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CLINICAL REPORT

Digital tools and 3D printing technologies integrated into the workflow of restorative treatment: A clinical report

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ABSTRACT

The development of technologies including intraoral scanners, dental software for digital restoration design, and additive manufacturing has improved the digital workflow of restorative treatment. The present article describes a digital workflow with intraoral scanning, computer-aided design (CAD) software, and subtractive and additive manufacturing procedures for a patient receiving lithium disilicate laminate veneers. (J Prosthet Dent 2019;121:3-8)

The 3 fundamental steps of a digital workflow for dental applications are data acquisition or digitalization, data processing with computer-aided design and computer-aided manufacturing (CAD-CAM).[1-5] Data can be obtained from a range of different sources including computed tomography, magnetic resonance imaging, extraoral scanning (contact or laser), and intraoral scanning. The introduction of intraoral scanning devices has minimized human manipulation, decreasing processing errors and saving time and expense.[6-8] Moreover, digital scans have better acceptance by patients.[9,10] The scan strategy[11,12] and the learning curve[13] are important to the final outcome with these devices. Furthermore, studies have reported high levels of accuracy with no significant difference between the measurements on stone and digital casts.[14-20] Dental restorations fabricated from digital scans exhibited similar marginal and internal discrepancies to those fabricated from conventional impressions.[21,22]

As an alternative to the subtractive methods, additive manufacturing (AM) technologies provide manufacturing procedures in which the powder or liquid base material is built into a solid object.[23-28] The most common polymer AM technologies used for dental applications are vat-photopolymerization processes such as stereolithography apparatus or direct light processing (DLP) and multijet printing technologies. The present article describes a digital workflow with intraoral scanning, CAD software, and subtractive and DLP AM procedures for a patient receiving lithium disilicate laminate veneers.

CLINICAL REPORT

A 58-year-old man attended a private practice for esthetic treatment. The anamnesis indicated a healthy general condition. The extraoral examination showed discrepancies in the facial and dental midlines and the maxillary and mandibular dental midline. The man had a medium lip line, concave smile line, and 0 mm of tooth visibility at rest. The clinical examination showed acceptable oral health with periodontal probing depths of no more than 3 mm but generalized moderate periodontitis, localized gingival recession, and disproportionate gingival levels.

The maxillary anterior teeth had been restored with composite resin with defective margins and poor color

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Figure 1. A, Lower third frontal extraoral photograph at rest. B, Smile position. C, Intraoral pretreatment view.

match to the adjacent teeth. Also, most of the posterior teeth had been restored with metal-ceramic fixed prostheses with adequate marginal integrity. Porcelain chipping was observed on the left second mandibular molar. The maxillary and mandibular anterior teeth were overerupted and had a decreased mesiodistal width, with wear facets caused by parafunctional habits. The occlusal plane was altered, and the anteroposterior compensating curve was exaggerated.

Extraoral and intraoral photographs (Fig. 1A-C), videos, radiographs (Fig. 2), and a digital scan were made with an intraoral scanner (TRIOS 3; 3Shape) following the manufacturer's scanning protocol. Treatment options were presented, and, despite the benefits of an interdisciplinary complete-mouth treatment with orthodontic, periodontal, and prosthodontic rehabilitation, the patient elected to restore only the maxillary anterior teeth. The objectives of the selected treatment were to increase the tooth visibility at rest, change the concave smile line, level the gingival margins of the maxillary anterior teeth, cover the Miller class III[29] root exposure of the maxillary canines as much as possible, and replace the defective composite resin restorations of the maxillary anterior teeth.

A digital diagnostic waxing was prepared using software (Dental System; 3Shape) to import the direct connection mode file obtained from the digital scan (Fig. 3). The diagnostic tools of the CAD software were used to measure the addition on the incisal and facial surfaces of the virtually waxed teeth and the amount of gingivectomy or crown lengthening virtually designed on the maxillary anterior teeth. The length of the maxillary central incisors was increased by 1.17 mm, and the increase to the facial surfaces of the maxillary anterior teeth ranged from 0.4 to 1.2 mm. Software (RealView Dental System; 3Shape) was used to superimpose the digital diagnostic waxing on the patient's photographs (Fig. 4). When this process was completed, a standard tessellation language (STL) file of virtual waxing was exported.

A digitally designed silicone index was prepared using software (Dental System; 3Shape) and DLP additive manufactured (D30 RapidShape; RapidShape) with clear flexible photopolymer resin (Ortho IBT Clear; NextDent Vertex Dental) (Fig. 5). The facial finishing

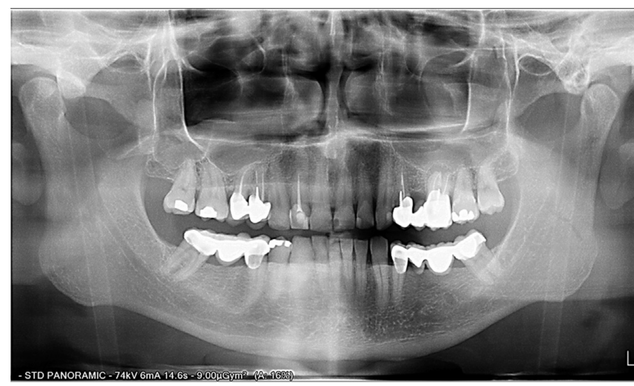

Figure 2. Pretreatment panoramic radiograph.

line of the silicone index was virtually determined on the new gingival margin of the maxillary anterior teeth, and the index was prepared with a uniform 8-mm thickness. Trial restorations were prepared from the 3-dimensional (3D) printed silicone index and an interim composite resin material (Protemp 4 A2; 3M ESPE). The esthetics, function, and phonetics were evaluated (Fig. 6).[30,31] No modifications of the trial restorations were needed.

The gingivectomy and crown lengthening of the maxillary incisors was referred to a periodontist in private practice, with the trial restorations as a reference. A free connective tissue graft was performed to cover the buccal root exposure of the maxillary canines. A period of 9 months after surgery was allowed for healing.

The defective composite resin restorations of the maxillary anterior teeth were replaced, achieving the tooth dimensions of the digital diagnostic waxing to evaluate the function, phonetics, and esthetics for 3 months. A digital scan of the maxillary (pre-preparation scan) and mandibular (antagonist scan) arches and interocclusal relationship (occlusal scan) was made using the same intraoral scanner according to the manufacturer's scanning protocol (Fig. 7). The diagnostic restorations were used to prepare the maxillary anterior teeth for lithium disilicate milled veneer restorations[32,33] using medium grit and fine grain diamond rotary

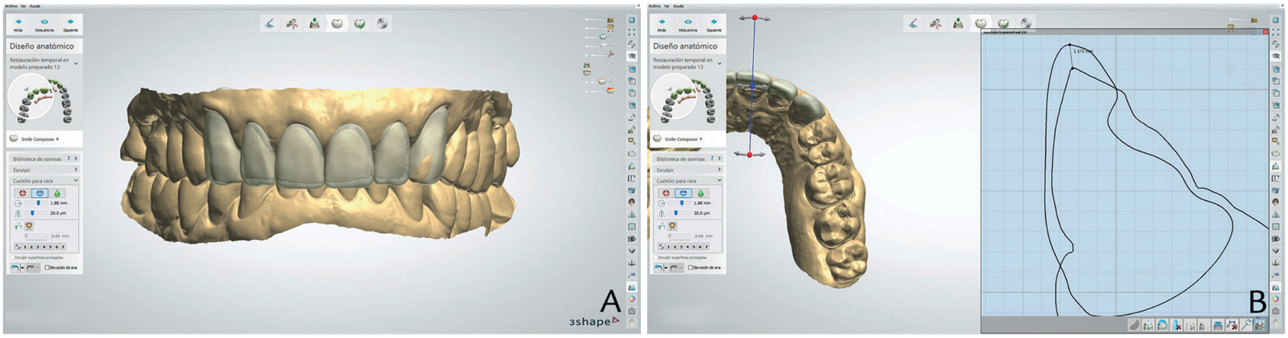

Figure 3. A, Diagnostic virtual waxing of maxillary anterior teeth. B, Measurement of amount of coronal lengthening of maxillary left central incisor achieved with virtual diagnostic waxing.

Figure 4. Virtual simulation of 3-dimensional digital diagnostic waxing on 2-dimensional photograph of patient using dental software (RealView Dental System; 3Shape). A, Rest position. B, Smile position.

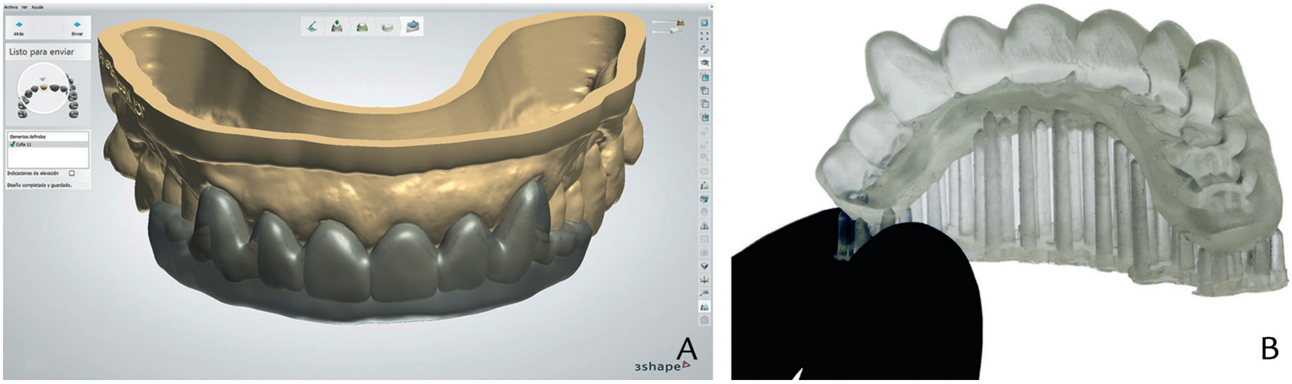

Figure 5. A, Virtual design of silicone index with dental software (Dental System; 3Shape). B, 3-dimensionally printed flexible clear polymer index (Ortho IBT; Vertex NextDent).

instruments (868.314.012/016, 8868.314.012/016 bur; Komet Dental); line angles were rounded with polishing disks (Sof-lex XT Discs; 3M ESPE). Two displacement cords (000, 00 Ultrapack Retraction Cord; Ultradent Products, Inc) were packed, and the digital scan of the prepared tooth (preparation scan) was made using the same intraoral scanner (Fig. 8A). The absence of undercuts on the veneer preparations and the restorative interocclusal space was verified using the intraoral scanner software, and the file was sent to the dental laboratory through an internet connection. Interim restorations were fabricated from a composite resin interim material (Protemp 4 A2; 3M ESPE) by using the 3D printed silicone index (Fig. 8B).

The monolithic lithium disilicate veneer restorations were designed with software (Dental System; 3Shape).

Figure 6. A, Clinical evaluation of additive manufactured silicone index. B, Rest position. C, Smile position with trial restorations.

Figure 7. A, Digital scan of trial restorations (pre-preparation scan). B, Digitalization of mandibular arch (antagonist scan). C, Interocclusal record (occlusal scan) completed with intraoral scanner device (TRIOS 3 intraoral scanner; 3Shape).

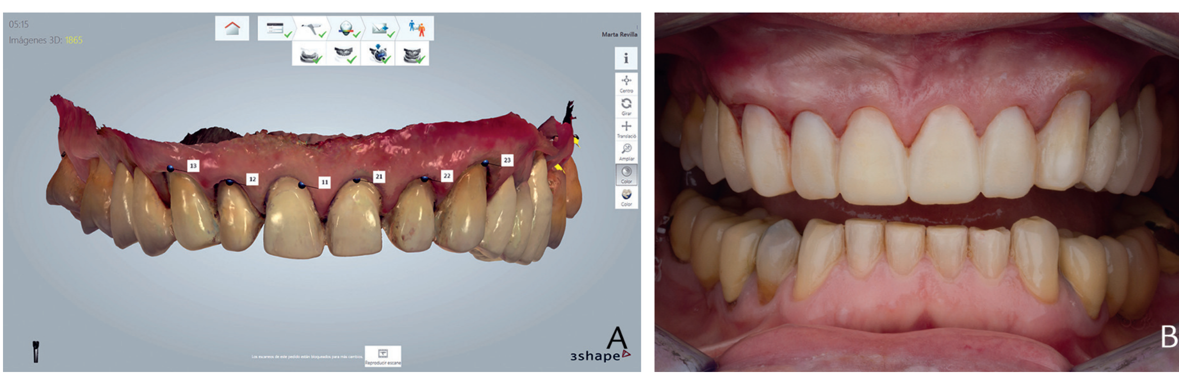

Figure 8. A, Digital scan of tooth preparation of maxillary anterior teeth (preparation scan) using same intraoral scanner (TRIOS 3 intraoral scanner; 3Shape). B, Composite resin interim restorations on maxillary anterior teeth.

The trial restorations acted as a reference and were scanned as the pre-preparation situation that provided the information for the dental maxillary midline, shape, dimensions, and position of the maxillary anterior teeth. When the design was completed, the STL file was exported and used to mill (Zenotec Select Hybrid Wieland; Ivoclar Vivadent AG) the lithium disilicate restorations (IPS e.max CAD LT-A2 ingots; Ivoclar Vivadent AG). The same STL file was used to prepare the maxillary and mandibular definitive casts using software (Model Builder; 3Shape). The casts were fabricated with DLP AM technology (D30 RapidShape; RapidShape) with a 25-µm thickness of photopolymer (NextDent Model, Oker color; NextDent Vertex Dental).

At the delivery appointment, the interim restorations were removed, and the teeth were cleaned with a prophylaxis brush (1102F.204.060 fine prophylaxis brush; Jota AG) and pumice (Topex Prep & Polishing Paste; Sultan Healthcare). The veneers were evaluated (RelyX Veneer Try-in TRT; 3M ESPE) to verify the marginal fit, proximal contacts, and color match with the adjacent teeth. The ceramic veneers were cemented with a light-polymerizing cement (RelyX Veneer Cement Translucent; 3M ESPE) (Fig. 9). Radiographs were made after the restorations were delivered (Fig. 10), and the patient was scheduled for yearly follow-up appointments.

DISCUSSION

The digital tools allowed efficient evaluation of the diagnostic information, including 3D measurements of

Figure 9. Photographs after treatment. A, Rest position. B, Smile position. C, Frontal view of cemented lithium disilicate veneers.

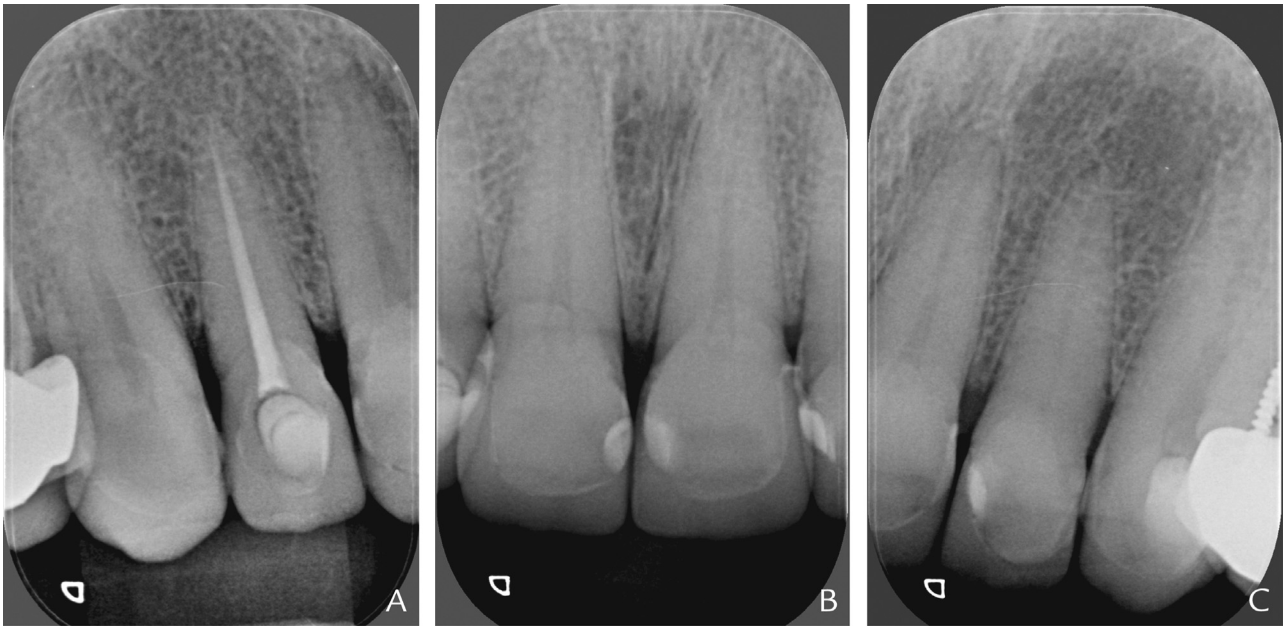

Figure 10. Periapical radiographs after treatment. A, Maxillary right canine and lateral. B, Maxillary right and left central incisors. C, Maxillary right lateral and canine.

the virtual waxing thicknesses to determine the amount of tooth reduction needed and the available restorative space.[34,35] Additionally, the CAD software allowed alignment of the 3D virtual waxing with a 2-dimensional patient photograph, which could have been used as a communication tool. However, for this patient, trial restorations were used because these represented a more realistic estimation of the treatment.[29,36-38] The flexible clear polymer that was fabricated with AM connected the virtual diagnostic waxing to the patient's mouth. This step avoided 3D printing of the cast.

Polymer AM technologies also allow replication of the definitive casts for fabrication of the veneers.[26,28] Through the CAD software, a solid or working definitive cast can be generated. However, for this patient, monolithic lithium disilicate veneers were provided, so the definitive cast could have been omitted because the interproximal and occlusal contact points were designed and manufactured with CAD-CAM. Definitive casts are, however, essential when a labial cut back is designed on the ceramic veneers for feldspathic porcelain application.

SUMMARY

This clinical report describes the provision of laminate veneers in a completely digital workflow. An intraoral scanner, CAD software, and subtractive and additive manufacturing procedures were used.

REFERENCES

1. Young JM, Altschuler BR. Laser holography in dentistry. J Prosthet Dent 1977;38:216-25.
2. Kalpakjian S, Schmid SR. Manufacturing engineering and technology. 7th ed. New York: Addison-Wesley: New York; 2014. p. 1-10.
3. Van Noort R. The future of dental devices is digital. Dent Mater 2012;28:3-12.
4. Horn TJ, Harrysson OLA. Overview of current additive manufacturing technologies and selected applications. Sci Prog 2012;95:255-82.
5. Al-Jubouri O, Azzari A. An introduction to dental digitizers in dentistry: systematic review. J Chem Pharm Res 2015;7:10-20.
6. Christensen GJ. Impressions are changing: deciding on conventional, digital or digital plus in-office milling. J Am Dent Assoc 2009;140:1301-4.
7. Joda T, Brägger U. Digital vs. conventional implant prosthetic workflows: a cost/time analysis. Clin Oral Implants Res 2015;26:1430-5.

8. Lee JS, Gallucci GO. Digital vs. conventional implant impressions: efficiency outcomes. Clin Oral Implants Res 2013;24:111-5.
9. Wismeijer D, Mans R, van Genuchten M, Reijers HA. Patients' preferences when comparing analogue implant impressions using a polyether impression material versus digital impressions (Intraoral Scan) of dental implants. Clin Oral Implants Res 2014;25:1113-8.
10. Joda T, Brägger U. Patient-centered outcomes comparing digital and conventional implant impression procedures: a randomized crossover trial. Clin Oral Implants Res 2016;27:e185-9.
11. Anh JW, Park JM, Chun YS, Kim M, Kim M. A comparison of the precision of three-dimensional images acquired by 2 digital intraoral scanners: effects of tooth irregularity and scanning direction. Korean J Orthod 2016;46:3-12.
12. Müller P, Joda T, Katsoulis J. Impact of digital intraoral scan strategies on the impression accuracy using the TRIOS Pod scanner. Quintessence Int 2016;47:343-9.
13. Kim J, Park JM, Kim M, Heo SJ, Shin IH, Kim M. Comparison of experience curves between two 3-dimensional intraoral scanners. J Prosthet Dent 2016;116:221-30.
14. International Organization for Standardization. ISO 5725-1:1994. Accuracy (trueness and precision) of measurement methods and results - Part 1: general principles and definitions. Geneva: International Organization for Standardization; 1994. Available at: https://www.iso.org/obp/ui/#iso:std:iso:5725:-1:ed-1:v1:en
15. Keating AP, Knox J, Bibb R, Zhurov AI. A comparison of plaster, digital and reconstructed study model accuracy. J Orthod 2008;35:191-201.
16. Cuperus AMR, Harms MC, Rangel FA, Bronkhorst EM, Schols JGJ, Beruning KH. Dental models made with an intraoral scanner: a validation study. Am J Orthod Dentofacial Orthop 2012;142:308-13.
17. Patzelt SB, Emmanouilidi A, Stampf S, Strub JR, Att W. Accuracy of full-arch scans using intraoral scanners. Clin Oral Investig 2014;18:1687-94.
18. Ender A, Mehl A. In-vitro evaluation of the accuracy of conventional and digital methods of obtaining full-arch dental impressions. Quintessence Int (Berl) 2015;46:9-17.
19. Aragon MLC, Pontes LF, Bichara LM, Flores-Mir C, Normando D. Validity and reliability of intraoral scanners compared to conventional gypsum models measurements: a systematic review. Eur J Orthod 2016;38:429-34.
20. Goraci C, Franchi L, Vichi A, Ferrari M. Accuracy, reliability, and efficiency of intraoral scanners for full-arch impressions: a systematic review of the clinical evidence. Eur J Orthod 2016;38:422-8.
21. Chochlidakis KM, Papaspyridakos P, Geminiani A, Chen CJ, Feng IJ, Ercoli C. Digital versus conventional impressions for fixed prosthodontics: a systematic review and meta-analysis. J Prosthet Dent 2016;116:184-90.
22. Budak I, Vukelić D, Bračun D, Hodolič J, Soković M. Pre-processing of point-data from contact and optical 3D digitization sensors. Sensors 2012;12:1100-26.
23. ASTM, Committee F42 on Additive Manufacturing Technologies. Standard terminology for additive manufacturing—general principles and terminology. ISO/ASTM52900–2015. West Conshohocken, PA: ASTM International; 2009. Available at https://www.iso.org/standard/69669.html.
24. Azari A, Nikzad S. The evolution of rapid prototyping in dentistry: a review. Rapid Prototyping J 2009;15:216-25.
25. Sun J, Zhang FQ. The application of rapid prototyping in prosthodontics. J Prosthodont 2012;21:641-4.
26. Stansbury JW, Idacavage MJ. 3D printing with polymers: challenges among expanding options and opportunities. Dent Mater 2016;32:54-64.
27. Abduo J, Lyons K, Bennamoun M. Trends in computer-aided manufacturing in prosthodontics: a review of the available streams. Int J Dent 2014;2014:783948.
28. Revilla-León M, Sánchez-Rubio JL, Oteo-Calatayud J, Özcan M. Impression technique for a complete-arch prosthesis with multiple implants using additive manufacturing technologies. J Prosthet Dent 2017;117:714-20.
29. Miller PD Jr. A classification of marginal tissue recession. Int J Periodontics Restorative Dent 1985;5:8-13.
30. Magne P, Magne M, Belser U. The diagnostic template: a key element to the comprehensive esthetic treatment concept. Int J Periodontics Restorative Dent 1996;16:560-9.
31. Magne P, Magne M, Belser U. Natural and restorative oral esthetics. Part I: rationale and basic strategies for successful esthetic rehabilitations. J Esthet Dent 1993;5:161-73.
32. Gurel G. The science and art of porcelain laminate veneers. Chicago: Quintessence Publishing Co; 2003. p. 43-54.
33. Magne P, Belser UC. Novel porcelain laminate preparation approach driven by a diagnostic mock-up. J Esthet Restor Dent 2004;16:7-18.
34. Seelbach P, Brueckel C, Wostmann B. Accuracy of digital and conventional impression techniques and workflow. Clin Oral Investig 2013;17:1759-64.
35. Syrek A, Reich G, Ranftl D, Klein C, Cerny B, Brodesser J. Clinical evaluation of all-ceramic crowns fabricated from intraoral digital impressions based on the principle of active wavefront sampling. J Dent 2010;38:553-9.
36. Simon H, Magne P. Clinically based diagnostic wax-up for optimal esthetics: the diagnostic mock-up. J Calif Dent Assoc 2008;36:355-62.
37. Patzelt SB, Vonau S, Stampf S, Att W. Assessing the feasibility and accuracy of digitizing edentulous jaws. J Am Dent Assoc 2013;144:914-20.
38. Ender A, Mehl A. Influence of scanning strategies on the accuracy of digital intraoral scanning systems. Int J Comput Dent 2013;16:11-2.

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