Miguel Gómez-Polo, Juan Ballesteros, Pedro Perales-Padilla, Pedro Perales-Pulido, Marta Revilla-León, Rocío Ortega

Merging intraoral scans and CBCT: a novel technique for improving the accuracy of 3D digital models for implant-supported complete-arch fixed dental prostheses

Abstract

Aim: A technique for merging digital intraoral and CBCT scans for implant-supported complete-arch fixed dental prostheses (FDPs) is described. The aim is to improve the dimensional accuracy of intraoral scans in edentulous arches.

Materials and method: Two files are recorded: an intraoral scan and a CBCT scan, both obtained with scan bodies connected to the implants in the same position. The intraoral scan is then divided into several fragments and realigned, taking as reference the position of the implants recorded in the CBCT file.

Results: An improved intraoral digital model with corrected implant positions appropriate for complete-arch implant FDPs is generated.

Conclusion: The methodology proposed can minimize possible intraoral scanning error and deliver more reliable digital impressions for implant-supported complete-arch FDPs.

Keywords: *fixed dental prosthesis (FDP), dental implants, complete-arch rehabilitation, passive fit, intraoral scanners (IOSs), CBCT*

Introduction

Digital intraoral scanning systems may eventually replace conventional dental impressions[1], with several advantages not only for clinicians but also for patients. Advantages reported for clinicians include enhanced chairside communication, time and space savings[2,] and simplifying procedures in complex cases such as severe undercuts. Furthermore, patients have shown their preference for digital impressions, finding them more comfortable and with less gag reflex[3]. Moreover, intraoral scanners (IOSs) have improved greatly since they were first introduced due to the elimination of the need for intraoral powder, the change from monochrome to color imaging, the heightened accuracy, and the wider range of recommended uses[4].

Drawbacks of IOSs include their cost, the learning curve involved in their use, and reduced accuracy for long-span restorations[5]. It must also be taken into account that various factors can have an influence on the accuracy of complete-arch digital impressions, including the scanner[6], the light conditions[7], the position of the implants[8] or the design of the scan body[9]. The accuracy of intraoral scans results from the size of the wand, which must be small enough to fit into the interarch space to record less accessible areas of the mouth. For multiunit restorations, including complete-arch rehabilitations, most IOSs compensate for their limited field of amplitude by capturing a series of narrower fields, which they then stitch together to form the whole. The result may compound any inaccuracies with each new stitch: the longer the span, the lower the accuracy[10]. To address this issue, a number of similar scanning strategies and techniques have been developed[11-16].

Inaccuracies appear particularly when the IOS has few or less reliable references, such as when scanning edentulous areas[17]. In such situations, inaccuracies are significant because the IOS must reproduce moist, mobile mucosa that has fewer reference points than teeth[18]. When scanning for implant-supported complete-arch fixed dental prostheses (FDPs), great accuracy is needed to ensure a satisfactory passive fit, the absence of which may induce technical and biologic complications[19].

CBCT is a widely used imaging technique in dentistry, providing a cross-sectional 3D image with much less radiation than any other 3D radiographic technique, with a dose (0.019 to 0.061 mSv) similar to that of a periapical radiograph[20-22]. The use of CBCT in prosthetic dentistry has also been described with good results, specifically to record implant positioning[23]. Unlike IOSs, CBCT systems also collect extraoral information, and are not subject to cumulative error when larger areas are scanned, with errors being reported to

Fig 1 Original intraoral scan.

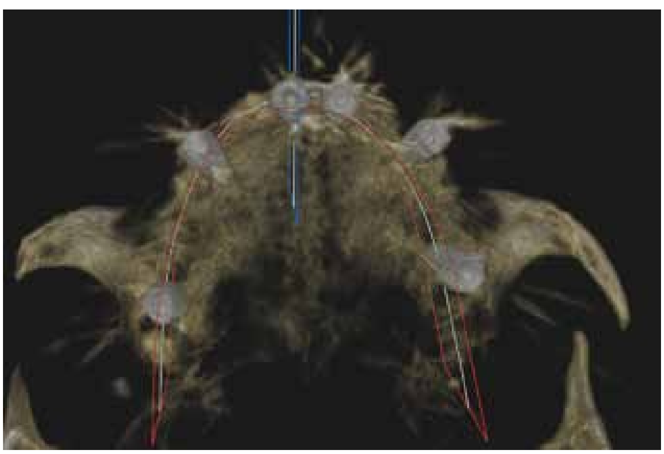

Fig 2 Original CBCT.

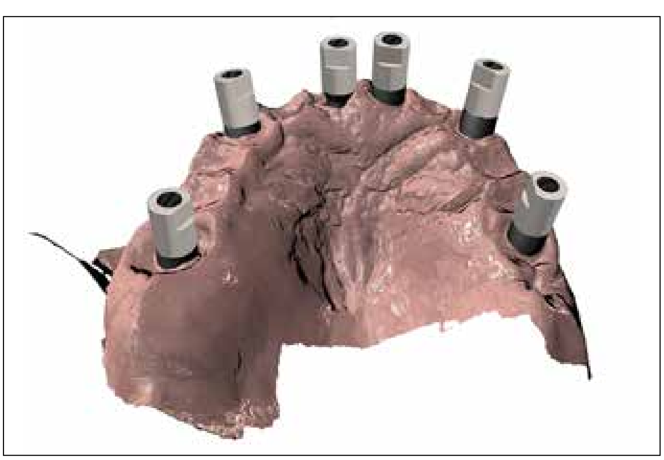

Fig 3 Modified intraoral scan.

be < 100 µm over a linear span, equivalent to a complete arch[24]. The images are not distorted because the non-magnified images that are generated exhibit isotropic resolution (the same in the three directions of Cartesian space). CBCT scans also provide enhanced image resolution because of the small pixel size used[25]. The accuracy of CBCT scans is largely contingent upon scanner quality, voxel density, and the patient's ability to sit still while the record is being made. Its inaccuracies differ from those of IOSs because they are not compounded over longer spans.

As IOS images are accurate for a short span, the first implants recorded in complete arches will be close to their actual position, whereas the ones farthest from the access point will deviate more[26]. CBCT scans, however, are less accurate in short spans, but the deviation is not compounded by the length of the span. Consequently, the stitching-induced compounding of errors and loss of references in intraoral scans for implant-supported complete-arch FDPs could be offset with CBCT scanning, providing the images from the two systems can be satisfactorily merged.

The technical procedure described in this article constitutes a method of merging intraoral and CBCT scans to heighten the accuracy of digital images for complete-arch FDPs.

Technique

1. Connect scan bodies (Core Scanbody; Core 3D City? Country?) to the implants or abutments and make an intraoral scan (Trios 3; 3Shape, Copenhagen, Denmark). Label this standard tessellation language (STL) file 'original intraoral scan' (Fig 1).
2. Obtain a CBCT scan (CS 9300; Carestream, Atlanta, USA) with the scan bodies connected to the implants. The scan bodies must be located exactly as in the intraoral scan, so this scan should be obtained sequentially without removing the scan bodies. Label this DICOM file 'original CBCT' (Fig 2).
3. Edit the 'original intraoral scan,' replacing the scan bodies registered in the original intraoral scan by virtual scan bodies. Label the resulting file 'modified intraoral scan' (Fig 3).
4. Convert the original DICOM CBCT file to STL format with a software program (InVesalius v. 3.1; InVesalius). Then, isolate the 3D positions of the scan bodies joined to the implants from the rest of the information (Fig 4). Finally, identify the height and angle of each implant with a soft-

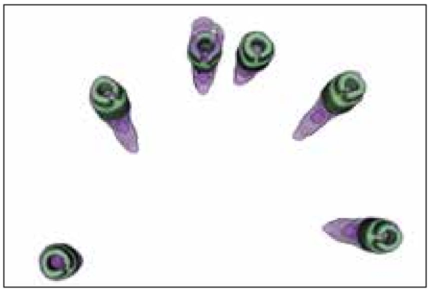

Fig 4 Scan body-implant locations from original CBCT.

Fig 5 Modified CBCT.

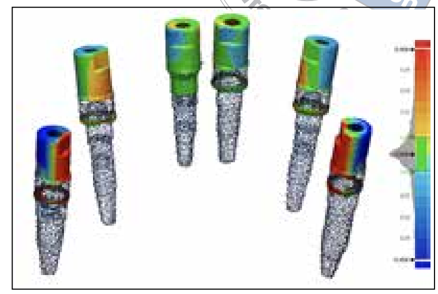

Fig 6 Comparison between 'modified intraoral scan' and 'modified CBCT' files.

ware program (Meshmixer v. 3.4.35; Autodesk), and place a virtual scan body on each (Fig 5). Label this model 'modified CBCT.' Unlike with intraoral scans, the location of the implants in this record will not be affected by the stitching procedure, thus providing more reliable scan body locations.

5. Compare the implant locations in the 'modified intraoral scan' file with those in the 'modified CBCT' file by superimposing both files and identifying differences in the position of the scan bodies joined to the implants. A color map (Geomagic Control X 1.1; 3D Systems, Rock Hill, USA) can be made to provide a better understanding of these deviations (Fig 6). If no differences are found, the following steps are unnecessary.
6. Align the 'modified intraoral scan' with the 'modified CBCT' by dividing the 'modified intraoral scan' file into fragments and overlaying each fragment on the 'modified CBCT' file (Fig 7). Thus, a digital model with an implant location based on the CBCT scan is obtained. This yields a complete intraoral scan with corrected implant positions that also shows the soft tissue (except the division lines, which appear as a type of scar in the final image). Label this file 'improved intraoral scan' (Fig 8). Note: although the file was divided into six fragments in the original example used to describe this technique, there could be situations where a minor number of cuts and alignments may be enough to obtain an accurate file.
7. Verify the implant alignment by making a new comparison between the files to ensure correct alignment. Align the location of the implant connections of the 'improved intraoral scan' and 'modified CBCT,' and identify the deviations between them. If no deviations are shown, the alignment procedure can be considered correct (Fig 9).
8. Compare the 'original intraoral scan' file with the 'improved intraoral scan' file to estimate the magnitude of the corrections made with this technique (Fig 10). This step is not mandatory but can be used to observe differences by comparing the position of the most distal scan bodies.

Discussion

The described methodology uses CBCT technology to offset intraoral scan inaccuracies in the positioning of implants for complete-arch FDPs. While some authors report no differences in accuracy between digital and conventional impression taking, or even better results with the former[27-30], others observe lower precision in intraoral scan-based impressions[3,31-35]. Note that little scientific evidence is available in this regard, and clinical studies are still needed to assess the accuracy and efficiency of the digital workflow for full-arch restorations[36,37]. Nevertheless, intraoral records are generally deemed to be less accurate in the fragments farthest from the access point[26]. As the soft tissue affords fewer references, those inaccuracies are greater in implants than in teeth, and, due to fragment stitching, are greater in the last implant compared with the first one.

The methodology described in this article aims to reduce such inaccuracies with scan body-based CBCT complete-arch scanning. CBCT alone is not reliable because in short spans it defines scan bodies less precisely than does intraoral scanning. The methodology proposed here capitalizes on the strengths of the two types of imaging with a view to producing more accurate digital records.

Different techniques have recently been described with the same objectives. Comparing the technique proposed here with previous ones, it can be noted that it does not need an extra device[13-15], the splinting of the scanbodies or more than one intraoral scan [unclear? Authors?]. On the

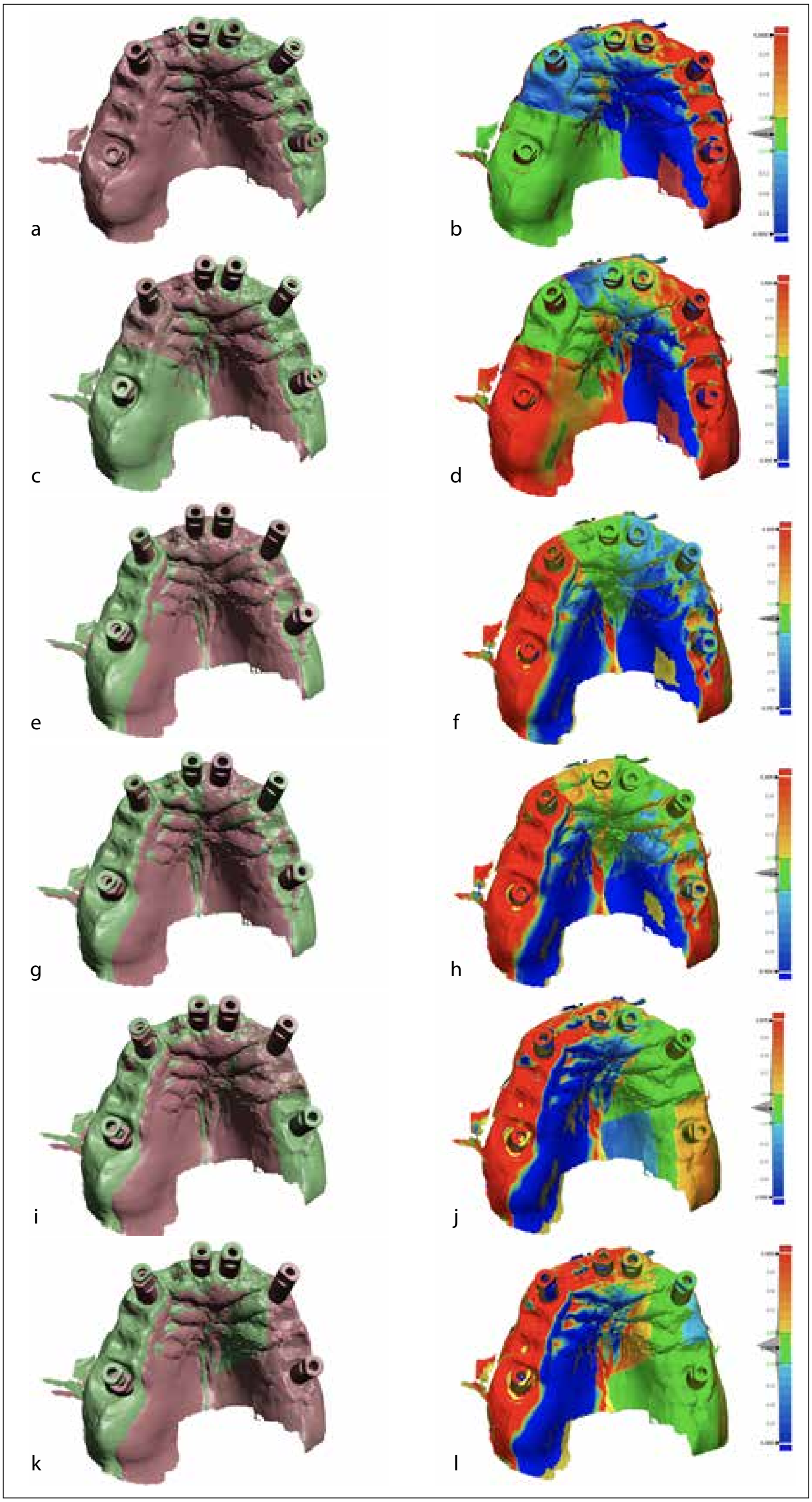

Fig 7 Alignment of fragments implant by implant between 'modified CBCT' and 'modified intraoral scan' files: maxillary right first molar (a and b); maxillary right canine (c and d); maxillary right central incisor (e and f); maxillary left central incisor (g and h); maxillary left canine (i and j); maxillary left first molar (k and l).

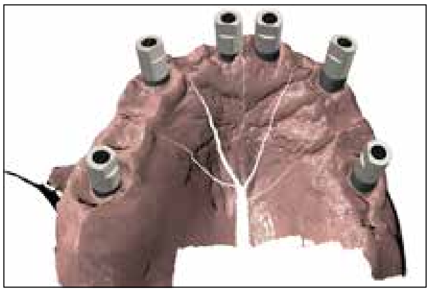

Fig 8 Improved intraoral scan.

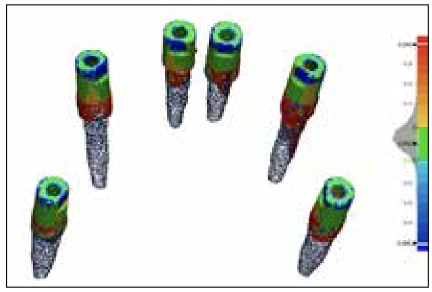

Fig 9 Verification of correct alignment procedure.

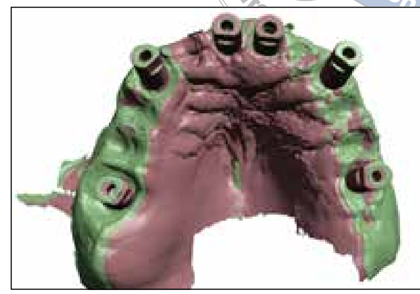

Fig 10 Comparison between 'original intraoral scan' (red) and 'improved intraoral scan' files (green).

other hand, the main drawback of the presented technique is that patients are exposed to additional radiation (intraoral scan plus CBCT). In this regard, although CBCT emits a low dose of radiation, its use in the proposed technique could constitute a problem in several countries. Another issue around the use of CBCT in this approach is the need for high definition, which depends on multiple factors such as scanner quality, voxel density, and patient immobility during the procedure. Finally, it should be taken into account that the proposed technique requires the use of software that can be operator sensitive. The methodology proposed can minimize possible intraoral scanning error and deliver more reliable digital impressions for implant-supported complete-arch FDPs.

The method has been registered by the World Intellectual Property Organisation under patent WO2018220248: Method for designing a dental prosthesis using digital techniques.

Summary

The dental technique proposed in this article aims to reduce compounded error in intraoral scans for implant-supported complete-arch FDPs and deliver more accurate digital impressions for such restorations. Two records are needed: a CBCT scan and an intraoral scan, both made with the scan bodies connected to the implants in the same location. Based on the implant location of the CBCT scan, the fragments of the intraoral scan are aligned to obtain a more accurate digital model. The main disadvantage of the technique is the additional radiation exposure. The file generated is suitable for fabricating complete-arch FDPs, minimizing the dimensional errors of long-span intraoral scans.

References

1. Ting-Shu S, Jian S. Intraoral digital impression technique: a review. J Prosthodont 2015;24:313–321.
2. Joda T, Brägger U. Patient-centered outcomes comparing digital and conventional implant impression procedures: a randomized crossover trial. Clin Oral Implants Res 2016;27:e185–e189.
3. Mangano F, Gandolfi A, Luongo G, Logozzo S. Intraoral scanners in dentistry: a review of the literature. BMC Oral Health 2017;17:149.
4. Fukazawa S, Odaira C, Kondo H. Investigation of accuracy and reproducibility of abutment position by intraoral scanners. J Prosthodont Res 2017;61:450–459.
5. Rehmann P, Sichwardt V, Wöstmann B. Intraoral scanning systems: need for maintenance. Int J Prosthodont 2017;30:27–29.
6. Mangano FG, Hauschild U, Veronesi G, Imburgia M, Mangano C, Admakin O. Trueness and precision of 5 intraoral scanners in the impressions of single and multiple implants: a comparative in vitro study. BMC Oral Health 2019;19:101.
7. Revilla-León M, Jiang P, Sadeghpour M, et al. Intraoral digital scans – Part 1: Influence of ambient scanning light conditions on the accuracy (trueness and precision) of different intraoral scanners. J Prosthet Dent 2020;124:372–378.
8. Arcuri L, Pozzi A, Lio F, Rompen E, Zechner W, Nardi A. Influence of implant scanbody material, position and operator on the accuracy of digital impression for complete-arch: a randomized in vitro trial. J Prosthodont Res 2020;64:128–136.
9. Schmidt A, Billig JW, Schlenz MA, Rehmann P, Wöstmann B. Influence of the accuracy of intraoral scanbodies on implant position: differences in manufacturing tolerances. Int J Prosthodont 2019;32:430–432.
10. Giménez B, Özcan M, Martínez-Rus F, Pradíes G. Accuracy of a digital impression system based on parallel confocal laser technology for implants with consideration of operator experience and implant angulation and depth. Int J Oral Maxillofac Implants 2014;29: 853–862.
11. Müller P, Ender A, Joda T, Katsoulis J. Impact of digital intraoral scan strategies on the impression accuracy using the TRIOS Pod scanner. Quintessence Int 2016;47:343–349.

12. Basaki K, Alkumru H, De Souza G, Finer Y. Accuracy of digital vs conventional implant impression approach: a three-dimensional comparative in vitro analysis. Int J Oral Maxillofac Implants 2017;32: 792–799.
13. Mandelli F, Zaetta A, Cucchi A, Mangano FG. Solid index impression protocol: a hybrid workflow for high accuracy and passive fit of full-arch implant-supported restorations. Int J Comput Dent 2020;23: 161–181.
14. Iturrate M, Minguez R, Pradies G, Solaberrieta E. Obtaining reliable intraoral digital scans for an implant-supported complete-arch prosthesis: a dental technique. J Prosthet Dent 2019;121:237–241.
15. Gómez-Polo M, Ballesteros J, Perales-Padilla P, Perales-Pulido P, Gómez-Polo C, Ortega R. Guided implant scanning: A procedure for improving the accuracy of implant-supported complete-arch fixed dental prostheses. J Prosthet Dent 2020;124:135–139.
16. Imburgia M, Kois J, Marino E, Lerner H, Mangano FG. Continuous Scan Strategy (CSS): A novel technique to improve the accuracy of intraoral digital impressions. Eur J Prosthodont Restor Dent 2020;28: 128–141.
17. Flügge TV, Att W, Metzger MC, Nelson K. Precision of dental implant digitization using intraoral scanners. Int J Prosthodont 2016;29: 277–283.
18. Andriessen FS, Rijkens DR, van der Meer WJ, Wismeijer DW. Applicability and accuracy of an intraoral scanner for scanning multiple implants in edentulous mandibles: a pilot study. J Prosthet Dent 2014;111:186–194.
19. Abduo J, Judge RB. Implications of implant framework misfit: a systematic review of biomechanical sequelae. Int J Oral Maxillofac Implants 2014;29:608–621.
20. Harris D, Horner K, Gröndahl K, et al. E.A.O. guidelines for the use of diagnostic imaging in implant dentistry 2011. A consensus workshop organized by the European Association for Osseointegration at the Medical University of Warsaw. Clin Oral Implants Res 2012;23: 1243–1253.
21. De Vos W, Casselman J, Swennen GR. Cone-beam computerized tomography (CBCT) imaging of the oral and maxillofacial region: a systematic review of the literature. Int J Oral Maxillofac Surg 2009;38:609–625.
22. Benic GI, Elmasry M, Hämmerle CH. Novel digital imaging techniques to assess the outcome in oral rehabilitation with dental implants: a narrative review. Clin Oral Implants Res 2015;26(suppl 11):86–96.
23. Corominas-Delgado C, Espona J, Lorente-Gascón M, Real-Voltas F, Roig M, Costa-Palau S. Digital implant impressions by cone-beam computerized tomography: a pilot study. Clin Oral Implants Res 2016;27:1407–1413.
24. Loubele M, Bogaerts R, Van Dijck E, et al. Comparison between effective radiation dose of CBCT and MSCT scanners for dentomaxillofacial applications. Eur J Radiol 2009;71:461–468.
25. Loubele M, Jacobs R, Maes F, et al. Image quality vs radiation dose of four cone beam computed tomography scanners. Dentomaxillofac Radiol 2008;37:309–318.
26. Vandeweghe S, Vervack V, Dierens M, De Bruyn H. Accuracy of digital impressions of multiple dental implants: an in vitro study. Clin Oral Implants Res 2017;28:648–653.
27. Papaspyridakos P, Hirayama H, Chen CJ, Ho CH, Chronopoulos V, Weber HP. Full-arch implant fixed prostheses: a comparative study on the effect of connection type and impression technique on accuracy of fit. Clin Oral Implants Res 2016;27:1099–1105.
28. Albayrak B, Sukotjo C, Wee AG, Korkmaz İH, Bayındır F. Three-dimensional accuracy of conventional versus digital complete arch implant impressions. J Prosthodont 2021;30:163–170.
29. Lo Russo L, Caradonna G, Troiano G, Salamini A, Guida L, Ciavarella D. Three-dimensional differences between intraoral scans and conventional impressions of edentulous jaws: a clinical study. J Prosthet Dent 2020;123:264–268.
30. Pesce P, Pera F, Setti P, Menini M. Precision and accuracy of a digital impression scanner in full-arch implant rehabilitation. Int J Prosthodont 2018;31:171–175.
31. Ajioka H, Kihara H, Odaira C, Kobayashi T, Kondo H. Examination of the position accuracy of implant abutments reproduced by intra-oral optical impression. PLoS One 2016;11:e0164048.
32. Andriessen FS, Rijkens DR, van der Meer WJ, Wismeijer DW. Applicability and accuracy of an intraoral scanner for scanning multiple implants in edentulous mandibles: a pilot study. J Prosthet Dent 2014;111:186–194.
33. Ahlholm P, Sipilä K, Vallittu P, Jakonen M, Kotiranta U. Digital versus conventional impressions in fixed prosthodontics: a review. J Prosthodont 2018;27:35–41.
34. Di Fiore A, Meneghello R, Graiff L, et al. Full arch digital scanning systems performances for implant-supported fixed dental prostheses: a comparative study of 8 intraoral scanners. J Prosthodont Res 2019;63:396–403.
35. García-Gil I, Cortés-Bretón-Brinkmann J, Jiménez-García J, Peláez-Rico J, Suárez-García MJ. Precision and practical usefulness of intraoral scanners in implant dentistry: a systematic literature review. J Clin Exp Dent 2020;12:e784–e793.
36. Flügge T, van der Meer WJ, Gonzalez BG, Vach K, Wismeijer D, Wang P. The accuracy of different dental impression techniques for implant-supported dental prostheses: a systematic review and meta-analysis. Clin Oral Implants Res 2018;29(suppl 16):374–392.
37. Cappare P, Sannino G, Minoli M, Montemezzi P, Ferrini F. Conventional versus digital impressions for full arch screw-retained maxillary rehabilitations: a randomized clinical trial. Int J Environ Res Public Health 2019;16:829.

Merging von Intraoralscan und DVT: neue Technik zur Verbesserung der Genauigkeit digitaler 3-D-Modelle für implantatgetragene Full-arch-Brücken

Zusammenfassung

Ziel: Es wird eine Technik zum Merging von Intraoralscan und DVT für die Herstellung implantatgetragener Full-Arch-Brücken beschrieben. Ziel ist eine Verbesserung der Dimensionsgenauigkeit von Intraoralscans zahnloser Kiefer.
Material und Methode: Zunächst werden zwei Datensätze gewonnen: ein Intraoralscan und eine DVT, die beide mit in gleichbleibender Position auf den Implantaten befestigten Scankörpern durchgeführt werden. Anschließend wird der Intraoralscan in mehrere Fragmente zerlegt und in neuer Ausrichtung wieder zusammengesetzt, wobei die Implantatpositionen der DVT als Referenz dienen.
Ergebnisse: Die Technik liefert ein optimiertes digitales Modell mit korrekteren Implantatpositionen, das sich als Grundlage für die Herstellung von Full-arch-Brücken eignet.
Schlussfolgerung: Die vorgeschlagene Methode kann mögliche intraorale Scanfehler minimieren und zuverlässigere digitale Abformungen für implantatgetragene Full-arch-Brücken liefern.

Indizes: *Brücke, Dentalimplantate, Full-arch-Rehabilitation, spannungsfreie Passung, Intraoralscanner, IOS, DVT*

Author please send a portrait of the first author (min. width 20 cm at 72 dpi)

Miguel Gómez-Polo

Miguel Gómez-Polo, DDS, PhD
Department of Prosthodontics and Restorative Dentistry, School of Dentistry, Complutense University of Madrid, Madrid, Spain

Juan Ballesteros, DDS
Department of Medicine, University of Córdoba, Spain

Pedro Perales-Padilla, ?
Dentalesthetic Dental laboratory, Úbeda, Jaén, Spain

Pedro Perales-Pulido, ??
Dentalesthetic Dental laboratory, Úbeda, Jaén, Spain

Marta Revilla-León ??
College of Dentistry, Texas A&M University, Dallas, TX; Prosthodontics, University of Washington, Seattle, WA; Revilla Research Center, Madrid, Spain

Rocío Ortega, DDS, PhD
Department of Prosthetic Dentistry, School of Dentistry, European University of Madrid, Madrid, Spain

Address Prof Miguel Gómez-Polo, Department of Prosthodontics and Restorative Dentistry, School of Dentistry, Complutense University of Madrid, Pza. Ramón y Cajal s/n, 28040 Madrid, Spain; Tel: +003 4913942029; Email: mgomezpo@ucm.es