14 ± 1
Average total exposure	204.7 ± 64.8	201.3 ± 59.4	226.5 ± 45	206.6 ± 59.9
Average training exposure	175.7 ± 53.9	175.3 ± 50	196.2 ± 36.3	178.7 ± 50
Average match exposure	29.4 ± 12.9	26.7 ± 11.4	30.3 ± 10.6	27.9 ± 12.4

Table 4.II.2 – Number of days lost/1000h (95% CI) according to relative skeletal maturity status in U14 football players, and rate ratios (95% CI) for comparisons between groups.

	Number of days lost/1000h			**Rate-Ratios**		
	Early	**On-time**	**Late**	**Early *vs.* On-time**	**Early *vs.* Late**	**On-time *vs.* Late**
Overall burden	392.1 (253.7-559.4) ^{L}	265.2 (172.8-377.4)	140 (60.4-256) ^{E}	1.48 (0.88-2.57)	**2.80 (1.32-6.81)***	1.89 (0.89-4.62)
Growth-related injuries	205.5 (104.1-327.6)	184.2 (106.6-280.8)	100 (35.3-190.9)	1.12 (0.51-2.31)	2.06 (0.81-6.32)	1.84 (0.76-5.71)
Sever's disease	2.2 (0.2-5.2)	5.8 (0.6-13.5)	9.1 (0.9-20.2)	0.37 (0.03-4.45)	0.24 (0.02-2.68)	0.64 (0.05-6.89)
Osgood-Schlatter's disease	6.4 (0.6-15.4)	12.5 (3.1-26.5)		0.52 (0.04-3.24)		
Ischial tuberosities injuries	11.5 (0.1-30.5)	17.6 (5-36.3)	18.9 (0.1-51)	0.66 (0.01-3.02)	0.61 (0.01-$9.16\cdot10^{7}$)	0.93 (0.21-$1.25\cdot10^{8}$)
AIIS injuries	19.9 (1.9-47.6)	49.7 (19.6-83.7)	64.1 (13.2-132.8)	0.40 (0.03-1.40)	0.31 (0.03-1.80)	0.78 (0.25-4.14)
ASIS injuries	63.5 (0.1-252.5)					
Spondylolysis	67.6 (14.1-144.5)	73.3 (9.6-168.7)		0.92 (0.16-12.06)		
Muscle injuries	76.2 (3-144.5) ^{O,L}	17.7 (5.3-35) ^{E}	18.8 (2.9-44.9) ^{E}	**4.30 (1.34-16.48)***	**4.06 (1.23-31.02)***	0.94 (0.21-6.62)
Hamstring	35 (7.4-73.5) ^{O}	5.6 (0.7-14.1) ^{E}	7.1 (0.1-22.4)	**6.23 (1.07-53.03)***	4.95 (0.78-$2.71\cdot10^{8}$)	0.79 (0.10-$5.49\cdot10^{7}$)
Quadriceps	35.9 (3.1-89.4)	4.5 (0.1-14)	3.4 (0.1-16.7)	7.99 (0.68-$1.67\cdot10^{9}$)	10.59 (0.74-$4.20\cdot10^{9}$)	1.32 (0.01-$2.77\cdot10^{8}$)
Joint/Ligament injuries	35.5 (12.6-62.9) ^{L}	19.11 (6.6-35.3) ^{L}	2.84 (0.2-7.5) ^{E,O}	1.86 (0.59-6.06)	**12.51 (3.35-175.09)****	**6.73 (1.69-93)***
Knee	0.4 (0.11-1.5)	8.2 (0.6-19.6)	0.9 (0.1-3.9)	0.05 (0.01-830)	0.43 (0.01-$1.58\cdot10^{9}$)	9.55 (0.66-$3.14\cdot10^{14}$)
Ankle	31.3 (10.3-58.4) ^{L}	8.9 (1.2-20.1)	1.98 (0.1-5.7) ^{E}	3.52 (0.87-25.14)	**15.76 (3.37-$1.85\cdot10^{8}$)****	4.47 (0.52-$6.17\cdot10^{7}$)

Note: AIIS: anterior inferior iliac spine; ASIS: anterior inferior iliac spine.

Significant differences (*p<0.05, **p<0.01) between maturity status groups: ^{E}(early), ^{O}(on-time), or ^{L}(late).

Table 4.II.3 – Number of days lost/1000h (95% CI) in trainings according to relative skeletal maturity status in U14 football players, and rate ratios (95% CI) for comparisons between groups.

	Number of days lost/1000h			Rate-Ratios		
	Early	**On-time**	**Late**	**Early *vs.* On-time**	**Early *vs.* Late**	**On-time *vs.* Late**
Overall burden	292.4 (170.6-434) [L]	188.9 (101-315)	81.6 (23.9-174.3) [E]	1.55 (0.75-3.28)	**3.58 (1.42-12.75)***	2.31 (0.88-8.92)
Growth-related injuries	165 (77.7-283)	127.5 (53.3-227)	59.5 (7.2-153.7)	1.29 (0.52-3.76)	2.77 (0.85-23.21)	2.14 (0.63-18.25)
Sever's disease	2.54 (0.15-6.07)	4.6 (0.1-13.6)	10.2 (1-22.6)	0.56 ($0.03-6.28\cdot10^9$)	0.25 (0.02-2.60)	0.45 (0.01-6.43)
Osgood-Schlatter's disease	6.4 (0.3-14.7)	7.8 (1.4-16.2)		0.83 (0.07-4.98)		
Ischial apophyseal injuries	9.9 (0.1-24.3)	10.4 (0.1-28.9)		0.95 ($0.01-4.73*10^8$)		
AIIS apophyseal injuries	10 (0.1-33.6)	25.3 (0.1-58.5)	49 (0.1-159.6)	0.40 (0.01-3.21)	0.20 ($0.01-8.65\cdot10^7$)	0.52 ($0.07-2.49\cdot10^8$)
ASIS apophyseal injuries	38.3 (0.1-117.2)					
Spondylolysis	64.9 (9.9-145.5)	56.8 (0.1-160)		1.14 ($0.09-1.29\cdot10^9$)		
Muscle injuries	79 (26.3-150.3) [O,L]	10.8 (0.9-28.1) [E]	19 (2.6-47) [E]	**7.30 (1.78-89.98)***	**4.16 (1.04-29.77)***	0.57 (0.04-5.62)
Hamstring	37.2 (6.7-88.9) [O]	0.3 (0.1-1.5) [E]	7.9 (0.1-23.6)	**12.17 ($1.24-6.15\cdot10^{10}$)***	4.73 ($0.70-1.44\cdot10^9$)	0.04 ($0.01-1.41\cdot10^7$)
Quadriceps	37.2 (5.2-80.9)	4.9 (0.1-17.1)	3.8 (0.1-18.9)	7.60 ($0.94-1.01\cdot10^{10}$)	9.71 ($0.96-2.69\cdot10^9$)	1.28 ($0.01-1.99\cdot10^8$)
Joint/Ligament injuries	19.1 (3.9-40) [L]	17.4 (3.3-36.7)	3.3 (0.2-8.3) [E]	1.09 (0.22-6.45)	**5.84 (1.11-116.49)***	5.34 (0.89-77.94)
Knee	0.4 (0.1-1.9)	9.4 (0.2-24.9)	1 (0.1-4.5)	0.05 (0.01-1.87)	0.43 ($0.01-7.74\cdot10^8$)	9.40 ($0.26-2.57\cdot10^{10}$)
Ankle	13.9 (1.1-35)	7.1 (0.1-20.1)	2.3 (0.1-6.6)	1.97 ($0.2-6.20\cdot10^9$)	6.13 ($0.60-1.57\cdot10^8$)	3.12 ($0.01-8.92\cdot10^7$)

Note: AIIS: anterior inferior iliac spine; ASIS: anterior inferior iliac spine.

Significant differences (*p<0.05) between maturity status groups: [E](early), [O](on-time), or [L](late).

Table 4.II.4 – Number of days lost/1000h (95% CI) in matches according to relative skeletal maturity status in U14 football players, and rate ratios (95% CI) for comparisons between groups.

	Number of days lost/1000h			Rate-Ratios		
	Early	**On-time**	**Late**	**Early vs. On-time**	**Early vs. Late**	**On-time vs. Late**
Overall burden	773.7 (417.8-1192)	450.5 (232.1-723)	736.8 (213.9-1491.1)	1.72 (0.77-3.66)	1.05 (0.43-3.85)	0.61 (0.24-2.33)
Growth-related injuries	496 (207.8-886.8)	265 (110.3-453.1)	463.4 (0.1-1304.6)	1.87 (0.66-5.47)	1.07 ($0.26-5.60 \cdot 10^{8}$)	0.57 ($0.14-2.96 \cdot 10^{8}$)
Sever's disease	5.4 (0.1-14.5)	4.3 (0.1-14.9)		1.23 ($0.01-8.84 \cdot 10^{37}$)		
Osgood-Schlatter's disease	44.6 (0.1-167.3)	3.9 (0.1-18.3)		11.39 ($0.01-1.31 \cdot 10^{12}$)		
Ischial apophyseal injuries	104.5 (10.6 -238.4)	20 (0.1-50)	64.7 (0.1-228.5)	5.23 ($0.41-2.37 \cdot 10^{8}$)	1.62 ($0.09-8.77 \cdot 10^{8}$)	0.31 ($0.26-1.85 \cdot 10^{8}$)
AIIS apophyseal injuries	46.9 (5.6-103.6)	122.2 (45.3-212.9)	320.3 (0.1-703.4)	0.38 (0.05-1.25)	0.15 ($0.02-1.28 \cdot 10^{8}$)	0.38 ($0.11-3.61 \cdot 10^{8}$)
ASIS apophyseal injuries	196.3 (0.1-603.9)					
Spondylolysis	119.1 (0.1-341.1)					
Muscle injuries	19.7 (0.5-51.6)	39.5 (9.2-83.9)	52.3 (2.3-143.9)	0.44 ($0.01-1.17 \cdot 10^{9}$)	0.25 ($0.01-9.64 \cdot 10^{7}$)	0.56 ($0.01-1.17 \cdot 10^{8}$)
Hamstring	10.3 (0.1-32.4)	23.1 (0.1-63.1)	41.2 (0.1-114.5)	0.44 ($0.01-1.17 \cdot 10^{9}$)	0.25 ($0.01-9.64 \cdot 10^{7}$)	0.56 ($0.01-2.38 \cdot 10^{8}$)
Quadriceps		1 (0.1-4)				
Joint/Ligament injuries	35.2 (0.1-99.5)	92.2 (8-213.4)	48.3 (4.6-118.8)	0.38 (0.01-4.22)	0.73 (0.01-8.46)	1.91 (0.17-27.30)
Knee						
Ankle	35.2 (0.1-89.4)	84.2 (5.5-212.5)	48.3 (2.4-115.5)	0.42 (0.01-6.22)	0.73 (0.01-12.14)	1.74 (0.12-38.08)

Note: AIIS: anterior inferior iliac spine; ASIS: anterior inferior iliac spine.

DISCUSSION

This study aimed to describe and compare overall and specific injury burden in early, on-time and late maturing U14 academy football players. Injuries of early maturers were more burdensome than those of late developers. Concerning specific injuries, muscle injuries were more burdensome in early *vs*. on-time/late maturers while joint/ligament injuries were more burdensome in early/on-time *vs*. late maturers.

In line with previous data in elite football academies, our research showed a clear underrepresentation of U14 late maturers (15%). It must be highlighted that the less conservative band of ± 0.5 years applied in our study and in previous research (31,49,81,84) identified a greater proportion of early maturers than those studies using a more conservative ± 1 band (84,85). Significant differences between early, on-time and late maturers were not found for total, training and match exposure. This is in accordance with previous research which only found longer pitch time in U9 and U10 early maturers (86). Nevertheless, recent studies suggested that advanced maturity status in U14s is associated with higher grades in match-running metrics (78) and coaches' evaluations of match performance (81); which might lead the coaches to rely more on early maturers and thus, to higher match exposure. However, apart from coaches' perceptions, other factors such as availability might also have an impact in player's average exposure. Although we did not study player's availability, our results showed 2.8-times higher injury burden (3.6-times in trainings) in early *vs*. late maturers and as a consequence, early maturers might have been less available due to longer periods of absence caused by injuries (5).

The higher injury burden (product of incidence and severity) found in early maturers is in line with results in previous research which found a higher incidence in this group (38,39,42,80). Concerning the severity of injuries, contrary to our results, Le Gall et al. (38) found longer average layoff time per injury and longer periods of absence in U14 on-time and late maturers. Nonetheless, comparisons with previous studies must be made cautiously as they applied different methods for skeletal age estimation, used different cut-off values for classifying players and were carried out in different populations. Most importantly, they did not account for individual exposure data.

There are multiple reasons that might explain the higher overall injury burden in early maturers compared with U14 on-time and late maturers. In line with our results, previous research has already shown that players who are closer to their biological maturity have more burdensome injuries (30,31,60) and early maturers might be more mature than their on-time and late peers. Furthermore, covering greater distances at higher speeds (78,87), a more aggressive way of playing football and assuming more leadership roles (88) might lead to more burdensome injuries in early maturers. Besides, different injury patterns in early, on-time and late maturers might also have contributed to differences in total injury burden.

Growth-related injuries were the most burdensome injuries in all maturity status groups, which is in line with previous research which found that growth-related injuries were the most common time-loss injuries in U14 players (8). Significant differences between early, on-time and late maturers were not found for absolute growth-related injury burden. However, different specific growth-related injury burdens were found in early, on-time and late maturers, which might be explained by the distal to proximal sequence of the physeal endochondral ossification from cartilage to complete bony fusion (89). Our results showed that distal growth-related injuries (e.g., Sever’s disease) were more burdensome in U14 late maturers while injuries in the hip/trunk (ASIS apophyseal injuries and spondylolysis) peaked in early maturers. Nevertheless, we cannot forget that ossification centers in the same bone can follow different ossification patterns. For instance, the appearance and closure of the AIIS ossification center occurs earlier than other centers in the pelvis (e.g., AIIS and ischial tuberosity) (90) and may explain why AIIS apophyseal injuries peaked in late maturers despite being a proximal segment injury.

On the other hand, the burden of muscle injuries was higher in early maturers compared with U14 on-time and late maturers and there are multiple factors which might have contributed to it. Firstly, in players with advanced skeletal maturity, which are more likely to have ossification centers closed in different regions of the body, muscle might be the structural point of for injuries (60). Besides, early maturers, who are physically superior to their on-time and late peers, might develop a more physical way of playing football (91) that may predispose them to further muscle injuries. Moreover, recent evidence has suggested that in U14 category early maturers were quicker, made more accelerations and cover greater distances at high speed (87). Taking into account that high-intensity running has been associated with hamstring injuries (92), the more physical way of playing of early maturers might have contributed to the higher burden of hamstring injuries observed in the results.

Besides, the burden of joint/ligament injuries was lower in late maturers compared to on-time and late mature. Furthermore, 16-times lower burden for ankle join/ligament injuries was found in late *vs*. early maturers. U14 late maturers might be pre- or circa-PHV, periods at which join/ligament injury burden has been shown to be lower (60). Moreover, ankle sprains in players with less delayed maturation and decreased bone density might lead to ankle epiphyseal injuries (34); which were classified as growth-related injuries in our study. Regarding late maturers way of playing, it is possible that smaller and lighter late maturers avoid contact and risk-taking situations that could lead them to acute join/ligament injuries (37).

Methodological considerations

The present study provides a robust injury recording methodology by having medical staff from the same club diagnose, treat, and record injuries, avoiding potentially unreliable data that might come from medical staffs at different clubs (93). Besides, some of the weaknesses identified for earlier research on growth, maturation, and injuries have been addressed; using gold-standard skeletal age instead of less accurate non-invasive methods, accounting for individual exposure, recording specific injury data and calculating injury burden to detect injuries that cause the greatest disruption.

Yet, some important methodological limitations must be acknowledged. Concerning the skeletal age assessment, TW2-RUS method overlooks the time lag between onset and completion of union in the criterion for the final stage of the distal radial epiphysis. Nevertheless, U14 players are rarely at this final stage (3% of our players) and this limitation might not have impacted our results. Furthermore, the less conservative ± 0.5-year band for classifying players according to their relative skeletal maturity status differs with previous research studying skeletal maturity status and injury risk (38,39,80). However, this band has already been applied in other studies for SA-CA (49) and relative somatic maturation (31,81,84). Criterion that is too conservative (SA-CA ± 1.0 years) may have failed to differentiate between on-time maturers that are markedly different in terms of maturity status, increasing the likelihood for type two errors. However, it should be noted that the less conservative criterion for determining maturity status (SA-CA ± 0.5 years) also increases the likelihood of the researcher making a type one error (i.e., detecting a bias when no such bias exists). The ± 0.5 years range used for the current study is well outside the range of the error of bone age assessment (~0.18 years) so it might be relevant for the sample in this study. Besides, the skeletal age determination was based on the maturity of the hand and wrist, which does not necessarily reflect the maturation of other bones, tissues, and organ systems. Not only that, the wrist x-rays were only available in preseason. As maturation progresses at different rates (tempo) (13), players' maturity status might change during the season. Besides, only U14 players were included in the study and future research should consider studying other age-groups. Finally, total match exposure was smaller than exposure in training and it might have contributed to not finding significant differences between groups in matches.

PERSPECTIVE

Our results showed higher overall injury burden in U14 early maturing academy football players and different injury patterns in early, on-time and late maturers. Hence, monitoring maturity status seems crucial to detect players at higher risk of being disrupted by injuries and potential injuries that cause the greatest disruption. This would facilitate design of targeted injury prevention programs to reduce the impact of burdensome injuries which might negatively affect individual development and long-term performance (94).

Growth and maturation are non-modifiable risk factors and there is little that can be done to influence these processes. However, educating key stakeholders (players, coaches, directors, parents) about the effect of maturation seems vital. Firstly, coaches should be aware that the tendency to rely more on early maturers in U14 category (81) can lead them to higher exposure, more leadership roles and higher injury burden. In this context, load management strategies such as modifying training sessions (e.g., selecting players as "floaters" during possession drills) or utilising maturity-categorised strategies (bio-banding) (79,88,91) would enable better management of the frequency and volume of exposure. Besides, prescribing activities to facilitate development (e.g., working on technical proficiency of movement, core strength or mobility) whilst preventing unwanted mechanical stress would enable better management of the frequency and volume of exposure to stressful activities (79). Considering injuries that cause the greatest disruption according to each players maturation profile would be crucial when prescribing those activities. Nonetheless, injuries are multifactorial, and we cannot forget other risk factors (training load, neuromuscular and biomechanical factors, physiotherapy, coaching, communication, psychosocial factors...) when designing injury prevention programs (95).

PAPER III: INJURIES ACCORDING TO THE PERCENTAGE OF ADULT HEIGHT IN AN ELITE SOCCER ACADEMY

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ABSTRACT

Objectives: This study aimed to ascertain if there is a defined pattern of injury related to the percentage of attained adult height and classify injuries according to maturity status bands.

Design: Prospective cohort study

Methods: From 1998–2019, 63 elite male soccer players of at least the U12 category from a Spanish LaLiga club's academy were followed until reaching their final height. Medical staff recorded injuries following the FIFA consensus and measured height 2–3 times per season. The percentage of adult height at which each injury occurred was calculated using the player's closest height to the injury and his final adult height. Injuries were classified in maturity bands, pre-peak-height-velocity (PHV) <88%, circa-PHV 88%–96%, and post-PHV >96%.

Results: There were 509 injuries among the 63 players. Growth-related injuries occurred at a median (IQR) of 91.2% (86.7%–95.2%) of adult height, predominating in pre-PHV and PHV bands. Muscle injuries predominantly occurred at post-PHV, with 77.78% of those conditions occurring within that time frame and at 98.7% (96%–99.5%) of adult height. Likewise, knee and ankle joint/ligament injuries predominated at post-PHV (87% and 65% of total cases, respectively) occurring at 99.0% (97.9%–99.9%) and 98.4% (89.2%–99.4%) of adult height, respectively.

Conclusion: Injuries follow a specific pattern according to the percentage of adult height.

Keywords: Football; Injury risk; Injury prevention; Child; Adolescent; Youth sport.

INTRODUCTION

According to a recent systematic review (96), high level football players have a high probability of sustaining time-loss injuries. Indeed, pooled estimates for total incidence per 1000h were 7.9 for youth players aged under 17 to under 21 years and 3.7 for under 9 to under 16 years. Injuries result in increased susceptibility for future injuries and long-term health risks in adulthood (35), have a high economic cost and negatively impact team performance (97). Therefore, preventing injuries is a priority for soccer academies.

During adolescent growth and maturation, players experience anthropometrical (36,37,98), neuromuscular (99,100), and structural changes (13), which might increase injury risk. Injury risk is higher near peak-height-velocity (PHV) period (30,31,41,101) and quick growth rates in stature and leg length seem to be highly associated to growth-related injuries (37,98). However, a recent review demonstrated that there is still considerable uncertainty regarding the aetiological role of maturation and growth in adolescent musculoskeletal conditions (35). Therefore, investigations to provide clearer insight on this subject are warranted.

Assessment of maturity is challenging due to the invasiveness of the different methods. As a solution, the percentage of adult height has been proposed as maturity indicator (28,102). As measurement of adult height requires a longitudinal follow-up until reaching full stature, various methods and formulas have been proposed in order to predict adult height (21,28). Despite the percentage of predicted adult height at time of observation has gained popularity as a maturity indicator (28,102), yet no study has investigated the association of the maturity status measured through the percentage of adult height with specific injury risk in soccer. Therefore, we propose a longitudinal registry of injuries and height-growth from childhood to adulthood to ascertain if there is a defined pattern of injury related to the percentage of attained adult height and classify injuries according to maturity status bands. Using the percentage of adult height to identify bands or periods of increased specific injury risk seems a reasonable step towards successfully managing injury risk.

METHODS

Athletic Club male players were prospectively followed from 1998–2019. Males professional team plays in the Spanish LaLiga, and development of academy players is key to the club's success because only players developed in the academy or born in the Basque Country can play on this club. The academy has different categories according to age (U11-U19). Attempting to represent all pre-, circa- and post-PHV periods, we included only players who were ≤U12 when they entered the academy and continued until they attained adult height. Players were single sports athletes, trained 3 or 4 times per week depending on the age category (3 times for U11-U12 and 4 for the other) and played a game every weekend. This study was approved by the Ethics Committee of the University of the Basque Country (CEISH/340/2015).

Height of each player was measured by the club's doctors every 3-4 months using a stadiometer. Measurements were carried out before afternoon trainings. A player was considered to have attained final height once growth-velocity was <1 cm/year during one year (13). Curve-fitting techniques were used to plot growth-velocities (103). Injuries were classified according to maturity bands: pre-PHV <88%, circa-PHV 88%–96%, and post-PHV >96% (79).

The club's medical staff diagnosed, treated, and recorded all time-loss injuries. From the 2007–2008 season, this was done following the consensus on definitions and data collection procedures outlined by the International Federation of Association Football (FIFA) (12). Two of the four current doctors have been working in the club since 1998, thereby reducing the chance of bias, differences in injury interpretation, and changes in observation methods between doctors. Injuries were recorded when a player was unable to participate in a future training session or match due to a physical complaint. A player was considered injured until the medical staff cleared the player for full participation. Only injuries that caused >7 days of absence (moderate and severe) were considered to avoid confounding effects of minimal and mild injuries. Once the player had attained his final height, only injuries within the next year were considered to avoid overrepresentation of injuries at 100% of adult height. In the same line, injuries were only recorded >U11 to avoid overrepresentation in pre-PHV period.

Injuries were classified into 5 groups: growth-related injuries (Sever's disease, Osgood Schlatter disease, osteochondrosis' of the anterior inferior iliac spine, ischial tuberosity, anterior superior iliac spine, and spondylolysis), muscle injuries (quadriceps, hamstring, adductor, gluteal, psoas), groin pain, knee joint/ligament injuries (anterior cruciate ligament rupture, medial collateral ligament, and meniscal injuries), and ankle joint/ligament injuries (lateral collateral ligament and syndesmotic sprain). We defined growth-related injuries as unique injuries not seen in adults but common in skeletally immature athletes, including growth plate fractures, apophysitis, apophyseal avulsion fractures, and greenstick fractures (9).

All statistical analysis was conducted using R version 3.2.3. Median ± interquartile range (IQR) percentage of adult height at which each injury occurred was calculated using the player's closest height to the injury and final adult height. Number of injuries and frequency (percentage of number of total injuries) of each injury in each band was calculated.

RESULTS

There were 63 players that met the inclusion criteria. They were on average (± SD) 10.7 ± 0.4 years old at the time of first height measurement (80.8 ± 2.1% of adult height). Subjects attained adult stature at 18.3 ± 1.1 years of age with a stature of 179.2 ± 4.78. Percentages of adult height at each age category are shown in Figure 4.III.1, with medians of: 81.1% (79.4%–82.8%) at U11, 83.8% (82%–85.6%) at U12, 87% (85.1%–89.1%) at U13, 91% (88.4%–94.1%) at U14, 95.8% (93.6%–97%) at U15, 97.8% (96.8%–98.6%) at U16, 98.9% (98.3%–99.4%) at U17, 99.4% (98.9%–99.9%) at U18, and 99.9% (99.7%–100%) at U19.

There were 509 injuries: 74, 102 and 333 injuries occurred in pre-, circa- and post-PHV periods, respectively. Concerning type of injuries, 111 growth-related, 168 muscle, 5 cases of groin pain, 67 ankle join/ligament and 40 knee joint/ligament injuries were recorded. Growth-related injuries were the most frequent injuries in pre- and circa-PHV accounting for 45% and 46% of all the injuries, respectively. Muscle (18% and 24% in pre- and circa-PHV), knee joint/ligament (4% and 2%) and ankle joint/ligament injuries (16% and 11%) were not as common during pre- and circa-PHV periods. However, their proportion increased in post-PHV period. Muscle, knee and ankle join/ligament injuries accounted for 39%, 11% and 13% of all injuries in post-PHV while growth-related injuries only represented 9% of the injuries.

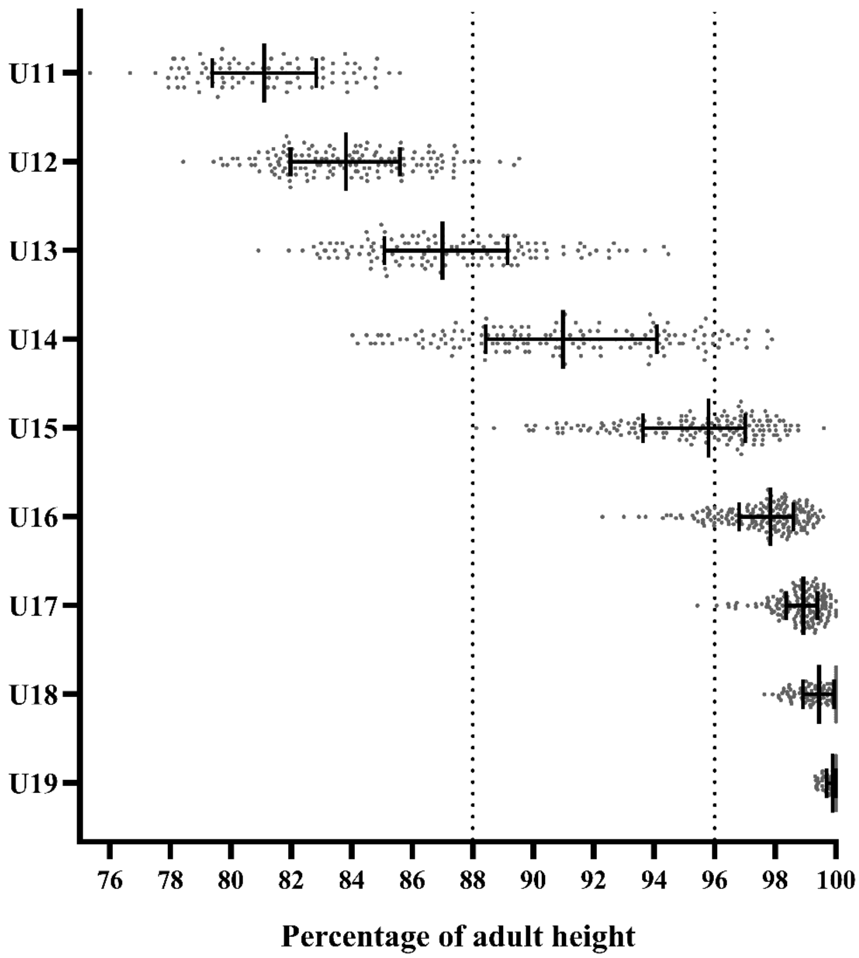

Figure 4.III.1: Percentage of adult height at each age category (median and interquartile range). Each dot represents a player’s height measurement. Dotted lines represent the limits for the maturity bands.

Figure 4.III.2 shows the percentage of adult height at which growth-related injuries occurred and the number and frequency of injuries in each maturity band. Growth-related-injuries occurred at a median (IQR) of 91.2% (86.7%–95.2%) of adult height, predominating in the pre-PHV and PHV bands. Individually, Sever’s disease occurred at a median of 85.6% (82.0%–91.3%), more frequently at pre-PHV, while Osgood-Schlatter disease occurred at 88.5% (85.6%–91.2%; 50% pre-PHV and 39% circa-PHV). Avulsions of the anterior inferior iliac spine injuries happened at 91.0% (88.8%–94.0%; 69% circa-PHV), ischial tuberosities at 91.2% (89.7%–95.3%; 58% circa-PHV), and anterior superior iliac spine avulsions at 98.1% (97.0%–98.3%; 86% post-PHV). On the other hand, spondylolysis occurred at 98.7% (97.5%–99.5%) of adult height, predominating in the post-PHV band (92%).

Figure 4.III.3 shows that 77.8% of all muscle injuries occurred post-PHV at 98.7% (96.0%–99.5%) of adult height. Quadriceps injuries occurred at 98.2% (94.5%–99.5%; 72% post-PHV) and hamstring injuries at 98.5% (96.2%–99.4%; 78% post-PHV). Adductor injuries occurred at 98.7% (93.5%–99.9%) while gluteal and psoas injuries occurred only post-PHV, at 99.0% (98.0%–99.4%) and 99.4% (98.6%–99.9%), respectively. Figure 4.III.3 also shows that groin pain was uncommon.

Moreover, knee and ankle joint/ligament injuries are shown in Figure 4.III.3. Both injury types were more prevalent post-PHV (88% and 65% of total such injuries, respectively) occurring at 99.0% (97.9%–99.9%) and 98.4% (89.2%–99.4%) of adult height, respectively (Figure 4.III.3). Among knee joint/ligament injuries, medial collateral ligament injuries occurred at 98.9% (89.2%–99.8%; 67% post-PHV), meniscal injuries at 99.0% (98.1%–99.8%; 100% post-PHV), and anterior cruciate ligament ruptures at 98.7% (97.3%–100%; 100% post-PHV). Ankle lateral collateral ligament injuries occurred at 98.5% (89.5%–99.2%). They had a broader distribution than other joint/ligament injuries, being more frequent in the post-PHV band (67%) but also relatively frequent in pre-PHV (21%) and circa-PHV (12%) bands. However, syndesmotic injuries occurred later at 98.8% (98.4%–99.5%) and were only recorded post-PHV.

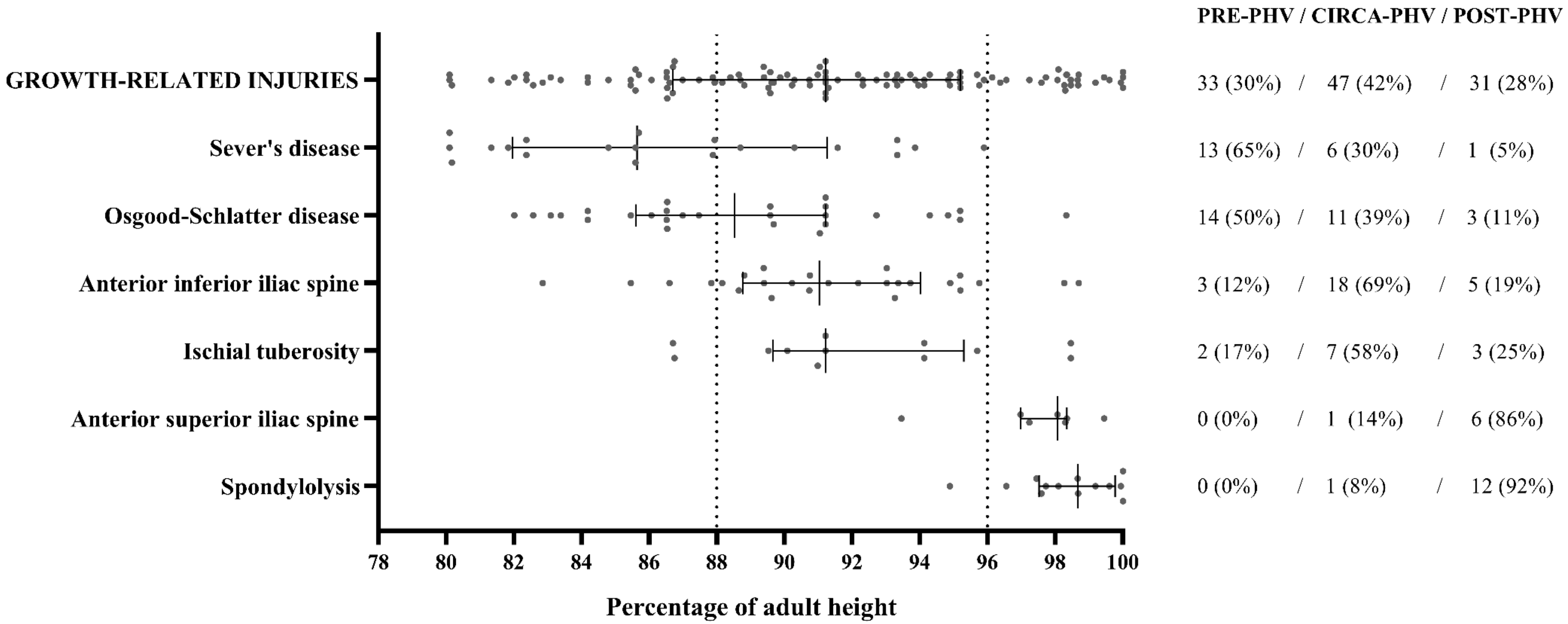

Figure 4.III.2: Percentage of adult height for growth-related injuries (each dot is an injury, and lines represent median and interquartile range) and number and frequency (%) of each injury in each maturity band (pre-PHV | circa-PHV | post-PHV). Dotted lines represent the limits for the maturity bands.

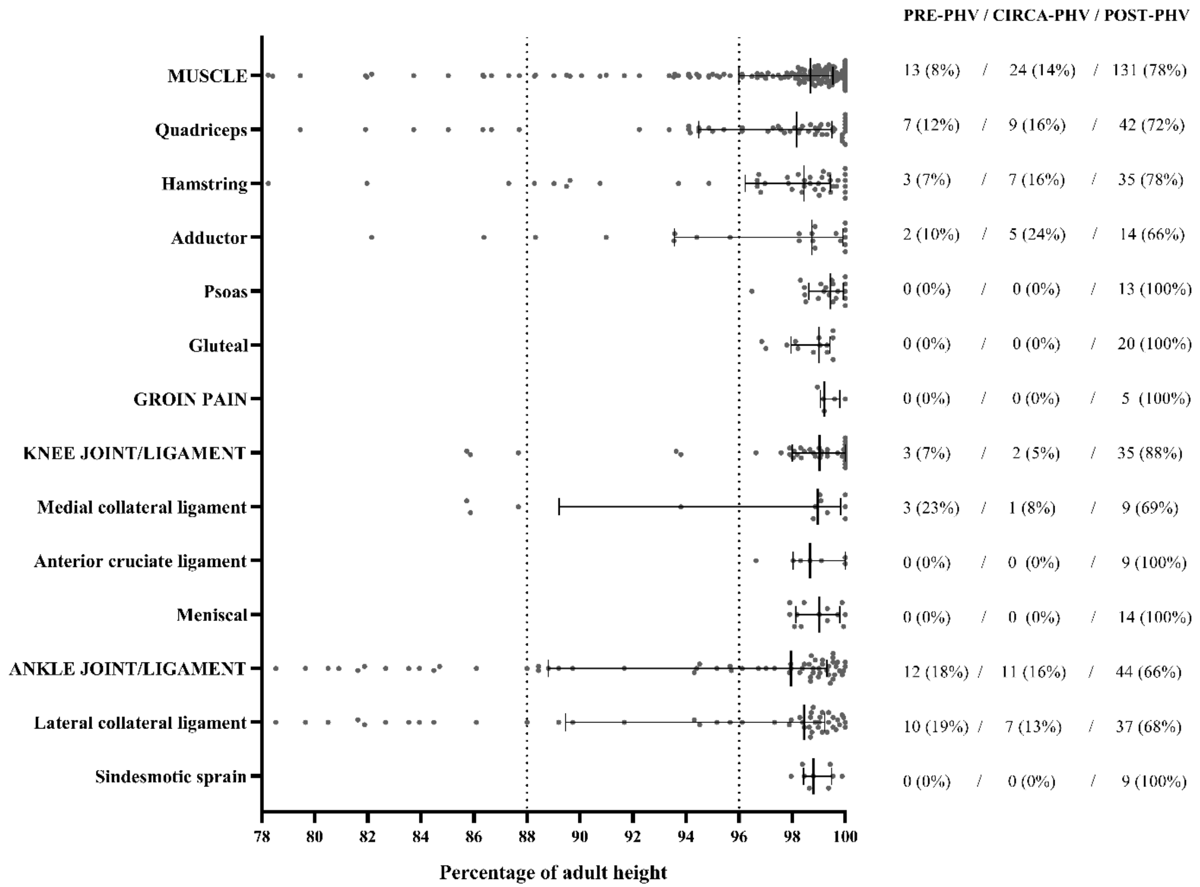

Figure 4.III.3: Percentage of adult height for muscle injuries, groin pain and joint/ligament injuries (each dot is an injury, and lines represent median and interquartile range) and number and frequency (%) of each injury in each maturity band (pre-PHV | circa-PHV | post-PHV). Dotted lines represent the limits for the maturity bands.

DISCUSSION

To provide deeper insight into the relationship between maturation and injuries in soccer, we longitudinally analysed height and injuries of players from childhood until attainment of adult stature in the setting of a professional soccer academy. All in all, we observed that specific injuries were sustained at different percentages of adult heights. Precisely, growth injuries followed a chronological distal to proximal pattern, and muscle and joint injuries occurred more frequently in mature players.

Among the 1071 players that were followed, 63 players met the inclusion criteria of the study. For a detailed description of the sample and possible drop-out reason's readers are directed to Gil et al. (2019) (104) and Bidaurrazaga-Letona et al. (2017) (105). Players attained adult height at 18.3 ± 1.1 years of age, which is in line with Fels study (13) and longitudinal data in Basque population (106).

A clear overrepresentation of injuries (total number) in the post-PHV period was found. These results seem contradictory with previous research which found increased injury-risk in circa-PHV period (30,31,41,101). Nonetheless, due to methodological differences for PHV's estimation and definition of maturity status periods, our results are not comparable with previous research that aimed to investigate injury incidence and burden in pre-, circa- and post-PHV (30,31,41,101). As growth-velocities during post-PHV period are slower than in circa-PHV, it might take longer to advance from 96% to 100% of adult height. This fact supposes a longer exposure during post-PHV percentages, which might have resulted in an overrepresentation of injuries. Our results are in line with previous data in a Spanish elite football academy that found a higher occurrence of injuries in post-PHV ages (107); which might be a consequence of higher intensities and exposure times during these ages. The same argument would have supposed injuries' overrepresentation during pre-PHV period but being injury risk, significantly smaller during pre-PHV (30,31,41,101), it did not occur. To the best of our knowledge, this is the first study measuring injuries along the growth of elite soccer players to specifically describe the type, occurrence, and maturity status according to real attained adult stature.

According to a recent systematic review (108), the risk of sustaining musculoskeletal overuse injuries is higher for athletes that specialize in a single sport. High training volume in soccer academies associated with early specialisation may impact development of growth-related injuries. Muscles, tendons, and apophyses adapt slowly to changes in extremity length, mass, and moments of inertia caused by PHV (36,37,98). Consequently, this slow adaptation might increase the stress on muscle-tendon junctions and apophyses, making the prevalence of total growth-related injuries higher than that of other injuries near circa-PHV percentages. However, our results showed that growth-related injuries also occur during pre-PHV and post-PHV periods. Growth and maturation start from more distal segments of the lower limbs and then, it continues with the development of the lower extremities and the trunk. Therefore, even if the higher growth-rates for stature are attained at circa-PHV, PHV for the lower extremities occurs in pre-PHV and PHV for the trunk occurs in post-PHV (13). Previous research has shown that incidence of growth-related injuries increased when athletes experience larger changes in stature and leg length over a season (98). These results are in accordance with our findings. The IQR for growth-related injuries (86.7%–95.2%) coincided with the transition from pre- to circa-PHV; the moment when PHV for leg length occurs (13). The growth and maturation pattern (13) seems to also have affected specific growth-related injuries' occurrence, as our results showed that injuries occurred from distal to proximal segments (Figure 4.III.2). Previous research in academy footballers showed that Sever's disease occurred more often in early-stage players (U10–U14, peaking at U11), while Osgood-Schlatter's disease was more frequent at later stages (U12–U16, peaking at U13–U14) (109). Our results also showed an earlier occurrence of Sever's disease based on adult height percentage. Moreover, the percentage of adult height at which Osgood-Schlatter's disease occurred, 88.5% was similar to the percentage of adult height of categories at which this disease peaked. However, the median for Sever's disease (85.6%) was higher than the median height for U11 (81,1%), the previously reported category for disease peak. A possible explanation for this could be that we only recorded injuries since U11 category, while the prior study showed that calcaneal apophysitis was frequent following U10 (109).

The incidence of muscle injuries progressively increases with age (107,110), which is in line with the higher occurrence of muscle injuries at higher percentages of adult height. The longitudinal growth of the bones, during the adolescent growth spurt, occurs prior of the increase in muscle mass (13). This implies an increase in the moments of inertia of the athletes' segments, which might not be met with sufficient muscle capacity. Greater moments of inertia increase the demand for muscles possibly leading them to higher risk of injury (111). In the same line, tendons increase their cross-sectional area slower than the adjoining muscles during adolescence (13). Imbalance between muscle and tendon growth might lead to increased overuse injuries' risk such as groin pain (111).

Similarly, joint/ligament injuries predominated post-PHV and near adult height. It seems as though changes in the moments of inertia lead to changes in frontal plane's neuromuscular control (99,100). Post-PHV footballers until age 18 have been shown to have a greater ipsilateral trunk flexion in single countermovement-jump (99). Interestingly, hip abductors, which have a vital role in frontal plane's neuromuscular control, have been linked to ankle injuries (112) and knee injuries (113). Thus, it is possible that neuromuscular changes caused by PHV have an effect on joint/ligament injuries' occurrence.

Our research showed that injury targets vary according to percentage of adult height. Therefore, estimating each player's percentage of adult height seems to be an appropriate way to design specific injury prevention programs, especially, in categories with large inter-individual differences in maturity status (U13–U15). Although the most accurate method for predicting adult height is based on skeletal age (Greulich-Pyle, Tanner-Whitehouse, Fels methods) (13), the Khamis-Roche method is a feasible non-invasive alternative to that method (21,28). On the one hand, players at earlier percentages should try to prevent growth-related injuries, with load management being vital for minimizing the risk for those injuries (9). On the other hand, more mature players should have injury-prevention programs focused on motor skill development (99,100) to reduce risk for muscle and joint-ligament injuries. Additionally, it is important for injury prevention programs to account for the strength and conditioning peculiarities of each maturity stage (79). Nonetheless, we cannot forget that injuries are multifactorial, and risk factors apart from those related to maturity must be taken into account when designing injury prevention programs. Owing to the fact that maturation progresses at different times (maturity timing) and at different rates (maturity tempo) between individuals, significant maturity status differences within boys of the same age (same category) can be found (13). In the same way, players change at different maturity status stages throughout the season.

There are inherent limitations in the present study. Firstly, only players who entered the club when they were ≤U12 and continued until they reached their adult height were included in the study. Considering that injuries have a negative impact on player progression in the academy (3), players who sustained severe or recurrent injuries may have been missed. Secondly, another limitation would be that closest height measurement (with a maximum difference of 2 months) was used to calculate the percentage at which injuries occurred. Moreover, injury management strategies have changed over the last decades and load management strategies during the adolescent growth spurt have been put in place in the last years. Unfortunately, information about preventive strategies was not registered, and the effect of different strategies on injury risk could not be taken into account. Not only that, we did not account for training content, individual exposure or other risk factors such as risk of re-injury. As an additional limitation, this study focused on a specific group of male players from a single soccer academy and may not be generalizable to other populations. Nonetheless, previous studies only recorded injuries for 2–3 years (30,31,41,101), while the present study used a long longitudinal methodology covering late childhood through adolescence until adulthood. By using a precise measure based on final obtained adult height, our study has improved on others by using other non-invasive methods such as the maturity offset and percentage of estimated adult height. These metrics, despite being used to establish the relationship between maturity status and injury risk (30,31,41,101), have been questioned (21,28,114). Previous studies (30,31,41,101) also failed to record the epidemiology of each specific injury. To better understand the relationship between maturity status and specific injuries, future studies should examine this association using reliable methods such as curve-fitting techniques (13).

CONCLUSION

Injuries follow a specific pattern according to the percentage of adult height. Growth-related injuries occur more often at earlier height percentages (i.e., pre-PHV and circa-PHV phases), while muscular injuries and knee and ankle articular injuries are more common at more advanced height percentages (i.e., post-PHV phase). Owing to the fact that inter-individual differences in percentage of adult height between players in the same age category exist, determining each players’ percentage of predicted adult height might help design of targeted injury prevention programs. Especially in categories where inter-individual differences in maturity status are more evident (U13–U15).

PAPER IV: THE BURDEN OF INJURIES ACCORDING TO MATURITY STATUS AND TIMING: A TWO-DECADE STUDY WITH 110 GROWTH CURVES IN AN ELITE FOOTBALL ACADEMY

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ABSTRACT

Injuries have a negative impact on the development of football players. Maturation is a potential risk factor for football injuries but available data on this topic provide limited evidence due to methodological shortcomings. The aim of this study was to describe the injury burden of male academy football players according to growth curve-derived maturity status and timing. Injury and growth data were collected from 2000 to 2020. Longitudinal height records for 110 individual players were fitted with the Super-Imposition by Translation and Rotation model to estimate age at peak height velocity (PHV). Players were clustered according to maturity status (pre-, circa-, post-PHV, or adults) and timing (early, on-time, late maturers). Overall and specific injury burdens (days lost/player-season) and rate ratios for comparisons between groups were calculated. Overall injury burden increased with advanced maturity status; pre-PHV players had 3.2-, 3.7-, and 5.5-times lower burden compared with circa-PHV, post-PHV, and adult players, respectively. Growth-related injuries were more burdensome circa-PHV, while muscle and joint/ligament injuries had a higher impact post-PHV and in adults. Further, in the pre-PHV period, late maturers showed lower burden of overall, growth-related, anterior inferior iliac spine osteochondrosis, and knee joint/ligament injuries compared with on-time maturers. In adult players, however, injuries were less burdensome for early maturers than on-time and late maturers. In addition, joint/ligament injuries of adult late maturers were 4.5-times more burdensome than those of early maturers. Therefore, monitoring maturity seems crucial to define each player's maturation profile and facilitate design of targeted injury prevention programs.

Keywords:

epidemiology, football, growth and development, maturation, injury and prevention, injury burden.

INTRODUCTION

Elite academy football players have a high probability of sustaining injuries due to contact situations, changes of direction, high training volume (specialization), among other factors (7,115). Injuries result in significant loss in training and match time and negatively affecting players' progression (3). Further, they lead to increased susceptibility for future injuries and long-term health risks in adulthood (1). Therefore, identifying risk factors is important for injury prevention and rehabilitation.

Maturation, which can be defined in terms of status, timing, and tempo (13), is a potential risk factor for football injuries. Maturity status refers to the stage of maturation at the time of observation [pre-, circa-, or post-peak height velocity (PHV)], while timing refers to the age at which PHV occurs (early, on-time, late) (13). The circa- and post-PHV maturity stages are linked to increased injury incidence (frequency of injuries) and burden (the product of injury incidence and mean severity) (30,31). However, findings of injury risk according to maturity timing are conflicting (35). While some studies found increased injury incidence in early maturers (38,39), others observed higher risk in later maturers (43). Interestingly, a recent study found contrasting results depending on the age category (42). Only one study analysed both maturity status and timing with regard to injury burden; there were no significant differences between timing groups in maturity status periods (31).

The conflicting results in available data on maturation and injuries might be due to methodological differences and limitations (35). Non-invasive methods such as the Khamis-Roche equation (based on prediction of adult height using player's height and weight and parents' height) and Mirwald equation (based on anthropometric measurements) are widely used to estimate age at PHV due to their simplicity and accessibility, but they demonstrate reduced accuracy in comparison with the gold-standard growth-fitting techniques (28,29). In addition, most studies were either cross-sectional or short longitudinal studies with a relatively small number of players and lasting only 1–4 years (28,30,31,38,39,42). Hence, they did not follow individuals over a sufficient period of time (from pre-puberty to adulthood) to model individual growth curves and estimate age at PHV (29). Further, although injury risk varies between young and adult elite football players (115), available research does not differentiate post-PHV and adult players. Most of these studies measured injury incidence, which does not account for injury severity (5), and none has recorded specific injury data.

Thus, identifying the most burdensome injuries according to each player's maturation status and timing may be vital to identify targets for injury prevention strategies and focus on injuries that most impact player availability.

This study aimed to build on these limitations by using two decades of longitudinal anthropometric measurements to model the growth curves of elite academy football players, which were used to estimate age at PHV and investigate how maturity status (pre-, circa-, post-PHV, and adult) and timing (early, on-time, late) are associated with overall and specific injury burden.

MATERIALS AND METHODS

Study design

Data were registered for twenty consecutive seasons (2000–2020) in an elite football academy whose professional male team plays in the Spanish LaLiga. The academy has different categories according to age (U11–U19) and two reserve teams (Spanish 3rd and 4th Division). Players were single-sport athletes, played a game every weekend, and trained three times per week for U11–U12 or four times per week for U13–U19 and Reserves.

Among the 1071 followed players, 110 players met the inclusion criteria of fitting the Super-Imposition by Translation and Rotation (SITAR) model (50), having at least ten height measurements before and after their estimated age at PHV (116).

The study was approved by the Ethics Committee of the University Basque Country (UPV/EHU) (CEISH/340/2015). Written informed consent to use regularly collected data for research purposes was obtained from the athlete's guardians.

Height measurement and PHV estimation

Stature was measured by doctors before afternoon trainings at least twice annually. Similar equipment was used over the study and two of the four doctors worked in the academy during the entire study period, thereby reducing chance of bias.

The SITAR model (50,116) was used to summarize individual longitudinal changes in height throughout childhood and adolescence and estimate individual's age at PHV. For each player, we defined pre-PHV (>6 months before PHV), circa-PHV (±6 months from PHV), post-PHV (>6 months after PHV, until growth velocity was <1 cm/year), and adult periods (until players left the academy) (13). Maturity timing was defined by comparing players' age at PHV to that of the Basque male population (average 13.3 years) (117), categorised as early (<0.5 year compared to average), on-time (±0.5 year), or late (>0.5 year) maturers (31) (Figure 4.IV.1).

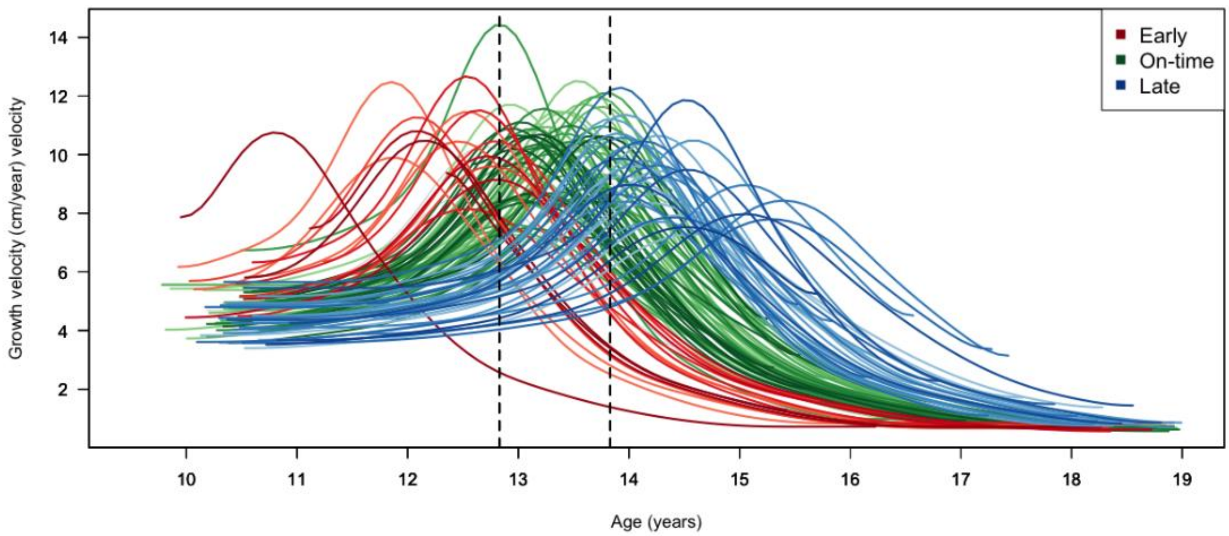


Figure 4.IV.1. Individual growth curves modelled with SITAR for 110 football players. Vertical dashed lines indicate cut-off values for early (peak-height velocity <12.8 years), on-time (12.8–13.8 years), and late (>13.8 years) maturers.

Injury definitions, exposure, and recording procedures

Injury was defined as a physical complaint that prevented players from participating in future training sessions or matches. A player was considered injured until medical staff cleared the player for full participation. Missed days between the injury and returning to full training or match play were recorded. From the 2007–2008 season onward, injuries were described following the International Federation of Association Football (FIFA) Consensus (12). In the previous seasons, the criteria for recording the diagnosis and absence days of time-loss injuries was the same as in the consensus.

Injuries were classified into five groups based on previous studies and practitioner experience: 1) growth-related injuries (Sever's disease, Osgood Schlatter disease, spondylolysis, and osteochondrosis of the anterior inferior iliac spine, ischial tuberosity, or anterior superior iliac spine), 2) muscle injuries (quadriceps, hamstring, and adductor), 3) groin pain, 4) knee joint/ligament injuries (anterior cruciate ligament, medial collateral ligament, and meniscal), and 5) ankle joint/ligament injuries (lateral collateral ligament, and syndesmotic sprain). Growth-related injuries were not explicitly considered by the consensus statement (12); thus, they were defined as “unique injuries not seen in adults but common in skeletally immature athletes”, including growth plate fractures, apophysitis, apophyseal avulsion fractures, and greenstick fractures (9).

Player-season was defined as the unit of exposure (40). Each player's exposure days – number of days lost in each period were counted and divided by 365.25 to convert them to player/seasons.

Data analysis

Injury burdens were calculated, accounting for both frequency (incidence) and severity (mean absence) of injuries, which likely is more comprehensive of the consequences of injuries (5). Injury burdens are presented as number of days lost per player-season and were compared by calculating rate ratios (pre- vs. circa- vs. post-PHV vs. adult, and early vs. on-time vs. late in each status period). Rate ratios of 1.2, 1.9, and 3.0 can be taken as small, medium, and large, respectively (82). Zero-inflated negative binomial models were fitted to account for the excess of zeros and the overdispersion in the data (83) using the glmmTMB package in R (version 3.6.2). To account for the longitudinal data structure, a random effect for the individual player was included. Confidence intervals were calculated at the 95% confidence level for rates and rate ratios using a parametric bootstrap procedure. P-values were adjusted for multiple comparison with the Benjamini & Hochberg method using the R function p.adjust of the package stats. The significance level was set at <0.05.

RESULTS

In total, we analysed 901 player-seasons for 110 players, of whom 19 were early, 63 on-time, and 28 late maturers (Figure 4.IV.1). Numbers of player-seasons in each maturity status period were 264 in pre-PHV, 110 in circa-PHV, 385 in post-PHV, and 142 in adults. Numbers of player-seasons by maturity timing were 169 for early, 472 for on-time, and 260 for late maturers. A total of 1311 injuries resulting in 33060 days of absence were recorded. Age (mean ± SD) at initial and final observation were 10.7 ± 0.6 and 17.9 ± 2.8 years, respectively, and each player had 20.2 ± 5.5 height measurements. PHV occurred at 13.4 ± 0.8 years, with a growth rate of 9.9 ± 1.8 cm/year.

Injuries and maturity status

Overall injury burden increased with advanced maturity status, and significant differences were detected in all comparisons except post- vs. circa-PHV and adult vs. post-PHV (Table 4.IV.1). Injury burden was 3.2-, 3.7-, and 5.5-times lower in pre-PHV (15 days lost/player-season) compared with circa-, post-PHV, and adults (50, 58, and 86 days lost/player-season), respectively. Injury patterns depended on maturity status, and growth-related injury burden peaked circa-PHV. Regarding specific growth-related injuries, Sever's disease was most burdensome pre-PHV, while Osgood Schlatter's disease and ischial/anterior inferior iliac spine osteochondrosis were most burdensome circa-PHV. Conversely, anterior superior iliac spine osteochondrosis only occurred post-PHV, and spondylolysis was most burdensome post-PHV. Injury burden of muscle injuries was significantly increased post-PHV and in adults compared to pre- and circa-PHV. This pattern was similar in specific hamstring, quadriceps, and adductor muscle injuries. Groin pain was only recorded in post-PHV and adult players, with higher rates in adults. The burden of joint/ligament injuries increased with advanced maturity status, and significant differences were found between all groups except for pre- vs. circa-PHV. Knee medial collateral ligament and anterior cruciate ligament peaked in adults, while the impact of meniscal injuries and ankle joint/ligament injuries was highest post-PHV and in adults.

Injuries, maturity status, and timing

The number of days lost/player-season for each injury according to maturity status and timing are presented in Table 4.IV.2, and rate ratios for comparisons between timing groups in each maturity status period are shown in Table 4.IV.3. In the pre-PHV period, compared with on-time maturers, the burden of injuries in late maturers was 1.9-times lower for all injuries (on-time vs. late: 20 vs. 10 days lost/player-season), 2.5-times lower for growth-related injuries (11 vs. 4 days lost/player-season), 5-times lower for anterior inferior iliac spine osteochondrosis (4 vs. 0.8 days lost/player-season), and 6.7-times lower for knee joint/ligament injuries (0.8 vs. 0.1 days lost/player-season).

Conversely, in adult players, injuries of early maturers (43.4 days lost/player-season) were 2.6- and 2.9-times less burdensome compared to on-time and late maturers (112 and 125 days lost/player-season), respectively. Moreover, the burden of joint/ligament injuries in adult late maturers (97 days lost/player-season) was 4.5-times higher than in adult early maturers (22 days lost/player-season).

Table 4.IV.1 – Number of days lost/player-season (95% CI) according to maturity status for each injury, and rate ratios (95% CI) for comparisons between groups.

	Pre-PHV	Circa-PHV	Post-PHV	Adult	Circa vs. Pre	Post vs. Pre	Adult vs. Pre	Post vs. Circa	Adult vs. Circa	Adult vs. Post
Overall burden	15.43 (11.16-20.34)	49.71 (37.04-65.19)	58.12 (45.77-73.39)	85.63 (57.61-121.31)	**3.19 *** **(2.16-4.64)**	**3.74 *** **(2.73-5.24)**	**5.50 *** **(3.65-8.22)**	1.17 (0.85-1.68)	**1.72 *** **(1.12-2.70)**	1.47 (0.93-2.12)
Growth-related injuries	7.31 (4.71-11.43)	25.56 (16.33-38.42)	15.00 (9.11-23.68)	0.88 (0-6.11)	**3.49 *** **(1.99-5.94)**	**2.05 *** **(1.13-3.53)**	**0.12 *** **(0.01-0.95)**	0.59 (0.32-1.05)	**0.03 *** **(0.01-0.28)**	**0.06 *** **(0.01-0.45)**
Sever's disease	1.47 (0.77-2.35)	1.15 (0.33-2.19)	0.15 (0.02-0.33)		0.78 (0.20-2.03)	**0.10 *** **(0.01-0.29)**		**0.13 *** **(0.01-0.57)**		
Osgood-Schlatter's disease	1.51 (0.45-2.87)	4.12 (1.50-7.41)	0.18 (0.01-0.58)		2.73 (0.83-10.61)	**0.12 *** **(0.01-0.61)**		**0.04 *** **(0.01-0.18)**		
Ischial osteochondrosis	0.61 (0.12-1.43)	4.17 (0.46-9.45)	1.44 (0.33-2.92)		6.81 (0.67-42.01)	2.35 (0.45-12.55)		0.35 (0.07-2.63)		
AIIS osteochondrosis	2.74 (1.16-4.74)	9.85 (3.74-17.96)	2.40 (0.76-4.44)		**3.60 *** **(1.25-10.06)**	0.88 (0.24-2.50)		**0.24 *** **(0.07-0.75)**		
ASIS osteochondrosis			1.92 (0.52-3.82)							
Spondylolysis		8.10 (0.17-24.92)	21.40 (7.72-40.60)					2.64 (0.66-133.42)		
Muscle injuries	1.31 (0.64-2.16)	3.55 (1.57-6.19)	10.65 (8.13-12.87)	12.61 (8.06-17.72)	**2.71 *** **(1.20-6.12)**	**8.12 *** **(4.61-17.65)**	**9.61 *** **(5.01-21.42)**	**3.00 *** **(1.64-6.86)**	**3.55 *** **(1.74-8.45)**	1.18 (0.78-1.79)
Hamstring	0.32 (0.10-0.69)	1.27 (0.40-2.96)	1.98 (1.11-3.11)	3.61 (1.97-6.03)	**3.96 *** **(1.04-15.46)**	**6.15 *** **(2.64-20.94)**	**11.22 *** **(4.43-38.99)**	1.55 (0.59-5.09)	2.83 (0.97-9.64)	1.82 (0.96-3.60)
Quadriceps	0.57 (0.13-1.27)	1.09 (0.03-3.24)	3.20 (1.70-4.64)	3.43 (1.47-5.37)	1.91 (0.02-13.03)	**5.62 *** **(2.06-24.83)**	**6.00 *** **(1.89-28.00)**	2.95 (0.86-105.34)	3.15 (0.83-144.92)	1.07 (0.50-2.14)
Adductor	0.29 (0.05-0.663)	0.72 (0.04-1.75)	0.74 (0.29-1.27)	1.39 (0.47-2.55)	2.51 (0.30-18.31)	2.59 (0.83-15.30)	**4.87 *** **(1.42-30.67)**	1.03 (0.30-17.47)	1.94 (0.56-32.54)	1.88 (0.67-4.88)
Joint/ligament injuries	1.99 (1.05-2.95)	4.29 (1.66-7.36)	16.48 (10.96-22.37)	57.72 (30.31-88.83)	2.16 (0.80-4.83)	**8.29 *** **(4.81-16.28)**	**29.04 *** **(14.79-60.82)**	**3.85 *** **(2.00-10.41)**	**13.46 *** **(6.59-36.79)**	**3.50 *** **(1.86-6.22)**
Knee	0.57 (0.18-1.08)	2.43 (0.45-5.95)	9.10 (4.63-15.37)	53.25 (22.05-98.18)	4.24 (0.72-17.23)	**15.86 *** **(6.14-47.22)**	**92.78 *** **(30.61-277.27)**	**3.74 *** **(1.14-22.60)**	**21.90 *** **(5.61-123.97)**	**5.85 *** **(1.91-15.17)**
ACL			3.03 (0.63-6.54)	29.17 (7.59-55.25)						**9.63 *** **(2.02-54.77)**
LCL	0.21 (0.06-0.43)		0.70 (0.21-1.41)	1.11 (0.29-2.13)		3.28 (0.72-13.60)	**5.17 *** **(1.16-22.43)**			1.57 (0.37-6.11)
Meniscal			2.61 (0.55-5.66)	2.25 (0.14-5.88)						0.86 (0.05-4.59)
Ankle	0.98 (0.41-1.93)	1.01 (0.23-2.67)	4.01 (2.43-6.25)	5.56 (2.57-10.48)	1.03 (0.20-3.56)	**4.12 *** **(1.94-9.96)**	**5.81 *** **(2.14-15.21)**	**5.81 *** **(2.14-15.21)**	**5.63 *** **(1.81-28.28)**	1.41 (0.63-2.75)
Lateral sprain	0.84 (0.31-1.77)	0.43 (0.01-1.50)	2.63 (1.47-4.22)	2.66 (0.87-5.33)	0.51 (0.02-2.13)	**3.13 *** **(1.37-9.19)**	3.16 (0.94-9.43)	**6.13 *** **(1.81-124.89)**	**6.20 *** **(1.44-133.07)**	1.01 (0.35-2.44)
Syndesmosis			1.35 (0.33-2.87)	4.23 (0.38-10.44)						3.11 (0.33-15.33)
Groin pain			2.45 (0.16-7.39)	14.92 (1.46-42.82)						0.17 (0.01-1.74)

PHV: peak height velocity; CI: confidence interval; AIIS: anterior inferior iliac spine; ASIS: anterior superior iliac spine; ACL: anterior cruciate ligament; LCL: lateral collateral ligament

* Significant differences (p<0.05) between maturity status groups.

Table 4.IV.2 – Number of days lost/player-season (95% CI) according to maturity status and timing for each injury, and rate ratios (95% CI) for comparisons between timing groups.

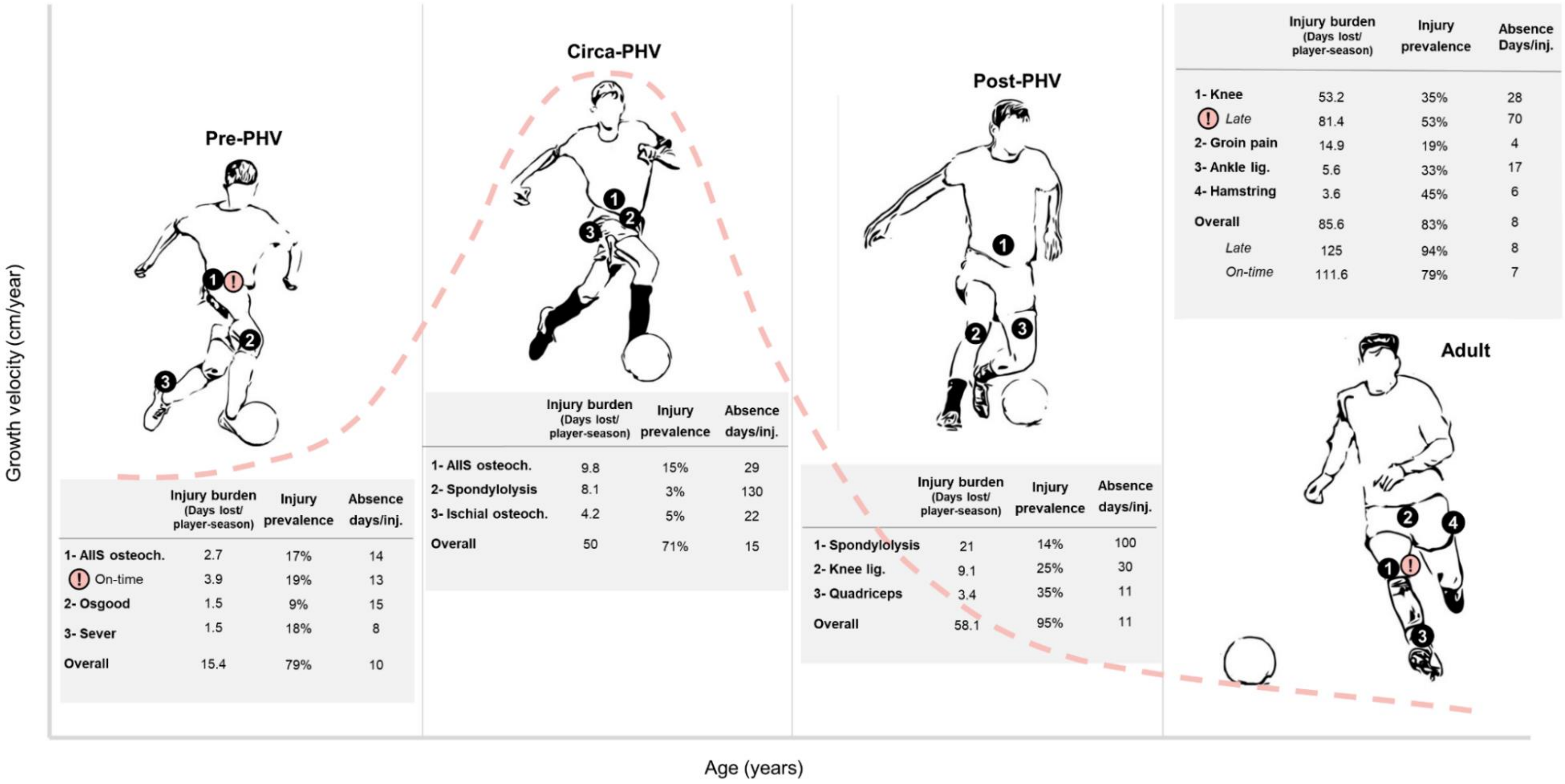
	Pre- PHV (n=107)			**Circa-PHV (n=110)**			**Post-PHV (n=110)**			**Adult (n=58)**		
	Early (n=17)	**On-time (n=62)**	**Late (n=28)**	**Early (n=19)**	**On-time (n=63)**	**Late (n=28)**	**Early (n=19)**	**On-time (n=63)**	**Late (n=28)**	**Early (n=12)**	**On-time (n=29)**	**Late (n=17)**
Overall burden	12.02 (4.58-21.64)	**19.72 ^{L} (14.30-26.03)**	**10.49 ^{O} (6.26-15.55)**	59.04 (25.97-100.2)	59.87 (39.41-84.90)	40.99 (21.56-66.51)	53.62 (30.31-83.71)	77.96 (57.61-100.63)	53.12 (33.65-76.68)	**43.40 ^{O,L} (14.29-85.27)**	**111.65 ^{E} (55.10-183.87)**	**125.00 ^{E} (57.84-213.34)**
Growth-related injuries	8.23 (2.00-17.98)	**11.44 ^{L} (6.37-17.84)**	**4.44 ^{O} (1.95-7.31)**	44.73 (9.13-104.43)	38.67 (22.52-58.78)	20.14 (5.27-42.87)	12.99 (2.81-28.73)	40.50 (19.43-68.31)	15.26 (4.29-35.31)			
Sever's disease	2.49 (0.27-5.88)	1.56 (0.44-3.16)	0.83 (0.26-1.74)		1.54 (0.01-3.32)	0.65 (0.01-1.80)		0.14 (0.01-0.31)				
Osgood-Schlatter's disease		1.28 (0.11-3.01)	1.17 (0.22-2.51)		4.67 (0.01-8.83)	2.16 (0.01-5.95)		0.31 (0.01-0.78)				
Ischial osteochondrosis			1.55 (0.01-2.61)		2.50 (0.01-6.02)				3.39 (0.01-7.35)			
AIIS osteochondrosis		3.92 ^{L} (1.27-7.56)	0.80 ^{O} (0.07-2.00)		8.85 (2.66-17.16)	18.81 (1.62-46.86)		2.06 (0.48-4.31)	3.55 (0.30-8.00)			
ASIS osteochondrosis								1.93 (0.05-5.20)				
Spondylolysis					14.01 (2.73-29)			33.87 (0.01-71.85)	5.20 (0.01-19.63)			
Muscle injuries		1.87 (0.96-2.92)	2.01 (0.27-4.64)		3.76 (1.38-6.66)	9.01 (2.73-17.57)	6.97 (3.29-11.32)	9.96 (7.08-13.02)	12.26 (7.74-17.92)	9.42 (3.42-17.32)	16.15 (8.57-24.89)	8.53 (4.67-13.00)
Hamstring		0.67 (0.01-1.48)	0.48 (0.01-1.55)		1.71 (0.01-3.39)	2.41 (0.01-5.74)	2.12 (0.61-4.24)	2.62 (1.38-4.08)	2.15 (0.83-3.92)	3.09 (0.84-5.82)	6.63 (2.56-11.81)	2.00 (0.66-3.75)
Quadriceps		0.59 (0.01-1.20)	1.12 (0.01-4.91)			3.03 (0.01-7.01)	1.98 (0.45-4.60)	3.60 (1.96-5.65)	3.39 (0.73-6.80)	4.97 (1.83-9.30)	3.68 (0.80-8.29)	2.38 (0.81-4.56)
Adductor		0.34 (0.01-0.75)	0.28 (0.01-1.19)		0.89 (0.01-2.19)			0.84 (0.29-1.53)	0.91 (0.14-2.01)	0.95 (0.16-2.18)	1.74 (0.15-4.25)	2.12 (0.44-4.46)
Joint/ligament injuries	2.04 (0.26-4.90)	2.24 (1.31-3.32)	1.52 (0.46-2.78)	3.25 (0.60-6.91)	4.28 (1.23-7.83)	5.20 (0.91-10.90)	23.04 (8.91-42.37)	17.42 (10.58-26.01)	13.21 (5.17-24.24)	**21.56 ^{L} (4.47-49.69)**	61.90 (13.34-137.36)	**97.02 ^{E} (31.05-197.77)**
Knee		**0.84 ^{L} (0.01-1.60)**	**0.12 ^{O} (0.01-0.35)**		3.59 (0.01-6.87)	1.19 (0.01-4.23)	12.60 (2.18-27.96)	9.52 (3.56-17.84)	5.77 (0.40-15.15)		58.10 (5.85-156.95)	81.37 (13.41-192.58)
ACL								4.21 (0.43-9.45)				70.84 (8.39-163.40)
LCL		0.34 (0.01-0.81)	0.07 (0.01-0.22)		1.86 (0.01-4.34)			0.53 (0.02-1.34)			1.07 (0.01-2.19)	1.43 (0.01-3.46)
Meniscal								2.30 (0.39-5.20)			3.08 (0.01-18.83)	
Ankle		0.91 (0.40-1.46)	1.16 (0.19-2.36)		0.33 (0.01-1.13)		6.26 (1.76-11.79)	3.76 (1.97-5.99)	6.95 (3.29-12.27)	19.22 (2.13-49.30)	2.69 (0.31-6.55)	12.84 (3.06-30.56)
Lateral sprain		0.76 (0.01-0.81)	0.88 (0.01-2.16)		0.31 (0.01-4.34)		4.62 (1.10-10.25)	2.51 (1.23-3.92)	4.65 (1.55-8.68)		2.14 (0.06-6.19)	10.72 (1.79-25.86)
Syndesmosis								0.66 (0.01-1.61)		17.19 (0.01-55.40)		2.22 (0.01-8.60)
Groin pain								3.75 (0.05-13.16)			27.98 (0.01-102.83)	3.41 (0.01-14.23)

PHV: peak height velocity; CI: confidence interval; AIIS: anterior inferior iliac spine; ASIS: anterior inferior iliac spine; ACL: anterior cruciate ligament; LCL: lateral collateral ligament
Significant differences (*$p<0.05$) between maturity timing groups among the same maturity status periods for ^{E}(early), ^{O}(on-time), or ^{L}(late).

Table 4.IV.3 – Rate ratios (95% CI) for comparison of overall and specific injury burden between timing groups in each maturity status period.

	Pre- PHV			**Circa-PHV**			**Post-PHV**			**Adult**		
	On-time vs. Early	**Late vs. Early**	**Late vs. On-time**	**On-time vs. Early**	**Late vs. Early**	**Late vs. On-time**	**On-time vs. Early**	**Late vs. Early**	**Late vs. On-time**	**On-time vs. Early**	**Late vs. Early**	**Late vs. On-time**
Overall burden	1.64 (0.85-4.32)	0.87 (0.39-2.49)	**0.53 * (0.31-0.90)**	1.01 (0.51-2.38)	0.69 (0.30-1.76)	0.69 (0.34-1.30)	1.45 (0.83-2.73)	0.99 (0.53-1.94)	0.68 (0.41-1.14)	**2.57 * (1.04-8.31)**	**2.88 * (1.03-9.15)**	1.12 (0.44-2.73)
Growth-related injuries	1.35 (0.54-6.36)	0.54 (0.20-2.33)	**0.40 * (0.16-0.84)**	0.86 (0.31-4.27)	0.45 (0.09-2.86)	0.52 (0.13-1.31)						
Sever's disease	0.63 (0.13-6.49)	0.33 (0.08-3.38)	0.53 (0.12-2.43)			0.42 (0.01-3.00)						
Osgood-Schlatter's disease			0.91 (0.14-13.32)			0.46 (0.01-2.21)						
Ischial osteochondrosis												
AIIS osteochondrosis			**0.20 * (0.02-0.92)**			2.13 (0.18-8.98)			1.73 (0.12-7.48)			
ASIS osteochondrosis												
Spondylolysis									0.15 (0.01-1.01)			
Muscle injuries			1.08 (0.13-3.24)			2.40 (0.64-7.60)	1.43 (0.77-3.21)	1.76 (0.92-4.00)	1.23 (0.74-2.02)	1.71 (0.71-5.36)	0.91 (0.37-2.68)	0.53 (0.25-1.08)
Hamstring			0.72 (0.01-5.24)			1.41 (0.01-7.08)	1.23 (0.46-4.61)	1.01 (0.30-4.23)	0.82 (0.30-1.88)	2.15 (0.66-8.57)	0.65 (0.18-2.57)	0.30 (0.08-0.87)
Quadriceps			1.91 (0.01-17.73)				1.82 (0.63-7.60)	1.71 (0.34-6.89)	0.94 (0.19-2.50)	0.74 (0.15-2.43)	0.48 (0.14-1.49)	0.65 (0.16-3.01)
Adductor			0.83 (0.01-6.61)						1.08 (0.15-4.10)	1.83 (0.14-14.88)	2.23 (0.40-14.83)	1.22 (0.21-15.80)
Joint/ligament injuries	1.10 (0.41-9.17)	0.74 (0.17-6.08)	0.68 (0.19-1.49)	1.32 (0.35-8.33)	1.60 (0.27-9.27)	1.21 (0.21-5.16)	0.76 (0.33-2.01)	0.57 (0.20-1.82)	0.77 (0.30-1.64)	2.87 (0.51-14.96)	**4.50 * (1.14-24.13)**	1.56 (0.42-7.62)
Knee			**0.15 * (0.01-0.72)**			0.33 (0.01-0.87)	0.76 (0.23-4.50)	0.46 (0.03-3.44)	0.61 (0.04-2.37)			1.40 (0.22-15.94)
ACL												
LCL			0.21 (0.01-1.69)									1.34 (0.01-8.74)
Meniscal												
Ankle			1.27 (0.19-3.70)				0.60 (0.23-2.24)	1.11 (0.40-4.35)	1.85 (0.74-4.42)	0.14 (0.01-1.38)	0.67 (0.12-7.21)	4.76 (0.94-34.93)
Lateral sprain			1.15 (0.01-4.89)				0.54 (0.18-2.58)	1.01 (0.26-4.68)	1.86 (0.55-4.97)			5.12 (0.78-209.56)
Syndesmosis											0.13 (0.01-61.65)	
Groin pain												0.12 (0.01-5.42)

PHV: peak height velocity; CI: confidence interval; AIIS: anterior inferior iliac spine; ASIS: anterior inferior iliac spine; ACL: anterior cruciate ligament; LCL: lateral collateral ligament
* Significant differences (p<0.05) between timing groups.



Graphical abstract: The most burdensome injuries in each maturity status period and corresponding injury burden (number of days lost per player-season), prevalence (percentage of players that suffer the injury in the specific phase), and median absence days per injury. Exclamations indicate timing groups that were significantly more burdensome.

DISCUSSION

This is the first study analysing how maturity status in combining with timing affect injury burden of elite academy football players using longitudinal height data and growth curve-fitting techniques. The main findings were increased overall injury burden with advanced maturity status, linked to specific injury burden variation according to maturity status and timing. Growth-related injuries peaked in pre- and circa-PHV players while muscle and joint/ligament injuries peaked in adults (particularly in late maturers) (Graphical abstract).

Injury burden increases with maturation

In line with previous data (30,31), our results showed an increase in overall injury burden with advanced maturity status. Anthropometrical (36,37,98), neuromuscular (61,99,118), and physiological (e.g., mechanical properties) (119) changes induced by PHV may contribute to increased injury risk from circa-PHV onwards. Further, adult players' injury burden was significantly greater than players in earlier maturity periods, which is in line with results from the systematic review by Pfirrmann et al. that found significant differences between elite academy youth and adult players (115). This may be a consequence of increased risk of re-injury and higher training volume and match intensity in chronologically older players (120). We must highlight that this is the first study to use a clear cut-off (growth-velocity <1 cm/year) (13) to segregate immature post-PHV players and those who progressed towards full maturity (adults). However, comparisons with previous studies (30,31,35) must be made cautiously as previous studies estimated age at PHV using methods such as the maturity offset and Khamis-Roche equations (28,29,35). Besides, there is discrepancy in the cut-off values of maturity status periods (30,31,35).

Injury patterns in different maturation periods

Growth-related injuries had the highest impact circa-PHV. The slow adaptation of muscles, tendons, and apophyses to quick changes in extremity length, mass, and moments of inertia may increase stress on muscle-tendon junctions and apophyses (13), leading to injury. Interestingly, due to progressive distal to proximal growth and maturation patterns (13,77,117) these injuries also occurred pre- and post-PHV. Distal growth-related injuries peaked in pre- (Sever's disease) and circa-PHV (Osgood-Schlatter's disease), and injuries in more proximal segments occurred post-PHV (spondylolysis).

Nevertheless, muscle injuries had a larger impact in post-PHV and adult players. After bone-plate and apophysis ossification (13), muscle might be the structural point of failure for neuromuscular (61,99,118), and physiological (119) alterations induced by PHV, resulting in increased burden post-PHV. Further, re-injuries and higher demands in older players (120) also may influence muscle injury burden, especially in adults. Tendons also increase their cross-sectional area slower than adjoining muscles during adolescence (13) and imbalance between muscle and tendon growth might lead to increased susceptibility for groin pain, which only occurred since post-PHV.

The burden of joint/ligament injuries also increased with advanced maturation and peaked in post-PHV and adult players. The longitudinal growth of the bones, during the adolescent growth spurt, occurs prior of the increase in muscle mass (13). This implies an increase in the moments of inertia of the athletes' segments, which might not be met with sufficient muscle capacity (119). Therefore, "adolescent awkwardness" (119), alterations in force production (118), reduced neuromuscular control (61,99) and interlimb asymmetry (61) occur near PHV, which may lead to increased lower extremity joint/ligament injury risk (61). Besides, ankle sprains in immature bodies with decreased bone density (13) may have resulted in epiphyseal injuries pre- and circa-PHV, which were recorded as growth-related injuries (9). Further, increased risk of re-injury and greater acute volumes of training and matches (120) may partly explain increased injury burden post-PHV.

Pre-PHV growth-related and knee joint/ligament injuries are less burdensome in late than on-time maturers

Pre-PHV players who matured late had lower overall injury burden, and specifically growth-related and knee joint/ligament injuries. This pattern remained circa-PHV but was not significant, which may be a consequence of the small exposure in the short 1-year circa-PHV period. On one hand, teenagers who reach PHV at later ages usually have slower velocity and tempo in PHV (13). This might cause less stress on apophyses (32) and not so great neuromuscular alterations (61,99,118), leading to decreased burden of overall, growth-related, and knee joint/ligament injuries. Further, the tendency of coaching staff to rely less on late-maturers (81) might result in decreased match exposure (86) and thus decreased injury risk.

In line with our results, recent research found increased overall injury risk in immature (39) and U13–U14 early maturers (42). However, the only research studying overall burden in each maturity status period found no significant differences between timing groups pre-PHV (31). Concerning specific injury risk, Materne et al. found more hip/pelvis apophyseal injuries in early maturers (39). However, Van der Sluis et al. (43) described increased overuse injury risk in pre-PHV later maturers, although the study had a small sample of 23 players, compared “later” and “earlier” maturers, and estimated PHV with the Mirwald equation. Also contrary to our results, research in U14 players found a significantly higher incidence of osteochondrosis in normal/late maturers (38). However, early maturers in this category may have been post-PHV, while on-time and late maturers may have been pre-/circa-PHV. Thus, as osteochondrosis is more frequent in circa-PHV (77), the study results may have been a consequence of players’ maturity status rather than timing.

Adult joint/ligament injuries are more burdensome in late than early maturers

Anthropometrical, physical, and technical differences might partly explain why late maturers had greater burden of overall and joint/ligament injuries compared with early maturers. Later maturers are usually taller and have longer legs when adults (121) and may be more susceptible to injury due to greater forces impacting through joints (122). Further, late-maturing players, who may be physically inferior and smaller in chronological-based categories, usually develop more of their technical and tactical skills at young ages. These skills become more apparent in bio-banding formats, at which late maturers are not physically inferior due to maturity equality (91,123). Late maturers are provided with more opportunities to show technical-tactical skills in bio-banding format, which reflects a similar situation to the adult state with no maturational differences (123). Therefore, they have more conquered and attack balls, as well as a higher volume of play and efficiency on the ball (123). It is possible that once late maturers attain adult height and are physically equal to their counterparts, they show their technical skills more and perform more dribbles and pivoting actions, predisposing them to joint/ligament injuries (61).

Methodological considerations

The principal strength of the current study is its longitudinal design over two decades, which allowed us to model 110 individual growth curves and calculate age at PHV. As opposed to previous research with shorter data periods and non-invasive estimating methods such as maturity offset and Khamis-Roche (28,29,35) we calculated age at PHV. Most importantly, this is the first study to analyse the burden of specific injuries according to maturity status and timing.

Nevertheless, the present study has limitations. Our findings apply to a single elite football academy, and early and late maturers were underrepresented. Therefore, the number of specific injuries (specially in early and late maturers) was limited. Further, only male players with height data that fit the SITAR model were included in the study. Considering that injuries have a negative impact on academy progression (3), players who sustained severe injuries may have been missed. Moreover, many factors such as preventive strategies might have changed over the study time period and were not controlled for in analyses. Regarding injury registration, specific injury diagnosis and days of absence were recorded following the same criteria during the whole study, and in line with the definitions in the 2006 FIFA consensus. However, there were no protocols to check intra- and inter-tester reliability for height and injury recording, and it is unclear how this might have influenced maturity classifications or consistency in injury data before and after the consensus. The retrospective design of our study also made it impossible to account for individual exposure in minutes or available training and match days for all seasons. Thus, as suggested by the latest international Olympic Committee consensus statement (40), exposure was expressed as the number of player-seasons. In addition, higher training and match volume in more mature players (120) might partly explain increased burden found in advanced maturity status periods. Finally, caution must be taken when interpreting these findings, as injuries are complex and other factors contribute to risk beyond those analysed in this study (95).

Future research is needed to analyse the influence of growth and maturation together with other relevant data (technical, physical, psychosocial factors) to better understand differences in injury burden between groups. In absence of accurate methods to estimate PHV, it is crucial to collect longitudinal height data, and collaboration among many clubs seems necessary to perform sufficiently powered future studies.

Practical application

In conclusion, injury patterns varied according to maturity status and timing, and the main findings are summarized in the graphical abstract. Growth-related injuries peaked in pre- and circa-PHV players while muscle and joint/ligament injuries peaked in adults. Besides, early maturers had more burdensome injuries in pre-PHV while late maturers had more burdensome joint/ligament injuries when adults. Hence, regular monitoring of maturity seems crucial to define each player’s maturation profile, detect potential injuries that cause the greatest disruption, and facilitate design of targeted injury prevention programs.

Educating key stakeholders (players, coaches, directors, parents) about the effects of maturation on injury burden is also vital. Load management strategies would be beneficial to reduce growth-related injuries. Such strategies could include not scheduling consecutive training days (91), modifying sessions of players at higher risk (91) and utilising existing maturity-categorised strategies such as bio-banding in training and competitions (91,123). Besides, prescribing activities to facilitate development whilst preventing unwanted mechanical stress would enable better management of the frequency and volume of exposure to stressful activities (91). For example, grouping circa-PHV players together and focusing on technical proficiency of movement for one session each week may innately reduce the repetitive, high-stress mechanical loads associated with rapid decelerations and changes of direction. This seems particularly necessary in earlier maturers, whose growth-related injuries were more burdensome. On the other hand, post-PHV and adult players should prioritise injury-prevention programs focused on hypertrophy and motor skill development to reduce risk of muscle and joint-ligament injuries (61,91,99). Special attention should be given to adult late maturers, who have been shown to be more time unavailable due to higher joint/ligament injury burden. Nonetheless, injuries are multifactorial, and risk factors apart from those related to maturity (training load, neuromuscular and biomechanical factors, physiotherapy, coaching, communication, psychosocial factors...) must be taken into account when designing injury prevention programs (95)

PAPER V: THE COMBINED EFFECTS OF GROWTH AND MATURITY STATUS ON INJURY RISK IN AN ELITE FOOTBALL ACADEMY

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ABSTRACT

Introduction: Growth and maturation are potential risk factors for football injuries; however, no study has analysed the combined effects of growth rate and maturity status on specific injury risk. This study aimed to explore the interaction between growth rate on specific injury incidence and burden on pre-, circa- and post-peak height velocity (PHV) periods.

Methods: Injury and stature data collected during the 2000-2020 seasons in an elite football academy were retrospectively analysed. Only players with height measurements from childhood until the attainment of adult height were included in the study (N=84). Growth data were smoothed using a cubic spline to calculate daily growth rate and height. Growth rate was categorised into three groups: fast (>7.2 cm/year), moderate (3.5-7.2 cm/year) and slow (<3.5 cm/year). Percentage of observed adult height was used to classify players as pre-PHV (<88%), circa-PHV (88%-95%) or post-PHV (>95%). Overall and specific injury incidence and burden and rate ratios for comparisons between growth rate groups were calculated on pre-, circa- and post-PHV periods, separately.

Results: Overall injury incidence and burden were greater in pre-PHV players with quicker growth rates compared to players growing moderately and slowly. All in all, players with more rapid growth-rates were at higher risk for growth-related injuries in all pre-, circa- and post-PHV periods. Post-PHV, the incidence and burden of joint/ligament injuries were 2.4 and 2.6-times greater in players growing slowly compared to players growing moderately.

Conclusions: Practitioners should monitor growth rate and maturity status and consider their interaction to facilitate the design of targeted injury prevention programs.

INTRODUCTION

Injuries can result in long absences from training and matches in academy football players, reducing the opportunity for players to develop their fitness and skills (96). Consequently, injuries negatively impact players' academy progression (3). Injuries occurring during youth can also result in long-term consequences (124), making players more susceptible to future injuries and long-term health risks (e.g., osteoarthritis) (72). Thus, injury prevention in youth footballers is vital to ensure the development of healthy professional players and ensure the long term health of adolescent players regardless of footballing success.

During adolescence, players experience a marked and rapid period of somatic growth (13), leading to evident changes in limb length, limb mass, and moments of inertia (13). As a consequence of these changes, temporary delays or regressions in sensorimotor mechanisms and motor control may be observed during this period (33), adversely impacting injury risk. Accordingly, the International Olympic Committee (2) and league governmental bodies (e.g., English Premier League) (125) have highlighted the importance of assessing and monitoring inter-individual variations in growth and maturity.

Growth rate is used to describe changes of a physical dimension (e.g., standing height) over a given time (13). During the adolescence there is an increase in the rate of growth, with highest point known as peak height velocity (PHV). PHV is observed around the age of 13–14 years in boys, reaching maximal growth rates of 5.6–12.4 cm/year (13). To date, a limited number of studies in youth football academies have investigated the influence of adolescent growth rates upon injury (36,37,45,126). Kemper et al. (36) and Rommers et al. (37) observed that injured male adolescent players had a higher rate of growth compared to non-injured players. Similarly, Johnson et al. (45) reported that players with a rate of growth rate >7.2 cm/year were 74% more likely to be injured than players growing less than 7.2 cm/year. Not only that, but they also showed that there was a linear increase in injury risk associated with growth rate (45). Concerning the risk for specific types of injuries, Wik et al. (98) found that overall growth rate was associated with a greater risk of bone and growth plate injures in adolescent athletics.

Biological maturation is a separate and more complex concept. The level of biological maturation at a given point, defined as maturity status, indicates where along the process towards a mature state a given tissue or organ system (somatic, skeletal, or sexual) is at the time of measurement (13). The percentage of adult height at the time of observation is an indicator of somatic maturity that is increasingly used in youth athletes and allows to easily classify players as pre- (<88%), circa- (88%-95%), or post-PHV (>95%) (79). Available research has suggested that injury incidence and burden is higher in circa-PHV compared to pre-PHV period (31), whilst a recent study has found that the occurrence of specific injuries varies according to the percentage of adult height (77). Growth-related injuries were more frequent in percentages around PHV (91.2%) while muscle and joint/ligament injuries were more common in post-PHV (77). Interestingly, growth-related injuries occurred from distal to proximal body regions, following the pattern of growth and maturation (77). As a result, growth-related injuries occurring on distal segments (e.g., Sever´s and Osgood-Schlatter´s disease) peaked in pre- and circa-PHV periods while proximal injuries (e.g., spondylolysis) peaked in post-PHV (77).

To date, only one study has analysed the interaction between growth-rate and maturity status upon injury risk. Johnson et al. (45) showed that there is an increase in estimated injury likelihood at a high growth rate circa-PHV. However, they found an increase in estimated injury burden likelihood at a lower growth rate and a higher percentage of predicted adult stature (post-PHV). Despite the novel results found by Johnson et al. (45), this study has potential limiting factors. First, the data were recorded over a single season period, making it impossible to follow individuals during a sufficient interval of time to model individual growth curves and account for the non-linear characteristic of growth (29). Further, the Khamis-Roche equation was used to estimate adult height. The median and 90% error for this equation translates to approximately 1.5-3.0% of predicted height, respectively, for the average male and might lead some players to be in or out of a band due to errors associated with the prediction (79). Most importantly, this research did not study the interaction between growth-rate and injury risk of specific injuries in pre-, circa- and post-PHV periods, separately. Considering that growth-rates (13) and injury patterns (60,77) differ according to maturity status, studying the impact of growth-rate on specific injury risk in each period seems vital.

The present study builds upon the abovementioned limitations by using height and injury data recorded in an elite football academy over two decades. This permits a more accurate estimation of daily growth rate and percentage of the observed adult height of players and affords the opportunity to explore potential interactions between growth rate (cm/year) and risk for specific types of injuries (incidence and burden) in pre-, circa- and post-PHV periods, separately.

METHODS

Study design and participants

This retrospective analysis studied height and injury data recorded longitudinally for 20 consecutive seasons (2000–2020) in Athletic Club's elite soccer academy whose professional male team plays in Spanish La Liga. Among the 1123 players who were followed, only players who were ≤U12 when they entered the academy and continued until they attained adult height were included in the study (n=84) attempting to equally represent pre-, circa- and post-PHV periods.

This study was approved by the Ethics Committee of the University of the Basque Country (UPV/EHU) (CEISH/340/2015). Written informed consent to use regularly collected data for research purposes was obtained from the players.

Height measurement, growth-rate estimation, and maturity status assessment

Stature was measured by trained doctors before afternoon trainings at least twice annually. A portable stadiometer (Añó Sayol, Barcelona, Spain) was used to measure standing stature following the International Society for the Advancement of Kinanthropometry (ISAK) guidelines. The staff members' intra-rater typical error of measurement for standing stature was 0.23 cm while the inter-rater error was 0.29 cm (127).

Growth rate was calculated as the change in stature over the change in time (cm/year). Growth data were smoothed using a Cubic spline to provide an estimated height and growth rate for each day (51). This variable was categorised into three groups: fast (>7.2 cm/year), moderate (7.2-3.5 cm/year) and slow (<3.5 cm/year), based on previous literature (36,45) and to achieve an approximately equal number of observations per group.

The percentage of observed adult height was used as a maturity status indicator (79). A player was considered to have attained final height once growth-velocity was <1 cm/year for one year (13). The observed adult height allowed to calculate percentage of adult height using estimated daily height. Players were classified as: pre-PHV (<88%), circa-PHV (88%-95%) or post-PHV (>95%) (45,79).

Injury definitions, exposure, and recording procedures

Time-loss injuries were recorded in the club's online database when a player was unable to take part in full football training or match due to a physical complaint (12). Absence days were calculated as the number of days elapsed between the initial injury date and the player's return to full availability for training and matches (12).

Injury classification was based on FIFA consensus (12) and practitioner experience. As the Consensus by Fuller et al. (12) did not explicitly consider growth-related injuries, they were defined as "unique injuries not seen in adults but common in skeletally immature athletes (e.g., growth plate fractures, apophysitis, apophyseal avulsion fractures, and greenstick fractures)" (9). Two of the four doctors who recorded data worked in the club throughout the study, thereby reducing the chance of different injury interpretation between doctors.

Daily exposure in matches and training sessions was estimated based on the number and duration of matches and trainings, squad size and the number of players on the pitch in each category (40). Players had 3 (U11-U12) or 4 (U13-Reserves) 90-minutes training sessions per week and played a match every weekend. Match length was 70 minutes for U11-U14, 80 minutes for U15-U16 and 90 minutes for older age-groups. The number of players on the pitch was 11 for all categories except for U11-U12, in which 7 players played in each team.

Data analysis

Injury incidence (number of time-loss injuries/1000 hours) and injury burden (number of days lost/1000 hours) were calculated with 95% CI assuming a Poisson distribution (128). Generalized linear mixed-effects models (GLMM) were used to compare incidence and burden between growth-rate groups (fast *vs*. moderate *vs*. slow) in each maturity status period (pre-, circa- or post-PHV) using a Poisson distribution and log-link function. The predictor variables were modelled as categorical fixed effects and player ID was included as a random effect to account for repeated observations. Statistical significance was accepted at $p<0.05$ for incidences, while significant differences for injury burden were considered when the 95% confidence intervals did not overlap (129). Bonferroni adjustments were performed to control the Type I error rate when making multiple comparisons. All analyses were performed using R version 4.1.2 (R Core Team 2021, R Foundation for Statistical Computing, Vienna, Austria).

RESULTS

Player demographics, growth, and maturity data according to maturity status are presented in Table 4.V.1. There were 782 injuries and 162,314 hours of total exposure. The mean exposure for each player was 1932.3 (± 439.9) hours, furthermore, the mean (SD) values for the percentage of observed adult stature and growth rate were 92.38 (± 6.64) % and 5.57 (± 3.35) cm/year, respectively. The overall injury incidence rate was 4.82 injuries per 1,000 hours (95% CI 4.49–5.17), the mean severity of injuries was 23 days (95% CI 21–26) and injury burden was 113 days absent per 1,000 hours (95% CI 105–121). Injury incidence, severity, and burden in each maturity status period are shown in Table 4.V.1.

Overall injury incidence was 1.65- and 2.38- times greater in pre-PHV players with fast growth rates (4.1 injuries/1000h, 95% CI: 2.8-5.2/1000h) compared to players growing moderately (2.6 injuries/1000h, 95% CI: 1.9-3.0/1000h) and slowly (1.8 injuries/1000h, 95% CI: 0.8-3.1/1000h), respectively. Similarly, overall injury burden in pre-PHV players growing fast (86 days lost/1000h, 95% CI: 59-125/1000h) was 2.9- and 4.4- times higher compared to pre-PHV players with moderate (33 days lost/1000h, 95% CI: 25-44/1000h) and slow (20 days lost /1000h, 95% CI: 8-46/1000h) growth rates (Figure 4.V.1).

Concerning growth-related injuries, in the pre-PHV period, incidence and burden were 2.5- and 5.4-times higher in players with fast growth rates (1.9 injuries/1000h, 95% CI: 1.2-2.8/1000h and 58 days lost/1000h, 95% CI: 34-101/1000h) compared to players growing moderately (0.9 injuries/1000h, 95% CI: 0.5-1.1/1000h and 14 days lost/1000h, 95% CI: 9-23/1000h). In the same line, circa-PHV players growing fast showed 2.8- and 3.4-times greater injury incidence and burden (2.5 injuries/1000h, 95% CI: 1.7-3.2/1000h and 96 days lost/1000h, 95% CI: 68-136/1000h) compared to players growing moderately (0.9 injuries/1000h, 95% CI: 0.4-1.6/1000h and 24 days lost/1000h, 95% CI: 10-57/1000h) (Figure 4.V.2). In post-PHV, growth-related injury incidence was 2.4-times higher in players growing fast (0.8 injuries/1000h, 95% CI: 0.2-3.4/1000h) compared to players growing slowly (0.3 injuries/1000h, 95% CI: 0.2-0.5/1000h) (Figure 4.V.2). Concerning injury risk for specific growth-related injuries, pre-PHV players growing fast showed a 4.4-times higher Osgood-Schlatter´s disease incidence (0.2 injuries/1000h, 95% CI: 0.1-1.2/1000h) compared to players growing moderately (0.1 injuries/1000h, 95% CI: 0.1-0.3/1000h) (Figure 4.V.3). Moreover, post-PHV players growing fast had a higher incidence of anterior inferior iliac apophyseal injuries (0.4 injuries/1000h, 95% CI: 0.1-3.9/1000h) compared to players growing slowly (0.01 injuries/1000h, 95% CI: 0.01-0.2/1000h) (RR: 257.9) (Figure 4.V.3).

Significant differences for incidence and burden of muscle injuries were not found between any of the growth rates groups in pre-, circa- and post-PHV periods. Nevertheless, the incidence and burden of joint/ligament injuries were 2.4 and 2.6-times greater in post-PHV players growing slowly (1.7 injuries/1000h, 95% CI: 1.3-2.1/1000h and 62 days lost/1000h, 95% CI: 47-81/1000h) compared to those growing moderately (0.7 injuries/1000h, 95% CI: 0.4-1.1/1000h and 24 days lost/1000h, 95% CI: 12-45/1000h) (Figure 4.V.2).

Table 4.V.1 – Stature, growth velocity, percentage of observed adult height, injury counts, exposure, incidence rates, mean severity, and injury burden according to maturity status.

Maturity status	Stature (cm)	Growth velocity (cm/year)	Percentage of observed adult height	Injury count	Exposure (hours)	Injury incidence (per 1000 hours)	Mean severity (days)	Injury burden (per 1000 hours)
Pre-PHV	149.7 ± 6.0	5.8 ± 2.5	83.5 ± 2.6	147	51544	2.85 (2.43-3.35)	15.4 (12.6-18.2)	43.9 (37.3-51.6)
Circa-PHV	165.9 ± 6.3	7.7 ± 2.7	92.4 ± 2.4	234	40417	5.79 (5.09-6.58)	23.5 (19.7-27.3)	136.0 (119.6-154.6)
Post-PHV	176.8 ± 5.2	2.0 ± 1.9	98.4 ± 1.1	401	70353	5.70 (5.17-6.29)	26.5 (21.8-31-2)	151.1 (137.0-166.6)

Anthropometrical variables are shown as mean ± SD.

Incidence, severity, and injury burden are expressed with 95% confidence intervals

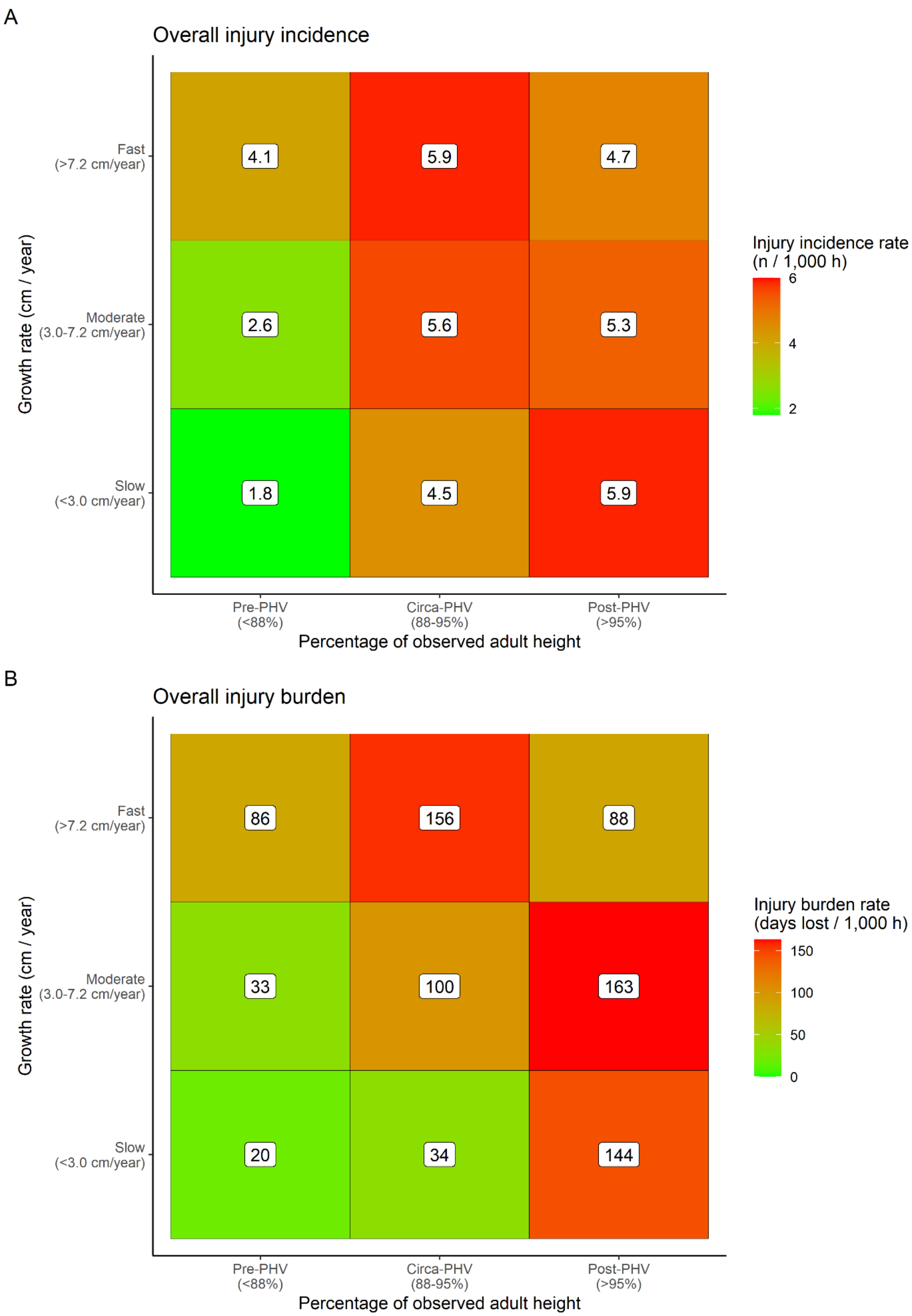

Figure 4.V.1: Overall injury incidence (1A) and burden (1B) according to growth rate and percentage of observed adult height.

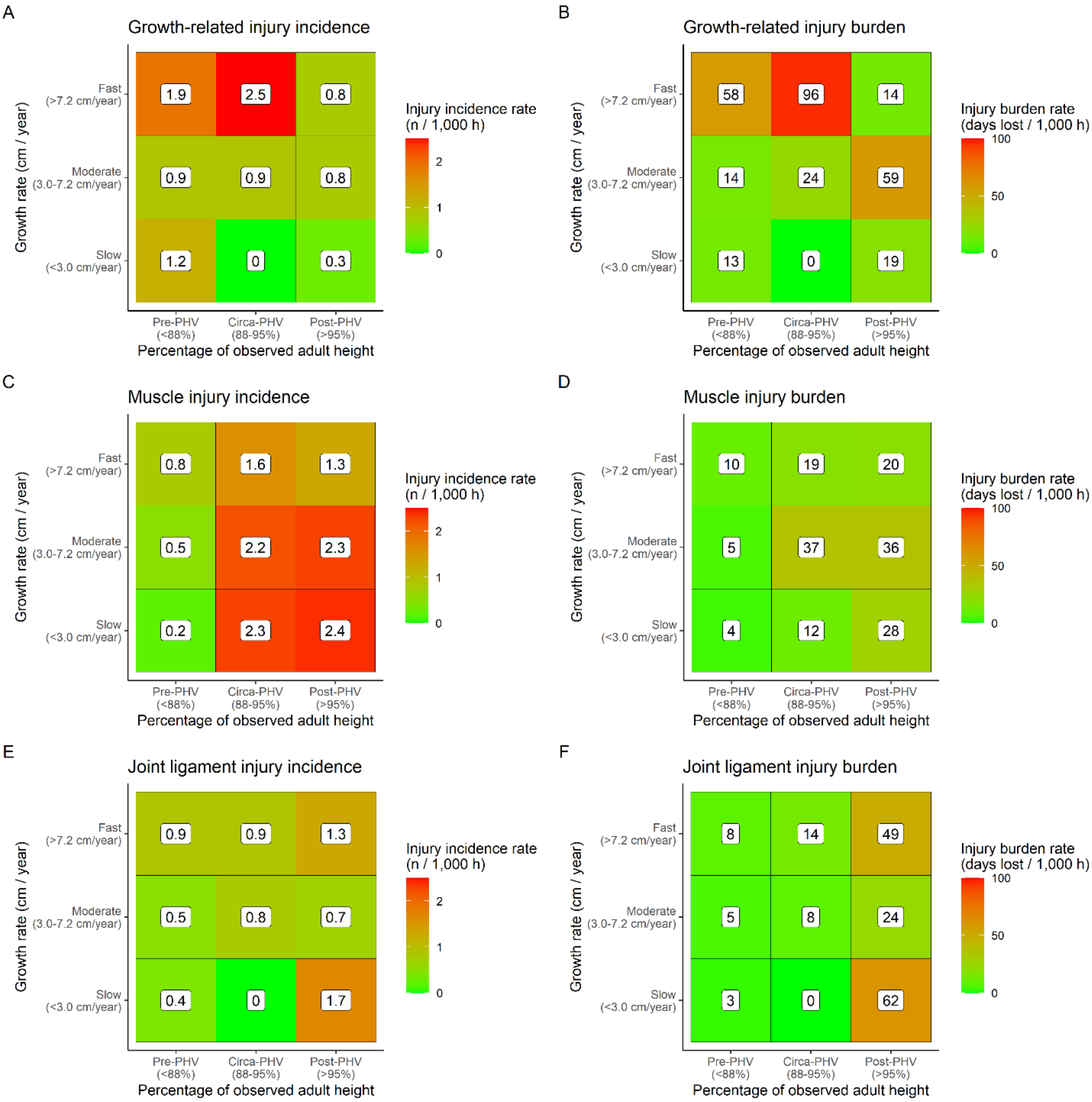

Figure 4.V.2: Incidence (A,C,E) and injury burden (B,D,F) of growth-related (A,B), muscle (C.D) and joint/ligament injuries (E,F) according to growth rate and percentage of observed adult height.

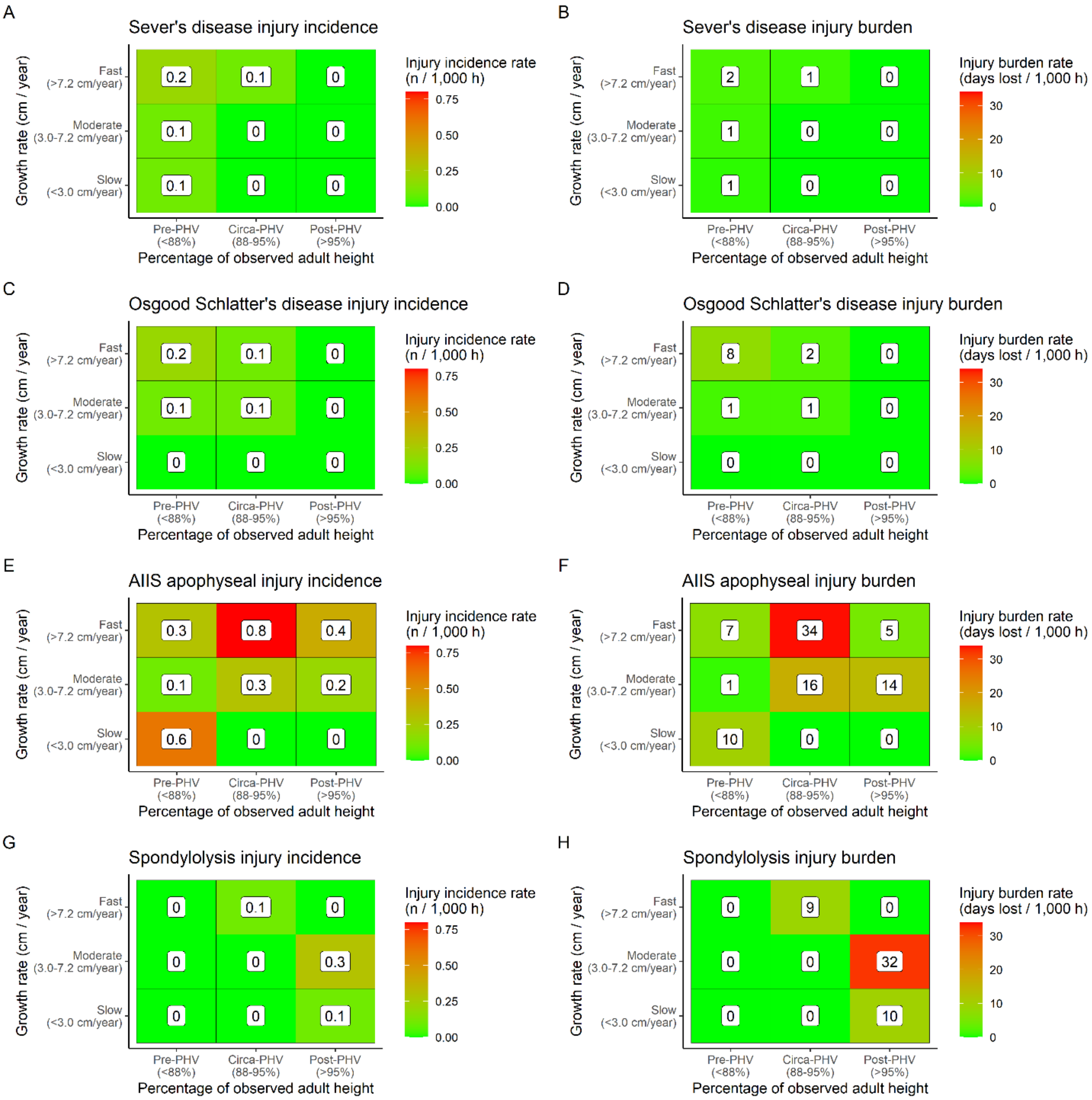

Figure 4.V.3: Incidence (A,C,E,G) and injury burden (B,D,F,H) of specific growth-related injuries according to growth rate and percentage of observed adult height.

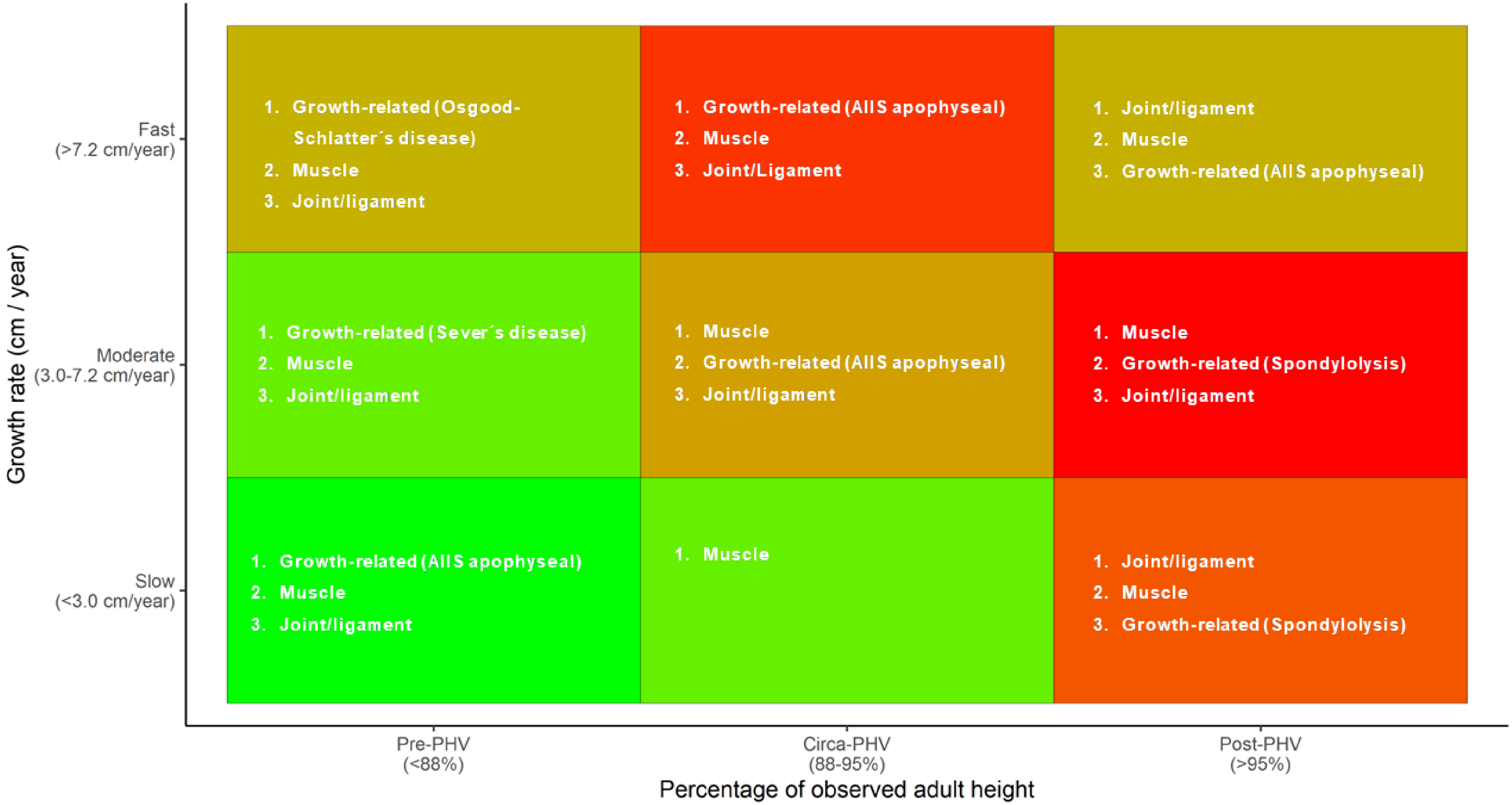

Figure 4.V.4: Ranking for most burdensome type of injuries according to growth rate and maturity status.

DISCUSSION

This is the first research studying the main and interactive effects of growth rate and maturity status on risk for specific types of injuries in academy football. We improved upon the limitations of previous research by using longitudinal height data from childhood to adulthood to estimate daily growth rate and percentage of observed adult height to study how growth rate influences overall and specific incidence and burden in pre-, circa- and post-PHV periods. All in all, our results demonstrated that players with higher growth-rates were at higher risk for growth-related injuries in all pre-, circa- and post-PHV periods. Besides, a higher incidence/burden for joint/ligament injuries in players with slow growth rate post-PHV compared to players with moderate growth rate was found.

The first major finding of this study is that growth-rate affects overall injury risk in pre-PHV period, which highlights the importance of regular growth monitoring from an early age. Multiple injury mechanisms may explain increased injury risk in pre-PHV players with fast growth rates. Rapid growth might lead to larger changes to limb length, limb mass, and moments of inertia (130), alterations in motor control (33), which may adversely impact injury risk. Rapid longitudinal skeletal growth is also associated with a temporary decrease in bone mineral density and weakness of the epiphyseal growth plates (34), and may facilitate the appearance growth-related conditions (32). Considering that growth-related injuries are the injuries with the highest occurrence (77) and burden (60) in pre-PHV period, increased growth-related injury risk in players growing fast might have contributed to increased overall injury risk. Another reason that could explain the higher risk in pre-PHV players growing fast, might be that pre-PHV players with faster growth-rates could be earlier maturers (13). Players maturing earlier usually have faster growth rates (13) and might be physically superior to their peers (22). Thus, they may develop a more physical way of playing football (91) exposing them to a higher injury risk in pre-PHV (60). Future research should consider accounting for maturity timing when studying the interaction of growth-rate, maturity, and injury risk.

The results of the current investigation showed a higher incidence and burden of growth-related injuries in players with fast growth rates compared to those growing moderately in pre- and circa-PHV, and a higher incidence in players with moderate growth rates compared to those growing slowly in post-PHV. The small number of playing growing slowly (<3.5 cm/year) in pre- and circa-PHV might have led to not finding significant differences in those groups. In the same line, the lack of players growing fast in post-PHV period may explain why significant differences compared to this group were not found; however, players growing quick had the highest incidence of growth-related injuries in this period. The combination of altered sensorimotor mechanisms and motor control (33) and vulnerability of apophyses (34) might result in increased injury growth-related injury incidence and burden in players growing fast (32), which is in line with previous research by Wik et al. (98). Besides, it was not surprising to find that faster growth rates lead to higher risk for growth-related injuries in all pre-, circa- and post-PHV periods, as previous research has already shown that these injuries can occur all along the maturation process (60,77). Interestingly, our results showed that growth-rate affected risk for specific types of growth-related injuries differently according to maturity status, which is in accordance with the distal to proximal pattern of growth-related injuries found in previous research (60,77).

No significant results between incidence and burden of muscle injuries were found between growth rate groups (fast *vs*. moderate *vs*. slow) in pre-, circa- and post-PHV. These results are in line with previous research by Wik et al. (98), who only found an association between growth and risk of bone and growth-plate injuries. More research is needed to better understand if neuromuscular alterations that appear around PHV (118,119) are related to the higher muscle and joint/ligament injury risk in circa- and post-PHV periods (60,77).

Concerning injury risk for joint/ligament injuries, players growing slowly had a higher incidence and burden compared to those with fast/moderate growth rates in post-PHV. Our results are in accordance with recent results found by Monasterio et al. (60), who found a higher injury burden for joint/ligament injuries in adult players (growth rate <1cm/year), compared to post-PHV players who may have been growing at higher rates. Considering that post-PHV players growing slow may be more mature (and older) than players growing fast and moderately, our results might be explained by the accumulation of multiple seasons of training and competition throughout their careers (131), with previous injury increasing the risk of subsequent injury (132).

The principal strength of this study is its longitudinal design over two decades, which allowed to model growth rates and estimate daily growth rate and percentage of observed adult height. Our research has improved on previous data that recorded growth during short periods (36,37,45,98,126), not allowing to account for the non-linear characteristic of growth (29). Besides, this study used percentage of observed adult height as a maturity status indicator, while previous studies calculated percentage of predicted adult height (31,45). Most importantly, this is the first study investigating the interaction between growth rate and injury risk (incidence and burden) for specific types of injuries according to maturity status (pre-, circa- and post-PHV).

The limitations of the current investigation should also be noted. Firstly, we did not account for individual exposure. Thus, as suggested by the latest international Olympic Committee consensus statement (40), exposure was estimated based on the number and duration of matches and training sessions, squad size and the number of players on the pitch in each category. Besides, our findings apply to a single elite soccer academy, and only players who attained adult height were included in the study. Considering that injuries have a negative impact on academy progression (3), players who sustained severe injuries may have been missed. Further, many factors such as preventive strategies and training content might have changed over the study period and were not controlled for in analyses. Another limitation is that our sample size was not large enough to detect association with all specific injuries (133), and the limited number of specific injuries resulted in wide confidence intervals for the injury incidence and burden of many injuries. Thus, we only studied the most frequent injuries in our dataset. Future studies should build on this work by conducting multi-team collaborative studies with a sufficiently powered sample size.

PERSPECTIVE

This study highlights the importance of regular monitoring of growth-rate and maturity status when adjusting targeted injury prevention programmes. Academies should measure players every 3–4 months (16) to model individual growth curves and estimate growth velocities. In order to monitor maturity status, an x-ray of the hand-wrist complex is considered the best method to use (13). However, exposure to low-level radiation, the need for specialised equipment and trained technicians makes it impractical in academies. Thus, other non-invasive and cost-efficient alternatives such as the Khamis-Roche method (somatic maturity) (21) or SonicBone BAUSPORT system (skeletal maturity via ultrasound) (134) could be used to estimate percentage of adult height.

Once estimated each player´s growth rate and maturity status (pre-, circa-, post-PHV), Figure 4.V.4 could be used in a practical setting to identify players at higher risk (red colour). This figure will be helpful to facilitate the interpretation of our results to key decision-makers in football academies (players, coaches, and directors), who may be unfamiliar with scientific figures and data analysis. As a result, it may improve communication with key decision-makers and increase their engagement in injury management strategies. Practitioners may choose the adjust training content and training and competition load during periods of heightened injury risk (i.e., adolescent growth spurt) to mitigate injury risk. Jan Willem Teunnisen, a former movement scientist at Ajax Football Club describes an innovative bio-banding (i.e., maturity matching) strategy whereby the player's entering the adolescent growth spurt were prescribed a training programme that emphasised core strength, balance, coordination, the re-training of fundamental and sport-specific motor skills, and the maintenance mobility, in addition to a reduction in training and competition load (135). The purpose of this programme was to reduce injury risk and aid transition through this phase of development.

The growth/maturity heat maps also highlight the most burdensome injuries (5) in each quadrant and may guide practitioners to design targeted injury prevention programmes. As shown in previous research (60,77), reducing the impact of growth-related injuries seems vital in pre- and circa-PHV periods. Further, this research highlights the need for special attention to those players growing at velocities >7.2 cm/year. Strategies such as controlling week-to-week changes in load (15,45), changing training content (136) or monitoring symptoms of musculoskeletal complaints to detect early growth-related conditions (137) may be of the utmost importance in those players. Due to the distal to proximal patterns of growth-related injuries, special awareness to symptoms in the ankle/ knee should be taken in pre-PHV period, while focussing on complaints on the hip/pelvis and lower back is essential in circa- and post-PHV, respectively. On the other hand, reducing the impact of spondylolysis, muscle and joint/ligament injuries seems vital in post-PHV. For instance, controlling training load (15) or neuromuscular training programmes (61) might be beneficial to reduce injury risk during this period.

PAPER VI: PEAK HEIGHT VELOCITY AFFECTS INJURY BURDEN IN CIRCA-PHV SOCCER PLAYERS

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ABSTRACT

Growth and maturation are potential risk factors for soccer injuries. This research sought to describe how peak height velocity (PHV) affects overall and specific injury burden in circa- and post-PHV elite academy soccer players. Injuries and growth data collected from 2000–2020 were retrospectively studied. Longitudinal height records for 124 players were fitted with the Super-Imposition by Translation and Rotation model to calculate PHV (cm/year) and age at PHV. Players were classified according to PHV percentile (fast: ≥75th; average: 25–75th; slow: ≤25th) and maturity status (circa- or post-PHV). Overall and specific injury burden (days lost/player-season) and rate ratios for comparisons between groups were calculated based on zero-inflated negative binomial models. Confidence intervals were calculated at the 95% confidence level (CI) and the significance level was set at <0.05. In circa-PHV, players with fast PHV had 2.6 (CI: 1.4-4.8)- and 3.3 (CI:1.3-6.7)-times higher overall burden and 2.9 (CI:1.1-7.1)- and 4.1 (CI: 1.4-15.2)-times higher for growth-related injury burden compared to players with average and slow PHV, respectively. Regular monitoring of growth seems important to detect players at higher risk for being disrupted by growth-related injuries.

Keywords: injury risk, growth, maturation, youth sport, injury burden, soccer.

INTRODUCTION

Adolescence is characterised by marked somatic growth and significant musculoskeletal and physiological development (13). The burden of soccer injuries is high during this period (7,30), so growth and maturation have been identified as potential risk factors for injury (35). Injuries negatively affect player progression in elite soccer academies (3) and increase susceptibility for future injuries and long-term health risks in adulthood (124). Thus, better knowledge about growth and maturation as injury risk factors is vital (35).

Growth rate is used to describe changes of a physical dimension over a given time and is especially increased during the adolescent growth spurt, with peak height velocity (PHV) observed around the age of 13–14 years in boys, with maximal growth rates of 5.6–12.4 cm/year (13). Maturation is a more complex concept. The level of biological maturation at a given point, defined as maturity status, indicates where along the process towards a mature state a given tissue or organ system (somatic, skeletal, or sexual) is at the time of measurement (13). For instance, somatic maturity may be assessed using age at PHV as a landmark and defining players as pre-, circa-, or post-PHV (13).

The fast increase in adolescents' segment length due to rapid growth leads to increased tensile forces (13) and temporary delays or regressions in motor control (33), which may adversely impact injury risk. Recent research has associated faster growth rates (36,37,126) and circa- and post-PHV periods (30,31,60) with increased risk for soccer injuries. Kemper et al. (36) and Rommers et al. (37) reported that injured male adolescent soccer players had a higher rate of growth compared to non-injured players. In adolescent athletics, Wik et al (98) found that overall growth rate was associated with a greater risk of bone and growth plate injures. On the other hand, research suggests an increase in overall injury risk in the period around (circa-) and after (post-) PHV (30,31,60). Interestingly, a single study has considered to analyse the combined effects of growth rate and maturity status on injury risk (45). Johnson et al found that estimated injury risk was higher in players growing faster around PHV (45), which is in line with previous research, finding an association of injuries with growth (36,37,126) and maturity status (30,31,60). However, in this study estimated injury burden peaked near adult stature and slow growth-rates (45), which might be related to more severe muscle and joint/ligament injuries in more mature players (60).

Available research on this topic provides limited evidence due to methodological limitations (35). Firstly, studies analysing growth data were either cross-sectional or short longitudinal studies with a relatively small number of players and lasting only 1–4 years (36,37,126). Thus, they did not follow individuals from pre-puberty to adulthood to model individual growth curves and calculate age at PHV (35). Further, non-invasive estimating methods were used to estimate age at PHV, which have demonstrated reduced accuracy in comparison with the gold-standard growth-fitting techniques (28,29,44). Moreover, most of these studies measured injury incidence (frequency of injuries), without accounting for injury burden (the product of injury incidence and mean severity) (5) and did not record specific types of injury. Besides, no study has considered studying PHV (maximal growth-rate) as an injury risk factor in circa- and post-PHV periods. PHV leads to alterations in force production (100,118) and loss of movement coordination (61,99), which can also remain in post-PHV (99,118). As a result, PHV might influence injury burden in both circa- and post-PHV periods. Not only that, considering that injury-patterns differ according to maturity status (60,77), PHV might affect different injuries in each period.

In view of the limitations mentioned above, this study longitudinally followed adolescent elite male academy soccer players for two decades to model individual curves and investigated how PHV (fast, average, slow) is associated with overall and specific injury burden at circa- and post-PHV. We hypothesized that players with fast PHV would have greater burden for growth-related injuries in circa-PHV and a higher burden for muscle and joint/ligament injuries in post-PHV period.

MATERIAL AND METHODS

This retrospective analysis studied height and injury data recorded longitudinally for 20 consecutive seasons (2000–2020) in a Basque elite soccer academy whose professional male team plays in Spanish LaLiga. Similar data to that used in previous growth and maturation studies was used (60,77). Players were single sport athletes who trained 3–4 times per week depending on age (3 times for U11–U12, and 4 times for older groups) and played a game every weekend. Among the 1123 players who were followed, only 124 players met the inclusion criteria of fitting the Super-Imposition by Translation and

Rotation (SITAR) model (50) and having ≥10 height measurements per individual (116) with height data recorded both before and after their estimated age at PHV (28).

This study was approved by the Ethics Committee of the University of the Basque Country (UPV/EHU) (CEISH/340/2015). Written informed consent to use regularly collected data for research purposes was obtained from the players guardians. All procedures performed in the study meet the ethical standards of this journal (138).

Height measurement and PHV estimation

Stature was measured by trained doctors before afternoon trainings at least twice annually. A portable stadiometer (Añó Sayol, Barcelona, Spain) was used to measure standing stature to the nearest 0.1 cm as the distance from the standing surface to the vertex of the head. Participants stood barefoot with feet together and their head in the Frankfort plane and were required to take a deep breath and hold their head still while measuring. Longitudinal height records for 124 players were fitted with the SITAR model (50) to summarize individual longitudinal changes in height throughout childhood and adolescence and estimate PHV (cm/year) and age at PHV. Players were categorised according to their growth-rate percentile as fast (≥75th: ≥10.84 cm/year), average (25–75th: 8.98–10.84 cm/year), or slow (≥25th: ≤8.98 cm/year). Age at PHV was used to define players' circa-PHV (±6 months from PHV) and post-PHV periods (>6 months from PHV and until growth velocities were <1 cm/year) (13).

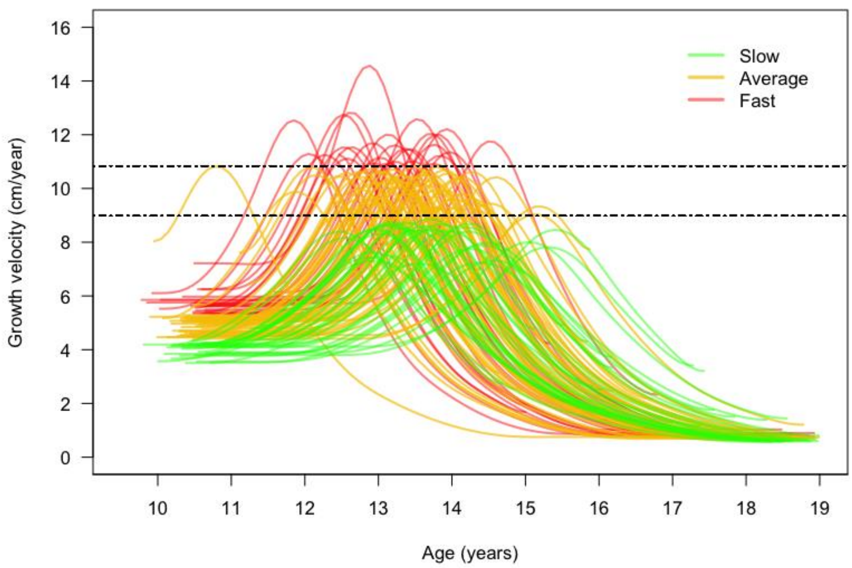

Figure 4.VI.1: Growth-curves for the 124 players included in the study. Horizontal dashed lines indicate cut-off values for fast, average, and slow peak height velocity curves.

Injury definitions, exposure, and recording procedures

Time-loss injuries were recorded in the club's online database when a player was unable to participate in a future training session or match due to a physical complaint resulting from a soccer training or match. The player was considered injured until medical staff cleared the player for full participation in training and matches. Absence days were recorded as the time elapsed between the day of injury and the day returning to full training or match play. Classification of injuries was based on FIFA consensus (12) and practitioner experience. FIFA Consensus did not explicitly consider growth-related injuries. Thus, growth-related injuries were defined as "unique injuries not seen in adults but common in skeletally immature athletes (e.g., growth plate fractures, apophysitis, apophyseal avulsion fractures, and greenstick fractures)" (9). Injuries were classified as: 1) growth-related injuries, 2) muscle injuries, and 3) joint/ligament injuries (knee and ankle). Two of the four doctors who recorded data worked in the club throughout the study, thereby reducing the chance of different injury interpretation between doctors.

As suggested by the latest international Olympic Committee consensus statement, player-season was defined as the unit of exposure (40). Each player's number of days lost in each period (circa- and post-PHV) were subtracted from the exposure days and divided by 365.25 to convert them to player/seasons.

Data analysis

All estimations were performed using R (version 3.6.2, R Foundation for Statistical Computing, Vienna, Austria). Injury burden (number of days lost/ player-season) was calculated to account for both frequency (incidence) and severity (mean absence) of injuries (5). Zero-inflated negative binomial models were fitted to account for the excess of zeros and overdispersion in the data (83) using the glmmTMB package. Player ID was included as a random effect to account for repeated observations. Injury burden of fast vs. average vs. slow growth groups were compared in circa- and post-PHV groups by calculating rate ratios (RRs). Confidence intervals were calculated at the 95% confidence level for rates and RRs using a parametric bootstrap procedure and the significance level was set at <0.05. Rate ratios of 1.2, 1.9, and 3.0 can be taken as small, medium, and large, respectively (82).

RESULTS

In total, 124 players were included for a total of 461 player-seasons: 108 circa-PHV, and 353 post-PHV. There were 29 players with fast PHV, 63 players with average PHV, and 32 players with slow PHV (Figure 4.VI.1). Mean age at initial observation was 10.7 ± 0.7 years, while age at final observation was 18.1 ± 2.5 years. Each player had 20.3 ± 5.2 height measurements. PHV occurred at a mean age of 13.4 ± 0.8 years with a velocity of 10.0 ± 1.7 cm/year. A total of 823 (166 circa-PHV, 657 post-PHV) time-loss injuries resulting in 22487 (4661 circa-PHV, 17826 post-PHV) days of absence were recorded (Supplementary Table 4.VI.1 and 4.VI.2).

In circa-PHV, players with fast PHV had three-times higher overall injury burden (107 days lost/player-season) than average and slow PHV groups (40 and 35 days lost/player-season) (Table 4.VI.1). The burden of growth-related injuries was three- and four-times greater in players with fast PHV (70 days lost/player-season) compared to players with slow PHV in circa-PHV (24 and 17 days lost/player-season, respectively) (Table 4.VI.1). However, significant differences were not found for muscle or joint/ligament injury burden (Table 4.VI.1) in circa-PHV. Significant differences were not found between fast, average, and slow PHV injury burden at post-PHV (Table 4.VI.2).

Table 4.VI.1 – Injury burden (number of days lost/player-season [95% CI]) in circa-PHV according to peak height velocity percentile and rate ratios (95% CI) for comparisons between groups.

	Number of days lost/player-season			**Rate-ratios**		
	Fast (PHV≥10.84 cm/year)	**Average (PHV:8.98–10.84 cm/year)**	**Slow (PHV ≤8.98 cm/year)**	**Fast vs. average**	**Fast vs. slow**	**Average vs. slow**
Overall burden	106.9 (58.8–167.7)	40.2 (26.1–55.9)	35.3 (17.6–60.5)	**2.66 (1.35–4.84) ***	**3.03 (1.34–6.67) ***	1.14 (0.57–2.49)
Growth-related injury	70.2 (28.2–124.7)	24 (12.3–38.4)	17 (5.1–34.5)	**2.93 (1.12–7.16) ***	**4.13 (1.38–15.23) ***	1.41 (0.53–4.74)
Muscle injury	6.8 (0.7–16.2)	2.7 (1–5.1)	10.6 (2.6–21.2)	2.46 (0.25–8.72)	0.64 (0.07–3.06)	0.26 (0.08–1.08)
Joint/ligament injury	4.8 (0.3–12.7)	6.9 (2.5–12.5)	2 (0.01–12.7)	0.70 (0.05–3.03)	2.38 (0.13–$5.82*10^{9}$)	3.41 (0.83–$1.28*10^{10}$)
Knee	2.7 (0.01–8.1)	5.4 (0.8–11.4)	1.6 (0.01–5)	0.51 (0.01–4.12)	1.67 (0.01–$1.52*10^{10}$)	3.30 (0.47–$2.82*10^{10}$)
Ankle	0.2 (0.01–0.6)	0.9 (0.05–2.2)	0.4 (0.01–1.6)	0.17 (0.01–2.65)	0.38 (0.01–$7.06*10^{12}$)	2.27 (0.11–$1.71*10^{15}$)

Bold indicates significant differences (*p<0.05) between groups.

Table 4.VI.2 – Injury burden (number of days lost/player-season [95% CI]) in post-PHV according to peak height velocity percentile and rate ratios (95% CI) for comparisons between groups.

	Number of days lost/player-season			**Rate-ratios**		
	Fast (PHV≥10.84 cm/year)	**Average (PHV:8.98–10.84 cm/year)**	**Slow (PHV ≤8.98 cm/year)**	**Fast vs. average**	**Fast vs. slow**	**Average vs. slow**
Overall burden	44 (29.3–61.6)	62 (45.9–79.3)	50.7 (33.5–69.2)	0.71 (0.45–1.12)	0.87 (0.52–1.48)	1.22 (0.79–2.04)
Growth-related injury	13.7 (4.4–28.1)	22.3 (11.7–35)	9.5 (2.4–20.3)	0.62 (0.16–1.68)	1.45 (0.37–6.68)	2.35 (0.87–10.13)
Muscle injury	13.2 (7.3–19.8)	8.8 (6–11.9)	11 (6.7–16.6)	1.50 (0.78–2.61)	1.20 (0.58–2.33)	0.81 (0.44–1.46)
Joint/ligament injury	8.6 (4.4–13.8)	12.7 (7.5–18.5)	20.9 (10–34)	0.68 (0.31–1.32)	0.41 (0.17–0.98)	0.61 (0.29–1.43)
Knee	1.8 (0.2–4.2)	6.3 (2.4–11.2)	9 (1.3–20.3)	0.28 (0.04–1.04)	0.20 (0.02–1.29)	0.70 (0.18–5.17)
Ankle	6.2 (2.6–11.5)	3.7 (1.9–5.8)	5.7 (1.9–11.5)	1.67 (0.65–4.37)	1.09 (0.35–3.35)	0.65 (0.26–1.92)

Bold indicates significant differences (*p<0.05) between groups.

Supplementary Table 4.VI.1 – Injury frequency, prevalence. number of days lost and median-time loss in circa-PHV according to peak height velocity percentile.

CIRCA-PHV	Fast (n=29)		Average (n=62)		Slow (n=32)	
	Frequency (% of injured players)	**Days lost (median time-loss)**	**Frequency (% of injured players)**	**Days lost (median time-loss)**	**Frequency (% of injured players)**	**Days lost (median time-loss)**
Overall	43 (82.8%)	1951 (21)	82 (66.1%)	1854 (12)	41 (59.4%)	856 (11)
Growth-related injuries	25 (55.2%)	1034 (20)	37 (41.9%)	1066 (19)	11 (31.2%)	377 (12)
Sever´s disease	4 (6.9%)	47 (11.5)	5 (8.1%)	53 (8)	1 (3.12%)	9
Osgood-Schlatter´s disease	4 (13.8%)	59 (12.5)	9 (9.7%)	169 (10)	4 (12.5%)	61 (11.5)
Anterior inferior iliac spine apophyseal injury	10 (24.1%)	426 (25.5)	8 (11.3%)	190 (24)	4 (9.4%)	196 (48)
Anterior superior iliac spine apophyseal injury						
Spondylolysis	1 (3.5%)	126	1 (1.6%)	89	1 (3.1%)	133
Muscle injuries	7 (20.7%)	412 (21)	15 (17.7%)	146 (10)	15 (25%)	269 (12)
Hamstring	2 (6.9%)	25 (12.5)	6 (8.1%)	74 (9.5)	6 (15.63%)	117 (12.5)
Quadriceps	3 (6.9%)	328 (25)			5 (9.4%)	103 (13)
Adductor	1 (3.4%)	21 (21)	1 (1.6%)	10	1 (3.1%)	3
Joint/ligament injuries	4 (13.8%)	90 (16)	16 (17.7%)	329 (12)	4 (9.4%)	59 (12.5)
Knee joint/ligament	2 (6.9%)	61 (30.5)	7 (8.1%)	248 (24)	2 (6.2%)	47 (23.5)
Anterior cruciate ligament rupture						
Knee´s medial collateral ligament			3 (3.2%)	81 (29)	1 (3.1%)	18
Meniscal			1 (1.6%)	120		
Ankle joint/ligament	1 (3.4%)	4	5 (6.5%)	49 (10)	2 (3.1%)	12 (6)
Lateral ankle sprain			4 (4.8%)	40 (11)	2 (3.1%)	12 (6)
Syndesmotic sprain						
Groin pain						

Supplementary Table 4.VI.2 – Injury frequency, prevalence. number of days lost and median-time loss at post-PHV according to peak height velocity percentile.

POST-PHV	Fast (n=28)		Average (n=59)		Slow (n=32)	
	Frequency (% of injured players)	**Days lost (median time-loss)**	**Frequency (% of injured players)**	**Days lost (median time-loss)**	**Frequency (% of injured players)**	**Days lost (median time-loss)**
Overall	162 (92.9%)	3123 (11)	329 (89.8%)	9622 (12)	166 (93.75%)	5081 (10)
Growth-related injuries	12 (35.7%)	613 (26.5)	47 (40.7%)	3148 (65)	14 (31.2%)	940 (38.5)
Sever´s disease	1 (3.6%)	10			3 (6.25)	26 (8)
Osgood-Schlatter´s disease			5 (3.4%)	154 (21)		
Anterior inferior iliac spine apophyseal injury	5 (14.3%)	81 (12)	9 (10.2%)	617 (67)		
Anterior superior iliac spine apophyseal injury	1 (3.6%)	72	8 (5.1%)	431 (63.5)	1 (3.1%)	10
Spondylolysis	3 (10.7%)	367 (103)	14 (16.9%)	1585 (97.5)	5 (12.5%)	612 (105)
Muscle injuries	73 (67.9%)	1071 (12)	108 (67.8%)	1399 (9)	72 (75%)	950 (8)
Hamstring	19 (39.3%)	302 (12)	34 (32.2%)	322 (7)	18 (28.12%)	220 (8)
Quadriceps	19 (32.1%)	352 (14)	32 (33.9%)	522 (11.5)	23 (40.6%)	386 (9)
Adductor	4 (14.3%)	36 (11)	14 (16.9%)	131 (7)	12 (18.7%)	117 (7)
Joint/ligament injuries	36 (64.3%)	754 (10.5)	76 (54.2%)	2477 (13.5)	43 (59.4%)	2330 (25)
Knee joint/ligament	7 (17.9%)	146 (15)	23 (22%)	1169 (30)	18 (21.2%)	1455 (34)
Anterior cruciate ligament rupture			1 (1.7%)	184	4 (12.5%)	896 (242)
Knee´s medial collateral ligament	4 (7.1%)	92 (18.5)	4 (5.1%)	138 (27)	2 (6.25%)	30 (15)
Meniscal	1 (3.6%)	32	7 (6.8%)	262 (14)	3 (9.4%)	235 (42)
Ankle joint/ligament	28 (50%)	553 (9)	44 (39%)	757 (9.5)	17 (40.6%)	366 (8)
Lateral ankle sprain	13 (35.7%)	247 (8)	29 (32.2%)	383 (8)	12 (31.2%)	165 (6.5)
Syndesmotic sprain	5 (17.9%)	267 (57.5)	3 (3.4%)	210 (102)	3 (9.4%)	64 (27)
Groin pain	1 (3.6%)	2	4 (5.1%)	748 (86)	3 (9.4%)	21 (3)

DISCUSSION

This is the first research analysing longitudinal growth data over two decades to study how PHV affect injury burden of circa- and post-PHV elite academy soccer players. Our results showed that the burden of growth-related injuries was greater in players with fast PHV compared to players with average and slow PHV in circa-PHV.

PHV (10.0 ± 1.7 cm/year) and age at PHV in our population (13.4 ± 0.8 years) was similar to that observed in other academies (28,29,139,140). However, our cohort had faster PHV than the average 9 cm/year velocity for the Basque male population (106). This might be explained by secular changes due to a combination of improved health and nutritional status and by the systematic selection and retention of players taller and earlier maturing players (141), who usually have a faster PHV (13). For instance, height has been identified as important for goalkeepers, defenders, and central strikers, which may be important for stopping the ball from entering the goal or heading the ball (142).

Growth-related injuries caused longer absence in circa-PHV players with fast PHV

Our data revealed that PHV affects overall and growth-related injury burden in circa-PHV academy soccer players. Considering that growth-related injuries are the injuries with the highest burden in circa-PHV (60), increased growth-related injury burden in circa-PHV players with fast PHV might have resulted in increased overall injury burden. Multiple injury mechanisms may explain increased growth-related injury burden in circa-PHV players with fast PHV. On the one hand, the longitudinal rapid growth of the bones implies an increase in the moments of inertia of the players segments (13). As growth of the bones occurs prior to the increase in soft tissue (i.e., tendon and muscle mass), the increase in the moments of inertia occurs prior to the adaptation to the altered level of mechanic stress (13). During this lag period, it is common for individuals to adopt modified movement kinematics (termed ‘adolescent awkwardness’) (33) and mechanical load-response pathways (13), potentially reducing their resilience to injury. On the other hand, rapid longitudinal skeletal growth also has been associated with temporary decrease in bone mineral density and weakness of the epiphyseal growth plates (34), which are especially vulnerable to shearing and tensile forces in growing athletes (32). As rapid lengthening of muscles increases “preload” in the muscle-tendon unit, it leads to chronic increased force through vulnerable apophyses causing growth-related injuries (32).

PHV was not associated with the burden of muscle and joint/ligament injuries

We hypothesized that fast PHV might have resulted in more intense neuromuscular (61,99,100,118) and physiological alterations (119) leading to increased muscle (111) and joint/ligament (61,99) injury risk in circa- and post-PHV. However, our study did not find significant differences in these injuries among players with fast, average, and slow PHV. In line with our results, Rommers et al. (126) found that general motor performance characteristics (motor coordination, muscular performance, flexibility, and endurance) do not mediate the causal effect of growth on injuries. However, they examined general motor performance test outcomes (i.e., standing broad jump) and it is possible that more specific strength tests (i.e., unilateral jumping assessments) (99) are more likely to be associated with the risk of muscle and joint/ligament injuries. Thus, more research is needed to better understand possible causal pathways from neuromuscular alterations induced by PHV to muscle and joint/ligament injury risk.

Practical application

This study highlights the importance of longitudinal growth registry to detect players at higher risk of being affected by injuries in circa-PHV period. According to a recent study, growth-related injuries account for 30% of all severe injuries (>40 days lost) in football academies (11). Thus, reducing the impact of growth-related injuries seems vital to ensure players´ development (2) and prevent long-term consequences (124).

Based on the present finding, the authors recommend using growth-fitting techniques to model longitudinal height records to detect circa-PHV players with fast PHV. Latest research in sport science used SITAR method to model individual growth curves of the players (28,29,60,140). However, other methods such as 5th order polynomial or natural cubic splines have been proposed as the best for estimating individual PHV and age at PHV in non-sportive population (116). Thus, future research should consider comparing different methods in football population. Not only that, the ability of those methods to estimate growth from limited longitudinal growth-data should be tested. In this line, recent research using data from the Brno Growth study highlighted the potential of SITAR method to predict PHV and age at PHV even 1 year before PHV (143). However, prediction was better when the measurements spanned the growth spurt (143). Thus, we recommend measuring height every 3–4 months during an annual season, with particular focus on players approaching and during PHV (16).

Once detected circa-PHV players with fast PHV, extra caution seems necessary to reduce the impact of growth-related injuries. Strategies such as controlling week-to-week changes in load (45) or monitoring symptoms of musculoskeletal complaints to detect early growth-related conditions (137) should be applied. Special monitoring of those players would allow to modify training content/load of players at higher risk and detecting growth-related conditions before players are unable to train/compete. In this context, educating key stakeholders (players, coaches, parents/guardians) about the importance of growth monitoring and the growth-related risk factors is also crucial.

Methodological considerations

The principal strength of this study is its longitudinal design over two decades, which allowed us to model 124 individual growth curves and calculate PHV and age at PHV. Our research has improved on previous data that recorded growth during short periods (36,37,126) or estimated PHV using methods with reduced accuracy (30,31,35,45). Besides, we studied injury burden accounting for both frequency (incidence) and severity (mean absence) of injuries, which likely is more comprehensive of the consequences of injuries (5). Most importantly, this is the first study investigating how PHV affects overall and specific injury burden in circa- and post-PHV elite academy soccer players. We did not consider studying PHV´s growth-rate impact on pre-PHV injuries as it seems impractical to see the impact of an event which has not occur yet.

The limitations of the current investigation should also be noted. Our findings apply to a single elite soccer academy, and only players with 10 height measurements with height data before and after PHV were included in the study. Considering that injuries have a negative impact on academy progression (3), players who sustained severe injuries may have been missed. Further, players were categorised according to maturity status and PHV, and differences between players categorised in different groups might be small. However, it is common within the literature and soccer academies to categorise players according to growth and maturity (22) and the narrow bands used for the fast/average/slow classification is well outside the error for the estimation of PHV by SITAR method (143). Moreover, there were no protocols to check intra- and inter-tester reliability for height recording, which might have influenced maturity/growth classifications. Furthermore, the retrospective design of our study made it impossible to account for individual exposure in minutes and availability. It is possible that players with quick PHV might had suffered adolescent awkwardness (33), leading to reduced performance and less exposure in matches. Besides, many factors such as preventive strategies and training content might have changed over the study period and were not controlled for in analyses. Thus, results must be interpreted with caution, as injuries are complex and other factors (e.g., injury mechanism, re-injuries, training experience, chronological age, training load, biomechanical factors, coaching, communication, psychosocial factors...) contribute to risk beyond those analysed in this study (95). Future work should overcome these limitations by including more detailed reporting of training load and individual exposure.

In summary, our results showed that elite male academy soccer players with fast PHV had a higher growth-related injury burden in circa-PHV compared with average and slow PHV groups. Regular monitoring of growth rate seems important to detect players who are at higher risk of being disrupted by growth-related injuries.

PAPER VII: ESTIMATING MATURITY STATUS IN ELITE YOUTH SOCCER PLAYERS: EVALUATION OF METHODS

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ABSTRACT

Background: Monitoring maturity status and timing may facilitate the effective evaluation and development of academy soccer players. Methods for estimating maturity status and timing differ, and it is essential to consider their relative effectiveness.

Hypothesis/Purpose: To evaluate the concordance of predicted maturity status classifications (pre-, circa- or post-PHV) relative to observed age at PHV in youth soccer players.

Study design: Cohort study

Methods: Longitudinal height records for 124 male soccer players were extracted from academy records spanning the 2000-2022 seasons. Age at PHV for each player was estimated with the SITAR model. Players were classified as pre-, circa- or post-PHV using both ±1 year and ±0.5 year criteria to define the circa-PHV interval. Maturity status was estimated with several prediction protocols: maturity offset (Mirwald, Moore-1, Moore-2), maturity ratio (Fransen), percentage of predicted adult height (PAH%) using the Khamis-Roche (KR) and Tanner-Whitehouse-2 (TW2-RUS) equations using several bands: 85%-96%, 88%-96%, 88%-93%, and 90%-93% for the circa-PHV interval, and visual evaluation of individual growth-curves alone or with PAH% based on KR and TW2-RUS. Concordance of maturity status classifications based on complete growth curves and predicted estimates of maturity status was addressed with percentage agreement and Cohen's kappa.

Results: Visual evaluation of the growth curves had the highest concordance (≈ 80%) with maturity status classifications (pre-, circa-, post-PHV) based on longitudinal data for individual players. Predicted maturity offset with the Mirwald, Moore-1 and Fransen equations misclassified about one- third to one-half of the players, while concordance based on PAH% varied with the band used, but not with the method of height prediction.

Conclusion: Visual assessment of the individual growth curves by an experienced assessor provides an accurate estimate of maturity status relative to PHV. Maturity

offset prediction equations misclassifies the majority of players, while PAH% provides a reasonably valid alternative.

Clinical relevance: The results highlight the limitations of prediction methods for classifying players as pre-, circa- or post-PHV. Educating coaches/trainers on the interpretation of individual growth curves, assuming they are relatively complete, may facilitate estimates of player maturity status relative to PHV.

Key terms: youth, peak height velocity, height prediction, team sport, injury prevention.

INTRODUCTION

The individualisation of training is vital to optimise performance, reduce injury risk and promote talent development (2). Academy soccer players ordinarily train and compete in categories based on chronological age (CA), e.g., U14 - under 14 years. However, youth of the same CA can vary considerably in maturity status (state of maturation at the time of observation) and maturity timing (age at which specific maturational events occur) (13). Practitioners who work with U12 (10-11 years) and U13 (11-12 years) male soccer players manage, teach, train, and evaluate youth who vary markedly in maturity status and timing; this biological and behavioural individuality makes identification and development of potentially talented young players more difficult (22). Males experience the most rapid interval of growth in stature, referred to as peak height velocity (PHV) at ~13.8 years of age, but the CA at which PHV occurs varies considerably among individuals (22). While early maturing boys may achieve PHV at 11 or 12 years of age, late maturing boys may not experience PHV until 15 or 16 years of age, though estimates of ages at PHV vary to some extent with the method of modelling longitudinal data. Nevertheless, the physical differences between early and late maturing players decline after the interval of PHV, although it is not until late adolescence and early adulthood that maturity-associated differences in size and athleticism are fully attenuated, and in some instances reversed (144).

It is common practice in soccer academies to classify players relative to PHV as pre-, circa- or post-PHV, often on the basis of predicted estimates of maturity status (22). Several studies (31,60,139,145,146) have also used this classification to address the potential impact of maturity status on performance and injury risk. Criteria used to classify players relative to PHV, however, vary and are within the range of errors associated with the prediction equations. Longitudinal studies indicate that boys experience significant gains in functional capacity (e.g., explosive strength, power, and speed) during the interval of PHV or shortly after PHV (139), but some may also experience temporary regressions in performance (i.e., adolescent awkwardness) (33) and growing pains/injuries (60,77) compared to youth who have not attained PHV or who are already beyond PHV, i.e., pre- or post-PHV. The focus on PHV per se must be tempered with the fact that age at PHV refers only to height; the timing and tempo of the adolescent spurt in body dimensions (e.g., estimate leg length, sitting height), functional characteristics and motor skills varies, on average, relative to the PHV (147).

By inference, estimating and monitoring growth status and timing of the growth spurt in height is potentially important in the design and implementation of conditioning and injury prevention programmes, in the evaluation of talent and in (de)selection decisions (16).

Longitudinal growth records spanning childhood through late adolescence/young adulthood permit the modelling of growth curves of individuals and provide perhaps the most accurate method of defining pre-, circa- or post-PHV periods in individual players (13). Such evaluations, however, are obviously retrospective and as such have limited applicability among those working with youth players at soccer academies. Thus, strategies for estimating time relative to PHV or age at PHV *per se* have gained traction in sports settings due to their relative simplicity and suitability in cross-sectional studies (22,35). Estimates of maturity offset, defined as time before PHV, using a linear [e.g., Mirwald (17) and Moore (18)] or non-linear (Fransen(19)) combinations of anthropometric dimensions and CA, are increasingly used in studies of youth athletes. CA minus predicted maturity offset provides an estimate of predicted age at PHV. Observations based on several longitudinal samples in the general population (44,114,148) and among soccer players (28,29) have indicated, however, that the prediction equations have reduced variability relative to observed maturity offset or observed age at PHV, and also major limitations among early and late maturing youth defined by observed ages at PHV. A band of ±1.0 year has been commonly used to define maturity groups in growth studies. The band approximates standard deviations for ages at PHV in longitudinal samples of the general population and allows for variation among methods of modelling longitudinal data. Further, this band provides for broad range of youth who are classified as on time or average in maturity status. A similar band is also used in studies applying skeletal age as the maturity indicator (14). Some studies applying the prediction equations have used the ± 1.0 year band, but a narrow band of ± 0.5 year is increasingly utilised to classify individuals are pre-, circa- or post-PHV.

Use of current height expressed as a percentage of predicted adult height (PAH%) as an indicator of maturity status was recommended by Roche and colleagues (149). Chronological age, height and weight of the player and midparent height (average of the heights of his biological parents) are the predictors in the sex-specific equations which were developed on participants of European ancestry in the Fels Longitudinal Study

(21). The prediction protocol is commonly labelled after the authors as the Khamis-Roche (KR) equations. Although skeletal age based on hand wrist radiographs is commonly included among predictors of adult height in the clinical context (13)., radiographs are commonly viewed as invasive and are relatively expensive and require expertise for the assessment of skeletal age that may not be available. Various bands based on PAH% have been used to classify players relative to age at PHV, e.g., 85%–96% or 88%–93% for the circa-PHV interval (22).

Longitudinal records of estimated velocities of growth in height permit the visualisation of when PHV occurs and have been used to classify players as pre-, circa- or post-PHV (136). The accuracy of the estimate depends upon the completeness of the growth records, although variability associated with measurements of height is often overlooked. Nevertheless, visual assessments of incomplete growth curves are commonly used to a define maturity status in an academy setting (16,136). It is also increasingly common for practitioners to use both estimated growth velocity and PAH% to estimate the maturity status of players relative to PHV.

In the context of the preceding discussion, the objective of the present study was to evaluate the concordance of maturity status classification (pre-, circa-, post-PHV) based on fitted complete growth-curves (50) for elite academy soccer players with classifications maturity status based on predicted maturity offset (Mirwald, Moore-1, Moore-2) and the estimated maturity ratio (Fransen), PAH% using two height prediction equations [KR and Tanner-Whitehouse II (TW2-RUS)], and visual assessment of incomplete growth curves alone or in combination with PAH% using KR and TW2-RUS. In addition, comparisons were made using different thresholds for defining circa-PHV (± 1 year and ± 0.5 years from PHV) and by competitive chronological age groups (U13-U15) in an effort to provide insights into the accuracy of the methods used to monitor maturity status in elite academy soccer players.

METHODS:

Participants and study design

The growth status of academy soccer players was regularly monitored from the 2000-2001 to the 2021-2022 seasons. The academy is part of a professional club which participates in Spanish La Liga. All measurements were taken as part of the regular programme at the academy and were supervised by the medical staff. Parents/guardians and players had signed a contract with the club agreeing that their child would take part in the academy's regular programme including professional testing and training. The study was also approved by the Ethics Committee of the University of the Basque Country (CEISH/340/2015).

Anthropometric assessment

Mass and stature were measured using a portable stadiometer (Añó Savol, Spain) and a portable weighing scale (Seca Bonn, Germany) every three to six months throughout the competitive playing season. Sitting height was measured and leg length was estimated at stature minus sitting height in two teams during the 2009–2010 through the 2015–2016 seasons as part of a longitudinal study (105). Measurements were made following recommendations of the International Society for the Advancement of Kinanthropometry (ISAK) (46); players wore light sportswear and were measured prior to afternoon training. The same three physicians measured the players across the entire study interval. The estimated intra-observer technical error of measurement for stature was typically 0.23 cm, while the corresponding estimate for inter-observer error was 0.29 cm. The intra-observer technical error for sitting height was 0.14 cm.

Defining pre-, circa- and post-PHV periods

The longitudinal height records for individual players were fitted with the Super-Imposition by Translation of Rotation (SITAR) model (50) to estimate age at PHV. To ensure a high temporal interval around the adolescent growth spurt that would permit a more precise estimate of PHV, only players with at least 10 observations before and after the estimated age at PHV were included in this analysis (n=124, 119 of European ancestry, 5 of non-European ancestry). Based on ages at PHV estimated with the SITAR model, pre-, circa- or post-PHV intervals using both ± 1year and ± 0.5 year thresholds for circa-PHV were determined for each player. Pre- and post-PHV periods refer to the intervals before and after the respective estimates of circa-PHV.

Predicted maturity status using maturity offset equations and maturity ratio

Predicted maturity offset was estimated using the original Mirwald equation (17), the first Moore et al. (18) equation using age and sitting height and the Fransen et al. (19) maturity ratio among players for whom both standing and sitting height measurements were available (n=20). The second Moore et al. (18) equation using age and height was used to predict maturity offset for all height measurements among players. Predicted age at PHV was estimated as CA minus predicted maturity offset. With the maturity ratio protocol (19), CA was divided by the ratio to estimate age at PHV. Subsequently, each player was classified as pre-, circa- or post-PHV at the time of each observation using both the ± 1 year and ± 0.5 year thresholds for circa-PHV interval.

Predicted maturity status using PAH%

The Khamis and Roche equations (KR) (21) were used to predict the adult height of players for whom parental heights were available (n=43). Self-reported parental heights were adjusted for overestimation (150). The equation utilises chronological age, height and weight of the player and midparent height. Adult height was predicted when both height and weight measurements at the same date were available; the height of the player was then expressed as a percentage of predicted adult height (PAH%).

Adult height was also predicted with the TW2-RUS protocol (47,151) for players for whom radiographs were taken at the beginning of the U14 season (n=78). The maturity status of the radius, ulna, and metacarpals and phalange of the first, third and fifth digits was evaluated relative to the TW2 criteria, and the sum of maturity scores was converted to an estimate of skeletal age. Adult height was predicted using stature, skeletal age, and chronological age at the time of observation (47,151). PAH% at the time of each stature observation was estimated using the height measurements for each player and adult height estimated at the start of the U14 season.

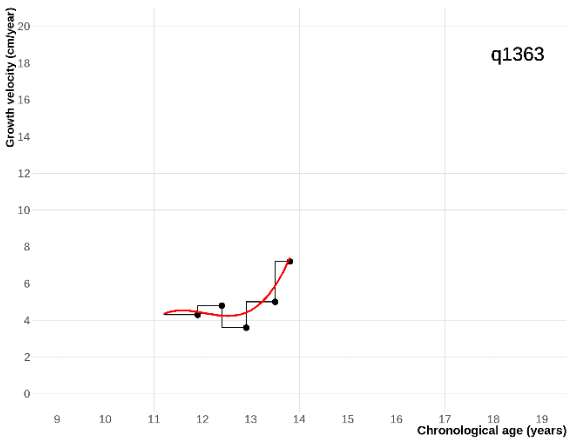
Players were classified into different bands based on each estimate of PAH%. The bands were based on those used in several studies to define the interval of circa-PHV: 85%-96% (28), 88%-96% (22), 88%-93% (25), and 90%-93% (79).

Maturity status assessment by growth-curve visualization

A questionnaire including 2560 incomplete growth-curves for anonymous individuals (https://sites.google.com/view/growthcurvessurvey) was completed by an experienced clinician who served as Head of Growth and Maturation at the soccer club for three years. The objective was to evaluate the clinician's ability to evaluate a player's status as pre-, circa- or post-PHV based on incomplete or limited data. The questionnaire was developed by removing data points from the complete growth-curves of the 124 players included in the study. Initial height measurements varied from U11 to U15 while the last measurement was among U13, U14 or U15 age-groups. The velocity curves spanned different intervals for individual players within the competitive age groups: U11-U13, U11-U14, U11-U15, U12-U13, U12-U14, U12-U15, U13, U13-U14, U13-U15, U14, U14-U15 and U15.

Velocities were estimated as the difference in standing height (cm) between observations divided by time interval (years) between measurements. Each curve indicated growth-velocity in cm/year (y axis) by CA (x axis), assigning the same growth-velocity to the whole period between measurements (e.g., if growth velocity of 5 cm/year between 12.9 and 13.5 years is estimated, graph shows this velocity for the whole period between these two measurements) (Figure 4.VII.1). Growth-velocities were modelled using cubic splines (152) to illustrate the projection of the curve (red line). A table including age-group, CA, height, and estimated velocity at each observation was included in the questionnaire. When PAH% based on KR and/or TW2-RUS was available, this information was also indicated in the table. As such, the same curve could be assessed a) without PAH% data, b) with PAH% estimated by KR, and c) with PAH% estimated by TW2-RUS. Questions were randomized to avoid assessing the same curve consecutively. The evaluator did not participate in the creation of the questionnaire and the curves were for anonymous players.

The clinician was instructed to separately assess the maturity status at the time of the last measurement based on the ±1 year and ±0.5 year circa-PHV threshold. Curves were re-assessed by the clinician a month later to evaluate intra-observer reliability.



Age group	Chronological age	Height	Growth velocity (cm/year)
U12	11.2	151.2	NA
U12	11.9	154.1	4.3
U13	12.4	156.5	4.8
U13	12.9	158.3	3.6
U14	13.5	161.2	5.0
U14	13.8	163.0	7.2

Figure 4.VII.1: Example of one of the growth-curves of the questionnaire.

Data analysis

Descriptive statistics (means and standard deviations) were calculated, and cross-tabulation analyses of maturity status classifications (pre-, circa- or post-PHV) based on the modelled complete growth-curve and each of the estimating methods were done for each age group. Consistent with prior studies of youth soccer players (134,153), concordance was assessed using percentage agreement and Cohen’s kappa (52). Strength of agreement based on Cohen’s Kappa was defined as slight (0–0.20), fair (0.21-0.40), moderate (0.41–0.60), substantial (0.61–0.80), or almost perfect (0.81–1) agreement (52). All analyses were performed using R (version 3.6.2).

RESULTS:

Based on complete records for the 124 players, mean ages at initial and final observations were 10.7±0.6 years and 18.7±2.5 years, respectively. Each player had 16±3 height measurements. Estimated age at PHV based on the SITAR model was 13.5±0.9 years and estimated PHV was 10.1±2.0 cm/year.

The percentage of concordance and Cohen´s Kappa for each method of classifying a player as pre-, circa- or post-PHV based on complete growth-curves using the ±1 year and ±0.5 year circa-PHV thresholds are summarized in Table 4.VII.1. Visual assessments of individual growth curves had the highest percentage of concordance. Concordance and percentage of agreement was also similar when assessing curves with or without PAH%. The experienced assessor also showed excellent intra-observer reliability (91% concordance) when assessing the growth curves using ±1 year and ±0.5 year circa-PHV criteria.

In contrast to the substantial agreement of classifications based on complete growth-curves and when assessing the growth curves using ±1 year and ±0.5year circa-PHV criteria, the other methods considered showed moderate, fair or slight agreement. The 85%-96% and 88%-93% PAH bands showed higher concordance with maturity status classification using the ±1 year circa-PHV criterion, while the 88%-93% and 90%-93% PAH bands showed higher concordance with classification using the ±0.5 year circa-PHV criterion. Classification by using the KR and TW2-RUS equations showed similar percentages of concordance and Cohen´s Kappa values.

Cross-tabulations of maturity status classifications (pre-, circa-, post-PHV) based on complete growth-curve modelling and the predicted estimates using both the ±1year and ±0.5 year criteria for circa-PHV are summarized in Table 4.VII.2. Growth-curve visualization detected only 42% of pre-PHV players using the ±1 year criterion but detected 85% and 83% of circa- and post-PHV players, respectively. With the ±0.5 year criterion, the experienced assessor detected 78%, 69% and 84% of pre-, circa- and post-PHV players respectively.

In contrast, the maturity offset and maturity ratio equations showed low concordance compared to classifications based on complete modelled growth-curves and specifically failed to detect circa- and post-PHV players. Wider bands of PAH% (85%-96% and 88%-96%) detected most of the circa-PHV players but failed to detect players at pre-and post-PHV players. In contrast, narrower bands of PAH% (88%-93% and 90%-93%) detected most of pre- and post-PHV players but failed to detect circa-PHV players.

Percentage of concordance and Cohen´s Kappa value for each method of estimation of pre-, circa- and post-PHV maturity status based on complete growth-curves for both ±1 year or ±0.5 year criteria for circa-PHV in U13, U14 and U15 players is summarized in Table 4.VII.3. Percentage concordance and Cohen Kappa values for visual assessments of growth curves based on longitudinal records of variable duration and for evaluation of the growth-curves of variable duration plus PAH% with KR and TW2-RUS are also included. The results suggest that classifications of the experienced assessor were better with longitudinal height records of longer duration, especially among U13 and U14 players. The Mirwald, Moore-1 and Fransen equations showed the lowest percentage concordance among U14 players. Concordance of classifications based on 85%-96% and 88%-96% PAH bands with both KR and TW2-RUS protocols showed a higher percentage of agreement among U13 and U14 players, while concordance of classifications based on 88%-93% and 90%-93% PAH bands with the KR and TW2-RUS protocols was higher among U15 players. Cross-tabulations of pre-, circa- and post-PHV maturity status classifications based on complete growth-curve modelling and the different methods of estimating maturity status among U13, U14 and U15 players are summarized in Supplementary Tables 4.VII.1, 4.VII.2, 4.VII.3 and 4.VII.4.

Table 4.VII.1 – Concordance and Cohen´s Kappa for maturity status classifications (pre-, circa-, post-PHV) between complete modeled growth-curves and different methods of estimation using ± 1 and ± 0.5-years criteria for circa-PHV period.

± 1 -year threshold			**± 0.5-years threshold**		
Estimation method	**Concordance**	**Kappa**	**Estimation method**	**Concordance**	**Kappa**
Growth-curve visual assesment	81%	0.65	Growth-curve visual assesment + PAH% TW2-RUS	81%	0.67
Growth-curve visual assesment + PAH% TW2-RUS	79%	0.62	Growth-curve visual assesment alone	79%	0.65
Growth-curve visual assesment + PAH% KR	75%	0.55	Growth-curve visual assesment + PAH% KR	79%	0.64
85%-96% PAH TW2-RUS	68%	0.33	Moore-2	71%	0.56
85%-96% PAH KR	68%	0.35	88%-93% PAH TW2-RUS	71%	0.56
88%-93% PAH TW2-RUS	66%	0.48	90%-93% PAH TW2-RUS	69%	0.53
Moore-2	64%	0.46	88%-93% PAH KR	67%	0.50
88%-96% PAH KR	63%	0.36	90%-93% PAH KR	67%	0.50
88%-96% PAH TW2-RUS	63%	0.34	Moore-1	66%	0.48
88%-93% PAH KR	63%	0.43	Mirwald	56%	0.34
90%-93% PAH TW2-RUS	58%	0.41	88%-96% PAH TW2-RUS	55%	0.33
90%-93% PAH KR	54%	0.35	88%-96% PAH KR	50%	0.29
Moore-1	53%	0.29	85%-96% PAH TW2-RUS	48%	0.23
Mirwald	50%	0.23	85%-96% PAH KR	45%	0.22
Fransen	37%	0.07	Fransen	44%	0.15

PAH: Predicted adult height; TW2-RUS: Tanner-Whitehouse 2; KR: Khamis-Roche

Table 4.VII.2 – Cross-tabulations of maturity status classifications based on complete modelled growth-curves and each method of estimating maturity status as pre-, circa- or post-PHV.

Estimation method		Estimated maturity status	Classification using ± 1-year threshold for circa-PHV period			Classification using ± 0.5-years threshold for circa-PHV period		
			Pre-PHV	Circa-PHV	Post-PHV	Pre-PHV	Circa-PHV	Post-PHV
Growth-curve visual assesment	**Alone**	Pre-PHV	**43**	39	3	**159**	75	20
		Circa-PHV	45	**591**	84	26	**246**	99
		Post-PHV	14	66	**415**	19	35	**621**
		Concordance	42%	85%	83%	78%	69%	84%
	+ PAH% KR	Pre-PHV	**13**	9	0	**49**	22	6
		Circa-PHV	26	**180**	38	11	**81**	35
		Post-PHV	3	27	**118**	6	9	**195**
		Concordance	31%	83%	76%	74%	72%	83%
	+ PAH% TW2-RUS	Pre-PHV	24	29	0	**93**	47	6
		Circa-PHV	26	**385**	52	14	**178**	56
		Post-PHV	12	55	**263**	16	26	**410**
		Concordance	39%	82%	83%	76%	71%	87%
Maturity offset equations	**Mirwald**	Pre-PHV	**7**	10	0	**12**	5	0
		Circa-PHV	0	**7**	6	0	**4**	9
		Post-PHV	0	0	**2**	0	0	**2**
		Concordance	100%	41%	25%	100%	44%	18%
	Moore-1	Pre-PHV	**7**	9	0	**12**	4	0
		Circa-PHV	0	**7**	5	0	**5**	7
		Post-PHV	0	1	**3**	0	0	**4**
		Concordance	100%	41%	38%	100%	56%	36%
	Moore-2	Pre-PHV	**109**	127	1	**175**	59	3
		Circa-PHV	22	**243**	27	56	**162**	74
		Post-PHV	7	120	**192**	13	39	**267**
		Concordance	79%	50%	87%	72%	62%	78%
Maturity ratio	**Fransen**	Pre-PHV	**7**	13	0	**12**	8	0
		Circa-PHV	0	**4**	7	0	**1**	10
		Post-PHV	0	0	**1**	0	0	**1**
		Concordance	100%	24%	13%	100%	11%	9%
Predicted adult height % with Khamis-Roche	**85%-96%**	Pre-PHV	**11**	6	0	**16**	1	0
		Circa-PHV	25	**122**	41	52	**63**	73
		Post-PHV	0	3	**24**	0	1	**26**
		Concordance	31%	93%	37%	24%	97%	26%
	88%-96%	Pre-PHV	**28**	33	0	**44**	17	0
		Circa-PHV	8	**95**	41	24	**47**	73
		Post-PHV	0	3	**24**	0	1	**26**
		Concordance	78%	73%	37%	65%	72%	26%
	88%-93%	Pre-PHV	**28**	33	0	**44**	17	0
		Circa-PHV	8	**62**	9	20	**36**	23
		Post-PHV	0	36	**56**	4	12	**76**
		Concordance	78%	47%	86%	65%	55%	77%
	90%-93%	Pre-PHV	**33**	59	0	**58**	31	3
		Circa-PHV	3	**36**	9	6	**22**	20
		Post-PHV	0	36	**56**	4	12	**76**
		Concordance	92%	27%	86%	85%	34%	77%
Predicted adult height % with Tanner-Whitehouse-2RUS	**85%-96%**	Pre-PHV	**25**	7	0	**32**	0	0
		Circa-PHV	60	**308**	95	124	**176**	163
		Post-PHV	5	14	**50**	5	2	**62**
		Concordance	28%	94%	34%	20%	99%	28%
	88%-96%	Pre-PHV	**64**	74	0	**104**	34	0
		Circa-PHV	21	**241**	95	52	**142**	163
		Post-PHV	5	14	**50**	5	2	**62**
		Concordance	71%	73%	34%	65%	80%	28%
	88%-93%	Pre-PHV	**64**	74	0	**104**	34	0
		Circa-PHV	20	**170**	6	48	**110**	38
		Post-PHV	6	85	**139**	9	34	**187**
		Concordance	71%	52%	96%	65%	62%	83%
	90%-93%	Pre-PHV	**79**	133	0	**135**	76	1
		Circa-PHV	5	**111**	6	17	**68**	37
		Post-PHV	6	85	**139**	9	34	**187**
		Concordance	88%	34%	96%	84%	38%	83%

Table 4.VII.3 – Concordance and Cohen´s Kappa for maturity status classifications (pre-, circa-, post-PHV) between complete modelled growth-curves and each method of estimation using ±0.5 and ± 1 year criteria for circa-PHV among players in the U13, U14 and U15 age groups.

Estimation method		First height measurement	Classification using ± 1-year threshold for circa-PHV period						Classification using ± 0.5-years threshold for circa-PHV period					
			U13		U14		U15		U13		U14		U15	
			Concordance	Kappa	Concordance	Kappa	Concordance	Kappa	Concordance	Kappa	Concordance	Kappa	Concordance	Kappa
Growth-curve visual assesment	**Alone**	U11	80%	0.50	78%	0.45	87%	0.69	72%	0.51	83%	0.71	84%	0.38
		U12	76%	0.40	85%	0.67	83%	0.62	72%	0.51	79%	0.65	88%	0.48
		U13	77%	0.39	75%	0.41	90%	0.76	64%	0.33	78%	0.64	88%	0.42
		U14			74%	0.33	85%	0.64			62%	0.39	85%	0.39
		U15					78%	0.47					89%	0.49
	+ PAH% KR	U11	74%	0.38	69%	0.21	82%	0.57	81%	0.65	74%	0.56	88%	0.15
		U12	74%	0.38	77%	0.43	82%	0.57	71%	0.46	77%	0.60	85%	0.11
		U13	68%	0.18	74%	0.38	85%	0.57	65%	0.34	74%	0.57	88%	-0.05
		U14			67%	0.03	79%	0.40			69%	0.50	88%	-0.05
		U15					73%	0.34					85%	-0.06
	+ PAH% TW2-RUS	U11	81%	0.44	80%	0.54	83%	0.59	72%	0.51	79%	0.64	87%	0.34
		U12	79%	0.42	79%	0.52	83%	0.59	75%	0.57	84%	0.72	91%	0.56
		U13	79%	0.38	79%	0.55	87%	0.67	72%	0.50	79%	0.64	90%	0.37
		U14			71%	0.25	83%	0.57			60%	0.34	91%	0.37
		U15					72%	0.29					88%	0.28
Maturity offset equations	**Mirwald**		64%	0.21	31%	-0.08	63%	0.33	73%	0.15	46%	0.18	50%	0.20
	Moore-1		64%	0.21	38%	-0.04	63%	0.25	73%	0.15	54%	0.29	75%	0.50
	Moore-2		58%	0.25	69%	0.28	66%	0.18	71%	0.37	60%	0.32	82%	0.29
Maturity ratio	**Fransen**		64%	0.21	15%	-0.15	38%	0.02	73%	0.15	31%	-0.04	25%	-0.04
Predicted adult height % with Khamis-Roche	**85%-96%**		62%	0.22	80%	-0.02	62%	0.30	52%	0.23	46%	-0.02	39%	0.09
	88%-96%		55%	0.14	73%	-0.08	62%	0.30	68%	0.20	47%	0.04	39%	0.09
	88%-93%		55%	0.14	66%	0.13	66%	0.19	68%	0.20	54%	0.21	78%	0.15
	90%-93%		48%	0.03	46%	0.04	65%	0.17	68%	0.02	54%	0.28	78%	0.16
Predicted adult height % with Tanner-Whitehouse-2RUS	**85%-96%**		72%	0.33	76%	0.09	56%	0.19	52%	0.21	48%	0.04	43%	0.12
	88%-96%		61%	0.29	72%	0.12	56%	0.19	69%	0.37	51%	0.14	43%	0.12
	88%-93%		60%	0.29	68%	0.32	71%	0.28	69%	0.39	60%	0.33	84%	0.34
	90%-93%		48%	0.15	56%	0.28	71%	0.28	68%	0.29	56%	0.32	84%	0.34

Supplementary Table 4.VII.1 – Cross-tabulations of players by maturity status classifications using ±1 year as the criterion for circa-PHV period based on complete modelled growth-curves and growth-curve observation based on age-group and age group at first measurement.

Estimation method	First height measurement	Estimate maturity status	U13			U14			U15		
			Pre-PHV	Circa-PHV	Post-PHV	Pre-PHV	Circa-PHV	Post-PHV	Pre-PHV	Circa-PHV	Post-PHV
Growth-curve visual assesment	U11	Pre-PHV	**21**	34	1	**4**	8	1	**0**	3	0
		Circa-PHV	2	**32**	0	1	**47**	0	0	**16**	2
		Post-PHV	0	10	**0**	2	22	**25**	1	13	**77**
		Concordance	91%	42%	0%	57%	61%	96%	0%	50%	97%
	U12	Pre-PHV	**20**	38	0	**3**	8	0	**0**	1	0
		Circa-PHV	3	**30**	0	2	**48**	1	0	**13**	2
		Post-PHV	0	8	**1**	2	21	**25**	1	18	**77**
		Concordance	87%	39%	100%	43%	62%	96%	0%	41%	97%
	U13	Pre-PHV	**21**	45	1	**5**	10	2	**0**	2	0
		Circa-PHV	2	**30**	0	0	**41**	1	0	**11**	2
		Post-PHV	0	1	**0**	2	26	**23**	1	19	**77**
		Concordance	91%	39%	0%	71%	53%	88%	0%	34%	97%
	U14	Pre-PHV				**2**	16	3	**0**	3	1
		Circa-PHV				3	**50**	4	0	**10**	5
		Post-PHV				2	11	**19**	1	19	**73**
		Concordance				29%	65%	73%	0%	31%	92%
	U15	Pre-PHV							**0**	1	0
		Circa-PHV							0	**10**	3
		Post-PHV							1	21	**76**
		Concordance							0%	31%	96%
Growth-curve visual assesment + PAH% KR	U11	Pre-PHV	**9**	9	0	**2**	2	0	**0**	0	0
		Circa-PHV	1	**11**	0	0	**19**	1	0	**3**	0
		Post-PHV	0	1	**0**	1	6	**8**	0	6	**24**
		Concordance	90%	52%		67%	70%	89%		33%	100%
	U12	Pre-PHV	**9**	10	0	**2**	1	0	**0**	0	0
		Circa-PHV	1	**11**	0	0	**20**	1	0	**3**	1
		Post-PHV	0	0	**0**	1	6	**8**	0	6	**23**
		Concordance	90%	52%		67%	74%	89%		33%	96%
	U13	Pre-PHV	**9**	11	0	**2**	2	1	**0**	0	0
		Circa-PHV	1	**10**	0	0	**17**	0	0	**1**	1
		Post-PHV	0	0	**0**	1	8	**8**	0	8	**23**
		Concordance	90%	48%		67%	63%	89%		11%	96%
	U14	Pre-PHV				**2**	4	1	**0**	0	0
		Circa-PHV				1	**19**	1	0	**1**	1
		Post-PHV				0	4	**7**	0	8	**23**
		Concordance				67%	63%	89%		11%	96%
	U15	Pre-PHV							**0**	0	1
		Circa-PHV							0	**1**	1
		Post-PHV							0	8	**22**
		Concordance								11%	92%
Growth-curve visual assesment +PAH% TW2-RUS	U11	Pre-PHV	**9**	28	0	**3**	5	0	**0**	1	0
		Circa-PHV	2	**23**	0	1	**34**	1	0	**7**	0
		Post-PHV	0	4	**1**	2	12	**17**	1	12	**48**
		Concordance	82%	42%	100%	50%	67%	94%	0%	35%	100%
	U12	Pre-PHV	**9**	27	0	**3**	2	0	**0**	2	0
		Circa-PHV	2	**23**	0	1	**35**	1	0	**6**	0
		Post-PHV	0	5	**1**	2	14	**17**	1	12	48
		Concordance	82%	42%	100%	50%	69%	94%	0%	30%	100%
	U13	Pre-PHV	**10**	29	0	**4**	3	0	**0**	1	0
		Circa-PHV	1	**25**	0	0	**34**	1	0	**3**	1
		Post-PHV	0	1	**1**	2	14	**17**	1	16	**47**
		Concordance	91%	45%	100%	67%	67%	94%	0%	15%	98%
	U14	Pre-PHV				**1**	8	1	**0**	0	0
		Circa-PHV				3	**34**	2	0	**3**	0
		Post-PHV				2	9	**15**	1	17	**48**
		Concordance				17%	67%	83%	0%	15%	100%
	U15	Pre-PHV							**0**	0	0
		Circa-PHV							0	**5**	0
		Post-PHV							1	15	**48**
		Concordance							0%	255	100%

PAH: Predicted adult height; TW2-RUS: Tanner-Whitehouse 2; KR: Khamis-Roche

Supplementary Table 4.VII.2 – Cross-tabulations of players by maturity status classifications using ±0.5 year as the criterion for circa-PHV period based on complete modelled growth-curves and growth-curve observation based on age-group and age group at first measurement.

Estimation method	First height measurement	Estimate maturity status	U13			U14			U15		
			Pre-PHV	Circa-PHV	Post-PHV	Pre-PHV	Circa-PHV	Post-PHV	Pre-PHV	Circa-PHV	Post-PHV
Growth-curve visualization	U11	Pre-PHV	**41**	13	2	**8**	4	1	**1**	2	0
		Circa-PHV	5	**27**	2	2	**38**	8	1	**5**	12
		Post-PHV	1	5	**4**	2	2	**45**	1	2	**88**
		Concordance	87%	60%	50%	67%	86%	83%	33%	56%	88%
	U12	Pre-PHV	**43**	15	0	**7**	4	0	**1**	0	0
		Circa-PHV	4	**25**	4	3	**37**	11	1	**6**	8
		Post-PHV	0	5	**4**	2	3	**43**	1	3	**92**
		Concordance	91%	56%	50%	58%	84%	80%	33%	67%	92%
	U13	Pre-PHV	**41**	21	5	**9**	5	3	**1**	1	0
		Circa-PHV	6	**23**	3	0	**34**	8	0	**5**	8
		Post-PHV	0	1	**0**	3	5	**43**	2	3	**92**
		Concordance	87%	51%	0%	75%	77%	80%	33%	56%	89%
	U14	Pre-PHV				**5**	8	8	**1**	2	1
		Circa-PHV				4	**35**	18	0	**5**	10
		Post-PHV				3	1	**28**	2	2	**89**
		Concordance				42%	80%	52%	33%	56%	89%
	U15	Pre-PHV							**1**	0	0
		Circa-PHV							0	**6**	7
		Post-PHV							2	3	**93**
		Concordance							33%	67%	93%
Growth-curve visualization + PAH% KR	U11	Pre-PHV	**14**	3	1	**2**	2	0	**0**	0	0
		Circa-PHV	1	**10**	1	1	**14**	5	1	**0**	2
		Post-PHV	0	0	**1**	1	1	**13**	0	1	**29**
		Concordance	93%	77%	33%	50%	82%	72%	0%	0%	94%
	U12	Pre-PHV	**14**	5	0	**2**	1	0	**0**	0	0
		Circa-PHV	1	**8**	3	1	**15**	5	1	**0**	3
		Post-PHV	0	0	**0**	1	1	**13**	0	1	**28**
		Concordance	93%	62%	0%	50%	82%	72%	0%	0%	94%
	U13	Pre-PHV	**13**	6	1	**2**	2	1	**0**	0	0
		Circa-PHV	2	**7**	2	1	**13**	3	0	**0**	2
		Post-PHV	0	0	**0**	1	2	**14**	1	1	**29**
		Concordance	87%	54%	0%	50%	76%	78%	0%	0%	94%
	U14	Pre-PHV				**2**	3	2	**0**	0	0
		Circa-PHV				2	**14**	5	0	**0**	2
		Post-PHV				0	0	**11**	1	1	**29**
		Concordance				50%	82%	61%	0%	0%	94%
	U15	Pre-PHV							**0**	0	1
		Circa-PHV							0	**0**	2
		Post-PHV							1	1	**28**
		Concordance							0%	0%	90%
Growth-curve visualization + PAH% TW2-RUS	U11	Pre-PHV	**24**	13	0	**5**	2	1	**0**	1	0
		Circa-PHV	3	**20**	2	1	**27**	8	1	**2**	4
		Post-PHV	0	1	**4**	2	2	**27**	1	2	**58**
		Concordance	89%	59%	67%	63%	87%	75%	0%	40%	94%
	U12	Pre-PHV	**25**	11	0	**5**	0	0	**1**	1	0
		Circa-PHV	2	**21**	2	1	**29**	7	0	**3**	3
		Post-PHV	0	2	**4**	2	2	**29**	1	1	**59**
		Concordance	93%	62%	67%	63%	87%	75%	0%	40%	94%
	U13	Pre-PHV	**25**	13	1	**6**	1	0	**0**	1	0
		Circa-PHV	2	**21**	3	0	**26**	9	0	**2**	2
		Post-PHV	0	0	**2**	2	4	**27**	2	2	**60**
		Concordance	93%	62%	33%	75%	84%	75%	0%	40%	97%
	U14	Pre-PHV				**2**	4	4	**0**	0	0
		Circa-PHV				4	**23**	12	0	**2**	1
		Post-PHV				2	4	**20**	2	3	**61**
		Concordance				25%	74%	56%	0%	40%	98%
	U15	Pre-PHV							**0**	0	0
		Circa-PHV							0	**2**	3
		Post-PHV							2	3	**59**
		Concordance							0%	40%	95%

PAH: Predicted adult height; TW2-RUS: Tanner-Whitehouse 2; KR: Khamis-Roche

Supplementary Table 4.VII.3 – Cross-tabulations of players by maturity status classifications using the ± 1 year criterion for circa-PHV period based on complete modelled growth-curves and different estimation methods by age-group at observation.

Estimation method		Estimate maturity status	U13			U14			U15		
			Pre-PHV	Circa-PHV	Post-PHV	Pre-PHV	Circa-PHV	Post-PHV	Pre-PHV	Circa-PHV	Post-PHV
Maturity offset equations	Mirwald	Pre-PHV	**6**	4	0	**1**	6	0	**0**	0	0
		Circa-PHV	0	**1**	0	0	**3**	3	0	**3**	3
		Post-PHV	0	0	**0**	0	0	**0**	0	0	**2**
		Concordance	100%	20%		100%	33%	0%		100%	40%
	Moore-1	Pre-PHV	**6**	4	0	**1**	5	0	**0**	0	0
		Circa-PHV	0	**1**	0	0	**4**	3	0	**2**	2
		Post-PHV	0	0	**0**	0	0	**0**	0	1	**3**
		Concordance	100%	20%		100%	44%	0%		67%	60%
	Moore-2	Pre-PHV	**101**	109	1	**8**	18	0	**0**	0	0
		Circa-PHV	7	**63**	3	13	**158**	17	2	**22**	7
		Post-PHV	0	0	**0**	5	32	**21**	2	88	**171**
		Concordance	94%	37%	0%	31%	76%	55%	0%	20%	96%
Maturity ratio	Fransen	Pre-PHV	**6**	4	0	**1**	8	0	**0**	1	0
		Circa-PHV	0	**1**	0	0	**1**	3	0	**2**	4
		Post-PHV	0	0	**0**	0	0	**0**	0	0	**1**
		Concordance	100%	20%		100%	11%	0%		67%	20%
PAH% KR	85%-96%	Pre-PHV	**11**	5	0	**0**	1	0	**0**	0	0
		Circa-PHV	21	**32**	0	4	**59**	10	0	**31**	31
		Post-PHV	0	0	**0**	0	0	**0**	0	3	**24**
		Concordance	34%	86%		0%	98%	0%		91%	44%
	88%-96%	Pre-PHV	**28**	27	0	**0**	6	0	**0**	0	0
		Circa-PHV	4	**10**	0	4	**54**	10	0	**31**	31
		Post-PHV	0	0	**0**	0	0	**0**	0	3	**24**
		Concordance	88%	27%		0%	90%	0%		91%	44%
	88%-93%	Pre-PHV	**28**	27	0	**0**	6	0	**0**	0	0
		Circa-PHV	4	**10**	0	4	**44**	5	0	**8**	4
		Post-PHV	0	0	**0**	0	10	**5**	0	26	**51**
		Concordance	88%	27%		0%	73%	50%		24%	93%
	90%-93%	Pre-PHV	**32**	36	0	**1**	22	0	**0**	1	0
		Circa-PHV	0	**1**	0	3	**28**	5	0	**7**	4
		Post-PHV	0	0	**0**	0	10	**5**	0	26	**51**
		Concordance	100%	3%		25%	47%	50%		21%	93%
PAH% TW2-RUS	85%-96%	Pre-PHV	**25**	6	0	**0**	1	0	**0**	0	0
		Circa-PHV	45	**113**	3	15	**139**	23	0	**56**	69
		Post-PHV	0	0	**0**	3	2	**2**	2	12	**48**
		Concordance	36%	95%	0%	0%	98%	8%	0%	82%	41%
	88%-96%	Pre-PHV	**60**	61	0	**4**	13	0	**0**	0	0
		Circa-PHV	10	**58**	3	11	**127**	23	0	**56**	69
		Post-PHV	0	0	**0**	3	2	**2**	2	12	**48**
		Concordance	86%	49%	0%	22%	89%	8%	0%	82%	41%
	88%-93%	Pre-PHV	**60**	61	0	**4**	13	0	**0**	0	0
		Circa-PHV	10	**53**	1	10	**100**	4	0	**17**	1
		Post-PHV	0	5	**2**	4	29	**21**	2	51	**116**
		Concordance	68%	45%	67%	22%	70%	84%	0%	25%	89%
	90%-93%	Pre-PHV	**68**	92	0	**11**	41	0	**0**	0	0
		Circa-PHV	2	**22**	1	3	**72**	4	0	**17**	1
		Post-PHV	0	5	**2**	4	29	**21**	2	51	**116**
		Concordance	97%	18%	67%	61%	51%	84%	0%	25%	99%

PAH: Predicted adult height; TW2-RUS: Tanner-Whitehouse 2; KR: Khamis-Roche

Supplementary Table 4.VII.4 – Cross-tabulations of players by maturity status classifications using the ± 0.5-year criterion for circa-PHV period based on complete modelled growth-curves and different estimation methods by age-group at observation.

Estimation method		Estimate maturity status	U13			U14			U15		
			Pre-PHV	Circa-PHV	Post-PHV	Pre-PHV	Circa-PHV	Post-PHV	Pre-PHV	Circa-PHV	Post-PHV
Maturity offset equations	Mirwald	Pre-PHV	**8**	2	0	**4**	3	0	**0**	0	0
		Circa-PHV	0	**0**	1	0	**2**	4	0	**2**	4
		Post-PHV	0	0	**0**	0	0	**0**	0	0	**2**
		Concordance	100%	0%	0%	100%	40%	0%		100%	33%
	Moore-1	Pre-PHV	**8**	2	0	**4**	2	0	**0**	0	0
		Circa-PHV	0	**0**	1	0	**3**	4	0	**2**	2
		Post-PHV	0	0	**0**	0	0	**0**	0	0	**4**
		Concordance	100%	0%	0%	100%	60%	0%		100%	67%
	Moore-2	Pre-PHV	**158**	50	3	**17**	9	0	**0**	0	0
		Circa-PHV	18	**45**	10	33	**104**	51	5	**13**	13
		Post-PHV	0	0	**0**	5	12	**41**	8	27	**226**
		Concordance	90%	47%	0%	31%	83%	45%	0%	33%	95%
Maturity ratio	Fransen	Pre-PHV	**8**	2	0	**4**	5	0	**0**	1	0
		Circa-PHV	0	**0**	1	0	**0**	4	0	**1**	5
		Post-PHV	0	0	**0**	0	0	**0**	0	0	**1**
		Concordance	100%	0%	0%	100%	0%	0%		50%	17%
PAH% KR	85%-96%	Pre-PHV	**16**	0	0	**0**	1	0	**0**	0	0
		Circa-PHV	31	**20**	2	16	**34**	23	5	**9**	48
		Post-PHV	0	0	**0**	0	0	**0**	0	1	**26**
		Concordance	34%	100%	0%	0%	97%	0%	0%	90%	35%
	88%-96%	Pre-PHV	**41**	14	0	**3**	3	0	**0**	0	0
		Circa-PHV	6	**6**	2	13	**32**	23	5	**9**	48
		Post-PHV	0	0	**0**	0	0	**0**	0	1	**26**
		Concordance	87%	30%	0%	19%	91%	0%	0%	90%	35%
	88%-93%	Pre-PHV	**41**	14	0	**3**	3	0	**0**	0	0
		Circa-PHV	6	**6**	2	13	**27**	13	1	**3**	8
		Post-PHV	0	0	**0**	0	5	**10**	4	7	**66**
		Concordance	87%	30%	0%	19%	77%	43%	0%	30%	89%
	90%-93%	Pre-PHV	**47**	20	1	**11**	11	1	**0**	0	1
		Circa-PHV	0	**0**	1	5	**19**	12	1	**3**	7
		Post-PHV	0	0	**0**	0	5	**10**	4	7	**66**
		Concordance	100%	0%	0%	69%	54%	43%	0%	30%	89%
PAH% TW2-RUS	85%-96%	Pre-PHV	**31**	0	0	**1**	0	0	**0**	0	0
		Circa-PHV	83	**69**	9	33	**85**	59	8	**22**	95
		Post-PHV	0	0	**0**	3	1	**3**	2	1	**59**
		Concordance	27%	100%	0%	3%	99%	5%	0%	96%	38%
	88%-96%	Pre-PHV	**92**	29	0	**12**	5	0	**0**	0	0
		Circa-PHV	22	**40**	9	22	**80**	59	8	**22**	95
		Post-PHV	0	0	**0**	3	1	**3**	2	1	**59**
		Concordance	81%	58%	0%	32%	93%	5%	0%	96%	38%
	88%-93%	Pre-PHV	**92**	29	0	**12**	5	0	**0**	0	0
		Circa-PHV	22	**37**	5	21	**65**	28	5	**8**	5
		Post-PHV	0	3	**4**	4	16	**34**	5	15	**149**
		Concordance	81%	54%	44%	32%	76%	55%	0%	35%	97%
	90%-93%	Pre-PHV	**110**	50	0	**25**	26	1	**0**	0	0
		Circa-PHV	4	**16**	5	8	**44**	27	5	**8**	5
		Post-PHV	0	3	**4**	4	16	**34**	5	15	**149**
		Concordance	96%	23%	44%	68%	51%	55%	0%	35%	97%

PAH: Predicted adult height; TW2-RUS: Tanner-Whitehouse 2; KR: Khamis-Roche

DISCUSSION:

This study evaluated the agreement between maturity status classification based on fitted complete growth-curves (the reference) and different estimation methods in elite academy soccer players. Previous studies have generally focused on the validation of the maturity offset predictions in longitudinal series of the general population (44,114,148,154,155), of soccer players (27–29), and of female gymnasts (156) for whom age at PHV was known. The studies of the general population were consistent in showing major limitations of the prediction equations, especially in early and late maturing youth classified as such by observed age at PHV, while the studies of athletes noted consistent difference between observed and predicted ages at PHV. The studies, however, did not consider the concordance of maturity status classifications relative to PHV, i.e., pre-, circa- or post-PHV, which are commonly estimated in studies of youth soccer players. The present study is novel in that it included visual assessments of growth curves as an approach to classify players by maturity status relative to PHV. Further, this study evaluated maturity offset prediction equations (Mirwald, Moore-1, Moore-2) and the predicted maturity ratio (Fransen), and also player classifications using different bands based on the percentage of predicted adult height (PAH%) using both KR and TW2-RUS height prediction equations in a longitudinal sample of male soccer players.

Growth-curve visual assessment: a potential approach to classify players as pre-, circa- or post-PHV

While previous research has recommended the use of plotted growth curves to estimate the status of an athlete relative to PHV (16,25,157), the accuracy of such assessments in classifying players as pre-, circa- or post-PHV has not been evaluated. Results of the present study indicated substantial agreement and a high percentage of concordance with maturity status classification (pre-, circa-, post-PHV) based on complete growth-curves using ±1 year and ±0.5 year circa-PHV thresholds, recognizing the limitations of the narrow band.

Growth-curves were evaluated by an experienced assessor who demonstrated high intra-observer reliability (91%) when classifying the players as pre-, circa- or post-PHV. Of interest, adding PAH% based on predictions with the KR and TW2-RUS equations did not improve the classification of the players' status. It appears that the capacity of the assessor to interpret the growth-curves, i.e., to detect the onset of the growth spurt, increase/decrease in growth velocities, PHV, and so on, is important to the proper assessment of the maturity status of players. The duration of the longitudinal records was a key factor which influenced maturity status classifications; classifications were more accurate for players with longitudinal height records spanning a longer duration.

Although potentially useful, it should be noted that sequential height measurements over relatively short intervals have major limitations. Growth in height occurs in a saltatory manner with "mini-spurts" followed by intervals of no increments (29,158), and measurements of height show both seasonal and diurnal variation (13). Moreover, the time of measurements should be standardized, and measurements should be taken after an interval of rest before training sessions. Given the impact of running and jumping, specifically on the compression of the intervertebral discs and player fatigue, heights measured after training sessions are generally shorter. The preceding considerations merit attention in studies that use longitudinal measurements of height taken at relatively brief intervals. Moreover, individual differences in estimated peak velocities of growth in height during the interval of the growth spurt vary considerably and also with methods used to estimate age at PHV (13). It is thus possible that two players with similar estimated growth velocities may be differently classified as pre-, circa- or post-PHV. In this context, considering PAH% and/or CA may assist in differentiating pre- and post-PHV players who may be growing at a slower estimated rate (e.g., 4 cm/year). On the other hand, variation in percentage of predicted adult height at the time of PHV (28) may limit PAH% as a predictor of maturity status, specifically when a player is pre- to circa-PHV or circa- to post-PHV. Consistent with the preceding, the accuracy the assessor's evaluation of the growth curves was poorest among U13 players many of whom were pre- or circa-PHV.

Predicting if a player will reach the interval of PHV, depending on the circa-PHV criterion, may be difficult when available height records are limited. By inference, having more complete growth records spanning a longer longitudinal is essential, as they provide a more complete picture of a player's growth trajectory and shape of the growth-curve, and in turn facilitate classifications of status relative to PHV. The use of height records of healthcare systems/schools or in previous clubs/academies of a player may be potentially useful – assuming the measurements were taken in a standardized manner (i.e., fully erect without shoes) and precise date of measurement is known.

The preceding approach is not without limitations. Longitudinal height records are needed to estimate growth-velocity. In addition, heights are not ordinarily measured at the same interval over time; as such the velocity estimates need to be adjusted for the different intervals between observations. And as noted, measurements of height show seasonal and diurnal variation, and the visual assessment of growth curves can be time-consuming. If applied to specific clubs, the protocol would require education of coaches/trainers in the process of velocity estimation and interpretation.

Maturity offset equations and maturity ratio misclassify a third to a half of the data

The maturity offset prediction equations had only fair to moderate agreement with classifications based on complete growth-curves. Although based on 20 players with complete longitudinal records (105), the classifications based on the Mirwald, Moore-1 and Fransen equations showed low concordance compared to observed age at PHV. Previous research has noted that predicted maturity offset and predicted age at PHV were consistently later than observed maturity offset and age at PHV among early maturing soccer players, and earlier than observed in late maturing players (27). That is, the maturity offset equations tend to "normalise" age at PHV in early and late maturing players which may lead to incorrect maturity status classifications. Given that the cohort of players in the study experienced PHV across a relatively broad CA range, 10.1 to 16.5 years, predicted maturity offset likely incorrectly classified the maturity status of the earliest and latest maturing players. This issue is of particular concern to those working in football academies as the number of early maturing male players is disproportionally high in such contexts (84,85), which is consistent with advanced skeletal maturity status documented in other samples of soccer players (48,85).

The "normalisation" of PHV in early maturing players has the potential to classify them as pre-PHV when they are in fact circa-PHV and as circa-PHV when they are post-PHV (especially among U14 and U15 players). Misclassification due limitations of the prediction equations also have the potential to influence the practice and training protocols and loads to which the players are exposed.

Use of different bands for PAH% affects pre-, circa- and post-PHV classifications

Results of the present study showed that wider PAH% bands (e.g., 85%-96% and 88%-96%) had higher concordance with maturity status classification using ±1.0 year circa-PHV threshold, while narrower PAH% bands (e.g., 88%-93% and 90%-93%) had higher concordance with classification using ±0.5 year circa-PHV threshold. Similar results were observed with the KR and TW2-RUS height prediction equations, which was somewhat surprising as height prediction methods utilising skeletal age are generally accepted as more reliable and valid estimates of predicted adult height (13). Of course, the two height prediction protocols were based on different samples. Accordingly, the results suggested that the KR equation provides a satisfactory protocol for predicting the adult height of academy players compared to the more time-consuming TW2-RUS method which requires a radiograph of the hand-wrist and assessment of skeletal age. However, it should be acknowledged that TW2-RUS PAH% was assessed using adult height estimation based on a single x-ray taken at the start of the U14 season. Considering that maturation progresses at different timing and tempo (13), estimations might had improved if x-rays had been taken at the time of each stature measurement and PAH% estimation. Nevertheless, the academy only permitted a single x-ray assessment.

Consistent with the observations of the study by Salter et al. (25), the wider PAH% bands (e.g., 85%-96%) detected most circa-PHV players. Similarly, Parr et al. (28) noted that PHV occurred within the KR 85%-96% band in 96% of the players. In contrast, the present results showed that wider bands tended to classify pre- and post-PHV players as circa-PHV, and the narrower PAH% bands (e.g., 90%-93%) failed to detect circa-PHV players but detected most of the players classified as pre- and post-PHV. By inference, those applying PAH% should choose bands relative to the objective of the classifications. Overall, 85%-96% and 88%-93% showed the highest concordance when compared to circa-PHV classification based on complete growth curves using ±1.0 and ±0.5 year thresholds, respectively. Thus, using those bands would result in classifying most of the players in pre-, circa- and post-PHV periods, with an equal error across the three intervals. However, if the objective is to identify players in a specific interval, other bands should be considered. For instance, in order to be protective and reduce the load on circa-PHV players to minimise injury risk (16,45), an 85%-96% band detects most of circa-PHV players. On the other hand, if the objective is to identify post-PHV players for specific training (i.e., strength training), a more stringent band for the circa-PHV interval (e.g., 88%-93% or 90%-93%) should be used.

Using PAH% to estimate maturity status seems especially useful when longitudinal height data are not available. It also showed better results compared to predicted maturity offset and the maturity ratio. Of course, the differences between the prediction protocols must be noted. PAH% is an estimate of maturity status at the time of observation, while maturity offset is an estimate of maturity timing; though related, the two are not equivalent. However, PAH% requires parental heights (KR) or skeletal age assessment, which may not be available for all players/academies.

It should be noted that the KR prediction equations were based on well-off American children of European ancestry, while the standardizing group for the TW-2 skeletal age method was of British ancestry and of average socioeconomic status (13). However, the present study used an adaptation of TW-2 equation to estimate adult height; the equation was based on a growth study of children and youth in the Basque Country in 1978-1987 (47). Similarly, the Mirwald (17) and Moore (18) prediction equations were based on samples of European ancestry, while the maturity ratio of Fransen (19) was based on a sample of European ancestry and validated in sample of elite Belgian soccer players. Of relevance, relatively few studies of soccer players indicate the ethnic composition of the samples, although identification of youth by ethnicity may not be permitted in some countries. Nevertheless, the study of Teunissen et al. (29) included players of European, African and Middle Eastern ancestry, while the study of Parr et al. (28) based on English players noted that non-European players were taller with a lower sitting height/height ratio, i.e., proportionally longer legs, than European players.

Methodological considerations

Several limitations of the study should be noted. First, the results apply to a relatively small sample of Basque players at a professional soccer academy who were mostly of European ancestry. Generalization of results to players from other countries or of other ethnicities and to players competing at different levels needs to be done with care. Also, the small sample sizes have likely limited the statistical power of the analyses. Further, radiographs were available only at the beginning of the U14 season and adult height estimated with the TW2-RUS method at this moment was used to estimate PAH% across the interval of the longitudinal observations.

CONCLUSION:

The present study considered the concordance of maturity status classifications (pre-, circa, post-PHV) based on estimated ages at PHV in a longitudinal sample of players and predicted ages at PHV in elite academy soccer players. The results suggested that visual assessment of longitudinal growth curves by an experienced assessor was the best method to classify players as pre-, circa- or post-PHV. Classifications as pre-, circa, post-PHV based on predicted ages at PHV resulted in misclassifications for a major portion of the sample, while classification based %PAH varied with the bands used. By inference, the misclassifications by the prediction methods have the potential to influence the practice/training protocols to which youth players are exposed. Future studies should evaluate inter-tester reliability of growth-curve evaluation and the applicability of machine learning techniques to estimate maturity status (159). Overall, the results of the current study are relevant to efforts at improving the classification of soccer players relative to the timing of PHV.

5. EZTABAIDA OROKORRA ETA APLIKAZIO PRAKTIKOA

5. *EZTABAIDA OROKORRA ETA APLIKAZIO PRAKTIKOA*

Tesi honen helburu nagusiak Athletic Club taldeko harrobiko gizonezkoen zein emakumezkoen lesioen epidemiologia kategoriaz kategoria deskribatzea, gizonezko jokalari gazteen hazkundeak eta heltzeak lesioetan duen eragina ezagutzea eta heltze-egoera (*pre*-, *circa*-, *post*-PHV) estimatzeko metodoak aztertzea eta konparatzea izan ziren.

5.1 HARROBIKO JOKALARIEN EPIDEMIOLOGIA DESKRIBATZEAREN GARRANTZIA

Futbolarien lesio-profila ulertzea lesioen prebentziorako eta errehabilitaziorako ezinbestekoa da. Larruskain et al.-k (66) Athletic Clubeko gizonen eta emakumeen lehen taldeen epidemiologia deskribatu eta alderatu zuen; hala ere, ikerketa honetan harrobiko taldeak ez ziren ikertu. Gazteen taldeetan (batez ere emakumezkoetan) egindako ikerketa gutxi zeudela kontuan hartuta, Athletic Clubeko gizonezkoen eta emakumezkoen talde guztien epidemiologia aztertu zen *I. ikerlanean*; gazteenetatik lehen taldera arte. Lan honek harrobiko taldeetan *injury burden* handieneko lesioak identifikatu zituen. Ume eta gazteetan inpaktu handieneko lesioak identifikatzeak *burden* handieneko lesioen arriskua murrizteko prebentzio-neurriak diseinatzea eta gauzatzea ahalbidetzen du. Prebentzio-neurri horien helburu nagusia haur eta nerabeen osasuna zaintzea izango litzateke. Izan ere, gorago aipatu den bezala, jokalarien harrobian jarraitzeko aukeretan (3), osasun mentalean (6) eta epe-luzeko osasun-arazoetan (1,62,72) eragin zuzena dute gaztetan izandako lesioek. Ume eta nerabeen ongizatea zaintzea Athletic Clubeko kideentzat ezinbestekoa da, eta horren adibide garbia da ATERPE proiektuaren sorrera (https://www.athletic-club.eus/eu/aterpe-athletic-club-erakundearen-babes-politika). Harrobiko futbolarien babes integrala lortzea da proiektu honen helburu nagusia eta aipagarria da UEFAk (Union of European Football Associations) 2020-2021 denboraldian saritu zuela (https://www.uefa.com/news/0274-14d3cbacd3c8-7a0b5e20bd74-1000--athletic-bilbao-take-prestigious-uefa-grassroots-award/).

I. ikerlaneko 4.I.1 Irudian Athletic Clubeko harrobian inpaktu handiena duten lesioak zeintzuk diren ikus daiteke: batetik, belauneko lotailu/giltzaduretako lesioak (bereziki, emakumezkoen taldeetan), eta bestetik, hazkunde-lesioak (bereziki, 13, 14 eta 15 urtez azpiko taldeetan). Tesi honen sarreran aipatua izan den bezala, behin inpaktu handieneko lesioak identifikatuta, lesio horien agerpena baldintzatzen duten arrisku-faktoreak identifikatzea izango litzateke hurrengo urratsa. Hazkunde eta heltzeari lotutako arrisku-faktoreei buruzko interesa nabarmen igo da azken hamarkadan, eta horren adibide garbia da azken urteetan gai honi buruz argitaratu diren ikerlanen kopurua. Hala ere, Swain et al.-k (35) egindako berrikuspen sistematikoaren arabera, orain arte egindako ikerketek muga metodologikoak dituzte eta horren ondorioz, askotan ikerlan horien emaitzak kontraesankorrak dira. Beraz, muga metodologiko horiek hobetzeko diseinatu eta egin zen tesi hau.

5.2 HAZKUNDEAREKIN ETA HELTZEAREKIN ERLAZIONATUTAKO ARRISKU-FAKTOREEN ERAGINA ATHLETIC CLUBEKO JOKALARIEN LESIOETAN

Tesi honetako *II.-IV. ikerlanek* Athletic Clubeko gizonezkoen harrobiko futbolarien hazkunde eta heltzeari lotutako arrisku-faktoreak ikertu zituzten.

Heltze-egoerari dagokionez (*pre*-, *circa*-, *post*-PHV edo helduak), tesi honetako emaitzek lesio espezifikoen agerpena eta inpaktua fasearen arabera aldatzen dela erakutsi zuten. *Circa*-PHVn eragin handiagoa izan zuten hazkunde-lesioek. *Post*-PHVn eta bereziki, jokalari helduetan, muskulu eta giltzadura/lotailuetako lesioek. Bestalde, aipatu beharra dago hazkunde-lesioak *pre*-, *circa*- eta *post*-PHVn eman zirela; hazkunde-lesio distalek (adibidez, Severren gaixotasunak) eragin handiagoa izan zuten *pre*-PHVn eta hazkunde-lesio proximalek (adibidez, espondilolisiak), berriz, *post*-PHVn. *IV. ikerlaneko* laburpen irudiak (*graphical abstract*) heltze-egoeraren fase bakoitzean *burden* handiena zuten lesioak, hau da, prebenitu beharreko lesioak identifikatu zituen.

Bestetik, heltze-*timing*ak (goiztiarra, normala edo berantiarra) ere lesio-mota espezifikoen *burden*ean eragina zuela ondorioztatu zuen *IV. ikerlanak*. Alde batetik, *pre*-PHVn, heltze-*timing* normala zuten jokalariek hazkunde-lesio eta belauneko giltzadura/lotailuetako lesioen *burden* handiagoa izan zuten heltze berantiarra izan zutenekin konparatuta. Ezberdintasun adierazgarririk aurkitu ez arren, *circa*-PHVn, hazkunde-lesioen *burden*a txikiagoa izan zen heltze-*timing* berantiarra zuten futbolarietan heltze goiztiarra/normala zutenen aldean. Oro har, PHVa lehenago duten pertsonek (goiztiarragoek) PHV bizkorragoa dute; hau da, hazkunde-abiadura gorena bizkorragoa izan ohi dute (160). PHVaren abiadura eta hazkunde-abiadura hazkunde-lesioekin harremana duela jakinda (*V. eta VI. ikerlanak*), baliteke jokalari goiztiarretan ikusitako hazkunde-lesioen *burden* handiagoa PHV bizkorrago batekin harremana izatea. Bestalde, heltze-*timing* berantiarra izan zuten jokalari helduek lesio orokor eta giltzadura/lotailuetako *burden* handiagoa izan zuten heldu goiztiarren aldean. Emaitza honen arrazoiak bi izan daitezke. Batetik, jokalari heldu berantiarrek hanka luzeagoak izan ohi dituzte heldutan (121) eta beraz, palanka luzeagoak izateagatik belauna lesionatzeko aukera gehiago izan daitezke (61). Bestetik, heltze berantiarra duten jokalariek jokaera teknikoago eta taktikoagoa izaten dute (91) eta baliteke horrek norabide aldaketa gehiago egitera eramatea eta beraz, lesionatzeko aukerak handiagotzea. Hala ere, ikerketa gehiago egin behar dira emaitza hauen zergatia zein den hobeto ulertzeko.

Bestalde, hazkunde-abiadurari dagokionez, abiadura bizkorrak *pre-*, *circa-* eta *post-*PHV periodoetan hazkunde-lesioen intzidentzia eta *burden* handiagotzen zuela erakutsi zuten emaitzek. Izan ere, 7,2 cm/urtetik gorako hazkunde-abiadura zuten jokalariek hazkunde-lesioen intzidentzia eta *burden* handiagoa izan zuten hazkunde-prozesu osoan zehar (*pre*-, *circa*- eta *post*-PHVn) (*V. ikerlana*). Beraz, nerabezaroaren hasieratik (*pre*-PHV) eta heldua izan arte (*post*-PHV) hazkunde-abiadura erregistratzea garrantzitsua zela erakutsi zuten emaitzek. Horrez gain, PHV bizkorra (>10,84 cm/urte) zuten jokalariek hazkunde-lesioen *burden* handiagoa izan zuten *circa*-PHVn (*VI. ikerlana*). Ondorioz, lesio arrisku handiagoa zuten jokalariak identifikatzeko hazkunde-abiadura jasotzea ezinbesteko dela erakutsi dute tesi honetako emaitzek.

Aipatzeko da tesiko ikerlanek aurretik egindako beste ikerketen hainbat muga metodologiko gainditu dituztela. Alde batetik, zeharkako ikerketa edota ikerketa longitudinal laburra egitearen ordez, 20 urtetako datu longitudinalak aztertu ziren eta bestetik, heltzea aztertzeko fidagarritasun eskasa duten estimazio ekuaziorik ez ziren erabili (35). Gainera, hazkundeak eta heltzeak lesio-mota espezifikoen *burden*ean duten eragina aztertu dute leheneko aldiz tesi honetako ikerlanek. Ondorioz, lesioen prebentzio programak diseinatu eta martxan jartzeko ekarpen garrantzitsua egin dute.

5.3 HAZKUNDEAREN ETA HELTZEAREN MONITORIZAZIOA

Hazkuntza eta heltzearekin lotutako arrisku-faktoreak identifikatu ondoren, jokalarien hazkundearen eta heltzearen monitorizazio zehatza bermatzea ezinbestekoa da arrisku handiagoa duten jokalariak detektatzeko. Horrela, jokalari bakoitzaren hazkunde eta heltze prozesua ezagututa eta *II.-VI. ikerlanetan* aurkitutako emaitzetan oinarrituta, prebentzio programa indibidualak diseinatu eta gauzatu daitezke.

Athletic Clubeko medikuek harrobiko jokalarien hazkunde eta heltzearen jarraipena egitearen garrantzia gogoan izan dute beti, eta horren adibiderik argiena tesi honetan aztertutako 20 denboraldiko datuak dira. Gainera, 14 urtez azpiko jokalarien hezur-adina aztertua izan da azken hamar denboraldi-aurreetan. Hogei urtetan zehar jasotako datu-basea erabiliz, heltze-egoera estimatzeko metodo ezberdinak alderatu zituen tesi honetako *VII. ikerlanak*. Are zehatzago, ikerlan honen helburua prospektiboki jokalariak *pre*-, *circa*- edo *post*-PHV gisa sailkatzeko metodorik onena aurkitzea izan zen. Gure emaitzen arabera, jokalariak sailkatzeko metodorik zehatzena esperientziadun aztertzaile batek hazkunde-kurben ebaluazio bisuala egitea izan zen. Hala ere, hazkunde-kurbak Athletic Clubeko jokalarien hazkundea eta heltzea aztertzen dituen profesionalak aztertu zituen bakarrik eta beraz, metodo honen bidez jokalariak *pre*-, *circa*- edo *post*-PHV gisa sailkatzeko gaitasuna aztertzailearen araberako den edo ez ez zen argitu.

Horrez gain, aztertzailearentzat iraupen luzeagoko jarraipen longitudinala (adibidez, 11 urtez azpiko kategoriatik datuak jasota zituzten jokalariak) zuten hazkunde-kurbak sailkatzea errazagoa zela erakutsi zuten emaitzek (bereziki, jokalariaren altueraren azken neurketa 13 eta 14 urtez azpiko kategorian hartu zenean). Hori dela eta, 11 urtez azpiko taldetik 16 urte azpiko kategoriara altuera eta pisua erregularki (denboraldian 4 aldiz) jasotzen hasi dira Athletic Clubeko zerbitzu medikoetako kideak. Izan ere, orain arte altuera urtean bitan edo hirutan jasotzen zen bakarrik (14 urtez azpiko taldean izan ezik). Horrez gain, harrobian sartzen diren jokalari berrien hazkunde eta heltze prozesuaren irudi argiagoa izateko asmoz, guraso/tutoreei osasun sistemak pediatriako kontroletan erregistratutako altuera eta pisuari buruzko datuak eskatzen hasi dira Athletic Cluben. Horrela, heltze-egoeraren (*pre*-, *circa*- eta *post*-PHV) sailkapena errazteaz gain, hazkunde-abiaduraren jarraipen longitudinalak nerabezaroaren hasierako (*pre*-PHVn) hazkunde-abiaduraren jarraipena egitea eta PHV (cm/urte) estimazio zehatzagoak egitea ahalbidetzen du (143). Aldagai hauek ahalik eta modu zehatzenean jasotzea garrantzia handia du esku-hartzeak diseinatu eta gauzatzeko orduan; alde batetik, nerabezaroaren hasieratik (*pre*-, *circa*- eta *post*-PHVn) hazkunde-abiadurak hazkunde-lesioen agerpenean eragin zuzena izan dezakeelako (*V. ikerlana*) eta bestetik, PHV bizkorra *circa*-PHVko hazkunde-lesioen *burden*aren handitzearekin harremanean dagoelako (*VI. ikerlana*).

Jokalari baten hazkunde-abiaduraren jarraipen longitudinala eskuragarri ez dagoenean (adibidez, jokalari berri bat harrobira sartzen denean) hazkunde-abiadura eta PHVa estimatzea ezinezkoa da; izan ere, hazkunde-abiadura kalkulatzeko denboran banatutako altueraren bi neurketa behar dira gutxienez. Hala ere, heltzea estimatzeko ekuazioak erabilita neurketa bakarrarekin jokalariak *pre*-, *circa*- edo *post*-PHV bezala sailkatu daitezke. *VII. ikerlaneko* emaitzen arabera, heltze-egoeraren arabera jokalariak sailkatzeko bigarren aukerarik onena iragarritako helduaroko altueraren ehunekoa (PAH%) da. Helduaroko altuera estimatzeko beharrezkoak diren gurasoen altuera edota hezur-adina eskura ez izatekotan, *maturity offset* ekuazioak erabiltzea da hirugarren aukera. Hala ere, *VII. ikerlaneko* emaitzen arabera ekuazio hauek jokalarien herena edo erdia gaizki sailkatzen dituzte. PAH% erabiltzearen arazo nagusia *circa*-PHV periodoa definitzeko hainbat banda egotea (adibidez, %85-%96 edo %88-%93) da. Ikerlan eta klub bakoitzean banda ezberdinak erabiltzen dira eta nahiz eta helduaroko altuera estimatzeko metodo berdina erabili, banda ezberdinak erabiltzeak jokalariak okerreko faseetan sailkatzea eragin dezake. *VII. ikerlaneko* emaitzen arabera, *circa*-PHVrako %85-96 eta %88-93 bandekin egindako sailkapena PHV adina ± 1 urteko *circa*-PHV irizpidea erabiliz egindako sailkapenaren antzekoa izango litzateke. %88-%93 eta % 90-%93 bandak erabiltzea, ordea, PHV adina ± 0,5 urteko sailkapenaren parekoa izango litzateke. Emaitza hauek banda aukeratzeko orduan edota banda ezberdinak erabili direnean konparaketak egiteko lagungarriak izan daitezke.

Helduaroko altuera iragarri eta PAH% kalkulatzeko metodoei dagokienez, emaitzen arabera, lehenengo aukera Khamis-Roche (KR) ekuazioa izango litzateke; beti ere, gurasoen altuera eskuragarri badago. Informazio hori ez izatekotan, hezur-adinaren bidezko estimazioa [gure kasuan, Tanner-Whitehouse2-RUS metodoarekin (TW2-RUS)] egin daiteke. *VII. ikerlanean* heltze-egoeraren (*pre*-, *circa*-, *post*-PHV) sailkapenerako emaitza antzekoak izan ziren KR eta TW2-RUS ekuazioekin. Harrobiko zerbitzu medikoetako kideentzat ezustekoak izan ziren emaitza hauek. Izan ere, hezur-adinaren bidez egindako estimazioa helduaroko altuera estimatzeko metodo *gold* *standard*a izan da orain arte (13,14). Gainera, nahiz eta informazioa ikerlanetan ez agertu, KR eta TW-2-RUS metodoen bidez egindako helduaroko altueraren estimazioa benetako helduaroko altuerarekin konparatu zen tesi honetan. Emaitzen arabera, bi estimazio metodoen errore estandarra oso antzekoa izan zen (KR: 3,42 cm; TW-2RUS: 3,40 cm). Beraz, ez dirudi metodo bat bestea baino hobea denik. Ondorioz, bien errorea antzerakoa izanda, zein da erabiltzeko metodorik egokiena? Momentuan hau da zerbitzu medikoko kideen zalantza nagusia. Izan ere, x izpien bidezko estimazioa *gold standard*a izan arren, denbora asko kontsumitzen du (jokalaria ospitalera joan behar da erradiografia egitera eta aztertzaile aditu batek irudiaren azterketa egin behar du). Gainera, umeentzat kaltegarria izan daitekeen erradiazioa eragiten du. Hain zuzen ere, bi arrazoi hauengatik Athletic Clubeko jokalari bakoitzari ebaluazio bakarra egiten zaio heltze prozesu osoan zehar (14 urtez azpiko denboraldiaren hasieran). Hau jadanik muga bat da, tesian hainbat aldiz aipatu den bezala, hazkundea eta heltzea prozesu ez-lineala izanda (13), irudi bakarra egiteak estimazioaren zehaztasunean eragina izan dezakeelako. KR ekuazioa, aldiz, azkar burutzen den metodo ez-inbaditzailea da eta *gold standard*aren antzeko errorea duela erakutsi dute tesi honetako emaitzek. Aipatutako guztiaren ondorioz, inbaditzaileak ez diren eta denbora gutxiago behar duten teknikak lehenestea gogoan hartzen ari dira Athletic Clubeko zerbitzu medikoek; hala nola, KR ekuazioa edota klub askotan erabiltzen hasi diren SonicBone sistema (134). Dena den, KR ekuazioak zenbait muga ere badituela aipatu beharra dago. Alde batetik, gurasoek euren altueraren neurri ez oso zehatzak ematen dituzte askotan (orokorrean, guraso gehienak benetan duten altuera baino garaiagoak direla esaten dute). Hori dela eta, KR ekuazioa erabili aurretik Epsteinen ekuazioaren bidez gurasoen neurriak zuzentzea gomendagarria da (150). Beste alde batetik, estimazioan eragina izan dezakeen beste faktore bat jokalariaren aita benetako aita biologikoa ez izatea da. Bai x izpien bidezko estimazioak eta baita KR ekuazioak dituen mugak ikusita, Athletic Clubeko zerbitzu medikoko kideek SonicBone gailua erostea pentsatzen ari dira. Izan ere, ultrasonografia-gailu honek adin eskeletikoa eta helduaroko altuera estimatzeko aukera ematen du erradiaziorik igorri gabe, azkar (4-5 minutu), ebaluatzaile aditu baten ebaluazioren beharrik gabe eta gurasoen neurria izan gabe.

Hazkunde eta heltze estimazio zehatzagoak lortzeko kontuan hartu beharreko beste puntu bat altuera neurketak ISAK estandarrei jarraituz (46) egin zirela da. Altuera datu zehatzagoak izateko, altuera birritan neurtzea eta bataz bestekoa kalkulatzea izango litzateke gomendagarriena. Horrela, bi neurketen arteko aldea 0,4 cm-tik gorakoa bada, hirugarren neurketa bat egin eta mediana kalkulatzea izango litzateke egokiena. Hala ere, orain arte, denbora falta dela eta, ebaluazio bakoitzean baten bakarrik neurtu dira jokalariak Athletic Cluben. Neurketen errore teknikoari dagokionez, aztertzaileen artekoa 0,23 cm-koa izan zen, eta aztertzailearen barne-errorea 0,29 cm-koa (46). Gure aztertzaileen neurketa-errorea altueraren neurketa errepikatzeko ezarritako atalasearen (0,4 cm) azpitik dagoen arren, argi dago neurketa birritan eginda neurketak zehatzagoak izango liratekeela. Izan ere, 0,23 cm-ko errorea "onargarria" dela dirudien arren, errorea hazkuntza-abiadurara itzultzean, akatsa nabariagoa izan liteke eta jokalarien sailkapenean eragina izan dezake. Adibidez, 0,23 cm-ko errorea azken 3 hilabeteetako (Athletic Clubeko harrobiko jokalariak neurtzen diren maiztasuna) altueraren aldaketara pasatzeak (0,23 cm /0,25 urte), 1 cm/urte inguruko errorea eragingo luke. Honen ondorioz, zerbitzu medikoko kideak neurketak errepikatzea planteatzen ari dira (bi edo hiru aldiz, behar izanez gero).

Bestalde, neurketen kalitatea eta maiztasuna ezin hobea izateko, klubeko gainerako langileei (adibidez, entrenatzaileak eta prestatzaile fisikoak) datuak jasotzea ezinbestekoa dela jakinarazi eta transmititu behar zaie. Ez hori bakarrik, gurasoek/tutoreek ere hazkundeari eta heltzeari buruzko datuak ematea (adibidez, gurasoen altuera edo osasun-sistemak egindako altuera neurketak) garrantzitsua dela jakin behar dute. Datuak jasotzearen garrantziaren berri emateko, hazkunde eta heltzeak jokalarietan izan dezakeen eraginaz informatzea eta jokalariei buruz jasotako datuak konpartitzea behar-beharrezkoa izango litzateke.

5.4 HEZKUNTZA ETA DATUEN PARTEKATZEA

Aurreko atalean aipatua izan den bezala, azken 20 denboraldietako harrobiko jokalarien hazkunde eta heltzeari buruzko datuak erregistratu dituzte Athletic Clubeko zerbitzu medikoek. Hala ere, askotan, jasotako datuak ez ziren klubeko gainerako sail edo lankideetara (adibidez, entrenatzaile eta prestatzaile fisikoetara) heldu.

Hori dela eta, klubeko beste sailekin komunikazio hobetzea eta eurentzat interesgarriak izan daitezkeen gaiei buruzko informazioa partekatzea zerbitzu medikoetako kideen helburu nagusietariko bat da. Gai desberdinen artean, hazkundea eta heltzea klubeko sail ezberdinetarako interesgarria den gaietako bat izan daiteke. Tesi honen helburua lesioen arrisku-faktoreak aztertzea izan den arren, jokalarien partiduetako errendimenduan (81,146), errendimendu fisikoan (144), talentuaren identifikazioan (142) eta psikologian (88) ere eragina izan dezakete hazkundeak eta heltzeak. Hori dela eta, azkenengo denboraldietan gai hauei buruzko formazio saioak antolatu dituzte sail ezberdinetako langileak hezi eta euren eguneroko lanean hazkundea eta heltzea kontuan har dezaten.

Horrez gain, 3 hilabetero jasotako datuak klubeko profesionalekin partekatzen dira; formazio saioetan ikasitakoa euren jokalariekin praktikara eraman ahal izateko. Batetik, talde mailako txosten bat bidaltzen zaie (5.1 Irudia), zeinean jokalarien hazkundeari eta heltzeari buruzko informazio orokorra azaltzen den. Txosten honetan, jokalari bakoitzaren argazkia hazkunde-kurban kokatzen da jokalariaren heltze-egoeraren arabera. Jokalariaren heltze-egoera zehazteko, jokalariaren hazkunde-kurba indibiduala eta PAH% hartzen dira kontuan; izan ere, harrobiko jokalariak sailkatzeko metodorik egokiena dela erakutsi zuen *VII. ikerlanak*. Talde-txosteneko hazkunde-kurbak 5 heltze-egoera fase bereizten ditu:

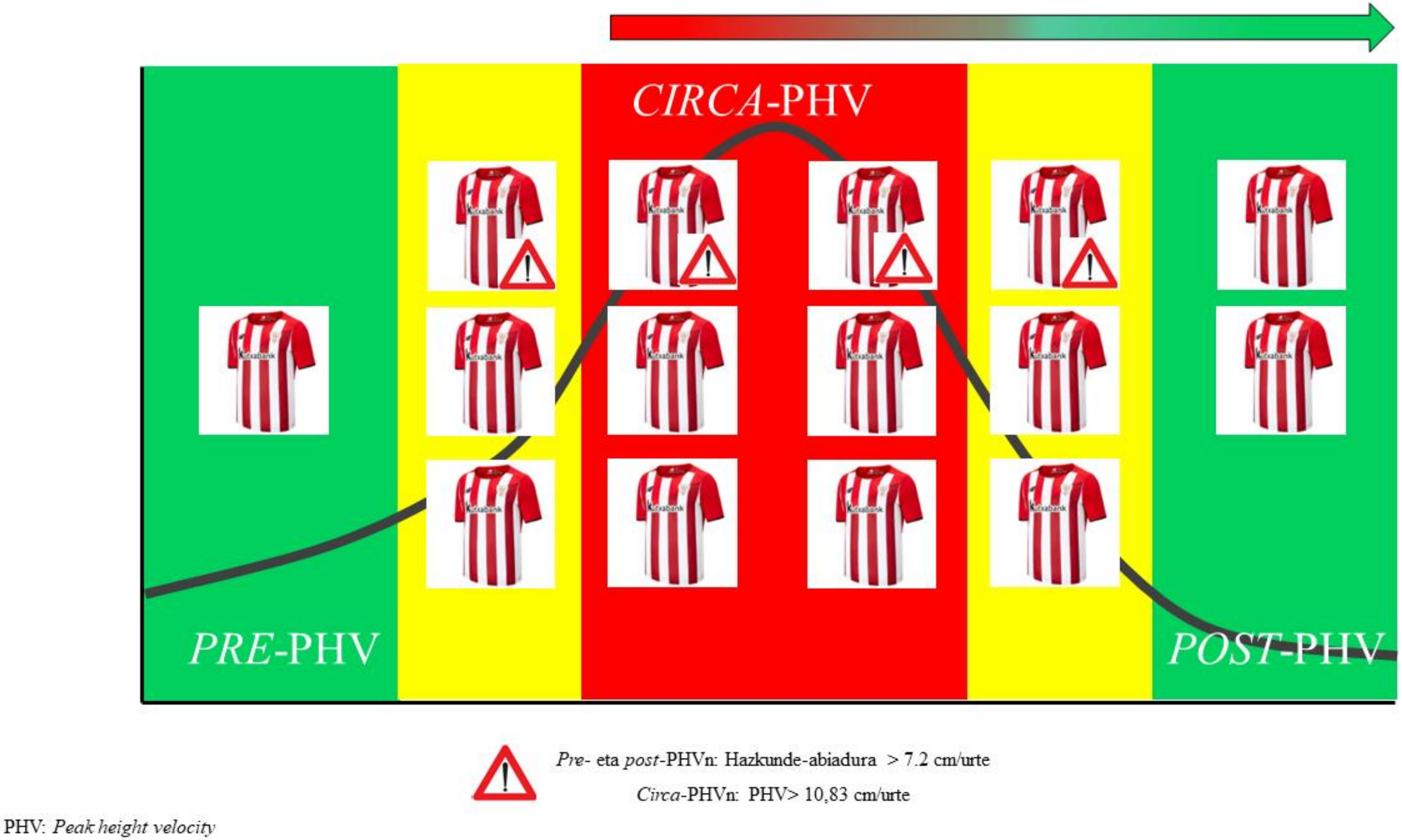
- *Pre*-PHV: Urtebete baino gehiago PHVa baino lehen.
- *Pre*- eta *circa*-PHV artean: PHVa baino 1-0,5 urte arinago.
- *Circa*-PHV: 0,5 urte PHVaren aurretik eta ostean.
- *Circa*- eta *post*-PHV artean: PHVaren ostean 0,5-1 urte bitartean.
- *Post*-PHV: PHVaren ostean urte bete baino gehiago.

Beraz, talde-txosteneko hazkunde-kurbako eskuinaldean egoteak helduagoa izatea adieraziko luke. Txosten honetan talde bereko jokalariak ($\simeq$ adin kronologikoa) agertzen direla kontuan izanik, oro har, eskuinaldean dauden jokalariek heltze-*timing* goiztiarragoa izango lukete (16).

Gainera, hazkunde-lesioak izateko aukera gehiago dituzten jokalariei harridura marka bat jartzen zaie; bai 7,2 cm/urtetik gorako hazkunde-abiadura izateagatik (*V. ikerlana*), edota *circa*-PHVn egonda PHV bizkorra (10,83 cm/urte) izateagatik (*VI. ikerlana*). Horrela, lesionatzeko aukera gehiago dituzten eta agian, neurri bereziren bat (adibidez, entrenamenduaren moldaketa) behar duten jokalariak errazago identifikatu ditzakete entrenatzaile, prestatzaile fisiko eta zerbitzu medikoko kideek.

Horrez gain, jokalari bakoitzaren hazkunde eta heltzeari buruzko informazio zehatzagoa (adibidez, iragarritako helduaroko altuera eta jokalariaren neurketa bakoitzaren altuera eta pisua) jasotzen dituen banakako txostenak ere partekatzen dira harrobiko sail ezberdinetako profesionalekin (5.2 Irudia).

Antolatutako formazio saioek eta jokalarien txostenen partekatzeak profil ezberdinetako profesionalek hazkundeari eta heltzeari buruz duten ezagutza, eta horren ondorioz, kontzientzia areagotuko dutela uste dute Athletic Clubeko zerbitzu medikoek. Gainera, langileak ikerketa galdera eta proiektu berrietan pentsatzera bultza ditzake.



5.1 Irudia: Talde mailako hazkunde eta heltze txostena. Kamiseta bakoitzak jokalari bat adieraziko luke.

Hazkunde eta heltze txostena

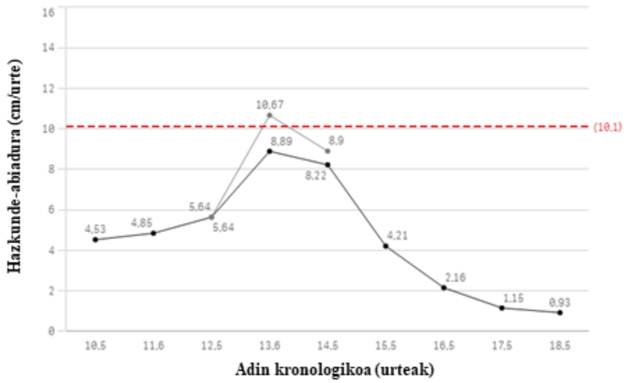
Jokalaria:
Taldea:
Jaiotze-data: 2007/03/07
Adin kronologikoa: 14,6

Heltze-egoera: Circa-post-PHV
(*Pre*-PHV, *Circa*-PHV, *Post*-PHV)

Heltze-*timinga*: Normala
(Goiztiarra, normala, berantiarra)

Estimatutako heldutasuneko altuera (PAH): 191,0

Estimatutako heldutasuneko altueraren ehunekoa (PAH%): 94,35%



Taldea	Data	Adin kronologikoa (urteak)	Altuera (cm)	Pisua (kg)
Alevin San Mames 2007	2018/09/19	11,6	155,5	40,5
Athletic Infantil San Mamés 2007	2019/09/04	12,5	160,9	44,0
Athletic Infantil San Mamés 2007	2020/10/05	13,6	172,5	54,2
Athletic Cadete B	2021/08/17	14,5	180,2	56,7

Oharrak:

5.2 Irudia: Hazkunde eta heltzearen banakako txostena.

PHV: *Peak height velocity*

5.5 HAZKUNDEAREKIN ETA HELTZEAREKIN ERLAZIONATUTAKO ARRISKU-FAKTOREEN ARABERAKO ESKU-HARTZEEN DISEINATZEA ETA GAUZATZEA

Ikerketa honetako emaitzek Athletic Clubeko harrobiko jokalarietan hazkunde-lesioak *burden* handiko lesioa zela (*I. ikerlana*) eta hazkundeak eta heltzeak lesio hauen arriskuan eragina zuela (*II-VI. ikerlanak*) adierazi zuten. Tesi honen sarreran aipatu den bezala, behin lesioen epidemiologia eta arrisku-faktoreak aztertuta, *burden* handieneko lesioen inpaktua murrizteko esku-hartzeak egitea izango litzateke hurrengo pausua. Esku-hartze horren diseinu eta gauzatzea da Athletic Clubeko zerbitzu medikoko kideen hurrengo erronka.

Oro har, gaur egun ez dago hazkunde-lesioen inpaktua murrizteko enpirikoki oinarritutako eta ondo kontrolatutako esku-hartzerik. Beraz, hazkunde-lesioen inpaktua murrizteko esku-hartzeak diseinatzerakoan ikuspegi pragmatikoa hartu ohi da futbol taldeetan; hots, orain arteko ebidentzian oinarrituta lesio-arriskua murrizten lagundu dezaketen estrategia potentzialak gauzatzen dira (15). Azken urteotan argitaratutako ikerketetan eta bereziki, tesi honetako ikerlanen emaitzetan oinarrituta, hazkunde-lesioen inpaktua murrizteko esku-hartzea diseinatu eta gauzatu da Athletic Cluben. Horrez gain, tesi honetako egonaldiari esker beste futbol talde profesionalekin izandako elkarrizketak (adibidez, Arsenal FC, Southampton FC eta Aspire Academy) esku-hartzeak diseinatzerako orduan oso lagungarriak izan dira.

Gaur egun, Athletic Clubeko gizonezkoen 14 urtez azpiko taldean egiten da prebentzio esku-hartzea. Talde honetan esku-hartzeko arrazoi nagusiak hurrengoak izan ziren: 1) hazkunde-lesioek inpaktu handiena duten adin-taldea izatea (*I. ikerlana*), 2) jokalarien arteko heltze-egoeran alde handiena dagoen adin-tartea izatea (*II. ikerlana*) eta 3) taldeko entrenatzaile eta prestatzaile fisikoen interesa eta motibazioa. Hala ere, behin esku-hartzearen emaitzak ikusten hasita, hazkunde-lesioen inpaktua handia den gainerako adin-taldeetan (U15-U13) ere inplementatzea da klubaren nahia.

Hazkunde-lesioen inpaktua murrizteko esku-hartzeak gauzatzerakoan kargaren kontrola kontuan hartzea ezinbestekoa dela aipatu dute hainbat ikerlanek (15,16,45,161). Hazten ari diren nerabeen hazkunde-plakak zaurgarriak dira trakzio- eta zizaila-indarren aurrean (13,32) eta beraz, futbolean ematen diren mugimendu errepikakorrek (hala nola, jaurtiketak eta norabide aldaketak) hazkunde-lesioen agerpenean eragina izan dezakete

(16). Heltze-egoera ezberdineko jokalarietan hazkunde-lesioak gertatu daitezkeela kontuan hartuta (*II.-VI. ikerlanak*), 14 urtez azpiko jokalari guztien karga kontrolatzea eta murriztea proposatu dute Athletic Clubeko zerbitzu medikoak. Horretarako, entrenamenduetan ariketen arteko atseden-denbora handitu eta azelerazio/dezelerazio zein jaurtiketa kopurua murriztu dira entrenamenduaren edukia moldatuz (15,16,161). Horrez gain, hazkunde-abiadura bizkorra duten jokalarietan (5.1 Irudiko talde-mailako txostenean identifikatutakoak) karga murrizteko neurri gehiago hartzen dira; izan ere, lesionatzeko aukera gehiago dituztela erakutsi zuten tesi honetako emaitzek (*V. eta VI. ikerlanak*). Alde batetik, partidetan jokatutako minutuak murriztu ziren (45) eta bestetik, jaurtiketa kopurua are gehiago murriztu ziren jokalari hauetan (16). Horrez gain, entrenamendu eta partida bakoitzaren ostean, jokalari bakoitzari saioak eragindako nekea puntuatzeko batetik hamarrera esaten zaio eta etorkizunean honen arabera entrenamendua moldatu nahi dute Athletic Clubeko langileek (15,161).

Bestalde, hazkunde-abiadura bizkorrak eragindako alterazio neuromuskularrek (33) eta malgutasun/mugikortasunaren gutxitzeak (162,163) hazkunde-lesioen agerpenean eragina izan dezakete. Hori dela eta, jokalarien egoera funtzionala aztertzeko malgutasuna/mugikortasuna (adibidez, orkatilako dortsiflexioa eta *Thomas Test*a) (164) eta oinarrizko mugimendu trebetasunak (*fundamental movement* skills: adibidez, sentadilla eta pisu hilaren mugimenduaren kalitatea) (135) aztertzeko testak egiten dira Athletic Clubeko harrobiko talde guztietan (14 urtez azpiko taldea barne). Malgutasun/mugikortasun testen emaitzetan oinarrituta, asteleheneko entrenamenduaren lehen zatian 20 minutuko ariketa programa bat gauzatzen dute jokalariek; hau da, jokalari bakoitzak testetan izandako defizitak lantzen dira. Horrez gain, astearteetako entrenamenduen hasieran, indarra eta oinarrizko mugimendu-trebetasunak eta indarra lantzeko 20 minutuko saioa egiten da, heltze-egoeraren arabera moldatzen dena. Izan ere, *pre*- eta *circa*-PHVn aldaketa neuromuskularren bidezko hobekuntza bilatzen da (ariketak pisu gabe edo pisu gutxirekin) eta *post*-PHVko jokalarietan, ordea, hipertrofia bidezkoa (ariketak pisuarekin) (79). Gainera, gure ikerketako emaitzak erakutsitako hazkunde-lesioen patroi distal-proximala kontuan hartuta, oinarrizko mugimendu-trebetasunak (adibidez, sentadilla ondo egiteko gaitasuna) lantzerakoan, *pre*- eta *circa*-PHVko jokalarietan segmentu distalei arreta gehiago jartzen zaie; *post*-PHVn daudenetan, aldiz, segmentu proximalei. Aipatu beharra dago ariketa hauen bidez ere talde-mailako karga murriztea lortzen dela; izan ere, futbol entrenamendu espezifikoaren denbora murrizten da partiduaren osteko bi saioetan (astelehena eta asteartea) eta beraz, azelerazio/dezelerazio mugimenduak eta jaurtiketak ere murrizten dira.

Amaitzeko, hazkunde-lesioen agerpena ahalik eta arinen detektatu nahian, taldeko aldageletan banakako gorputz-mapak jartzen dira, jokalariek edozein kaxa edo minaren kokapena eta intentsitatea adieraz dezaten (137). Horrez gain, entrenatzaileek jokalari batek min minimoa izatearen susmoa izatekotan (adibidez, herrenka ibiltzeagatik) edo jokalariak kexa minimoa izatekotan, zerbitzu medikoekin kontaktuan jartzen dira lesioak ahalik eta arinen detektatzeko.

Proposatutako esku-hartzeak lesioen inpaktua murrizten lagunduko duela espero da. Hala ere, lesioen agerpenean faktore askok eragiten dute (95), eta beraz, beste faktore askok eragina izan dezakete denboraldi honetan gertatutako lesioetan; hala nola, aurretik izandako lesioak, entrenamendu-edukiak eta entrenatzaileak. Beraz, denbora gehiago behar izango da diseinatutako eta aplikatutako esku-hartzeak lesioen inpaktuak eragina duen jakiteko.

6. MUGAK ETA INDARGUNEAK

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6.1 PARTE-HARTZAILEAK

Ikerketa honetako lagina Athletic Club taldeko jokalari kopuru txikiak osatu zuen. Gainera, klubeko filosofia dela eta, jokalari denak euskaldunak ziren eta gehienak jatorri kaukasoarra zuten. Emaitzak populazio espezifiko batean oinarrituta egoteak beste harrobi, herrialde eta etnia batzuetan aplikagarritasuna murriztua dute. Hala ere, beste populazioekin konparaketak egiteko erabilgarriak dira tesi honetako emaitzak.

Gizonezkoen eta emakumezkoen kategoria bakoitzeko lesioen epidemiologia aztertu zen arren (*I. ikerlana*), hazkundearekin eta heltzearekin erlazionatutako arrisku-faktoreak (*II.-VI. ikerlanak*) eta heltze-egoera aztertzeko metodoak gizonezkoetan bakarrik aztertu ziren (*VII. ikerlana*). Izan ere, orain dela denboraldi gutxi sortu ziren Athletic Cluben emakumezkoen harrobiko taldeak (U16 taldea 2017-2018 denboraldian eta U14 taldea 2018-2019 denboraldian) eta beraz, hazkunde prozesu osoan zehar altueraren jarraipen longitudinala zuten emakumerik ez zen egon. Tesi honen sarreran aipatu den bezala, gizonezkoekin konparatuta, PHVa arinago (11-12 urterekin) eta abiadura motelagoan (7-9 cm/urte) izan ohi dute emakumeek. Gaur egun Athletic Clubeko harrobiko emakumezkoen talderik gazteena U14 izanik, hazkundeak eta heltzeak lesio-arriskuan duen eragina aztertzea ezinezkoa izan zen; izan ere, harrobian zeudenerako ia denak *circa*- edo *post*-PHVn zeuden. Hala ere, hurrengo urteetan, emakumezkoetan hazkundeak eta heltzeak lesio-arriskuan duen eragina aztertzeko asmoa du Athletic Clubek.

Gainera, hazkundearen, heltzearen eta lesioen arteko harremana aztertu zituzten ikerlanen inklusio-irizpideak zirela eta, helduaroko altuera jasota zuten jokalariak (*III. eta V. ikerlanak*) edo PHV aurretik eta ostean guztira 10 neurketa zituzten jokalariak (*IV. eta VI ikerlanak*) aztertu ziren bakarrik. Horrela, lesioek harrobian jarraitzeko aukerak gutxitzen dituztela jakinda (3), lesio larriak edo lesio asko izan zituzten jokalari asko ziurrenik, ikerketatik kanpo gelditu ziren.

Amaitzeko, ikerketa honetan 20 denboralditan zehar jasotako datuak aztertu ziren, eta ikerketa periodoan zehar aldatu ziren faktore asko ez ziren kontuan hartu (95); hala nola, entrenatzaileak, jolasteko era, entrenamenduen edukiak…

6.2 LESIOEN ETA ESPOSIZIOAREN JASOTZEA

Lesioei dagokienez, baja-egunak eragin dituzten lesioak (*time-loss injuries*) baino ez ditu erregistratzen Athletic Club taldeko zerbitzu medikoak. Hori dela eta, parte-hartzean eragin zuzena ez zuten lesioak ez ziren aztertu ikerketa honetan. *Time-loss injury* edo baja-egunak eragiten duen lesioaren definizioa erabiliena, fidagarriena eta praktikan erabiltzeko errazena den arren, gutxika-gutxika agertzen ari diren gainkargazko min eta lesioak gutxiesten ditu; hala nola, hazkundearekin lotutako minak (137).

Bestalde, ikerketa osoan zehar lesioen diagnostiko espezifikoa irizpide berberei jarraituta egin zen arren, ikerketa honek aztertutako 20 denboraldietan zehar mediku ezberdinek jaso zituzten lesioak eta honek jasotako diagnostikoetan eragina izan zezakeen. Gainera, lesioak jasotzeko FIFAk egindako kontsentsuan (12) hazkunde-lesioak jasotzeko kategoria eta argibiderik ez dago eta beraz, lesio hauek sailkatzeko kategoria datu-basean gehigarri bat sortu eta medikuen esperientzian oinarrituta sailkatu ziren lesio hauek. Tesi hau martxan jarri zenetik hazkunde-lesioen epidemiologia zehatza aztertu zuten bi ikerlan argitaratu direla aipatu beharra dago (10,11), eta etorkizuneko ikerketek ikerlan hauetako sailkapenak kontuan hartu ahalko dituzte lesioak sailkatzerakoan.

Esposizioari dagokionez, metodologia orokorreko atalean aipatu den bezala, minutuetan jasotako esposizioa *I. eta II. ikerlanetan* erabili zen bakarrik. Gainerako ikerlanetan, esposizioa estimatu (*V. ikerlana*) edo denboraldi-jokariak esposizio unitatetzat erabili ziren (*IV. eta VI. ikerlanak*) (40).

Hala ere, aipagarria da tesi honetako ikerlanak hazkunde, heltze eta lesio espezifikoen arteko harremana aztertu zituen lehenengo ikerlanak izan zirela. Horrez gain, orain arte egindako ikerketa gehienek intzidentzia aztertu zuten bakarrik eta *injury burden*a ez zuten kontuan hartu. *Injury burdenak* lesioen intzidentzia (maiztasuna) eta larritasuna kontuan aztertzen dituela kontuan izanda, hazkundeak eta heltzeak jokalarien lesio eta disponibilitatean duen eragina aztertzeko aldagairik egokiena izango litzateke (5).

6.3 HAZKUNDEAREN ETA HELTZEAREN AZTERKETA

Tesi honetako ikerlanetan heltzea aztertzeko metodo ezberdinak erabili ziren.

II. eta VII. ikerlanetan TW-2RUS metodoaren bidez U14 jokalarien hezur-adina aztertu zen (151). Metodo honek Euskal Herriko ume eta nerabeen erreferentziazko datuak erabilita hezur-adina kalkulatzea eta helduaroko altuera aurresateko aukera ematen du (47). X izpiek eragindako irradiazioak nerabeengan kaltea egin dezakeenez, Athletic Clubeko jokalarien hazkunde eta heltze-prozesu osoan zehar hezur-adinaren balorazio bakarra egiten da (U14 denboraldiaren hasieran). Hazkundea eta heltzea prozesu ez-lineala dela kontuan hartuta (13), x-izpi bakar batekin egindako ebaluazioa egitea ez litzateke aukerarik egokiena izango, eta beraz, aurretik aipatua izan den bezala, neurketak errepikatzeko aukera ematen duten metodo ez-inbaditzaileak erabiltzea lehenesten ari dira Athletic Clubeko zerbitzu medikoko kideak.

Bestalde, *III.*, *V. eta VI. ikerlanek* helduaroko altueraren ehunekoa erabili zuten heltze-egoera somatikoaren indikatzailetzat. *VII. ikerlanean* aipatu zen bezala, *circa*-PHV periodoa definitzeko helduaroko altueraren portzentai banda ezberdinak erabiltzen dira; bai praktikan eta bai literaturan. Esate baterako, *III. eta V. ikerlanean* %88-%96 eta %88-%95 bandak erabili ziren *circa*-PHV periodoa definitzeko, hurrenez hurren. *IV. eta VI. ikerlanetan* erabilitako urtebeteko *circa*-PHV periodoaren antzerako luzera zuen helduaroko altueraren banda erabili nahian, *V. ikerlanean* banda estuagoa erabili zen (%88-%95 banda %88-%96ren ordez). Gainera, %88-%95 banda erabiltzeak Johnson et al.-n emaitzekin konparaketak egitea erraztu zuen (45), izan ere, banda bera erabili zuten. Aipatu beharra dago ikerlan horretako lehenengo hiru autoreek (Johnson, Cumming, Williams) tesi honetako *V. ikerlanean* kolaboratu zutela.

Horrez gain, hazkundea eta heltzea kategoriatan sailkatu ziren lesioetan zuten eragina aztertzeko: hezurraren heltze-egoera erlatiboa (goiztiarra, normala, berantiarra), heltze-egoera somatikoa (*pre*-, *circa*-, *post*-PHV edo heldua), heltze-*timing* somatikoa eta PHV/hazkunde-habiadura (bizkorra, normala, motela). Ondorioz, bi kategoria ezberdinetan jokalariek ezaugarri oso antzerakoak izan ditzakete (adibidez, 0,5eko hezurraren heltze-egoera erlatiboa duena goiztiarra izango litzateke eta 0,4 duenak normala) eta ondorioz, azkenengo ikerlanetan hazkundearekin eta heltzearekin lotutako aldagaiak aldagai jarrai bezala aztertzea proposatu dute (45). Hala ere, kategorizazioak praktikan lana asko errazten du eta Athletic Cluben aplikagarritasuna handiagoa izateko aldagai kategorikoak erabiltzea erabaki zen.

VII. ikerlanean hazkunde-kurben azterketa bisualaren bidez jokalariak *pre*-, *circa*- edo *post*-PHV bezala sailkatzeko gaitasuna aztertu zen. Hala ere, kurben aztertzailea Athletic Clubeko jokalarien hazkundea eta heltzea aztertzen dituen profesionalak egin zuen bakarrik eta beraz, jokalariak *pre*-, *circa*- edo *post*-PHV azterketa beste norbaitek eginda metodo emaitzak ezberdinak izan ahalko lirateke. Nolanahi ere, profesional honek Athletic Clubeko jokalarien hazkunde-kurbak aztertzen jarraitzen duen bitartean, hazkunde-kurben ebaluazio bisuala klubeko jokalariak sailkatzeko metodorik zehatzena izango litzatekeela ondorioztatu zuen *VII. ikerlanak* eta beraz, harrobiko praktikan eragin zuzena izan zuen.

Amaitzeko, tesi honetako ikerlanek aurretik egindako beste ikerketen hainbat muga metodologiko gainditu zituztela aipatu beharra dago. Alde batetik, zeharkako ikerketa edota ikerketa longitudinal laburra egitearen ordez, 20 urtetako datu longitudinalak aztertu zirelako eta bestetik, heltzea aztertzeko benetako PHV adina eta helduaroko altuera erabili zirelako (35).

7. ONDORIO OROKORRAK

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Tesi honek Athletic Club taldeko gizonezkoen zein emakumezkoen lesioen epidemiologia, jokalari gizonezkoen hazkunde eta heltzearekin erlazionatutako arrisku-faktoreak eta heltze-egoera estimatzeko metodoak aztertu ditu.

Hurrengoak izan ziren ikerketa honen ondorio nagusiak:

1. Lesio-mota bakoitzaren intzidentzia eta *burden*a adin-taldearen eta generoaren arabera ezberdina izan zen (*I. ikerlana*). Belauneko lesioak (emakumezkoen taldeetan) eta hazkunde-lesioak (U15 eta talde gazteagoetan) Athletic Clubeko taldeetan *burden* handieneko lesioak izan ziren. Beraz, etorkizunean lesio hauekin harremana duten arrisku faktoreen inguruan ikertzea ezinbestekoa da.
2. Hazkundeak eta heltzeak Athletic Clubeko jokalari gizonezkoen lesioetan eragina izan zuten (*II.-VI. ikerlanak*) eta beraz, lesioak murrizteko esku-hartzeak diseinatzerakoan kontuan hartu behar dira. Hurrengoak dira tesi honetako ikerlanetan aurkitutako arrisku-faktoreak:
   - 2.1 Hezurraren heltze-egoera erlatiboak (goiztiarra, normala, berantiarra) gizonezkoen U14 taldeko lesioen *burden*ean eragina izan zuen (*II. ikerlana*). Zehazki, jokalari goiztiarrek lesio orokorren, muskularren eta giltzadura/lotailuetako lesioen *burden* handiagoa izan zuten.
   - 2.2 Lesio espezifikoen gertaera (*III. ikerlana)* eta inpaktua (*IV.* ikerlana) heltze-egoeraren arabera (*pre*-, *circa*-, *post*-PHV edo heldua) aldatu ziren. Hazkunde-lesioek inpaktu handiagoa izan zuten *circa*-PHVn. Muskulu eta giltzadura/lotailuetako lesioak, berriz, *post*-PHVn, eta bereziki, jokalari helduetan. Hazkunde-lesioak *pre*-, *circa*- eta *post*-PHVn gertatu ziren; hala ere, lesio distalek (adibidez, Severren gaixotasunak) eragin handiagoa izan zuen *pre*-PHVn, eta lesio proximalek (adibidez, espondilolisiak), ordea, *post*-PHVn.
   - 2.3 Heltze-*timing*ari dagokionez (*IV. ikerlana*), *pre*-PHVn, hazkunde-lesioa eta belauneko giltzadura/lotailu lesioen *burden*a txikiagoa izan zen heltze berantiarra zuten jokalarietan heltze normala zuten jokalariekin konparatuta. Heltze berantiarra izan zuten helduetan *burden* orokorra eta

giltzadura/lotailuetako lesioen *burden*a handiagoa izan zen heltze goiztiarra izan zutenekin konparatuta.

2.4 Oro har, hazkunde-abiadura bizkorragoa zuten jokalariek hazkunde-lesioak izateko arrisku handiago zuten *pre*-, *circa*- eta *post*-PHVn (*V. ikerlana*).

2.5 PHV bizkorra (≥10.84 cm/urte) zuten jokalariek hazkunde-lesioen *burden* handiagoa izan zuten *circa*-PHVn (*VI. ikerlana*).

3. Jokalariak *pre*-, *circa*- eta *post*-PHV gisa sailkatzeko metodo onena esperientzia duen aztertzaile batek hazkuntza-kurba indibidualen ebaluazio bisuala egitea da. Beraz, altuera longitudinalki jasotzea eta hazkuntza-kurbak interpretatzen ikastea ezinbestekoa da. *Maturity offset* ekuazioek jokalari gehienak gaizki sailkatzen dituzte. Iragarritako helduaroko altueraren ehunekoa, aldiz, aukera aproposa izan daiteke altueraren jarraipen longitudinala ez dagoenean (*VII. ikerlana*).

8. MAIN CONCLUSIONS

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The current thesis research has gained greater understanding into men's and women's teams' injury epidemiology, men's growth- and maturation-related injury risk factors and maturity estimation methods in Athletic Club football academy. As such, main conclusions of this thesis were the following:

1. Injury patterns differ according to age-group category and genre. Knee joint/ligament injuries (in women's teams) and growth-related injuries (in U15 and younger) showed the largest injury burden values. Thus, studying risk factors related to these injuries seems vital (*Paper I*).
2. Growth and maturation affected injury risk of Athletic Club male academy football players (*Papers II-IV*). Therefore, monitoring growth- and maturity-related risk factors seems important when designing and implementing targeted injury prevention programmes. Risk-factors detected in this thesis were the following:
   - 2.1 Skeletal relative maturity status (early, on-time, late) affected injury burden in U14 male football players (*Paper II*). Specifically, early maturers showed a higher overall, muscle and joint/ligament injury burden.
   - 2.2 The occurrence (*Paper III*) and impact (*Paper IV*))of specific injuries varied according to maturity status (pre-, circa-, post-PHV or adult). Growth-related injuries had a higher impact in circa-PHV, while muscle and joint/ligament injuries were more burdensome in post-PHV and specially, adult players. Growth-related injuries occurred in all pre-, circa- and post-PHV periods; however, distal injuries (e.g., Sever's disease) have a higher impact in pre-PHV, while proximal injuries (e.g., spondylolysis) peak in post-PHV.
   - 2.3 Concerning to maturity timing (*Paper IV*), in pre-PHV period, growth-related and knee joint/ligament injuries had lower burden in late maturers than on-time maturers. Adult late maturers had greater burden of overall and joint/ligament injuries than early maturers.

2.4 All in all, players with more rapid growth-rates were at higher risk for growth-related injuries in all pre-, circa- and post-PHV periods (*Paper V*).

2.5 Players with a fast PHV (≥10.84 cm/year) had a higher growth-related injury burden in circa-PHV (*Paper VI*).

3 Visual assessment of the individual growth curves by an experienced assessor seems the best method to estimate to classify players as pre-, circa- or post-PHV, highlighting the importance of longitudinal height records and education on interpretating growth-curves. Maturity offset prediction equations misclassifies most players, while PAH% provides a reasonably valid alternative (*Paper VII*).

9. BIBLIOGRAFIA

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3 ARGITARATUTAKO LANAK

10. ARGITARATUTAKO LANAK

II. *Ikerlana:* Monasterio X., Bidaurrazaga-Letona I., Larruskain J Lekue J.A., Diaz-Beitia G., Santisteban J., Martin-Garetxana I., Gil S.M. *Scandinavian Journal of Medicine & Science in Sports*. 2022;32(9): 1400-1409.

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III. *Ikerlana:* Monasterio X., Gil S.M., Bidaurrazaga-Letona I., Lekue J.A., Santisteban J., Diaz-Beitia G., Martin-Garetxana I., Bikandi E., Larruskain J. Injuries according to the percentage of adult height in an elite soccer academy. *Journal of Science and Medicine in Sport*. 2021;24(3):218–223.

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Relative skeletal maturity status affects injury burden in U14 elite academy football players

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Maturation progresses at different times and at different rates between individuals. Thus, differences in maturity status exist among players in the same chronological age-based category, especially in U14 players. The purpose of this prospective study was to describe injury burden according to the relative skeletal maturity status in U14 elite academy football players. From 2011 to 2020, injuries and individual exposure (training and match) were prospectively recorded in 183 male U14 players. Skeletal age (SA) was assessed using the Tanner-Whitehouse 2 method. Relative skeletal maturity status [SA minus chronological age (CA)] was classified as follows: early (SA–CA > 0.5), on-time (SA–CA ± 0.5), and late (SA–CA < −0.5). Overall and specific injury burden (days lost/1000 h) and rate ratios for comparisons between groups were calculated. Overall injury burden was 2.8 times higher (3.6 times in training) in early maturers compared with late maturers. Growth-related injuries were the most burdensome injuries in all three groups, but significant differences were not found between groups. Muscle injuries were 4 times more burdensome in early maturers compared with on-time and late maturers. Besides, joint/ligament injuries were 7 and 12 times less burdensome in late maturers than in on-time and late maturers, respectively. Significant differences between groups in overall and specific injury burden were not found in matches. Our results showed different injury patterns in U14 early, on-time, and late maturers. Hence, monitoring maturity seems crucial to detect potential injuries that cause the greatest disruption, and facilitate design of targeted injury prevention programs.

KEYWORDS
adolescence, burden, epidemiology, football, growth and development, injury, maturation, youth

1 | INTRODUCTION

Professional football clubs invest many resources in their youth academies to develop young football players, with the aim of providing new players to the First team. Remaining free of injury is a key factor for progressing,[1] not only that, injuries lead to increased susceptibility for future injuries and long-term health risks in adulthood.[2] Thus, preventing injuries is a priority in football.

Injury incidence (injury frequency) and burden (the product of injury frequency and severity) peaks since early- (Under U12–U14) and mid-adolescence (Under U15–17),[3] when marked somatic growth and significant musculoskeletal and physiological development occur. U14 age group generally coincides with the peak height velocity (PHV) in males, which is the period of maximal growth during adolescence.[4] However, due to individual variance in pubertal timing, not all boys will experience the growth spurt at the same age.[4] Consequently, inter-individual differences in maturity status can be found among players of the same age-based category, especially in U14s.[5,6] The large variations in maturity status within chronological age groups have been proposed as factors that may influence injury risk in young footballers. On the one hand, it is assumed that early maturers, whose maturation occurs in advance of the mean and are likely to be bigger, heavier, and stronger,[4] may be at higher risk due to greater engagement and involvement in competitive play. Besides, inappropriate training load in groups of players with mixed maturity and developmental status is another related worry.[7] However, available data on growth, maturation, and injury risk in football provide conflicting evidence due to methodological differences and limitations.

Skeletal maturation is considered the single best maturity indicator, as the start (skeleton of cartilage) and endpoints (skeleton of mature bone) are known and can be followed throughout the maturation process with precise and reliable estimates.[4] Nevertheless, to date, most of the studies have used non-invasive methods with limited accuracy and only 3 studies have considered the effect of skeletal maturity on injuries in elite youth football players.[8–10] Available research assessing skeletal age suggests that early maturers, who have advanced skeletal age compared to their chronological age (relative maturity status), have a higher injury incidence compared with on-time and late maturers.[8–10] Regarding specific injury risk, early maturers seem to be more prone to muscle and tendon injuries, while on-time and late maturers have higher incidence for growth-related injuries.[8,9]

Available research which measured skeletal age also has inherent limitations. Firstly, they measured injury incidence, which does not account for injury severity. Identifying injuries with the highest injury burden is vital to detect potential injuries that cause the greatest disruption, and facilitate design of targeted injury prevention programs.[11] Secondly, they did not account for individual exposure data. Recent research suggests that advanced maturity status in U11, U13, and U14 groups is associated with higher grades in coaches' evaluations of match performance.[12] This may translate to more playing opportunities, and therefore, research which includes individual training and match exposure is needed to allow for direct comparisons and more nuanced interpretation.[13] This study aimed to build on these limitations by using 9-season injury, exposure (training and match), and skeletal maturation data to describe overall and specific injury burden in U14 early, on-time, and late maturing elite academy football players.

2 | MATERIALS AND METHODS

2.1 | Study design and study population

A prospective observational study of 183 male U14 players of an elite Spanish football academy was carried out between the 2011–2012 and 2019–2020 playing seasons. The male professional team plays in the Spanish LaLiga, and the development of academy players is key to the club's success because only players developed in the academy or born in the Basque Country can play in this club. Players were single sports athletes, trained 4 times per week, and played a game every weekend. This study was approved by the Ethics Committee of the University of the Basque Country (UPV/EHU). Written informed consent to use regularly collected data for research purposes was obtained from the players guardians.

2.2 | Recording of injuries and exposure

Players' training/match exposure in minutes (daily) and injuries were recorded. The club's medical staff diagnosed, treated, and recorded all time-loss injuries following the consensus on definitions and data collection procedures outlined by the International Federation of Association Football (FIFA).[14] Injuries were recorded when a player was unable to participate in a future training session or match due to a physical complaint. A player was considered injured until the medical staff cleared the player for full participation.

Growth-related injuries were not explicitly considered by the 2006 consensus statement on injury definitions.[14] Thus, we included an additional category for "growth-related injuries," defined as unique injuries not seen in adults but common in skeletally immature athletes (e.g.,

TABLE 1 Number of players, chronological age, skeletal age, and average exposure (hours per season) according to relative skeletal maturity status

	Early	On-time	Late	All
Number of players	74 (40.6%)	80 (44%)	28 (15.4%)	182
Height	169.79 ± 6.45	162.57 ± 6.42	158.92 ± 6.58	164.62 ± 7.68
Weight	55.84 ± 7.1	47.68 ± 6.45	43.36 ± 6.05	50.29 ± 8.18
Predicted adult height	181.2 ± 5.57	179.95 ± 4.92	181.46 ± 5.81	180.69 ± 5.33
Percentage of predicted adult height	93.72 ± 2.82	90.33 ± 1.98	87.64 ± 2.80	91.30 ± 3.30
Chronological age	13.5 ± 0.5	13.5 ± 0.4	13.7 ± 0.4	13.5 ± 0.5
Skeletal age	14.8 ± 0.8	13.7 ± 0.6	12.6 ± 0.9	14 ± 1
Average total exposure	204.7 ± 64.8	201.3 ± 59.4	226.5 ± 45	206.6 ± 59.9
Average training exposure	175.7 ± 53.9	175.3 ± 50	196.2 ± 36.3	178.7 ± 50
Average match exposure	29.4 ± 12.9	26.7 ± 11.4	30.3 ± 10.6	27.9 ± 12.4

growth plate fractures, apophysitis, apophyseal avulsion fractures, and greenstick fractures).[15] Injuries were classified into three groups based previous research[3,5,16,17] and practitioner experience: (1) growth-related injuries (Sever's disease, Osgood Schlatter disease, apophyseal injuries [osteochondrosis or avulsion] of the anterior inferior iliac spine, ischial tuberosity, or anterior superior iliac spine and spondylolysis), (2) muscle injuries (quadriceps, hamstring, and adductor), and (3) joint/ligament injuries (knee and ankle). The same doctor recorded injuries since the start of the study, thereby reducing the chance of bias, differences in injury interpretation, and changes in observation methods between doctors.

2.3 | Anthropometric measurements

Standing height (±0.1 cm; Añó Sayol, Barcelona, Spain) and weight (±0.1 kg; (Seca) were measured by doctors before afternoon trainings. The same two doctors measured players during the entire study period, thereby reducing chance of bias.

2.4 | Skeletal maturity status

Skeletal maturation was assessed at the beginning of the season, using X-ray images of the athlete's left hand and wrist complex. Skeletal age was determined using the Tanner–Whitehouse radius-ulna-short bone protocol (TW2 RUS) using sample data of the Basque Country.[18] This allowed us to make better comparisons with reference to sample data as our academy only admits players born or developed in the Basque Country. TW2 RUS has been shown to be the method of choice for those using the Tanner–Whitehouse protocol with youth football players.[19]

The images were interpreted by two experienced doctors who were based at the academy for over 20 years and were in place throughout the 9-season period of the present study. Doctors were trained in the use of this method and have a decade experience carrying out skeletal age assessments using TW2 RUS. To test the reproducibility of the assessments of the bone age, the investigators re-evaluated randomly selected hand–wrist radiographs from 10 subjects in 2021. The coefficients of intra-observer and inter-observer reliability were 0.99 (0.98–1) and 0.95 (0.84–0.99) with an error of 0.10 and 0.25 years, respectively.

Players were assigned into three categories according to their relative skeletal maturity status: early, on-time, or late. On-time maturers refer to players whose SA is within 0.5 years of the CA, early maturers refer to players whose SA is older than CA by more than 0.5 years and late maturers refer to players whose SA is younger than CA by more than 0.5 years. Mature players (SA > 18 years) with hand and wrist fully ossified were not found.

Adult height was estimated using bone age rates according to TW2-RUS method,[18] and percentage of predicted adult height was calculated using players standing height.

2.5 | Data analysis

Differences in exposure time were compared using Kruskal–Wallis test. Injury burden was calculated to account for both frequency (incidence) and severity (mean absence) of injuries[11] and was presented as the number of days lost/ 1000 player hours.[13] Injury burden of early versus on-time versus late maturers were compared by calculating rate ratios (RRs). Rate ratios of 1.2, 1.9, and 3.0 can be taken as small, medium, and large, respectively.[20] Zero-inflated negative binomial models were fitted to account for the excess of zeros and overdispersion in the data[21] using the glmmTMB package in R (version 3.6.2).

Confidence intervals were calculated at the 95% confidence level for rates and RRs using a parametric bootstrap procedure. *p*-values were adjusted for multiple comparison with the Benjamini and Hochberg method using R function *p*.adjust on the package stats. The significance level was set at <0.05.

3 | RESULTS

A total number of 277 injuries (157 during training and 120 in matches) were recorded which caused 7301 days lost (4405 in training and 2896 in matches). Descriptive data are shown in Table 1. Significant differences between groups were not found for average total, training and match exposure.

Overall injury burden was 2.8 times higher in early maturers compared with late maturers (Table 2). This difference was more pronounced during training sessions, as injury burden was 3.6 times higher in early maturers compared to late maturers (Table 3). Significant differences between groups were not found in the matches (Table 4).

Growth-related injuries were the most burdensome injuries in all maturity status groups. Despite not finding significant differences among maturity groups, Sever's disease and AIIS apophyseal injuries were more burdensome in late maturers while ASIS apophyseal injuries and spondylolysis were more burdensome in early maturers (Tables 2, 3 and 4).

Muscle injuries in early maturers were 4 times more burdensome compared with on-time and late maturers (Table 2). Differences in injury burden were more pronounced during trainings [RR for early versus on-time: 7.30 (1.78–89.98)] (Table 3). This trend remained similar for hamstring injuries, in which early maturers had 6 times higher (12 times in trainings) burden than on-time maturers (Tables 2 and 3). Significant differences between maturity groups were not found in matches (Table 4).

Joint/ligament injuries in late maturers were 7 and 12 times less burdensome than in on-time and early maturers, respectively (Table 2). In training sessions, significant differences were only found in early versus late maturers; with early maturers showing 6 times higher burden (Table 3). Concerning specific injuries, significant differences for ankle join/ligament injuries were also found, being injuries in early maturers 16 times more burdensome than in late maturers (Table 2).

4 | DISCUSSION

This study aimed to describe and compare overall and specific injury burden in early, on-time, and late maturing U14 academy football players. Injuries of early maturers were more burdensome than those of late developers. Concerning specific injuries, muscle injuries were more burdensome in early versus on-time/late maturers while joint/ligament injuries were more burdensome in early/on-time versus late maturers.

In line with previous data in elite football academies, our research showed a clear underrepresentation of U14 late maturers (15%). It must be highlighted that the less conservative band of ±0.5 years applied in our study and in previous research[12,22–24] identified a greater proportion of early maturers than those studies using a more conservative ±1 band.[22,25] Significant differences between early, on-time, and late maturers were not found for total, training and match exposure. This is in accordance with previous research which only found longer pitch time in U9 and U10 early maturers.[26] Nevertheless, recent studies suggested that advanced maturity status in U14s is associated with higher grades in match-running metrics[6] and coaches' evaluations of match performance[12]; which might lead the coaches to rely more on early maturers and thus, to higher match exposure. However, apart from coaches' perceptions, other factors such as availability might also have an impact in player's average exposure. Although we did not study player's availability, our results showed 2.8 times higher injury burden (3.6 times in trainings) in early versus late maturers, and as a consequence, early maturers might have been less available due to longer periods of absence caused by injuries.[11]

The higher injury burden (product of incidence and severity) found in early maturers is in line with results in previous research which found a higher incidence in this group.[8–10,27] Concerning the severity of injuries, contrary to our results, Le Gall et al.[8] found longer average layoff time per injury and longer periods of absence in U14 on-time and late maturers. Nonetheless, comparisons with previous studies must be made cautiously as they applied different methods for skeletal age estimation, used different cutoff values for classifying players and were carried out in different populations. Most importantly, they did not account for individual exposure data.

There are multiple reasons that might explain the higher overall injury burden in early maturers compared with U14 on-time and late maturers. In line with our results, previous research has already shown that players who are closer to their biological maturity have more burdensome injuries[17,24,28] and early maturers might be more mature than their on-time and late peers. Furthermore, covering greater distances at higher speeds,[6,29] a more

TABLE 2 Number of days lost/1000h (95% CI) according to relative skeletal maturity status in U14 football players, and rate ratios (95% CI) for comparisons between groups

	Number of days lost/1000h			Rate-Ratios		
	Early	On-time	Late	Early versus On-time	Early versus Late	On-time versus Late
Overall burden	392.1 (253.7–559.4) [L]	265.2 (172.8–377.4)	140 (60.4–256) [E]	1.48 (0.88–2.57)	**2.80 (1.32–6.81)***	1.89 (0.89–4.62)
Growth-related injuries	205.5 (104.1–327.6)	184.2 (106.6–280.8)	100 (35.3–190.9)	1.12 (0.51–2.31)	2.06 (0.81–6.32)	1.84 (0.76–5.71)
Sever's disease	2.2 (0.2–5.2)	5.8 (0.6–13.5)	9.1 (0.9–20.2)	0.37 (0.03–4.45)	0.24 (0.02–2.68)	0.64 (0.05–6.89)
Osgood-Schlatter's disease	6.4 (0.6–15.4)	12.5 (3.1–26.5)		0.52 (0.04–3.24)		
Ischial tuberosities injuries	11.5 (0.1–30.5)	17.6 (5–36.3)	18.9 (0.1–51)	0.66 (0.01–3.02)	0.61 (0.01–9.16·10^7)	0.93 (0.21–1.25·10^8)
AIIS injuries	19.9 (1.9–47.6)	49.7 (19.6–83.7)	64.1 (13.2–132.8)	0.40 (0.03–1.40)	0.31 (0.03–1.80)	0.78 (0.25–4.14)
ASIS injuries	63.5 (0.1–252.5)					
Spondylolysis	67.6 (14.1–144.5)	73.3 (9.6–168.7)		0.92 (0.16–12.06)		
Muscle injuries	76.2 (3–144.5) [O,L]	17.7 (5.3–35) [E]	18.8 (2.9–44.9) [E]	**4.30 (1.34–16.48)***	**4.06 (1.23–31.02)***	0.94 (0.21–6.62)
Hamstring	35 (7.4–73.5) [O]	5.6 (0.7–14.1) [E]	7.1 (0.1–22.4)	**6.23 (1.07–53.03)***	4.95 (0.78–2.71·10^8)	0.79 (0.10–5.49·10^7)
Quadriceps	35.9 (3.1–89.4)	4.5 (0.1–14)	3.4 (0.1–16.7)	7.99 (0.68–1.67·10^9)	10.59 (0.74–4.20·10^9)	1.32 (0.01–2.77·10^8)
Joint/Ligament injuries	35.5 (12.6–62.9) [L]	19.11 (6.6–35.3) [L]	2.84 (0.2–7.5) [E,O]	1.86 (0.59–6.06)	**12.51 (3.35–175.09)****	**6.73 (1.69–93)***
Knee	0.4 (0.11–1.5)	8.2 (0.6–19.6)	0.9 (0.1–3.9)	0.05 (0.01–830)	0.43 (0.01–1.58·10^9)	9.55 (0.66–3.14·10^{14})
Ankle	31.3 (10.3–58.4) [L]	8.9 (1.2–20.1)	1.98 (0.1–5.7) [E]	3.52 (0.87–25.14)	**15.76 (3.37–1.85·10^8)****	4.47 (0.52–6.17·10^7)

Note: Significant differences (*$p < 0.05$, **$p < 0.01$) between maturity status groups: [E](early), [O](on-time), or [L](late).

Abbreviations: AIIS, anterior inferior iliac spine; ASIS: anterior inferior iliac spine.

TABLE 3 Number of days lost/1000 h (95% CI) in trainings according to relative skeletal maturity status in U14 football players, and rate ratios (95% CI) for comparisons between groups

	Number of days lost/1000 h			Rate-Ratios		
	Early	On-time	Late	Early versus On-time	Early versus Late	On-time versus Late
Overall burden	292.4 (170.6–434)^{L}	188.9 (101–315)	81.6 (23.9–174.3)^{E}	1.55 (0.75–3.28)	**3.58 (1.42–12.75)***	2.31 (0.88–8.92)
Growth-related injuries	165 (77.7–283)	127.5 (53.3–227)	59.5 (7.2–153.7)	1.29 (0.52–3.76)	2.77 (0.85–23.21)	2.14 (0.63–18.25)
Sever's disease	2.54 (0.15–6.07)	4.6 (0.1–13.6)	10.2 (1–22.6)	0.56 (0.03–6.28·10^{9})	0.25 (0.02–2.60)	0.45 (0.01–6.43)
Osgood-Schlatter's disease	6.4 (0.3–14.7)	7.8 (1.4–16.2)		0.83 (0.07–4.98)		
Ischial apophyseal injuries	9.9 (0.1–24.3)	10.4 (0.1–28.9)		0.95 (0.01–4.73*10^{8})		
AIIS apophyseal injuries	10 (0.1–33.6)	25.3 (0.1–58.5)	49 (0.1–159.6)	0.40 (0.01–3.21)	0.20 (0.01–8.65·10^{7})	0.52 (0.07–2.49·10^{8})
ASIS apophyseal injuries	38.3 (0.1–117.2)					
Spondylolysis	64.9 (9.9–145.5)	56.8 (0.1–160)		1.14 (0.09–1.29·10^{9})		
Muscle injuries	79 (26.3–150.3)^{O,L}	10.8 (0.9–28.1)^{E}	19 (2.6–47)^{E}	**7.30 (1.78–89.98)***	**4.16 (1.04–29.77)***	0.57 (0.04–5.62)
Hamstring	37.2 (6.7–88.9)^{O}	0.3 (0.1–1.5)^{E}	7.9 (0.1–23.6)	**12.17 (1.24–6.15·10^{10})***	4.73 (0.70–1.44·10^{9})	0.04 (0.01–1.41·10^{7})
Quadriceps	37.2 (5.2–80.9)	4.9 (0.1–17.1)	3.8 (0.1–18.9)	7.60 (0.94–1.01·10^{10})	9.71 (0.96–2.69·10^{9})	1.28 (0.01–1.99·10^{8})
Joint/Ligament injuries	19.1 (3.9–40)^{L}	17.4 (3.3–36.7)	3.3 (0.2–8.3)^{E}	1.09 (0.22–6.45)	**5.84 (1.11–116.49)***	5.34 (0.89–77.94)
Knee	0.4 (0.1–1.9)	9.4 (0.2–24.9)	1 (0.1–4.5)	0.05 (0.01–1.87)	0.43 (0.01–7.74·10^{8})	9.40 (0.26–2.57·10^{10})
Ankle	13.9 (1.1–35)	7.1 (0.1–20.1)	2.3 (0.1–6.6)	1.97 (0.2–6.20·10^{9})	6.13 (0.60–1.57·10^{8})	3.12 (0.01–8.92·10^{7})

Note: Significant differences (*$p < 0.05$) between maturity status groups: ^{E}(early), ^{O}(on-time), or ^{L}(late).

Abbreviations: AIIS, anterior inferior iliac spine; ASIS, anterior inferior iliac spine.

TABLE 4 Number of days lost/1000h (95% CI) in matches according to relative skeletal maturity status in U14 football players, and rate ratios (95% CI) for comparisons between groups

	Number of days lost/1000h			Rate-Ratios		
	Early	On-time	Late	Early versus On-time	Early versus Late	On-time versus Late
Overall burden	773.7 (417.8–1192)	450.5 (232.1–723)	736.8 (213.9–1491.1)	1.72 (0.77–3.66)	1.05 (0.43–3.85)	0.61 (0.24–2.33)
Growth-related injuries	496 (207.8–886.8)	265 (110.3–453.1)	463.4 (0.1–1304.6)	1.87 (0.66–5.47)	1.07 (0.26–5.60·10^{8})	0.57 (0.14–2.96·10^{8})
Sever's disease	5.4 (0.1–14.5)	4.3 (0.1–14.9)		1.23 (0.01–8.84·10^{37})		
Osgood-Schlatter's disease	44.6 (0.1–167.3)	3.9 (0.1–18.3)		11.39 (0.01–1.31·10^{12})		
Ischial apophyseal injuries	104.5 (10.6–238.4)	20 (0.1–50)	64.7 (0.1–228.5)	5.23 (0.41–2.37·10^{8})	1.62 (0.09–8.77·10^{8})	0.31 (0.26–1.85·10^{8})
AIIS apophyseal injuries	46.9 (5.6–103.6)	122.2 (45.3–212.9)	320.3 (0.1–703.4)	0.38 (0.05–1.25)	0.15 (0.02–1.28·10^{8})	0.38 (0.11–3.61·10^{8})
ASIS apophyseal injuries	196.3 (0.1–603.9)					
Spondylolysis	119.1 (0.1–341.1)					
Muscle injuries	19.7 (0.5–51.6)	39.5 (9.2–83.9)	52.3 (2.3–143.9)	0.44 (0.01–1.17·10^{9})	0.25 (0.01–9.64·10^{7})	0.56 (0.01–1.17·10^{8})
Hamstring	10.3 (0.1–32.4)	23.1 (0.1–63.1)	41.2 (0.1–114.5)	0.44 (0.01–1.17·10^{9})	0.25 (0.01–9.64·10^{7})	0.56 (0.01–2.38·10^{8})
Quadriceps		1 (0.1–4)				
Joint/Ligament injuries	35.2 (0.1–99.5)	92.2 (8–213.4)	48.3 (4.6–118.8)	0.38 (0.01–4.22)	0.73 (0.01–8.46)	1.91 (0.17–27.30)
Knee						
Ankle	35.2 (0.1–89.4)	84.2 (5.5–212.5)	48.3 (2.4–115.5)	0.42 (0.01–6.22)	0.73 (0.01–12.14)	1.74 (0.12–38.08)

Abbreviations: AIIS: anterior inferior iliac spine; ASIS: anterior inferior iliac spine.

aggressive way of playing football and assuming more leadership roles[30] might lead to more burdensome injuries in early maturers. Besides, different injury patterns in early, on-time, and late maturers might also have contributed to differences in total injury burden.

Growth-related injuries were the most burdensome injuries in all maturity status groups, which is in line with previous research which found that growth-related injuries were the most common time-loss injuries in U14 players.[3] Significant differences between early, on-time, and late maturers were not found for absolute growth-related injury burden. However, different specific growth-related injury burdens were found in early, on-time, and late maturers, which might be explained by the distal to proximal sequence of the physeal endochondral ossification from cartilage to complete bony fusion.[31] Our results showed that distal growth-related injuries (e.g., Sever's disease) were more burdensome in U14 late maturers while injuries in the hip/trunk (ASIS apophyseal injuries and spondylolysis) peaked in early maturers. Nevertheless, we cannot forget that ossification centers in the same bone can follow different ossification patterns. For instance, the appearance and closure of the AIIS ossification center occur earlier than other centers in the pelvis (e.g., AIIS and ischial tuberosity)[32] and may explain why AIIS apophyseal injuries peaked in late maturers despite being a proximal segment injury.

On the contrary, the burden of muscle injuries was higher in early maturers compared with U14 on-time and late maturers and there are multiple factors which might have contributed to it. Firstly, in players with advanced skeletal maturity, which are more likely to have ossification centers closed in different regions of the body, muscle might be the structural point of for injuries.[17] Besides, early maturers, who are physically superior to their on-time and late peers, might develop a more physical way of playing football[33] that may predispose them to further muscle injuries. Moreover, recent evidence has suggested that in U14 category early maturers were quicker, made more accelerations and cover greater distances at high speed.[29] Taking into account that high-intensity running has been associated with hamstring injuries,[34] the more physical way of playing of early maturers might have contributed to the higher burden of hamstring injuries observed in the results.

Besides, the burden of joint/ligament injuries was lower in late maturers compared to on-time and late mature. Furthermore, 16 times lower burden for ankle join/ligament injuries was found in late versus early maturers. U14 late maturers might be pre- or circa-PHV, periods at which join/ligament injury burden has been shown to be lower.[17] Moreover, ankle sprains in players with less delayed maturation and decreased bone density might lead to ankle epiphyseal injuries[35]; which were classified as growth-related injuries in our study. Regarding late maturers way of playing, it is possible that smaller and lighter late maturers avoid contact and risk-taking situations that could lead them to acute join/ligament injuries.[36]

4.1 | Methodological considerations

The present study provides a robust injury recording methodology by having medical staff from the same club diagnose, treat, and record injuries, avoiding potentially unreliable data that might come from medical staffs at different clubs.[37] Besides, some of the weaknesses identified for earlier research on growth, maturation, and injuries have been addressed; using gold-standard skeletal age instead of less accurate non-invasive methods, accounting for individual exposure, recording specific injury data and calculating injury burden to detect injuries that cause the greatest disruption.

Yet, some important methodological limitations must be acknowledged. Concerning the skeletal age assessment, TW2-RUS method overlooks the time lag between onset and completion of union in the criterion for the final stage of the distal radial epiphysis. Nevertheless, U14 players are rarely at this final stage (3% of our players), and this limitation might not have impacted our results. Furthermore, the less conservative ±0.5-year band for classifying players according to their relative skeletal maturity status differs with previous research studying skeletal maturity status and injury risk.[8–10] However, this band has already been applied in other studies for SA–CA[23] and relative somatic maturation.[12,22,24] Criterion that is too conservative (SA–CA ± 1.0 years) may have failed to differentiate between on-time maturers that are markedly different in terms of maturity status, increasing the likelihood for type two errors. However, it should be noted that the less conservative criterion for determining maturity status (SA–CA ± 0.5 years) also increases the likelihood of the researcher making a type one error (i.e., detecting a bias when no such bias exists). The ±0.5 year range used for the current study is well outside the range of the error of bone age assessment (~0.18 years) so it might be relevant for the sample in this study. Besides, the skeletal age determination was based on the maturity of the hand and wrist, which does not necessarily reflect the maturation of other bones, tissues, and organ systems. Not only that, the wrist X-rays were only available in preseason. As maturation progresses at different rates (tempo),[4] players' maturity status might change during the season. Besides, only U14 players were included in the study, and future research should consider studying other age groups. Finally, total match exposure was smaller than exposure in training, and it might have contributed to not finding significant differences between groups in matches.

5 | PERSPECTIVE

Our results showed higher overall injury burden in U14 early maturing academy football players and different injury patterns in early, on-time, and late maturers. Hence, monitoring maturity status seems crucial to detect players at higher risk of being disrupted by injuries and potential injuries that cause the greatest disruption. This would facilitate design of targeted injury prevention programs to reduce the impact of burdensome injuries which might negatively affect individual development and long-term performance.[38]

Growth and maturation are non-modifiable risk factors, and there is little that can be done to influence these processes. However, educating key stakeholders (players, coaches, directors, parents) about the effect of maturation seems vital. Firstly, coaches should be aware that the tendency to rely more on early maturers in U14 category[12] can lead them to higher exposure, more leadership roles and higher injury burden. In this context, load management strategies such as modifying training sessions (e.g., selecting players as "floaters" during possession drills) or utilizing maturity-categorized strategies (bio-banding)[7,30,33] would enable better management of the frequency and volume of exposure. Besides, prescribing activities to facilitate development (e.g., working on technical proficiency of movement, core strength or mobility) while preventing unwanted mechanical stress would enable better management of the frequency and volume of exposure to stressful activities.[7] Considering injuries that cause the greatest disruption according to each players maturation profile would be crucial when prescribing those activities. Nonetheless, injuries are multifactorial, and we cannot forget other risk factors (training load, neuromuscular and biomechanical factors, physiotherapy, coaching, communication, psychosocial factors, etc.) when designing injury prevention programs.[39]

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DATA AVAILABILITY STATEMENT

The data that support the findings of this study are available from the corresponding author, [XM], upon reasonable request.

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Original research

Injuries according to the percentage of adult height in an elite soccer academy

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A B S T R A C T

Objectives: This study aimed to ascertain if there is a defined pattern of injury related to the percentage of attained adult height and classify injuries according to maturity status bands.
Design: Prospective cohort study.
Methods: From 1998–2019, 63 elite male soccer players of at least the U12 category from a Spanish LaLiga club's academy were followed until reaching their final height. Medical staff recorded injuries following the FIFA consensus and measured height 2–3 times per season. The percentage of adult height at which each injury occurred was calculated using the player's closest height to the injury and his final adult height. Injuries were classified in maturity bands, pre-peak-height-velocity (PHV) <88%, circa-PHV 88%–96%, and post-PHV >96%.
Results: There were 509 injuries among the 63 players. Growth-related injuries occurred at a median (IQR) of 91.2% (86.7%–95.2%) of adult height, predominating in pre-PHV and PHV bands. Muscle injuries predominantly occurred at post-PHV, with 77.78% of those conditions occurring within that time frame and at 98.7% (96%–99.5%) of adult height. Likewise, knee and ankle joint/ligament injuries predominated at post-PHV (87% and 65% of total cases, respectively) occurring at 99.0% (97.9%–99.9%) and 98.4% (89.2%–99.4%) of adult height, respectively.
Conclusions: Injuries follow a specific pattern according to the percentage of adult height.

Practical applications

- The occurrence of specific injuries varies according to percentage of adult height; growth-related injuries are more frequent in earlier percentages while muscle and joint/ligament injuries are more common later.
- Growth-related injuries follow the growth and maturation distal to proximal pattern.
- Due to inter-individual differences in maturity status in players at the same age category, estimating each player's percentage of adult height seems to facilitate design of targeted injury prevention programs.

1. Introduction

According to a recent systematic review,[1] high level football players have a high probability of sustaining time-loss injuries. Indeed, pooled estimates for total incidence per 1000 h were 7.9 for youth players aged under 17 to under 21 years and 3.7 for under 9 to under 16 years. Injuries result in increased susceptibility for future injuries and long-term health risks in adulthood,[2] have a high economic cost and negatively impact team performance.[3] Therefore, preventing injuries is a priority for soccer academies.

During adolescent growth and maturation, players experience anthropometrical,[4–6] neuromuscular,[7,8] and structural changes,[9] which might increase injury risk. Injury risk is higher near peak-height-velocity (PHV) period[10–13] and quick growth rates in stature and leg length seem to be highly associated to growth-related injuries.[5,6] However, a recent review demonstrated that there is still considerable uncertainty regarding the aetiological role of maturation and growth in adolescent musculoskeletal conditions.[2] Therefore, investigations to provide clearer insight on this subject are warranted.

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Assessment of maturity is challenging due to the invasiveness of the different methods. As a solution, the percentage of adult height has been proposed as maturity indicator.[14,15] As measurement of adult height requires a longitudinal follow-up until reaching full stature, various methods and formulas have been proposed in order to predict adult height.[15,16] Despite the percentage of predicted adult height at time of observation has gained popularity as a maturity indicator,[14,15] yet no study has investigated the association of the maturity status measured through the percentage of adult height with specific injury risk in soccer. Therefore, we propose a longitudinal registry of injuries and height-growth from childhood to adulthood to ascertain if there is a defined pattern of injury related to the percentage of attained adult height and classify injuries according to maturity status bands. Using the percentage of adult height to identify bands or periods of increased specific injury risk seems a reasonable step towards successfully managing injury risk.

2. Methods

Athletic Club male players were prospectively followed from 1998–2019. Males professional team plays in the Spanish LaLiga, and development of academy players is key to the club's success because only players developed in the academy or born in the Basque Country can play on this club. The academy has different categories according to age (U11-U19). Attempting to represent all pre-, circa- and post-PHV periods, we included only players who were ≤U12 when they entered the academy and continued until they attained adult height. Players were single sports athletes, trained 3 or 4 times per week depending on the age category (3 times for U11-U12 and 4 for the other) and played a game every weekend. This study was approved by the Ethics Committee of the University of the Basque Country (CEISH/340/2015).

Height of each player was measured by the club's doctors every 3–4 months using a stadiometer. Measurements were carried out before afternoon trainings. A player was considered to have attained final height once growth-velocity was <1 cm/year during one year.[9] Curve-fitting techniques were used to plot growth-velocities.[17] Injuries were classified according to maturity bands: pre-PHV <88%, circa-PHV 88%–96%, and post-PHV >96%[18]

The club's medical staff diagnosed, treated, and recorded all time-loss injuries. From the 2007–2008 season, this was done following the consensus on definitions and data collection procedures outlined by the International Federation of Association Football (FIFA).[19] Two of the four current doctors have been working in the club since 1998, thereby reducing the chance of bias, differences in injury interpretation, and changes in observation methods between doctors. Injuries were recorded when a player was unable to participate in a future training session or match due to a physical complaint. A player was considered injured until the medical staff cleared the player for full participation. Only injuries that caused >7 days of absence (moderate and severe) were considered to avoid confounding effects of minimal and mild injuries. Once the player had attained his final height, only injuries within the next year were considered to avoid overrepresentation of injuries at 100% of adult height. In the same line, injuries were only recorded > U11 to avoid overrepresentation in pre-PHV period.

Injuries were classified into 5 groups: growth-related injuries (Sever's disease, Osgood Schlatter disease, osteochondrosis' of the anterior inferior iliac spine, ischial tuberosity, anterior superior iliac spine, and spondylolysis), muscle injuries (quadriceps, hamstring, adductor, gluteal, psoas), groin pain, knee joint/ligament injuries (anterior cruciate ligament rupture, medial collateral ligament, and meniscal injuries), and ankle joint/ligament injuries (lateral collateral ligament and syndesmotic sprain). We defined growth-related injuries as unique injuries not seen in adults but common in skeletally immature athletes, including growth plate fractures, apophysitis, apophyseal avulsion fractures, and greenstick fractures.[20]

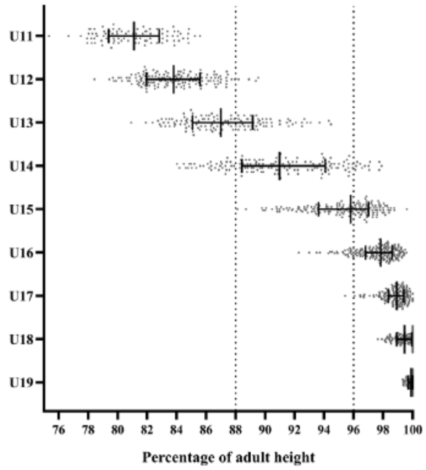

Fig. 1. Percentage of adult height at each age category (median and interquartile range). Each dot represents a player's height measurement. Dotted lines represent the limits for the maturity bands.

All statistical analysis was conducted using R version 3.2.3. Median ± interquartile range (IQR) percentage of adult height at which each injury occurred was calculated using the player's closest height to the injury and final adult height. Number of injuries and frequency (percentage of number of total injuries) of each injury in each band was calculated.

3. Results

There were 63 players that met the inclusion criteria. They were on average (± SD) 10.7 ± 0.4 years old at the time of first height measurement (80.8 ± 2.1% of adult height). Subjects attained adult stature at 18.3 ± 1.1 years of age with a stature of 179.2 ± 4.78. Percentages of adult height at each age category are shown in Fig. 1, with medians of: 81.1% (79.4%–82.8%) at U11, 83.8% (82%–85.6%) at U12, 87% (85.1%–89.1%) at U13, 91% (88.4%–94.1%) at U14, 95.8% (93.6%–97%) at U15, 97.8% (96.8%–98.6%) at U16, 98.9% (98.3%–99.4%) at U17, 99.4% (98.9%–99.9%) at U18, and 99.9% (99.7%–100%) at U19.

There were 509 injuries: 74, 102 and 333 injuries occurred in pre-, circa- and post-PHV periods, respectively. Concerning type of injuries, 111 growth-related, 168 muscle, 5 cases of groin pain, 67 ankle join/ligament and 40 knee joint/ligament injuries were recorded. Growth-related injuries were the most frequent injuries in pre- and circa-PHV accounting for 45% and 46% of all the injuries, respectively. Muscle (18% and 24% in pre- and circa-PHV), knee joint/ligament (4% and 2%) and ankle joint/ligament injuries (16% and 11%) were not as common during pre- and circa-PHV periods. However, their proportion increased in post-PHV period. Muscle, knee and ankle join/ligament injuries accounted for 39%, 11% and 13% of all injuries in post-PHV while growth-related injuries only represented 9% of the injuries.

Fig. 2 shows the percentage of adult height at which growth-related injuries occurred and the number and frequency of injuries

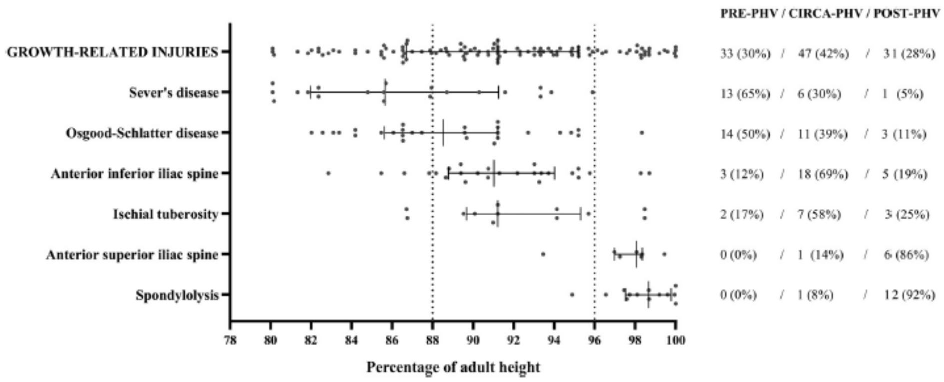

Fig. 2. Percentage of adult height for growth-related injuries (each dot is an injury, and lines represent median and interquartile range) and number and frequency (%) of each injury in each maturity band (pre-PHV / circa-PHV / post-PHV). Dotted lines represent the limits for the maturity bands.

in each maturity band. Growth-related-injuries occurred at a median (IQR) of 91.2% (86.7%–95.2%) of adult height, predominating in the pre-PHV and PHV bands. Individually, Sever's disease occurred at a median of 85.6% (82.0%–91.3%), more frequently at pre-PHV, while Osgood-Schlatter disease occurred at 88.5% (85.6%–91.2%; 50% pre-PHV and 39% circa-PHV). Avulsions of the anterior inferior iliac spine injuries happened at 91.0% (88.8%–94.0%; 69% circa-PHV), ischial tuberosities at 91.2% (89.7%–95.3%; 58% circa-PHV), and anterior superior iliac spine avulsions at 98.1% (97.0%–98.3%; 86% post-PHV). On the other hand, spondylolysis occurred at 98.7% (97.5%–99.5%) of adult height, predominating in the post-PHV band (92%).

Fig. 3 shows that 77.8% of all muscle injuries occurred post-PHV at 98.7% (96.0%–99.5%) of adult height. Quadriceps injuries occurred at 98.2% (94.5%–99.5%; 72% post-PHV) and hamstring injuries at 98.5% (96.2%–99.4%; 78% post-PHV). Adductor injuries occurred at 98.7% (93.5%–99.9%) while gluteal and psoas injuries occurred only post-PHV, at 99.0% (98.0%–99.4%) and 99.4% (98.6%–99.9%), respectively. Fig. 3 also shows that groin pain was uncommon.

Moreover, knee and ankle joint/ligament injuries are shown in Fig. 3. Both injury types were more prevalent post-PHV (88% and 65% of total such injuries, respectively) occurring at 99.0% (97.9%–99.9%) and 98.4% (89.2%–99.4%) of adult height, respectively (Fig. 3). Among knee joint/ligament injuries, medial collateral ligament injuries occurred at 98.9% (89.2%–99.8%; 67% post-PHV), meniscal injuries at 99.0% (98.1%–99.8%; 100% post-PHV), and anterior cruciate ligament ruptures at 98.7% (97.3%–100%; 100% post-PHV). Ankle lateral collateral ligament injuries occurred at 98.5% (89.5%–99.2%). They had a broader distribution than other joint/ligament injuries, being more frequent in the post-PHV band (67%) but also relatively frequent in pre-PHV (21%) and circa-PHV (12%) bands. However, syndesmotic injuries occurred later at 98.8% (98.4%–99.5%) and were only recorded post-PHV.

4. Discussion

To provide deeper insight into the relationship between maturation and injuries in soccer, we longitudinally analysed height and injuries of players from childhood until attainment of adult stature in the setting of a professional soccer academy. All in all, we observed that specific injuries were sustained at different percentages of adult heights. Precisely, growth injuries followed a chronological distal to proximal pattern, and muscle and joint injuries occurred in more frequently in mature players.

Among the 1071 players that were followed, 63 players met the inclusion criteria of the study. For a detailed description of the sample and possible drop-out reason's readers are directed to Gil et al.[21] and Bidaurrazaga-Letona et al.[22] Players attained adult height at 18.3 ± 1.1 years of age, which is in line with Fels study[9] and longitudinal data in Basque population.[23]

A clear overrepresentation of injuries (total number) in the post-PHV period was found. These results seem contradictory with previous research which found increased injury-risk in circa-PHV period.[10–13] Nonetheless, due to methodological differences for PHV's estimation and definition of maturity status periods, our results are not comparable with previous research that aimed to investigate injury incidence and burden in pre-, circa- and post-PHV.[10–13] As growth-velocities during post-PHV period are slower than in circa-PHV, it might take longer to advance from 96% to 100% of adult height. This fact supposes a longer exposure during post-PHV percentages, which might have resulted in an overrepresentation of injuries. Our results are in line with previous data in a Spanish elite football academy that found a higher occurrence of injuries in post-PHV ages[24]; which might be a consequence of higher intensities and exposure times during these ages. The same argument would have supposed injuries' overrepresentation during pre-PHV period but being injury risk, significantly smaller during pre-PHV,[10–13] it did not occur. To the best of our knowledge, this is the first study measuring injuries along the growth of elite soccer players to specifically describe the type, occurrence, and maturity status according to real attained adult stature.

According to a recent systematic review,[25] the risk of sustaining musculoskeletal overuse injuries is higher for athletes that specialize in a single sport. High training volume in soccer academies associated with early specialisation may impact development of growth-related injuries. Muscles, tendons, and apophyses adapt slowly to changes in extremity length, mass, and moments of inertia caused by PHV.[4–6] Consequently, this slow adaptation might increase the stress on muscle-tendon junctions and apophyses, making the prevalence of total growth-related injuries higher than that of other injuries near circa-PHV percentages. However, our results showed that growth-related injuries also occur during pre-PHV and post-PHV periods. Growth and maturation start from more distal segments of the lower limbs and then, it continues with the development of the lower extremities and the trunk. Therefore,

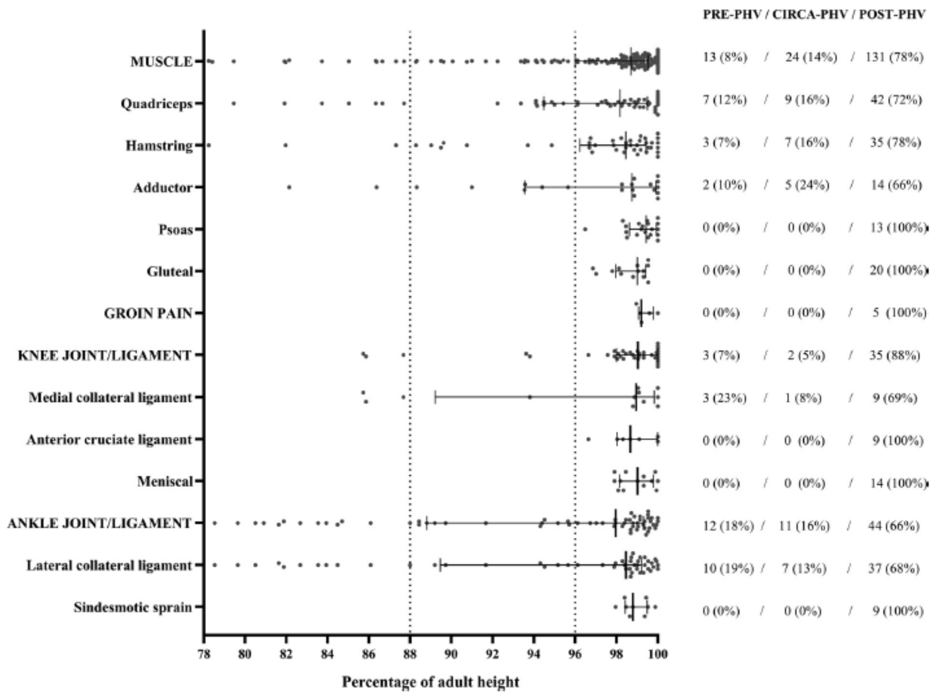

Fig. 3. Percentage of adult height for muscle injuries, groin pain and joint/ligament injuries (each dot is an injury, and lines represent median and interquartile range) and number and frequency (%) of each injury in each maturity band (pre-PHV / circa-PHV / post-PHV). Dotted lines represent the limits for the maturity bands.

even if the higher growth-rates for stature are attained at circa-PHV, PHV for the lower extremities occurs in pre-PHV and PHV for the trunk occurs in post-PHV.[9] Previous research has shown that incidence of growth-related injuries increased when athletes experience larger changes in stature and leg length over a season.[6] These results are in accordance with our findings. The IQR for growth-related injuries (86.7%–95.2%) coincided with the transition from pre- to circa-PHV; the moment when PHV for leg length occurs.[9] The growth and maturation pattern[9] seems to also have affected specific growth-related injuries' occurrence, as our results showed that injuries occurred from distal to proximal segments (Fig. 2). Previous research in academy footballers showed that Sever's disease occurred more often in early-stage players (U10–U14, peaking at U11), while Osgood-Schlatter's disease was more frequent at later stages (U12–U16, peaking at U13–U14).[26] Our results also showed an earlier occurrence of Sever's disease based on adult height percentage. Moreover, the percentage of adult height at which Osgood–Schlatter's disease occurred, 88.5% was similar to the percentage of adult height of categories at which this disease peaked. However, the median for Sever's disease (85.6%) was higher than the median height for U11 (81.1%), the previously reported category for disease peak. A possible explanation for this could be that we only recorded injuries since U11 category, while the prior study showed that calcaneal apophysitis was frequent following U10.[26]

The incidence of muscle injuries progressively increases with age,[24,27] which is in line with the higher occurrence of muscle injuries at higher percentages of adult height. The longitudinal growth of the bones, during the adolescent growth spurt, occurs prior of the increase in muscle mass.[9] This implies an increase in the moments of inertia of the athletes' segments, which might not be met with sufficient muscle capacity. Greater moments of inertia increase the demand for muscles possibly leading them to higher risk of injury.[8] In the same line, tendons increase their cross-sectional area slower than the adjoining muscles during adolescence.[9] Imbalance between muscle and tendon growth might lead to increased overuse injuries' risk such as groin pain.[8]

Similarly, joint/ligament injuries predominated post-PHV and near adult height. It seems as though changes in the moments of inertia lead to changes in frontal plane's neuromuscular control.[7,8] Post-PHV footballers until age 18 have been shown to have a greater ipsilateral trunk flexion in single countermovement-jump.[7] Interestingly, hip abductors, which have a vital role in frontal plane's neuromuscular control, have been linked to ankle injuries[28] and knee injuries.[29] Thus, it is possible that neuromuscular changes caused by PHV have an effect on joint/ligament injuries' occurrence.

Our research showed that injury targets vary according to percentage of adult height. Therefore, estimating each player's percentage of adult height seems to be an appropriate way to design specific injury prevention programs, especially, in categories with large inter-individual differences in maturity status (U13–U15). Although the most accurate method for predicting adult height is based on skeletal age (Greulich-Pyle, Tanner-Whitehouse, Fels methods),[9] the Khamis-Roche method is a feasible non-invasive alternative to that method [15,16]. On the one hand, players at earlier percentages should try to prevent growth-related injuries, with load management being vital for minimizing the risk for those injuries.[20] On the other hand, more mature players should have injury-prevention programs focused on motor skill development[7,8] to reduce risk for muscle and joint-ligament injuries. Additionally, it is important for injury prevention programs to account for the strength and conditioning peculiarities of each maturity stage.[18] Nonetheless, we cannot forget that injuries are multifactorial, and risk factors apart from those related to maturity must be taken into account when designing injury prevention programs. Owing to the fact that maturation progresses at different times (maturity timing) and at different rates (maturity tempo) between individuals, significant maturity status differences within boys of the same age (same category) can be found.[9] In the same way, players change at different maturity status stages throughout the season.

There are inherent limitations in the present study. Firstly, only players who entered the club when they were ≤ U12 and continued until they reached their adult height were included in the study. Considering that injuries have a negative impact on player progression in the academy,[1] players who sustained severe or recurrent injuries may have been missed. Secondly, another limitation would be that closest height measurement (with a maximum difference of 2 months) was used to calculate the percentage at which injuries occurred. Moreover, injury management strategies have changed over the last decades and load management strategies during the adolescent growth spurt have been put in place in the last years. Unfortunately, information about preventive strategies was not registered, and the effect of different strategies on injury risk could not be taken into account. Not only that, we did not account for training content, individual exposure or other risk-factors such as risk of re-injury. As an additional limitation, this study focused on a specific group of male players from a single soccer academy and may not be generalizable to other populations. Nonetheless, previous studies only recorded injuries for 2–3 years,[10–13] while the present study used a long longitudinal methodology covering late childhood through adolescence until adulthood. By using a precise measure based on final obtained adult height, our study has improved on others by using other non-invasive methods such as the maturity offset and percentage of estimated adult height. These metrics, despite being used to establish the relationship between maturity status and injury risk,[10–13] have been questioned.[15,16,30] Previous studies[10–13] also failed to record the epidemiology of each specific injury. To better understand the relationship between maturity status and specific injuries, future studies should examine this association using reliable methods such as curve-fitting techniques.[9]

5. Conclusion

Injuries follow a specific pattern according to the percentage of adult height. Growth-related injuries occur more often at earlier height percentages (i.e., pre-PHV and circa-PHV phases), while muscular injuries and knee and ankle articular injuries are more common at more advanced height percentages (i.e., post-PHV phase). Owing to the fact that inter-individual differences in percentage of adult height between players in the same age category exist, determining each players' percentage of predicted adult height might help design of targeted injury prevention programs. Especially in categories where inter-individual differences in maturity status are more evident (U13–U15).

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THE BURDEN OF INJURIES ACCORDING TO MATURITY STATUS AND TIMING: A TWO-DECADE STUDY WITH 110 GROWTH CURVES IN AN ELITE FOOTBALL ACADEMY

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Running head: Injuries and maturation in academy football players

ABSTRACT

Injuries have a negative impact on the development of football players. Maturation is a potential risk factor for football injuries but available data on this topic provide limited evidence due to methodological shortcomings. The aim of this study was to describe the injury burden of male academy football players according to growth curve-derived maturity status and timing. Injury and growth data were collected from 2000 to 2020. Longitudinal height records for 110 individual players were fitted with the Super-Imposition by Translation and Rotation model to estimate age at peak height velocity (PHV). Players were clustered according to maturity status (pre-, circa-, post-PHV, or adults) and timing (early, on-time, late maturers). Overall and specific injury burdens (days lost/player-season) and rate ratios for comparisons between groups were calculated. Overall injury burden increased with advanced maturity status; pre-PHV players had 3.2-, 3.7-, and 5.5-times lower burden compared with circa-PHV, post-PHV, and adult players, respectively. Growth-related injuries were more burdensome circa-PHV, while muscle and joint/ligament injuries had a higher impact post-PHV and in adults. Further, in the pre-PHV period, late maturers showed lower burden of overall, growth-related, anterior inferior iliac spine osteochondrosis, and knee joint/ligament injuries compared with on-time maturers. In adult players, however, injuries were less burdensome for early maturers than on-time and late maturers. In addition, joint/ligament injuries of adult late maturers were 4.5-times more burdensome than those of early maturers. Therefore, monitoring maturity seems crucial to define each player's maturation profile and facilitate design of targeted injury prevention programs.

HIGHLIGHTS

- Injury burden is significantly lower in football players at pre-peak height velocity (PHV). Growth-related injuries are most burdensome circa-PHV, while muscle and joint/ligament injuries are more burdensome post-PHV and especially in adults.
- Before PHV, growth-related and knee joint/ligament injuries have lower burden in players who mature late than those who mature on-time. Adult late maturers have greater burden of overall and joint/ligament injuries than early maturers.
- Football academies should regularly assess the maturity status and timing of young football players, as the impact of injuries varies with maturation status and timing.
- Management of the maturity-related injury risk profile, in combination with other relevant factors (training load, neuromuscular and biomechanical factors, physiotherapy,

coaching, communication, psychosocial factors...), might help improve the success of player development programs and protect the health of young football players.

KEYWORDS:

epidemiology, football, growth and development, maturation, injury and prevention, injury burden

INTRODUCTION

Elite academy football players have a high probability of sustaining injuries due to contact situations, changes of direction, high training volume (specialization), among other factors. [1,2] Injuries result in significant loss in training and match time and negatively affecting players' progression.[3] Further, they lead to increased susceptibility for future injuries and long-term health risks in adulthood.[4] Therefore, identifying risk factors is important for injury prevention and rehabilitation.

Maturation, which can be defined in terms of status, timing, and tempo,[5] is a potential risk factor for football injuries. Maturity status refers to the stage of maturation at the time of observation [pre-, circa-, or post-peak height velocity (PHV)], while timing refers to the age at which PHV occurs (early, on-time, late).[5] The circa- and post-PHV maturity stages are linked to increased injury incidence (frequency of injuries) and burden (the product of injury incidence and mean severity).[6,7] However, findings of injury risk according to maturity timing are conflicting.[8] While some studies found increased injury incidence in early maturers,[9,10] others observed higher risk in later maturers.[11] Interestingly, a recent study found contrasting results depending on the age category.[12] Only one study analysed both maturity status and timing with regard to injury burden; there were no significant differences between timing groups in maturity status periods.[6]

The conflicting results in available data on maturation and injuries might be due to methodological differences and limitations.[8] Non-invasive methods such as the Khamis-Roche equation (based on prediction of adult height using player's height and weight and parents' height) and Mirwald equation (based on anthropometric measurements) are widely used to estimate age at PHV due to their simplicity and accessibility, but they demonstrate reduced accuracy in comparison with the gold-standard growth-fitting techniques.[13,14] In addition, most studies were either cross-sectional or short longitudinal studies with a relatively small number of players and lasting only 1–4 years.[6,7,9–12] Hence, they did not follow individuals over a sufficient period of time (from pre-puberty to adulthood) to model individual growth curves and estimate age at PHV.[14] Further, although injury risk varies between young and adult elite football players,[2] available research does not differentiate post-PHV and adult players. Most of these studies measured injury incidence, which does not account for injury severity,[15] and none has recorded specific injury data. Thus, identifying the most burdensome injuries according to each player's maturation status and timing may be vital to identify targets for injury prevention strategies and focus on injuries that most impact player availability.

This study aimed to build on these limitations by using two decades of longitudinal anthropometric measurements to model the growth curves of elite academy football players, which were used to estimate age at PHV and investigate how maturity status (pre-, circa-, post-PHV, and adult) and timing (early, on-time, late) are associated with overall and specific injury burden.

MATERIALS AND METHODS

Study design

Data were registered for twenty consecutive seasons (2000–2020) in an elite football academy whose professional male team plays in the Spanish LaLiga. The academy has different categories according to age (U11–U19) and two reserve teams (Spanish 3rd and 4th Division). Players were single-sport athletes, played a game every weekend, and trained three times per week for U11–U12 or four times per week for U13–U19 and Reserves.

Among the 1071 followed players, 110 players met the inclusion criteria of fitting the Super-Imposition by Translation and Rotation (SITAR) model,[16] having at least ten height measurements before and after their estimated age at PHV.[17]

The study was approved by the Ethics Committee of the University XXXXXXXX. Written informed consent to use regularly collected data for research purposes was obtained from the athlete's guardians.

Height measurement and PHV estimation

Stature was measured by doctors before afternoon trainings at least twice annually. Similar equipment was used over the study and two of the four doctors worked in the academy during the entire study period, thereby reducing chance of bias.

The SITAR model[16,17] was used to summarize individual longitudinal changes in height throughout childhood and adolescence and estimate individual's age at PHV. For each player, we defined pre-PHV (>6 months before PHV), circa-PHV (±6 months from PHV), post-PHV (>6 months after PHV, until growth velocity was <1 cm/year), and adult periods (until players left the academy).[5] Maturity timing was defined by comparing players' age at PHV to that of the Basque male population (average 13.3 years),[18] categorised as early (<0.5 year compared to average), on-time (±0.5 year), or late (>0.5 year) maturers.[6]

Injury definitions, exposure, and recording procedures

Injury was defined as a physical complaint that prevented players from participating in future training sessions or matches. A player was considered injured until medical staff cleared the player for full participation. Missed days between the injury and returning to full training or match play were recorded. From the 2007–2008 season onward, injuries were described following the International Federation of Association Football (FIFA) Consensus.[19] In the previous seasons, the criteria for recording the diagnosis and absence days of time-loss injuries was the same as in the consensus.

Injuries were classified into five groups based on previous studies and practitioner experience: 1) growth-related injuries (Sever's disease, Osgood Schlatter disease, spondylolysis, and osteochondrosis of the anterior inferior iliac spine, ischial tuberosity, or anterior superior iliac spine), 2) muscle injuries (quadriceps, hamstring, and adductor), 3) groin pain, 4) knee joint/ligament injuries (anterior cruciate ligament, medial collateral ligament, and meniscal), and 5) ankle joint/ligament injuries (lateral collateral ligament, and syndesmotic sprain). Growth-related injuries were not explicitly considered by the consensus statement;[19] thus, they were defined as "unique injuries not seen in adults but common in skeletally immature athletes", including growth plate fractures, apophysitis, apophyseal avulsion fractures, and greenstick fractures.[20]

Player-season was defined as the unit of exposure.[21] Each player's exposure days – number of days lost in each period were counted and divided by 365.25 to convert them to player/seasons.

Data analysis

Injury burdens were calculated, accounting for both frequency (incidence) and severity (mean absence) of injuries, which likely is more comprehensive of the consequences of injuries.[15] Injury burdens are presented as number of days lost per player-season and were compared by calculating rate ratios (pre- *vs.* circa- *vs.* post-PHV *vs.* adult, and early *vs.* on-time *vs.* late in each status period). Rate ratios of 1.2, 1.9, and 3.0 can be taken as small, medium, and large, respectively.[22] Zero-inflated negative binomial models were fitted to account for the excess of zeros and the overdispersion in the data[23] using the glmmTMB package in R (version 3.6.2). To account for the longitudinal data structure, a random effect for the individual player was included. Confidence intervals were calculated at the 95% confidence level for rates and rate ratios using a parametric bootstrap procedure. P-values were adjusted for multiple comparison with the Benjamini & Hochberg method using the R function p.adjust of the package stats. The significance level was set at <0.05.

RESULTS

In total, we analysed 901 player-seasons for 110 players, of whom 19 were early, 63 on-time, and 28 late maturers (Figure 1). Numbers of player-seasons in each maturity status period were

264 in pre-PHV, 110 in circa-PHV, 385 in post-PHV, and 142 in adults. Numbers of player-seasons by maturity timing were 169 for early, 472 for on-time, and 260 for late maturers. A total of 1311 injuries resulting in 33060 days of absence were recorded. Age (mean ± SD) at initial and final observation were 10.7 ± 0.6 and 17.9 ± 2.8 years, respectively, and each player had 20.2 ± 5.5 height measurements. PHV occurred at 13.4 ± 0.8 years, with a growth rate of 9.9 ± 1.8 cm/year.

Injuries and maturity status

Overall injury burden increased with advanced maturity status, and significant differences were detected in all comparisons except post- *vs.* circa-PHV and adult *vs.* post-PHV (Table 1). Injury burden was 3.2-, 3.7-, and 5.5-times lower in pre-PHV (15 days lost/player-season) compared with circa-, post-PHV, and adults (50, 58, and 86 days lost/player-season), respectively. Injury patterns depended on maturity status, and growth-related injury burden peaked circa-PHV. Regarding specific growth-related injuries, Sever's disease was most burdensome pre-PHV, while Osgood Schlatter's disease and ischial/anterior inferior iliac spine osteochondrosis were most burdensome circa-PHV. Conversely, anterior superior iliac spine osteochondrosis only occurred post-PHV, and spondylolysis was most burdensome post-PHV. Injury burden of muscle injuries was significantly increased post-PHV and in adults compared to pre- and circa-PHV. This pattern was similar in specific hamstring, quadriceps, and adductor muscle injuries. Groin pain was only recorded in post-PHV and adult players, with higher rates in adults. The burden of joint/ligament injuries increased with advanced maturity status, and significant differences were found between all groups except for pre- *vs.* circa-PHV. Knee medial collateral ligament and anterior cruciate ligament peaked in adults, while the impact of meniscal injuries and ankle joint/ligament injuries was highest post-PHV and in adults.

Injuries, maturity status, and timing

The number of days lost/player-season for each injury according to maturity status and timing are presented in Table 2, and rate ratios for comparisons between timing groups in each maturity status period are shown in Table 3. In the pre-PHV period, compared with on-time maturers, the burden of injuries in late maturers was 1.9-times lower for all injuries (on-time vs. late: 20 vs. 10 days lost/player-season), 2.5-times lower for growth-related injuries (11 vs. 4 days lost/player-season), 5-times lower for anterior inferior iliac spine osteochondrosis (4 vs. 0.8 days lost/player-season), and 6.7-times lower for knee joint/ligament injuries (0.8 vs. 0.1 days lost/player-season).

Conversely, in adult players, injuries of early maturers (43.4 days lost/player-season) were 2.6- and 2.9-times less burdensome compared to on-time and late maturers (112 and 125 days lost/player-season), respectively. Moreover, the burden of joint/ligament injuries in adult late maturers (97 days lost/player-season) was 4.5-times higher than in adult early maturers (22 days lost/player-season).

DISCUSSION

This is the first study analysing how maturity status in combining with timing affect injury burden of elite academy football players using longitudinal height data and growth curve-fitting techniques. The main findings were increased overall injury burden with advanced maturity status, linked to specific injury burden variation according to maturity status and timing. Growth-related injuries peaked in pre- and circa-PHV players while muscle and joint/ligament injuries peaked in adults (particularly in late maturers) (Graphical abstract).

Injury burden increases with maturation

In line with previous data,[6,7] our results showed an increase in overall injury burden with advanced maturity status. Anthropometrical,[24–26] neuromuscular,[27–29] and physiological (e.g., mechanical properties)[30] changes induced by PHV may contribute to increased injury risk from circa-PHV onwards. Further, adult players' injury burden was significantly greater than players in earlier maturity periods, which is in line with results from the systematic review by Pfirrmann et al. that found significant differences between elite academy youth and adult players.[2] This may be a consequence of increased risk of re-injury and higher training volume and match intensity in chronologically older players.[31] We must highlight that this is the first study to use a clear cut-off (growth-velocity <1 cm/year)[5] to segregate immature post-PHV players and those who progressed towards full maturity (adults). However, comparisons with previous studies[6–8] must be made cautiously as previous studies estimated age at PHV using methods such as the maturity offset and Khamis-Roche equations[8,13,14]. Besides, there is discrepancy in the cut-off values of maturity status periods[6–8].

Injury patterns in different maturation periods

Growth-related injuries had the highest impact circa-PHV. The slow adaptation of muscles, tendons, and apophyses to quick changes in extremity length, mass, and moments of inertia may increase stress on muscle-tendon junctions and apophyses,[5] leading to injury. Interestingly, due to progressive distal to proximal growth and maturation patterns[5,18,32] these injuries also occurred pre- and post-PHV. Distal growth-related injuries peaked in pre- (Sever's disease) and circa-PHV (Osgood-Schlatter's disease), and injuries in more proximal segments occurred post-PHV (spondylolysis).

Nevertheless, muscle injuries had a larger impact in post-PHV and adult players. After bone-plate and apophysis ossification,[5] muscle might be the structural point of failure for neuromuscular,[27–29] and physiological[30] alterations induced by PHV, resulting in increased burden post-PHV. Further, re-injuries and higher demands in older players[31] also may influence muscle injury burden, especially in adults. Tendons also increase their cross-sectional area slower than adjoining muscles during adolescence[5] and imbalance between muscle and tendon growth might lead to increased susceptibility for groin pain, which only occurred since post-PHV.

The burden of joint/ligament injuries also increased with advanced maturation and peaked in post-PHV and adult players. The longitudinal growth of the bones, during the adolescent growth spurt, occurs prior of the increase in muscle mass.[5] This implies an increase in the moments of inertia of the athletes' segments, which might not be met with sufficient muscle capacity.[30] Therefore, "adolescent awkwardness",[30] alterations in force production,[27] reduced neuromuscular control[28,29] and interlimb asymmetry[28] occur near PHV, which may lead to increased lower extremity joint/ligament injury risk.[28] Besides, ankle sprains in immature bodies with decreased bone density[5] may have resulted in epiphyseal injuries pre- and circa-PHV, which were recorded as growth-related injuries.[20] Further, increased risk of re-injury and greater acute volumes of training and matches[31] may partly explain increased injury burden post-PHV.

Pre-PHV growth-related and knee joint/ligament injuries are less burdensome in late than on-time maturers

Pre-PHV players who matured late had lower overall injury burden, and specifically growth-related and knee joint/ligament injuries. This pattern remained circa-PHV but was not significant, which may be a consequence of the small exposure in the short 1-year circa-PHV period. On one hand, teenagers who reach PHV at later ages usually have slower velocity and tempo in PHV.[5] This might cause less stress on apophyses[33] and not so great neuromuscular alterations,[27–29] leading to decreased burden of overall, growth-related, and knee joint/ligament injuries. Further, the tendency of coaching staff to rely less on late-maturers[34] might result in decreased match exposure[35] and thus decreased injury risk.

In line with our results, recent research found increased overall injury risk in immature[10] and U13–U14 early maturers.[12] However, the only research studying overall burden in each maturity status period found no significant differences between timing groups pre-PHV.[6] Concerning specific injury risk, Materne et al. found more hip/pelvis apophyseal injuries in early maturers.[10] However, Van der Sluis et al.[11] described increased overuse injury risk in pre-PHV later maturers, although the study had a small sample of 23 players, compared “later” and “earlier” maturers, and estimated PHV with the Mirwald equation. Also contrary to our results, research in U14 players found a significantly higher incidence of osteochondrosis in normal/late maturers.[9] However, early maturers in this category may have been post-PHV, while on-time and late maturers may have been pre-/circa-PHV. Thus, as osteochondrosis is more frequent in circa-PHV,[32] the study results may have been a consequence of players’ maturity status rather than timing.

Adult joint/ligament injuries are more burdensome in late than early maturers

Anthropometrical, physical, and technical differences might partly explain why late maturers had greater burden of overall and joint/ligament injuries compared with early maturers. Later maturers are usually taller and have longer legs when adults[36] and may be more susceptible to injury due to greater forces impacting through joints.[37] Further, late-maturing players, who may be physically inferior and smaller in chronological-based categories, usually develop more of their technical and tactical skills at young ages. These skills become more apparent in bio-banding formats, at which late maturers are not physically inferior due to maturity equality.[38,39] Late maturers are provided with more opportunities to show technical-tactical skills in bio-banding format, which reflects a similar situation to the adult state with no maturational differences.[39] Therefore, they have more conquered and attack balls, as well as a higher volume of play and efficiency on the ball.[39] It is possible that once late maturers attain adult height and are physically equal to their counterparts, they show their technical skills more and perform more dribbles and pivoting actions, predisposing them to joint/ligament injuries.[28]

Methodological considerations

The principal strength of the current study is its longitudinal design over two decades, which allowed us to model 110 individual growth curves and calculate age at PHV. As opposed to previous research with shorter data periods and non-invasive estimating methods such as maturity offset and Khamis-Roche,[8,13,14] we calculated age at PHV. Most importantly, this is the first study to analyse the burden of specific injuries according to maturity status and timing.

Nevertheless, the present study has limitations. Our findings apply to a single elite football academy, and early and late maturers were underrepresented. Therefore, the number of specific injuries (specially in early and late maturers) was limited. Further, only male players with height data that fit the SITAR model were included in the study. Considering that injuries have a negative impact on academy progression,[3] players who sustained severe injuries may have been missed. Moreover, many factors such as preventive strategies might have changed over the study time period and were not controlled for in analyses. Regarding injury registration, specific injury diagnosis and days of absence were recorded following the same criteria during the whole study, and in line with the definitions in the 2006 FIFA consensus. However, there were no protocols to check intra- and inter-tester reliability for height and injury recording, and it is unclear how this might have influenced maturity classifications or consistency in injury data before and after the consensus. The retrospective design of our study also made it impossible to account for individual exposure in minutes or available training and match days for all seasons. Thus, as suggested by the latest international Olympic Committee consensus statement,[21] exposure was expressed as the number of player-seasons. In addition, higher training and match volume in more mature players[31] might partly explain increased burden found in advanced maturity status periods. Finally, caution must be taken when interpreting these findings, as injuries are complex and other factors contribute to risk beyond those analysed in this study.[40]

Future research is needed to analyse the influence of growth and maturation together with other relevant data (technical, physical, psychosocial factors) to better understand differences in injury burden between groups. In absence of accurate methods to estimate PHV, it is crucial to collect longitudinal height data, and collaboration among many clubs seems necessary to perform sufficiently powered future studies.

Practical application

In conclusion, injury patterns varied according to maturity status and timing, and the main findings are summarized in the graphical abstract. Growth-related injuries peaked in pre- and circa-PHV players while muscle and joint/ligament injuries peaked in adults. Besides, early maturers had more burdensome injuries in pre-PHV while late maturers had more burdensome joint/ligament injuries when adults. Hence, regular monitoring of maturity seems crucial to define each player's maturation profile, detect potential injuries that cause the greatest disruption, and facilitate design of targeted injury prevention programs.

Educating key stakeholders (players, coaches, directors, parents) about the effects of maturation on injury burden is also vital. Load management strategies would be beneficial to reduce growth-related injuries. Such strategies could include not scheduling consecutive training days,[38] modifying sessions of players at higher risk [38] and utilising existing maturity-categorised strategies such as bio-banding in training and competitions.[38,39] Besides, prescribing activities to facilitate development whilst preventing unwanted mechanical stress would enable better management of the frequency and volume of exposure to stressful activities.[38] For example, grouping circa-PHV players together and focusing on technical proficiency of movement for one session each week may innately reduce the repetitive, high-stress mechanical loads associated with rapid decelerations and changes of direction. This seems particularly necessary in earlier maturers, whose growth-related injuries were more burdensome. On the other hand, post-PHV and adult players should prioritise injury-prevention programs focused on hypertrophy and motor skill development to reduce risk of muscle and joint-ligament injuries.[28,29,38] Special attention should be given to adult late maturers, who have been shown to be more time unavailable due to higher joint/ligament injury burden. Nonetheless, injuries are multifactorial, and risk factors apart from those related to maturity (training load, neuromuscular and biomechanical factors, physiotherapy, coaching, communication, psychosocial factors...) must be taken into account when designing injury prevention programs.[40]

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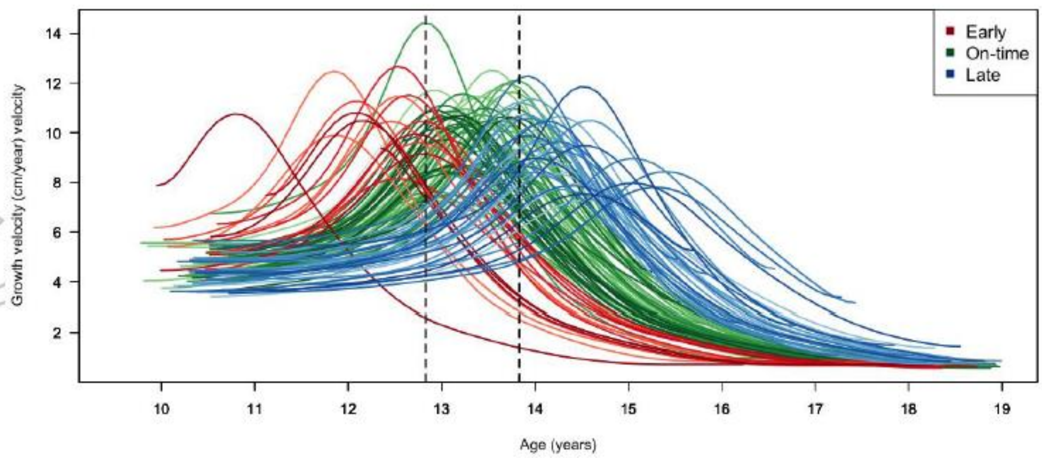

Figure 1. Individual growth curves modelled with SITAR for 110 football players. Vertical dashed lines indicate cut-off values for early (peak-height velocity <12.8 years), on-time (12.8–13.8 years), and late (>13.8 years) maturers.

Graphical abstract: The most burdensome injuries in each maturity status period and corresponding injury burden (number of days lost per player-season), prevalence (percentage of players that suffer the injury in the specific phase), and median absence days per injury. Exclamations indicate timing groups that were significantly more burdensome.

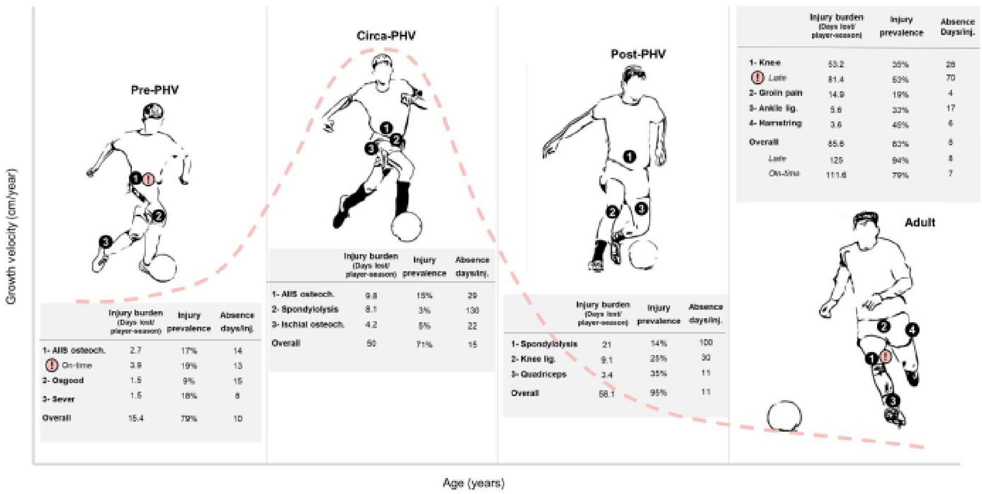

Table 1 – Number of days lost/player-season (95% CI) according to maturity status for each injury, and rate ratios (95% CI) for comparisons between groups.

	Pre-PHV	Circa-PHV	Post-PHV	Adult	Circa vs. Pre	Post vs. Pre	Adult vs. Pre	Post vs. Circa	Adult vs. Circa	Adult vs. Post
Overall burden	15.43 (11.16-20.34)	49.71 (37.04-65.19)	58.12 (45.77-73.39)	85.63 (57.61-121.31)	**3.19 * (2.16-4.64)**	**3.74 * (2.73-5.24)**	**5.50 * (3.65-8.22)**	1.17 (0.85-1.68)	**1.72 * (1.12-2.70)**	1.47 (0.93-2.12)
Growth-related injuries	7.31 (4.71-11.43)	25.56 (16.33-38.42)	15.00 (9.11-23.68)	0.88 (0-6.11)	**3.49 * (1.99-5.94)**	**2.05 * (1.13-3.53)**	**0.12 * (0.01-0.95)**	0.59 (0.32-1.05)	**0.03 * (0.01-0.28)**	**0.06 * (0.01-0.45)**
Sever's disease	1.47 (0.77-2.35)	1.15 (0.33-2.19)	0.15 (0.02-0.33)		0.78 (0.20-2.03)	**0.10 * (0.01-0.29)**		**0.13 * (0.01-0.57)**		
Osgood-Schlatter's disease	1.51 (0.45-2.87)	4.12 (1.50-7.41)	0.18 (0.01-0.58)		2.73 (0.83-10.61)	**0.12 * (0.01-0.61)**		**0.04 * (0.01-0.18)**		
Ischial osteochondrosis	0.61 (0.12-1.43)	4.17 (0.46-9.45)	1.44 (0.33-2.92)		6.81 (0.67-42.01)	2.35 (0.45-12.55)		0.35 (0.07-2.63)		
AIIS osteochondrosis	2.74 (1.16-4.74)	9.85 (3.74-17.96)	2.40 (0.76-4.44)		**3.60 * (1.25-10.06)**	0.88 (0.24-2.50)		**0.24 * (0.07-0.75)**		
ASIS osteochondrosis			1.92 (0.52-3.82)							

Spondylolysis		8.10 (0.17-24.92)	21.40 (7.72-40.60)					2.64 (0.66-133.42)		
Muscle injuries	1.31 (0.64-2.16)	3.55 (1.57-6.19)	10.65 (8.13-12.87)	12.61 (8.06-17.72)	**2.71 * (1.20-6.12)**	**8.12 * (4.61-17.65)**	**9.61 * (5.01-21.42)**	**3.00 * (1.64-6.86)**	**3.55 * (1.74-8.45)**	1.18 (0.78-1.79)
Hamstring	0.32 (0.10-0.69)	1.27 (0.40-2.96)	1.98 (1.11-3.11)	3.61 (1.97-6.03)	**3.96 * (1.04-15.46)**	**6.15 * (2.64-20.94)**	**11.22 * (4.43-38.99)**	1.55 (0.59-5.09)	2.83 (0.97-9.64)	1.82 (0.96-3.60)
Quadriceps	0.57 (0.13-1.27)	1.09 (0.03-3.24)	3.20 (1.70-4.64)	3.43 (1.47-5.37)	1.91 (0.02-13.03)	**5.62 * (2.06-24.83)**	**6.00 * (1.89-28.00)**	2.95 (0.86-105.34)	3.15 (0.83-144.92)	1.07 (0.50-2.14)
Adductor	0.29 (0.05-0.663)	0.72 (0.04-1.75)	0.74 (0.29-1.27)	1.39 (0.47-2.55)	2.51 (0.30-18.31)	2.59 (0.83-15.30)	**4.87 * (1.42-30.67)**	1.03 (0.30-17.47)	1.94 (0.56-32.54)	1.88 (0.67-4.88)
Joint/ligament injuries	1.99 (1.05-2.95)	4.29 (1.66-7.36)	16.48 (10.96-22.37)	57.72 (30.31-88.83)	2.16 (0.80-4.83)	**8.29 * (4.81-16.28)**	**29.04 * (14.79-60.82)**	**3.85 * (2.00-10.41)**	**13.46 * (6.59-36.79)**	**3.50 * (1.86-6.22)**
Knee	0.57 (0.18-1.08)	2.43 (0.45-5.95)	9.10 (4.63-15.37)	53.25 (22.05-98.18)	4.24 (0.72-17.23)	**15.86 * (6.14-47.22)**	**92.78 * (30.61-277.27)**	**3.74 * (1.14-22.60)**	**21.90 * (5.61-123.97)**	**5.85 * (1.91-15.17)**
ACL			3.03 (0.63-6.54)	29.17 (7.59-55.25)						**9.63 * (2.02-54.77)**
LCL	0.21 (0.06-0.43)		0.70 (0.21-1.41)	1.11 (0.29-2.13)		3.28 (0.72-13.60)	**5.17 * (1.16-22.43)**			1.57 (0.37-6.11)
Meniscal			2.61 (0.55-5.66)	2.25 (0.14-5.88)						0.86 (0.05-4.59)
Ankle	0.98 (0.41-1.93)	1.01 (0.23-2.67)	4.01 (2.43-6.25)	5.56 (2.57-10.48)	1.03 (0.20-3.56)	**4.12 * (1.94-9.96)**	**5.81 * (2.14-15.21)**	**5.81 * (2.14-15.21)**	**5.63 * (1.81-28.28)**	1.41 (0.63-2.75)
Lateral sprain	0.84 (0.31-1.77)	0.43 (0.01-1.50)	2.63 (1.47-4.22)	2.66 (0.87-5.33)	0.51 (0.02-2.13)	**3.13 * (1.37-9.19)**	3.16 (0.94-9.43)	**6.13 * (1.81-124.89)**	**6.20 * (1.44-133.07)**	1.01 (0.35-2.44)
Syndesmosis			1.35 (0.33-2.87)	4.23 (0.38-10.44)						3.11 (0.33-15.33)
Groin pain			2.45 (0.16-7.39)	14.92 (1.46-42.82)						0.17 (0.01-1.74)

PHV: peak height velocity; CI: confidence interval; AIIS: anterior inferior iliac spine; ASIS: anterior superior iliac spine; ACL: anterior cruciate ligament; LCL: lateral collateral ligament
* Significant differences (p<0.05) between maturity status groups.

Table 2 – Number of days lost/player-season (95% CI) according to maturity status and timing for each injury, and rate ratios (95% CI) for comparisons between timing groups.

	Pre- PHV (n=107)			Circa-PHV (n=110)			Post-PHV (n=110)			Adult (n=58)		
	Early (n=17)	On-time (n=62)	Late (n=28)	Early (n=19)	On-time (n=63)	Late (n=28)	Early (n=19)	On-time (n=63)	Late (n=28)	Early (n=12)	On-time (n=29)	Late (n=17)
Overall burden	12.02 (4.58-21.64)	**19.72 L (14.30-26.03)**	**10.49 O (6.26-15.55)**	59.04 (25.97-100.2)	59.87 (39.41-84.90)	40.99 (21.56-66.51)	53.62 (30.31-83.71)	77.96 (57.61-100.63)	53.12 (33.65-76.68)	**43.40 O,L (14.29-85.27)**	**111.65 E (55.10-183.87)**	**125.00 E (57.84-213.34)**
Growth-related injuries	8.23 (2.00-17.98)	**11.44 L (6.37-17.84)**	**4.44 O (1.95-7.31)**	44.73 (9.13-104.43)	38.67 (22.52-58.78)	20.14 (5.27-42.87)	12.99 (2.81-28.73)	40.50 (19.43-68.31)	15.26 (4.29-35.31)			
Sever's disease	2.49 (0.27-5.88)	1.56 (0.44-3.16)	0.83 (0.26-1.74)		1.54 (0.01-3.32)	0.65 (0.01-1.80)		0.14 (0.01-0.31)				
Osgood-Schlatter's disease		1.28 (0.11-3.01)	1.17 (0.22-2.51)		4.67 (0.01-8.83)	2.16 (0.01-5.95)		0.31 (0.01-0.78)				
Ischial osteochondrosis			1.55 (0.01-2.61)		2.50 (0.01-6.02)				3.39 (0.01-7.35)			
AIIS osteochondrosis		3.92 L (1.27-7.56)	0.80 O (0.07-2.00)		8.85 (2.66-17.16)	18.81 (1.62-46.86)		2.06 (0.48-4.31)	3.55 (0.30-8.00)			
ASIS osteochondrosis								1.93 (0.05-5.20)				
Spondylolysis					14.01 (2.73-29)			33.87 (0.01-71.85)	5.20 (0.01-19.63)			
Muscle injuries		1.87 (0.96-2.92)	2.01 (0.27-4.64)		3.76 (1.38-6.66)	9.01 (2.73-17.57)	6.97 (3.29-11.32)	9.96 (7.08-13.02)	12.26 (7.74-17.92)	9.42 (3.42-17.32)	16.15 (8.57-24.89)	8.53 (4.67-13.00)
Hamstring		0.67 (0.01-	0.48 (0.01-		1.71 (0.01-	2.41 (0.01-	2.12 (0.61-	2.62 (1.38-	2.15 (0.83-	3.09 (0.84-	6.63 (2.56-	2.00 (0.66-

		1.48)	1.55)		3.39)	5.74)	4.24)	4.08)	3.92)	5.82)	11.81)	3.75)
Quadriceps		0.59 (0.01-1.20)	1.12 (0.01-4.91)			3.03 (0.01-7.01)	1.98 (0.45-4.60)	3.60 (1.96-5.65)	3.39 (0.73-6.80)	4.97 (1.83-9.30)	3.68 (0.80-8.29)	2.38 (0.81-4.56)
Adductor		0.34 (0.01-0.75)	0.28 (0.01-1.19)		0.89 (0.01-2.19)			0.84 (0.29-1.53)	0.91 (0.14-2.01)	0.95 (0.16-2.18)	1.74 (0.15-4.25)	2.12 (0.44-4.46)
Joint/ligament injuries	2.04 (0.26-4.90)	2.24 (1.31-3.32)	1.52 (0.46-2.78)	3.25 (0.60-6.91)	4.28 (1.23-7.83)	5.20 (0.91-10.90)	23.04 (8.91-42.37)	17.42 (10.58-26.01)	13.21 (5.17-24.24)	**21.56 ^{L} (4.47-49.69)**	61.90 (13.34-137.36)	**97.02 ^{E} (31.05-197.77)**
Knee		**0.84 ^{L} (0.01-1.60)**	**0.12 ^{O} (0.01-0.35)**		3.59 (0.01-6.87)	1.19 (0.01-4.23)	12.60 (2.18-27.96)	9.52 (3.56-17.84)	5.77 (0.40-15.15)		58.10 (5.85-156.95)	81.37 (13.41-192.58)
ACL								4.21 (0.43-9.45)				70.84 (8.39-163.40)
LCL		0.34 (0.01-0.81)	0.07 (0.01-0.22)		1.86 (0.01-4.34)			0.53 (0.02-1.34)			1.07 (0.01-2.19)	1.43 (0.01-3.46)
Meniscal								2.30 (0.39-5.20)			3.08 (0.01-18.83)	
Ankle		0.91 (0.40-1.46)	1.16 (0.19-2.36)		0.33 (0.01-1.13)		6.26 (1.76-11.79)	3.76 (1.97-5.99)	6.95 (3.29-12.27)	19.22 (2.13-49.30)	2.69 (0.31-6.55)	12.84 (3.06-30.56)
Lateral sprain		0.76 (0.01-0.81)	0.88 (0.01-2.16)		0.31 (0.01-4.34)		4.62 (1.10-10.25)	2.51 (1.23-3.92)	4.65 (1.55-8.68)		2.14 (0.06-6.19)	10.72 (1.79-25.86)
Syndesmosis								0.66 (0.01-1.61)		17.19 (0.01-55.40)		2.22 (0.01-8.60)
Groin pain								3.75 (0.05-13.16)			27.98 (0.01-102.83)	3.41 (0.01-14.23)

PHV: peak height velocity; CI: confidence interval; AIIS: anterior inferior iliac spine; ASIS: anterior inferior iliac spine;
ACL: anterior cruciate ligament; LCL: lateral collateral ligament
Significant differences (*p<0.05) between maturity timing groups among the same maturity status periods for ^{E}(early), ^{O}(on-time), or ^{L}(late).

Table 3: Rate ratios (95% CI) for comparison of overall and specific injury burden between timing groups in each maturity status period.

	Pre-PHV			Circa-PHV			Post-PHV			Adult		
	On-time vs. Early	Late vs. Early	Late vs. On-time	On-time vs. Early	Late vs. Early	Late vs. On-time	On-time vs. Early	Late vs. Early	Late vs. On-time	On-time vs. Early	Late vs. Early	Late vs. On-time
Overall burden	1.64 (0.85-4.32)	0.87 (0.39-2.49)	**0.53 * (0.31-0.90)**	1.01 (0.51-2.38)	0.69 (0.30-1.76)	0.69 (0.34-1.30)	1.45 (0.83-2.73)	0.99 (0.53-1.94)	0.68 (0.41-1.14)	**2.57 * (1.04-8.31)**	**2.88 * (1.03-9.15)**	1.12 (0.44-2.73)
Growth-related injuries	1.35 (0.54-6.36)	0.54 (0.20-2.33)	**0.40 * (0.16-0.84)**	0.86 (0.31-4.27)	0.45 (0.09-2.86)	0.52 (0.13-1.31)						
Sever's disease	0.63 (0.13-6.49)	0.33 (0.08-3.38)	0.53 (0.12-2.43)			0.42 (0.01-3.00)						
Osgood-Schlatter's disease			0.91 (0.14-13.32)			0.46 (0.01-2.21)						
Ischial osteochondrosis												
AIIS osteochondrosis			**0.20 * (0.02-0.92)**			2.13 (0.18-8.98)			1.73 (0.12-7.48)			
ASIS osteochondrosis												
Spondylolysis									0.15 (0.01-1.01)			
Muscle injuries			1.08 (0.13-3.24)			2.40 (0.64-7.60)	1.43 (0.77-3.21)	1.76 (0.92-4.00)	1.23 (0.74-2.02)	1.71 (0.71-5.36)	0.91 (0.37-2.68)	0.53 (0.25-1.08)
Hamstring			0.72 (0.01-5.24)			1.41 (0.01-7.08)	1.23 (0.46-4.61)	1.01 (0.30-4.23)	0.82 (0.30-1.88)	2.15 (0.66-8.57)	0.65 (0.18-2.57)	0.30 (0.08-0.87)
Quadriceps			1.91 (0.01-17.73)				1.82 (0.63-7.60)	1.71 (0.34-6.89)	0.94 (0.19-2.50)	0.74 (0.15-2.43)	0.48 (0.14-1.49)	0.65 (0.16-3.01)
Adductor			0.83 (0.01-6.61)						1.08 (0.15-4.10)	1.83 (0.14-14.88)	2.23 (0.40-14.83)	1.22 (0.21-15.80)
Joint/ligament injuries	1.10 (0.41-9.17)	0.74 (0.17-6.08)	0.68 (0.19-1.49)	1.32 (0.35-8.33)	1.60 (0.27-9.27)	1.21 (0.21-5.16)	0.76 (0.33-2.01)	0.57 (0.20-1.82)	0.77 (0.30-1.64)	2.87 (0.51-14.96)	**4.50 * (1.14-24.13)**	1.56 (0.42-7.62)
Knee			**0.15 ***			0.33	0.76	0.46	0.61			1.40

			(0.01-0.72)			(0.01-0.87)	(0.23-4.50)	(0.03-3.44)	(0.04-2.37)			(0.22-15.94)
ACL												
LCL			0.21 (0.01-1.69)									1.34 (0.01-8.74)
Meniscal												
Ankle			1.27 (0.19-3.70)				0.60 (0.23-2.24)	1.11 (0.40-4.35)	1.85 (0.74-4.42)	0.14 (0.01-1.38)	0.67 (0.12-7.21)	4.76 (0.94-34.93)
Lateral sprain			1.15 (0.01-4.89)				0.54 (0.18-2.58)	1.01 (0.26-4.68)	1.86 (0.55-4.97)			5.12 (0.78-209.56)
Syndesmosis											0.13 (0.01-61.65)	
Groin pain												0.12 (0.01-5.42)

PHV: peak height velocity; CI: confidence interval; AIIS: anterior inferior iliac spine; ASIS: anterior inferior iliac spine; ACL: anterior cruciate ligament; LCL: lateral collateral ligament
* Significant differences (p<0.05) between timing groups.

11. ARGITARATU GABEKO LANAK

4 ARGITARATU GABEKO LANAK

I. *Ikerlana:* Larruskain J., Lekue J.A., Angulo P., Santisteban J.M., Diaz-Beitia G., Martin-Garetxana I., Gil S.M., Bidaurrazaga-Letona I., Monasterio X. An injury burden heat map of all the men's and women's teams of a professional football club over a decade. *Journal of Science and Medicine in Sport* aldizkarira bidalita. Urria 2022.

V. *Ikerlana:* Monasterio X., Cumming SP, Larruskain J, Johnson DM, Gil SM, Bidaurrazaga-Letona I., Lekue JA., Diaz-Beitia G., Santisteban J., Williams S. The combined effects of growth and maturity status on injury risk in an elite football academy. *Scandinavian Journal of Medicine & Science in Sports* aldizkarira bidalita. Maiatza 2022.

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VII. *Ikerlana:* Monasterio X., Gil SM.1, Bidaurrazaga-Letona I., Cumming SP, Malina RM, Williams S., Lekue JA., Santisteban J., Diaz-Beitia G., Larruskain J. Estimating maturity status in elite youth soccer players: evaluation of methods. *American Journal of Sports Medicine* aldizkarira bidalita. Abuztua 2022.

5 BESTE IKERLANAK

12. BESTE IKERLANAK

12.1 ABSTRACT LIBURUAK

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12.2 KONGRESUETAKO KOMUNIKAZIOAK

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12.3 SARIAK

European Collegue of Sport Science (ECSS) 2021 Young Investigators Award (equal 5th prize in the oral presentation). Monasterio X, Gil SM, Bidaurrazaga-Letona I, Lekue JA, Santisteban J, Diaz-Beitia G, Lee D, Zumeta-Olaskoaga L, Martin-Garetxana I, Bikandi E, Larruskain J. Overall and specic burden of injuries according to maturity status and timing: A two-decade study with 110 growth curves in an elite football academy.

12.4 DIBULGAZIO ZIENTIFIKOA

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Nire tesia 180 segundotan eta Euskaraz. Dokeariguneko 2020 sariak.

#HiloTesis Txapelketa: Espainia mailan finalista eta 3 onenen artean UPV/EHU-n.

- https://twitter.com/Xabi_b94/status/1383355124987228160
- https://twitter.com/Xabi_b94/status/1383343642631278592

“Hazkundea, heltzea eta lesioak Athletic Club-en”. Aurkezpenak:

- Futbol taldeak: Athletic Club, Arsenal FC, Southampton FC, Bristol FC, Aspire Academy.
- University of Bath Research Group
- Gloucestershire University
- Fisioterapia Graduko Ikasleak “Eliteko Kirola eta Fisioterapia” irakasgaian
- Biomedikuntzako Masterra (UPV/EHU)

13. NAZIOARTEKO EGONALDIAREN ZIURTAGIRIA

14. NAZIOARTEKO EGONALDIAREN ZIURTAGIRIA

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To whom it may concern:

My name is Dr. Sean Cumming and I am a professor of Paediatric Exercise science in the Department for Health. I am writing this letter confirming the visit of Xabier Monasterio, a researcher and physiotherapist from the University of the Basque Country and Athletic Bilbao football club, as a visiting researcher at the University of Bath.

Xabier was hosted by myself at the University of Bath from 20/1/22 to 19/4/22. During his visited Xabier worked closely with myself and Dr Sean Williams on the analysis of his data and the creation of two manuscripts which he hopes to submit for publication soon. Xabier also took the opportunity to visit a number of professional soccer academies during his visit to learn about best practice in his field and share his research and insight.

In summary, Xabier visit was a great success for both student and hosts. We extend our thanks to the funding body for support this exchange.

Sincerely,

Sean P Cumming

Dr. Sean Cumming