Accuracy of digital impressions for implant-supported complete-arch prosthesis, using an auxiliary geometry part – an in vitro study

Running title: Digital impression for implant-supported complete-arch prosthesis

Mikel Iturrate[a], Harkaitz Eguiraun[b], Eneko Solaberrieta[c]

[a] Associate Professor, Department of Business Management.

University of the Basque Country UPV/EHU; San Sebastian, Spain.

[b] Associate Professor, Department of Graphic Design and Engineering Projects.

University of the Basque Country UPV/EHU; Bilbao, Spain.

Research Centre for Experimental Marine Biology & Biotechnology

Plentzia Marine Station. University of the Basque Country UPV/EHU; Plentzia, Spain.

[c] Professor, Department of Graphic Design and Engineering Projects,

University of the Basque Country UPV/EHU; Donostia – San Sebastián, Spain.

Corresponding author:

Dr Eneko Solaberrieta

Department of Graphic Design and Engineering Projects

University of the Basque Country UPV/EHU, San Sebastián, Spain

Plaza Europa 1

20.018 Donostia – San Sebastián

Tel: +0034 943 01 8663

Email: eneko.solaberrieta@ehu.eus

ABSTRACT

Objectives: The aim of this study was to evaluate the accuracy of complete-arch digital impressions for fabrication of an implant-supported prosthesis in the edentulous maxilla using an auxiliary geometry part.

Material and Methods: A replica of the upper jaw of an edentulous patient with four scannable impression copings was fabricated in stainless steel. This model was scanned with an industrial non-contact 3D structured blue light 3D scanner and the measurements of three reference distances were established as reference values. Subsequently, the model was scanned in two different scenarios (with or without an auxiliary geometry part put in place and fixed to the model) using three intraoral scanners. Measurements were taken with 3D inspection software and a digital impression of the complete arch was built with mesh-processing software by combining 2 STL files obtained with an intraoral scanner.

Results: All measurements with the auxiliary geometry part gave significantly more accurate results ($p<0.05$). Trueness improved in the three reference distances, reaching values of 8 ±6μm at D12 reference distance, 20 ±11μm at D13 and 35 ±22μm at D14. Precision also improved significantly with the use of the auxiliary geometry part placed on the model ($p<0.05$). The best precision results at reference distances D13 and D14 were obtained with the True Definition scanner.

Conclusions: The proposed methodology significantly improves the accuracy of complete-arch digital impressions in edentulous patients obtained in vitro, regardless of which scanner is used.

Keywords:

Accuracy, digital impression, edentulous, implant-supported framework, intraoral scan, complete arch.

INTRODUCTION

Intraoral scanners were first introduced more than 30 years ago (Duret & Preston, 1991). Since then, continuous steps have been taken towards their development and nowadays, with the improvements implemented by new devices and software (Mangano, Gandolfi, Luongo, & Logozzo, 2017), together with social acceptance of these new technologies, conventional impressions are being replaced by digital ones(J.-F. Güth, Keul, Stimmelmayr, Beuer, & Edelhoff, 2013; J.-F. Güth et al., 2017).

Intraoral scanners offer many advantages: greater comfort, increased speed, reduced storage and transport requirements, and overall reduced cost (Ahrberg, Lauer, Ahrberg, & Weigl, 2016; Gjelvold, Chrcanovic, Korduner, Collin-Bagewitz, & Kisch, 2016; Lee & Gallucci, 2013; Patzelt, Lamprinos, Stampf, & Att, 2014; Yuzbasioglu, Kurt, Turunc, & Bilir, 2014). However, from a clinical point of view, more research is needed on the results achieved from digital impressions obtained directly in the mouth.

There is still a perceived lack of agreement regarding the accuracy and clinical acceptability of digital impressions (Giménez, Özcan, Martínez-Rus, & Pradíes, 2014; Papaspyridakos et al., 2016) and maximum acceptable deviations may vary depending on the patient’s emotional level and the biological reactions of bones or soft tissues (Kan, Rungcharassaeng, Bohsali, Goodacre, & Lang, 1999). However, maximum deviations should not exceed values that would lead to osseointegration problems of the implants.

Recent studies had established varying values when considering the acceptable osseointegration of restorations and the passive fit should be within the range of these values (Carr & Toth, 1995; Christensen, 1966; Dodmon, 1982; Jemt, 1991). The passive fit of an implant-supported dental prosthesis depends on the accuracy of the framework and there are several factors that influence this accuracy (Jemt & Hjalmarsson, 2012; Papaspyridakos & Lal, 2013). In addition, the larger the prosthesis to be fitted, the greater the potential for mismatch, which forces the use of different techniques, thus making the process more complicated (Kan et al., 1999).

Several studies have addressed these variables by examining the accuracy of intraoral scanners: in narrow spaces such as those for crowns or bridges (Ahrberg et al., 2016; Hack & Patzelt, 2015; Omar Ali, 2015; Pradíes, Zarauz, Valverde, Ferreiroa, & Martínez-Rus, 2014; Syrek et al., 2010); covering larger parts of the dental arch such as a quadrant (Ender, Zimmermann, Attin, & Mehl, 2016); and covering the complete arch (Andriessen, Rijkens, Van Der Meer, & Wismeijer, 2014; Ender, Attin, & Mehl, 2016; Ender & Mehl, 2013, 2014; Flügge, Att, Metzger, & Nelson, 2016; Güth, Edelhoff, Schweiger, & Keul, 2016; Patzelt, Bishti, Stampf, & Att, 2014; Patzelt, Emmanouilidi, et al., 2014; van der Meer et al., 2012; Zhang, Suh & Lee, 2016). Although the accuracy values in these studies differ from one case to another, it has been demonstrated that digital impressions are sufficiently accurate in small spaces (Ahrberg et al., 2016; Amin et al., 2017; Ender, Attin, et al., 2016; Ender & Mehl, 2013; Ender, Zimmermann, et al., 2016; Joda & Brägger, 2015; Joda et al., 2017; Pradíes, Zarauz, et al., 2014; Sakornwimon & Leevailoj, 2017; Schepke, Meijer, Kerdijk, & Cune, 2015; Syrek et al., 2010; Zhang et al., 2016) and the improvements implemented in the new versions of the scanners are resulting in improved accuracy (Imburgia et al., 2017; Mangano et al., 2017). However, in large spaces with uniform features (with no geometric differentiation in the radius of curvature), such as those typically associated with edentulous patients, the results are less impressive. The complete-arch impression of an edentulous patient can be one of the most challenging tasks for an intraoral scanner.

The aim of this study is to investigate the effects of the use of an auxiliary geometry part (AGP) and different intraoral scanners on the accuracy (trueness and precision) of the intraoral scans of edentulous patients. The lack of geometric variation can be overcome by simulation, thus providing a solution for the challenging task of obtaining a complete-arch digital impression for an edentulous patient. The null hypothesis states that there are no differences in the accuracy of digital impressions using the auxiliary geometry part regardless of which intraoral scanner was used.

MATERIAL AND METHODS

A stainless steel model was manufactured taking as reference a completely edentulous patient who had a restoration with four implants in the positions of maxilla right third molar, maxilla right canine, maxilla left canine and maxilla left third molar (Fig. 1A). This model was machined with four protrusions simulating four scannable impression copings placed in the aforementioned implant positions. The stainless steel model was scanned 10 times (n=10) with an industrial reference scanner (ATOS Compact Scan 5M/300, GOM) in order to replicate the presumed repeatability. Afterwards, strict measurement protocols were followed to measure three reference distances (D12, D13 and D14) in each of the 3D images obtained with the reference scanner. Based on these measurements, reference values were set (mean ±SD) which were later used to determine the accuracy values of the intraoral scanners used.

Then, the reference model was scanned with three intraoral scanners: Trios 3 (3Shape A/S) with 2015-1 software version (TRI group); 3M™ True Definition (3M ESPE) with 5.1.1 software version (TRU group); and Itero Element 1 (Align Technology Inc.) with 1.5.0.361 software version (ITE group), in two different scenarios (10 scans in each scenario and with each scanner, resulting in a total of 60 scans). The first scenario simulated a normal scanning process in which a specialist digitized the complete arch of a patient who had four scannable impression copings placed in the implants (agpN group). In the second scenario, the same complete arch was digitized, but in this case the AGP simulating a jaw with teeth was placed, thus filling in the gaps between the scannable impression copings (agpY group) (Fig 1B). The AGP was positioned by matching its circular holes with the corresponding scannable impression copings (Fig 1B). Then, to prevent movement during scanning it was fixed with light-polymerizing resin (CONLIGHT, Kuss Dental).The upper side of the scannable impression copings were left visible (Fig 1B) because they were used to perform best-fit alignments while generating the digital impression. This AGP was made in a 3D printing machine (Dimension Elite, Stratasys) using Acrylonitrile Butadiene Styrene (ABS Plus) material.

The 60 scans were performed at the Complutense University of Madrid by a single specialist and under the same humidity and temperature conditions. The scanning protocols defined by the manufacturers of each intraoral scanner were strictly adhered to. In addition, when using the True Definition scanner, the model – and when necessary, the AGP – were powdered (Lava COS Powder, 3M ESPE), as recommended by the manufacturer. This action was not recommended for scanning with Itero and Trios 3. In all cases, both with the reference scanner and the intraoral scanners, 3D images of the model in standard tessellation language file format (STL) were obtained.

For measurement, 3D mesh inspection and processing software were used (GOM Inspect, GOM) for all the digital impressions obtained. The first step was to determine the procedure for taking reference measurements. According to this protocol, it was necessary to create four points in each mesh, one in each model protrusion (parts resembling scan bodies). Each point was created at the intersection of a cylinder axis and a plane, which also had to be created in each mesh. By measuring three distances between these four points (as shown in Fig. 2), three reference distances, D12, D13 and D14, were defined. The procedure to determine the four points was based on the Gaussian best-fit method to create both the cylinders and the planes. For the creation of the geometry using this method approximately 99.7% of the polygons of the mesh resembling the scan body were selected. The intersection between the created planes and cylinders resulted in four points that were used to take distance measurements.

All measurements were taken, and data were exported for analysis as Microsoft Excel worksheet files (XLS). This analysis was performed using a program for statistical inquiry (IBM SPSS Statistics 24, IBM Corp). Accuracy of measurements was analyzed in terms of trueness and precision. Trueness assessment was achieved by measuring the deviation of each measurement from the reference measurement, whereas for precision assessment the dispersion of measurements in each reference distance was analyzed. This assessment was repeated for each reference distance (D12, D13 and D14) in each of the previously mentioned two scenarios (agpN group and agpY group) and with each of the intraoral scanners (TRI group, TRU group and ITE group). Mean values of accuracy and precision were obtained with their corresponding standard deviations and the differences were evaluated to determine whether or not they were statistically significant depending on the use of the AGP or the intraoral scanner (IBM SPSS Statistics 24, IBM Corp) employed.

Finally, using mesh-processing software (Geomagic Studio, 3D Systems, Inc), digital impressions of the edentulous arch were built by combining two STL files. One of these STLs was achieved in the first scenario (agpN group), that is without the AGP placed in the model, and the other was obtained in the second scenario (agpY group), with the AGP in place. The first showed the complete digital impression with the scannable impression copings and soft tissues surrounding them. The second gave a digital impression with spaces between the scannable impression copings hidden by the AGP but, predictably, in a more accurate position. The digital impression of the dental arch without the AGP was split into as many parts as scannable impression copings (Fig 3). At the same time, the AGP was virtually erased from the digital impression, leaving only the scannable impression copings accurately positioned (Fig. 4A and B). By aligning each partition of the first STL with the corresponding scannable impression coping of the second, a final model of the edentulous arch was built (Fig. 5).

RESULTS

Distances obtained with the reference scanner and used as reference values for evaluating the data obtained with intraoral scanners were established at 22.401 mm for D12 with a precision value of 2±2 µm; 42.290 mm for D13 with a precision value of 2±1 µm; and 44.528 mm for D14, with a precision value of 2±2 µm.

Regarding the effect of the AGP on each reference distance and taking into account the three intraoral scanners used, the significance of the effects of both the AGP and the type of scanner varied from one case to another. The 2-way ANOVA showed that at D12 and D13 reference distances, the intraoral scanner had no statistically significant effect ($p>0.05$) on trueness values, while the use of the AGP had statistically significant effects ($p<0.05$). The interaction between the intraoral scanner used and the AGP did not have any significant effect ($p>0.05$) (Table 1). However, in D14, the 2-way ANOVA showed that both the intraoral scanner used and the use of the AGP had a statistically significant effect ($p<0.05$) on the deviation measurement and consequently on trueness (Table 1). The interaction between the intraoral scanner and the use of the AGP had no significant effect ($p>0.05$).

Regarding trueness values for the three reference distances (D12, D13 and D14), the Levene test showed statistically significant differences ($p<0.05$) in the TRU group with or without the AGP, but not in the TRI group and ITE group ($p>0.05$).

The lowest measured mean deviation value was 8±6µm. It was achieved from digital impressions achieved with the True Definition scanner, using the AGP and at D12 reference distance. The highest mean deviation value of 189 ±70µm was achieved with Itero without using the AGP and at D14 reference distance. All deviation values influenced by the AGP are summarized for each reference distance in Table 2, which also takes into consideration which intraoral scanners was used.

Precision was also assessed at each reference distance, always differentiating which of the three intraoral scanners was used in each case. The 2-way ANOVA test showed that at both the reference distances D12 and D13, neither the scanner nor the interaction between it and the AGP had statistically significant effects on the results ($p>0.05$). In contrast, the use or not of the AGP did have a statistically significant effect on precision results ($p<0.05$). However, at reference distance D14 the intraoral scanner used did have statistically significant effects on the results ($p<0.05$) while the use or not of the AGP and the interaction with the scanner used did not have statistically significant effects ($p>0.05$) (Table 3).

Taking into consideration only the effect on the precision of AGP placement in the model, Levene's equal variance test showed different results of significance. At reference distance D12, with or without the AGP, the values differed significantly in the TRI group whereas no statistically significant differences were found in the TRU group and the ITE group values. In contrast, for reference distances D13 and D14, the precision values statistically did not differ significantly in the TRI group, whereas they were significantly different in the TRU group and ITE group.

As shown in the summary table (Table 4), with the analysis of descriptive statistics, all mean precision values and corresponding standard deviations were obtained. The highest mean precision values were 8 ±6µm and 7 ±7µm. They were measured in digital impressions achieved with the True Definition and Trios3, respectively, using the AGP and at D12 reference distance. The lowest mean precision values, 118 ±97µm, were achieved with Itero without using the AGP and at D14 reference distance.

DISCUSSION

The aim of this study was to analyse the effects of the use of the AGP on the accuracy of intraoral scans. It was pretended to demonstrate that large edentulous areas hinder the process of taking digital dental impressions and to offer a simple but effective solution. This solution basically consisted of concealing the large homogeneous surfaces that arise in edentulous patients by simulating the scanning process of a patient with teeth. The results support rejection of the null hypothesis. There are differences in the accuracy of digital impressions when they are obtained using the AGP. Both accuracy and precision are significantly improved.

Intraoral scanners build digital impressions by performing best-fit alignments of multiple captured images and in each best-fit alignment an error is generated. Therefore, the more alignments the scanner has to make, the greater the error. Geometry with differentiating radius of curvature facilitates the best-fit alignment; that is, dentition in the scanned areas facilitates the process, whereas the absence of teeth makes this process so difficult as to be impossible (Andriessen et al., 2014; Vandeweghe, Vervack, Dierens, & De Bruyn, 2016). Splinting the scannable impression copings (Papaspyridakos et al., 2016) or placing artificial markers on these edentulous spaces to help achieve more accurate dental impressions (Kim, Amelya, Shin, & Shim, 2017) are two proposed solutions.

Stereophotogrammetry technology also offers an accurate solution to these problems. Using an extraoral camera (PIC Camera, PIC DENTAL) together with external markers (PIC Abutments, PIC DENTAL), this technology combines two digital files to build a highly accurate digital impression. The external markers are positioned in each abutment and using the extraoral camera is determined their spatial position without making physical contact. The position of the implants and the distances and angles between them are stored as an STL file, however, this STL file does not contain information about the soft tissues or possible teeth (Peñarrocha-Oltra, Agustín-Panadero, Bagán, Giménez, & Peñarrocha, 2014; Pradíes, Ferreiroa, Özcan, Giménez, & Martínez-Rus, 2014). Meanwhile, the same arch is captured using an intraoral scanner to also produce an STL file of the surface to be restored, but in this case both the soft tissues and possible teeth in the mouth are digitized. Accurate complete-arch digital impressions are obtained from the combination of both STL files. However, this technology requires the use of two devices, the extraoral camera and an intraoral scanner, whereas the solution proposed in this study is to use a single device, which is more common in clinical practice.

The use of the proposed AGP requires additional processes, such as the customized design of the part and its manufacture, its placement in the mouth and the difficulty to secure it in the soft tissues of the upper or lower jaws, double scanning and the process of creating digital impressions from two scans. However, it could be a solution to overcome the difficulties involved in obtaining digital impressions of edentulous patients with implants. Furthermore, in the present study only digital impressions have been measured, i.e. virtual models, and it is yet to be verified whether a structure fabricated from this type of digital impression would in fact fit better on implants.

The study was carried out by digitalizing a replica of the complete upper jaw of an edentulous patient and even though the study was performed in vitro, there is no reason to believe that the results obtained are not transferable to in vivo work. The same technique can also be applied to the lower jaw even though it is known that digitization of the mandible is more challenging: the reduced space, the absence of firm palatal tissue and the interference of the tongue make scanning difficult. However, the use of the AGP is also possible since its purpose is to simulate a non-edentulous scenario. Indeed, accuracy values may vary, but it is a fact that the use of an AGP improves the accuracy of full-arch dental digital impressions of edentulous patients. Several authors have discussed the difficulties of obtaining dental impressions from edentulous patients (Andriessen et al., 2014; Kim et al., 2017; Vandeweghe et al., 2016), some even state the impossibility of obtaining them. During the present study, these difficulties were confirmed even before the results were obtained. With the Itero intraoral scanner it was even necessary to mark with a pen some spaces between the scannable impression copings in order to scan the complete arch. Regardless of the scanner used, in several cases the scanner confused the different scannable impression copings and took them to be one, thus generating faulty 3D images, just as Andriessen described (Andriessen et al., 2014).

After an analysis of these difficulties, it was decided to simulate a non-edentulous scenario by placing the AGP over the edentulous areas. As Kim recently proved, an artificial landmark placed in an edentulous space facilitates scanning (Kim et al., 2017), which is similar to the method used in this study. However in this case, the study was performed for a complete arch. A piece was specifically designed and manufactured to fit in the edentulous model and this model was scanned in two different scenarios: with the AGP in place and without the AGP.

Accuracy results improved both in precision and trueness. The improvement was repeated with the all three intraoral scanners and almost at all reference distances analyzed. The only exception was the precision in TRI Group and reference distance D14 (Table 4). It must be noted that when using the True Definition scanner, the model – and when necessary, the AGP – were powdered (Lava COS Powder, 3M ESPE), and this could have introduced a bias in comparing the outcomes of the 3 scanners The best mean values of trueness at each reference distance were obtained with the AGP in place and in all cases using the True Definition intraoral scanner. It is also remarkable that at each reference distance, the highest mean deviation achieved with the AGP was lower than the lowest mean deviation achieved without the AGP. In addition, this study also confirmed that the larger the area to be scanned, the greater the accumulated error. With the defined reference distances, the influence of the length to be restored was observed together with the corresponding error increase, and it was presumed that the larger the size of the dental arch to be digitized, the greater the error. Results confirmed this presumption.

In recent years, some authors have validated the usefulness of intraoral scanners to make digital impressions of crowns or even three-unit fixed dental prostheses (Ahrberg et al., 2016; Amin et al., 2017; Ender, Attin, et al., 2016; Ender & Mehl, 2013; Ender, Zimmermann, et al., 2016; Joda & Brägger, 2015; Joda et al., 2017; Pradíes, Zarauz, et al., 2014; Sakornwimon & Leevailoj, 2017; Schepke et al., 2015; Syrek et al., 2010; Zhang et al., 2016). However, when the area to be restored, and consequently the scanning area, grows, the results clearly worsened (Ender, Attin et al., 2016; Ender, Zimmermann, et al., 2016; Flügge et al., 2016; van der Meer et al., 2012). This fact was confirmed in the present study. However, during the study, there was evidence that the influence of the AGP was more significant than that of the intraoral scanner used. At reference distances D12 and D13, the differences between the use or non-use of the AGP were statistically significant ($p<0.05$) while the scanner used was not. In contrast, at reference distance D14, besides the use of the AGP, the scanner used also provided significantly different results.

As expected, there are differences between intraoral scanners in terms of measurement accuracy. Nevertheless, taking into consideration the studies on osseointegration of implants (Carr & Toth, 1995; Christensen, 1966; Dodmon, 1982; T Jemt, 1991), it can be confirmed that all three are valid for working on a dental quadrant, having maximum deviation values of 101 μm (CI95%) but mean deviations of less than 70 μm. This is not the case in complete arch, at the equivalent to distance D14, where the results were influenced by the scanner used, and the non-utilization of the AGP gives somewhat high deviation values. The maximum deviation was 239 μm (CI95%) and highest mean deviation 189 ±70 μm, both with the Itero and without using the AGP.

CONCLUSIONS

Despite the limitations of this in vitro study, we conclude that the use of an auxiliary geometry piece improved the accuracy of complete-arch digital impressions of the edentulous maxilla, as well as facilitating the scanning process itself. Both trueness and precision measurements obtained by covering wide edentulous spaces with the auxiliary geometry piece showed remarkable improvement in digital impressions.

AKNOWLEDGMENTS

The authors thank Dr Javier Etxaniz from dental clinic Trento, dental laboratory Odontolan Otaduy and Dr. Juan Carlos Aldasoro from the Business Management department of the University of the Basque Country UPV/EHU for their support and assistance in the conducting of this research work.

Funding: this work was supported by the Country Council of Gipuzkoa (75/18 and 70/19).

REFERENCES

Ahrberg, D., Lauer, H. C., Ahrberg, M., & Weigl, P. (2016). Evaluation of fit and efficiency of CAD/CAM fabricated all-ceramic restorations based on direct and indirect digitalization: a double-blinded, randomized clinical trial. *Clinical Oral Investigations*, *20*(2), 291–300. doi: 10.1007/s00784-015-1504-6

Amin, S., Weber, H. P., Finkelman, M., El Rafie, K., Kudara, Y., & Papaspyridakos, P. (2017). Digital vs. conventional full-arch implant impressions: a comparative study. *Clinical Oral Implants Research*, *28*(11), 1360–1367. doi: 10.1111/clr.12994

Andriessen, F. S., Rijkens, D. R., Van Der Meer, W. J., & Wismeijer, D. W. (2014). Applicability and accuracy of an intraoral scanner for scanning multiple implants in edentulous mandibles: A pilot study. *Journal of Prosthetic Dentistry*, *111*(3), 186–194. doi: 10.1016/j.prosdent.2013.07.010

Carr, A. B., & Toth, B. (1995). Fit discrimination of full arch implant frameworks. *J. Dent. Res*, 74–151.

Christensen, G. J. (1966). Marginal fit of gold inlay castings. *The Journal of Prosthetic Dentistry*, *16*(2), 297–305. doi: http://dx.doi.org/10.1016/0022-3913(66)90082-5

Dodmon, H. W. (1982). Disparity in expert opinion on size of acceptable margin openings. *Oper Dent*, *7*(3), 97–101.

Duret, F., & Preston, J. D. (1991). CAD/CAM imaging in dentistry. *Curr Opin Dent*, *1*(2), 150–154. Retrieved from http://www.ncbi.nlm.nih.gov/pubmed/1777659

Ender, A., Attin, T., & Mehl, A. (2016). In vivo precision of conventional and digital methods of obtaining complete-arch dental impressions. *Journal of Prosthetic Dentistry*, *115*(3), 313–320. doi: 10.1016/j.prosdent.2015.09.011

Ender, A., & Mehl, A. (2013). Accuracy of complete-Arch dental impressions: A new method of measuring trueness and precision. *Journal of Prosthetic Dentistry*, *109*(2), 121–128.

doi: 10.1016/S0022-3913(13)60028-1

Ender, A., & Mehl, A. (2014). In-vitro evaluation of the accuracy of conventional and digital methods of obtaining full-arch dental impressions. *Quintessence Int*, *46*(1), 9–17. doi: 10.3290/j.qi.a32244

Ender, A., Zimmermann, M., Attin, T., & Mehl, A. (2016). In vivo precision of conventional and digital methods for obtaining quadrant dental impressions. *Clinical Oral Investigations*, *20*(7), 1495–1504. doi: 10.1007/s00784-015-1641-y

Flügge, T., Att, W., Metzger, M., & Nelson, K. (2016). Precision of Dental Implant Digitization Using Intraoral Scanners. *The International Journal of Prosthodontics*, *29*(3), 277–283. doi: 10.11607/ijp.4417

Giménez, B., Özcan, M., Martínez-Rus, F., & Pradíes, G. (2014). Accuracy of a Digital Impression System Based on Parallel Confocal Laser Technology for Implants with Consideration of Operator Experience and Implant Angulation and Depth. *The International Journal of Oral & Maxillofacial Implants*, *29*(4), 853–862. doi: 10.11607/jomi.3343

Gjelvold, B., Chrcanovic, B. R., Korduner, E. K., Collin-Bagewitz, I., & Kisch, J. (2016). Intraoral Digital Impression Technique Compared to Conventional Impression Technique. A Randomized Clinical Trial. *Journal of Prosthodontics*, *25*(4), 282–287. doi: 10.1111/jopr.12410

Güth, J.-F., Keul, C., Stimmelmayr, M., Beuer, F., & Edelhoff, D. (2013). Accuracy of digital models obtained by direct and indirect data capturing. *Clinical Oral Investigations*, *17*(4), 1201–1208. doi: 10.1007/s00784-012-0795-0

Güth, J.-F., Runkel, C., Beuer, F., Stimmelmayr, M., Edelhoff, D., & Keul, C. (2017). Accuracy of five intraoral scanners compared to indirect digitalization. *Clinical Oral Investigations*, *21*(5), 1445–1455. doi: 10.1007/s00784-016-1902-4

Güth, J. F., Edelhoff, D., Schweiger, J., & Keul, C. (2016). A new method for the evaluation of the accuracy of full-arch digital impressions in vitro. *Clinical Oral Investigations*, *20*(7), 1487–1494. doi: 10.1007/s00784-015-1626-x [doi]

Hack, G. D., & Patzelt, S. B. M. (2015). Evaluation of the Accuracy of Six Intraoral Scanning Devices: An in-vitro Investigation. *American Dental Association*, *10*(4), 1–5.

Imburgia, M., Logozzo, S., Hauschild, U., Veronesi, G., Mangano, C., & Mangano, F. G. (2017). Accuracy of four intraoral scanners in oral implantology: a comparative in vitro study. *BMC Oral Health*, *17*(1), 92. doi: 10.1186/s12903-017-0383-4

Jemt, T. (1991). Failures and complications in 391 consecutively inserted fixed prostheses supported by Brånemark implants in edentulous jaws: a study of treatment from the time of prosthesis placement to the first annual checkup. *The International Journal of Oral & Maxillofacial Implants*, *6*(3), 270–276. Retrieved from http://www.ncbi.nlm.nih.gov/pubmed/1813395

Jemt, Torsten, & Hjalmarsson, L. (2012). In Vitro Measurements of Precision of Fit of Implant-Supported Frameworks. A Comparison between “Virtual” and “Physical” Assessments of Fit Using Two Different Techniques of Measurements. *Clinical Implant Dentistry and Related Research*, *14*(SUPPL. 1), e175–e182. doi: 10.1111/j.1708-8208.2011.00416.x

Joda, T., & Brägger, U. (2015). Time-Efficiency Analysis Comparing Digital and Conventional Workflows for Implant Crowns: A Prospective Clinical Crossover Trial. *The International Journal of Oral & Maxillofacial Implants*, *30*(5), 1047–1053. doi: 10.11607/jomi.3963

Joda, T., Lenherr, P., Dedem, P., Kovaltschuk, I., Bragger, U., & Zitzmann, N. U. (2017). Time efficiency, difficulty, and operator’s preference comparing digital and conventional implant impressions: a randomized controlled trial. *Clinical Oral Implants Research*, *28*(10), 1318–1323. doi: 10.1111/clr.12982

Kan, J. Y. K., Rungcharassaeng, K., Bohsali, K., Goodacre, C. J., & Lang, B. R. (1999). Clinical methods for evaluating implant framework fit. *The Journal of Prosthetic Dentistry*, *81*(1), 7–13. doi: http://dx.doi.org/10.1016/S0022-3913(99)70229-5

Kim, J.-E. E., Amelya, A., Shin, Y., & Shim, J.-S. S. (2017). Accuracy of intraoral digital impressions using an artificial landmark. *The Journal of Prosthetic Dentistry*, *117*(6), 755–761. doi: 10.1016/j.prosdent.2016.09.016

Lee, S. J., & Gallucci, G. O. (2013). Digital vs. conventional implant impressions: Efficiency outcomes. *Clinical Oral Implants Research*, *24*(1), 111–115. doi: 10.1111/j.1600-0501.2012.02430.x

Mangano, F., Gandolfi, A., Luongo, G., & Logozzo, S. (2017). Intraoral scanners in dentistry: A review of the current literature. *BMC Oral Health*, *17*(1), 149. doi: 10.1186/s12903-017-0442-x

Omar Ali, A. (2015). Accuracy of Digital Impressions Achieved from Five Different Digital Impression Systems. *Dentistry*, *05*(05), 300. doi: 10.4172/2161-1122.1000300

Papaspyridakos, P., Gallucci, G. O., Chen, C. J., Hanssen, S., Naert, I., & Vandenberghe, B. (2016). Digital versus conventional implant impressions for edentulous patients: Accuracy outcomes. *Clinical Oral Implants Research*, *27*(4), 465–472. doi: 10.1111/clr.12567

Papaspyridakos, P., & Lal, K. (2013). Computer-assisted design/computer-assisted manufacturing zirconia implant fixed complete prostheses: Clinical results and technical complications up to 4 years of function. *Clinical Oral Implants Research*, *24*(6), 659–665. doi: 10.1111/j.1600-0501.2012.02447.x

Patzelt, S. B. M., Bishti, S., Stampf, S., & Att, W. (2014). Accuracy of computer-aided design/computer-aided manufacturing–generated dental casts based on intraoral scanner data. *The Journal of the American Dental Association*, *145*(11), 1133–1140. doi: 10.14219/jada.2014.87

Patzelt, S. B. M., Emmanouilidi, A., Stampf, S., Strub, J. R., & Att, W. (2014). Accuracy of full-arch scans using intraoral scanners . *Clinical Oral Investigations*, *18*(6), 1687–1694. doi: 10.1007/s00784-013-1132-y [doi]

Patzelt, S. B. M., Lamprinos, C., Stampf, S., & Att, W. (2014). The time efficiency of intraoral scanners: An in vitro comparative study. *Journal of the American Dental Association*, *145*(6), 542–551. doi: 10.14219/jada.2014.23

Peñarrocha-Oltra, D., Agustín-Panadero, R., Bagán, L., Giménez, B., & Peñarrocha, M. (2014). Impression of multiple implants using photogrammetry: Description of technique and case presentation. *Medicina Oral, Patologia Oral y Cirugia Bucal*, Vol. 19, pp. 366–371. doi: 10.4317/medoral.19365

Pradíes, G., Ferreiroa, A., Özcan, M., Giménez, B., & Martínez-Rus, F. (2014). Using stereophotogrammetric technology for obtaining intraoral digital impressions of implants. *The Journal of the American Dental Association*, *145*(4), 338–344. doi: 10.14219/jada.2013.45

Pradíes, G., Zarauz, C., Valverde, A., Ferreiroa, A., & Martínez-Rus, F. (2014). Clinical evaluation comparing the fit of all-ceramic crowns obtained from silicone and digital intraoral impressions based on wavefront sampling technology. *Journal of Dentistry*, *43*(2), 201–208. doi: 10.1016/j.jdent.2014.12.007

Sakornwimon, N., & Leevailoj, C. (2017). Clinical marginal fit of zirconia crowns and patients' preferences for impression techniques using intraoral digital scanner versus polyvinyl siloxane material. *The Journal of Prosthetic Dentistry*, *118*(3), 386–391. doi: 10.1016/j.prosdent.2016.10.019

Schepke, U., Meijer, H. J. A., Kerdijk, W., & Cune, M. S. (2015). Digital versus analog complete-arch impressions for single-unit premolar implant crowns: Operating time and patient preference. *The Journal of Prosthetic Dentistry*, *114*(3), 403-406.e1. doi: 10.1016/j.prosdent.2015.04.003

Syrek, A., Reich, G., Ranftl, D., Klein, C., Cerny, B., & Brodesser, J. (2010). Clinical evaluation of all-ceramic crowns fabricated from intraoral digital impressions based on the principle of active wavefront sampling. *Journal of Dentistry*, *38*(7), 553–559. doi: http://dx.doi.org/10.1016/j.jdent.2010.03.015

van der Meer, W. J., Andriessen, F. S., Wismeijer, D., & Ren, Y. (2012). Application of intra-oral dental scanners in the digital workflow of implantology. *PLoS ONE, 7*(8), 1–8. doi: 10.1371/journal.pone.0043312

Vandeweghe, S., Vervack, V., Dierens, M., & De Bruyn, H. (2016). Accuracy of digital impressions of multiple dental implants: An in vitro study. *Clinical Oral Implants Research*, *28*(6), 648–653. doi: 10.1111/clr.12853

Yuzbasioglu, E., Kurt, H., Turunc, R., & Bilir, H. (2014). Comparison of digital and conventional impression techniques: evaluation of patients' perception, treatment comfort, effectiveness and clinical outcomes. *BMC Oral Health*, *14*, 10. doi: 10.1186/1472-6831-14-10

Zhang, F., Suh, K.-J., & Lee, K.-M. (2016). Validity of Intraoral Scans Compared with Plaster Models: An In-Vivo Comparison of Dental Measurements and 3D Surface Analysis. *Plos One*, *11*(6), e0157713. doi: 10.1371/journal.pone.0157713

TABLES

Table 1. 2-way ANOVA results for trueness analysis at each reference distance

Inter-subject effects tests			
Dependent variable: deviation	D12	D13	D14
Source	P*	P*	P*
SCANNER	0.369	0.171	0.001
AGP	0.004	0.001	0
SCANNER * AGP	0.486	0.816	0.111

*Significance at $P<0.05$

Table 2. Deviation values (µm) for each reference distance obtained with each of the intraoral scanners

			CI 95% Min.	**CI 95% Max.**	**Mean (SD)**
D12	**TRI Group**	**agp_N**	6	27	17±15
		agp_Y	7	17	12±7
	TRU Group	**agp_N**	8	32	20±16
		agp_Y	4	12	8±6
	ITE Group	**agp_N**	14	38	26±17
		agp_Y	4	20	12±11
D13	**TRI Group**	**agp_N**	38	101	70±44
		agp_Y	12	56	34±31
	TRU Group	**agp_N**	27	84	55±40
		agp_Y	12	28	20±11
	ITE Group	**agp_N**	41	97	69±39
		agp_Y	26	66	46±28
D14	**TRI Group**	**agp_N**	48	155	101±75
		agp_Y	30	116	73±61
	TRU Group	**agp_N**	43	126	85±58
		agp_Y	19	51	35±22
	ITE Group	**agp_N**	139	239	189±70
		agp_Y	46	121	83±52

CI=Confidence Interval

Table 3. 2-way ANOVA results for precision analysis for each reference distance

Inter-subject effects tests			
Dependent variable: Precision	**P12**	**P13**	**P14**
Source	**P***	**P***	**P***
SCANNER	0.478	0.118	0.048
AGP	0	0.049	0.174
SCANNER * AGP	0.509	0.387	0.263

*Significant at P<0.05

Table 4. Precision values (µm) for each reference distance obtained with each of the intraoral scanners

			CI 95% Mín.	CI 95% Max.	Mean (SD)
D12	**TRI Group**	**agp_N**	3	25	14±15
		agp_Y	2	12	7±7
	TRU Group	**agp_N**	6	30	18±17
		agp_Y	3	12	8±6
	ITE Group	**agp_N**	15	30	23±11
		agp_Y	3	12	8±6
D13	**TRI Group**	**agp_N**	15	58	37±30
		agp_Y	12	56	34±30
	TRU Group	**agp_N**	16	79	47±44
		agp_Y	11	26	19±11
	ITE Group	**agp_N**	38	79	58±29
		agp_Y	27	60	44±23
D14	**TRI Group**	**agp_N**	22	89	55±47
		agp_Y	26	113	70±61
	TRU Group	**agp_N**	34	122	78±62
		agp_Y	20	50	35±22
	ITE Group	**agp_N**	48	187	118±97
		agp_Y	56	110	83±38

CI=Confidence Interval

FIGURES

Fig. 1A. Stainless steel model.

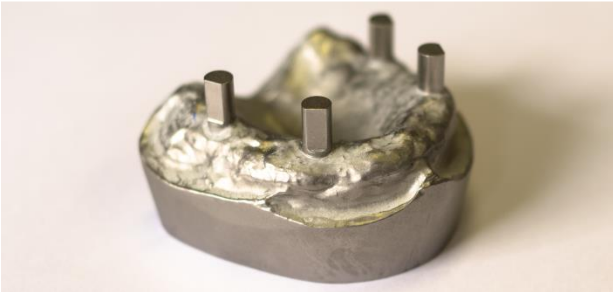


Fig. 1B. Stainless steel model with the AGP placed on it.

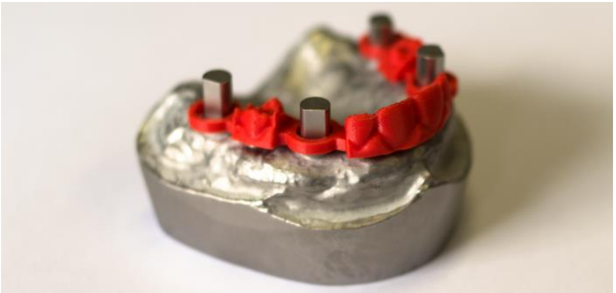


Fig. 2. D12, D13 and D14 reference distances.

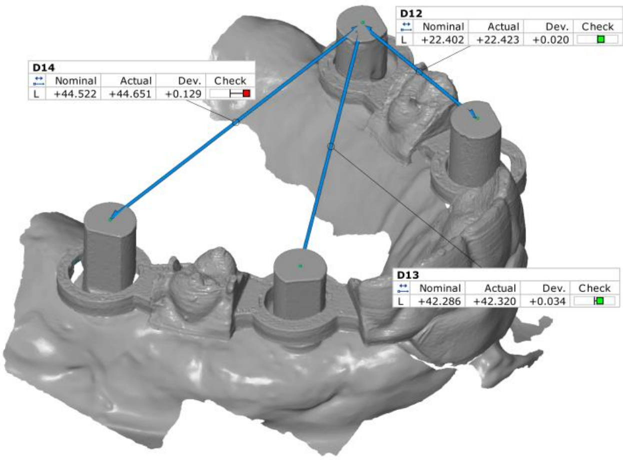


Fig. 3. Virtual partition of the full-arch digital impression.

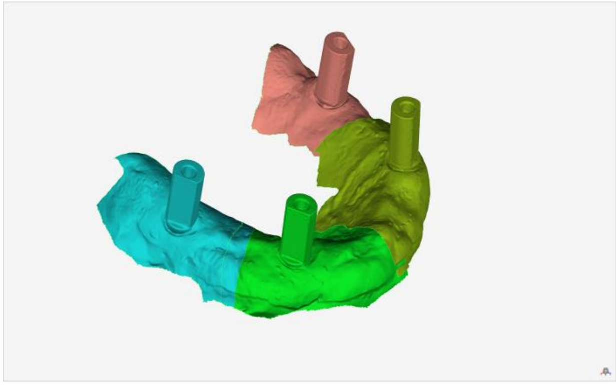
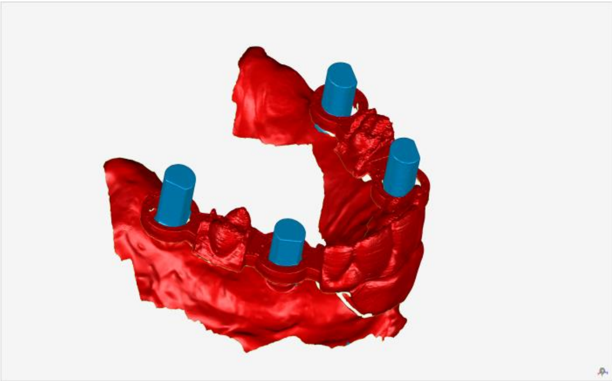


Fig. 4. AGP erasing process. A: In red, the area to be deleted. B: Highly accurately positioned scannable impression copings.

A



B

Fig. 5. Alignment of split parts. A: Aligning first split part. B: Aligning second split part. C: Aligning third split part. D: Aligning fourth split part.