RESEARCH AND EDUCATION

Accuracy of a chairside intraoral scanner compared with a laboratory scanner for the completely edentulous maxilla: An in vitro 3-dimensional comparative analysis

Fernando Zarone, MD, DDS,[a] Gennaro Ruggiero, DDS,[b] Marco Ferrari, MD, DMD, PhD,[c] Francesco Mangano, DDS, PhD,[d] Tim Joda, DDS, MSc, PhD,[e] and Roberto Sorrentino, DDS, MSc, PhD[f]

ABSTRACT

Statement of problem. Intraoral scanners are promising options for removable prosthodontics. However, analog aids, including occlusion rims, are still used, as a completely digital workflow is challenging and scientific evidence on the topic is scarce.

Purpose. The purpose of this in vitro study was to assess and compare the trueness and precision of scans obtained from a reference typodont of a completely edentulous maxilla by using an intraoral scanner (TRIOS 3 Pod; 3Shape A/S) with scans obtained by using a laboratory scanner (DScan 3; EGS S.R.L.) from both Type IV stone casts and polysulfide impressions.

Material and methods. The polyurethane resin reference typodont was replicated from a clinical cast and was scanned with a metrological machine to obtain a reference scan. Ten digital casts were obtained by applying standardized scanning strategies to the reference typodont with the intraoral scanner. A device was created to make 10 consistent polysulfide impressions, and a scan of each impression was made with the laboratory scanner and then digitally reversed to obtain 10 digital reversed casts. Ten Type IV stone casts were poured and then scanned with the laboratory scanner to obtain 10 digital extraoral scanner casts. The scans in standard tessellation language (STL) format were imported into a dedicated software program, and the trueness and precision were calculated in μm. In addition to descriptive statistics (confidence interval 95%), 1-way ANOVA followed by the Bonferroni test or the Kruskal-Wallis and the Dunn tests were used to analyze differences among groups (α=.05).

Results. The trueness values (95% confidence interval) were digital intraoral scanner cast=48.7 (37.8-59.5), digital reversed cast=249.9 (121.3-378.5), and digital extraoral scanner cast=308.8 (186.6-430.9); significant differences were detected between digital intraoral scanner cast and digital reversed cast (P<.001) and between digital IOS casts and digital extraoral scanner cast (P<.001). The precision values (95% confidence interval) were digital intraoral scanner cast=46.7 (29.7-63.7), digital reversed cast=271.2 (94.6-447.8), and digital extraoral scanner cast=341.4 (175.5-507.3); significant differences were detected between digital intraoral scanner cast and digital reversed cast (P=.003) and between digital intraoral scanner cast and digital extraoral scanner cast (P=.001).

Conclusions. Directly scanning a solid typodont of a completely edentulous maxilla with the intraoral scanner produced better trueness and precision than scanning the polysulfide impressions or the stone casts with a laboratory scanner. (J Prosthet Dent 2020;124:761.e1-e7)

Interest in fabricating completely digital complete dentures has focused on the use of intraoral scanners (IOSs), as these may offer faster treatment, better prosthesis fit, and ease of denture duplication.[1] Moreover, the fabrication of completely digital dentures based on computer-aided design and computer-aided manufacturing (CAD-CAM) technology might offer time and cost savings,[1,2] better mechanical performance,[1]

[a]Professor and Chair, Division of Prosthodontics and Digital Dentistry, Department of Neurosciences, Reproductive and Odontostomatological Sciences, University "Federico II" of Naples, Naples, Italy.

[b]PhD student, Division of Prosthodontics and Digital Dentistry, Department of Neurosciences, Reproductive and Odontostomatological Sciences, University "Federico II" of Naples, Naples, Italy.

[c]Professor and Chair, Division of Restorative Dentistry and Endodontics, Department of Medical Biotechnologies, University of Siena, Siena, Italy.

[d]Associate Professor, Department of Prevention and Communal Dentistry, Sechenov First State Medical University of Moscow, Moscow, Russia.

[e]Professor and Vice Chair, Department of Reconstructive Dentistry, University Center for Dental Medicine Basel, University of Basel, Basel, Switzerland.

[f]Research Professor, Division of Prosthodontics and Digital Dentistry, Department of Neurosciences, Reproductive and Odontostomatological Sciences, University "Federico II" of Naples, Naples, Italy.

Clinical Implications

Digitizing the completely edentulous maxilla is feasible with an intraoral scanner, whereas there is no difference in trueness and precision for scanning the elastomeric impression or the stone cast with a laboratory scanner.

optimum prosthetic fit,[1,3,4] and ease of denture duplication and reproduction.[1] Currently, laboratory costs are still higher than conventional denture processing by pressing heat-polymerizing resin,[1,2,5] as the resin disks are expensive.

The protocol for a digital complete denture starts by digitizing an edentulous arch; this can be accomplished in different ways.[6-8] A laboratory scanner can be used to obtain a file from a conventional stone cast. Alternatively, the physical impression can be scanned by using a laboratory scanner and then the file reversed to make a positive digital cast.[6-8] A third option is making a digital scan of the edentulous arch with an IOS.[6-12]

Studies on digital procedures for completely edentulous arches are still scarce, in particular with regard to scanning methods, clinical usage, and digitization accuracy. The accuracy of a measurement method is described by trueness and precision.[13] Trueness refers to the closeness of agreement among the mean of a large number of test results and the reference value; precision describes the closeness of agreement among intragroup data obtained by repetitive measurements.[13,14] Differences in accuracy have been reported among different IOSs,[15] between IOSs and laboratory scanners,[16] and between cone beam computed tomography (CBCT) and laboratory scans.[17]

Conventional elastomeric impression making and stone cast pouring lead to inaccuracy of the definitive cast[18,19] because of the expansion, shrinkage, and distortion of impression materials[20-24] and/or stone casts.[25,26] In addition, detachment of the impression material from the tray surface during impression removal,[23] transfer to the laboratory,[21] changes in temperature,[21,24] and the influence of disinfection agents[27-30] may also lead to errors. Conversely, the technology of the IOS, the scanning procedure, and the anatomy of the tissues can affect accuracy.[15,31] When a flat and smooth edentulous ridge and palatal vault are scanned, the stitching processing of images or videos can introduce errors because of the lack of anatomic landmarks.[15,31] Accurate border molding and providing a posterior palatal seal are not currently possible when using an IOS because a method of soft tissue displacement is lacking.[7,8,10,12]

The purpose of the present in vitro investigation was to compare the trueness and precision of different intraoral and extraoral scanning approaches on a reference typodont of a completely edentulous maxilla. The null hypothesis was that no difference would be found in trueness and precision among the protocols.

MATERIAL AND METHODS

A reference typodont (RT) (Fig. 1) was fabricated by pouring polyurethane resin (PRIMA-DIE; Gerhò S.P.A) into a mold of an edentulous maxilla obtained from a cast used for a clinical purpose and duplicated with a silicone material (Elite Double 8; Zhermack SpA). Polyurethane resin was used because of its high mechanical resistance[32] and optimal light diffusion.[33] The RT was then scanned with a metrological scanner (Atos Core 80; GOM GmbH) based on a structured white-light technology with a working distance=170 mm, point spacing=0.03 mm, and measure accuracy=±2.5 μm to obtain a digital reference typodont (dRT) in standard tessellation language (STL) format.

The RT was scanned by using an IOS (TRIOS 3 Pod; 3Shape A/S) with an accuracy of 6.9 ±0.9 μm. After the calibration procedure of the IOS, 10 initial scans were made as a test and then discarded. Subsequently, 10 digital IOS casts (dIOC) (Fig. 2) were obtained by scanning the RT along the ridge of the arch, starting from the right maxillary tuberosity and ending at the left one and then continuing on the buccal side and finally on the palatal vault with a clockwise movement (Fig. 3). One prosthodontist (G.R.) performed all the scans sequentially with an interval of 10 minutes to rest and allow the IOS to cool.[34,35] The numbers of images per scan varied between 743 and 1126, and the scanning time was between 1 and 2 minutes.

Ten conventional polysulfide (Permlastic, regular body; Kerr Corp) impressions of the RT were made in a standardized and reproducible way with a dedicated tester. The solid typodont in polyurethane resin was hydrophobic and had undercuts at the edentulous crests; for these reasons, polysulfide was chosen, as it is hydrophobic, with reduced rigidity and higher tear strength and flexibility during removal than polyether, polyvinyl siloxane, or condensation silicones.[6,36-38] A custom impression tray was made placing a 3-mm layer of wax (Tenasyle; Associated Dental Products Ltd) onto the RT as a spacer between the preformed light-polymerizing resin base (ValSax; Capuozzo S.r.l.) and the RT. The border area of the impression tray was 2-mm short of the buccal vestibule.[39] The tray was border molded with modeling plastic impression compound (ISO Functional Sticks; GC EUROPE A.G.). No handle was designed on the tray because the tray was secured to the tester base with 3 cylinders protruding from the external surface of the tray. The impression trays were replicated with a

Figure 1. Reference typodont in polyurethane resin.
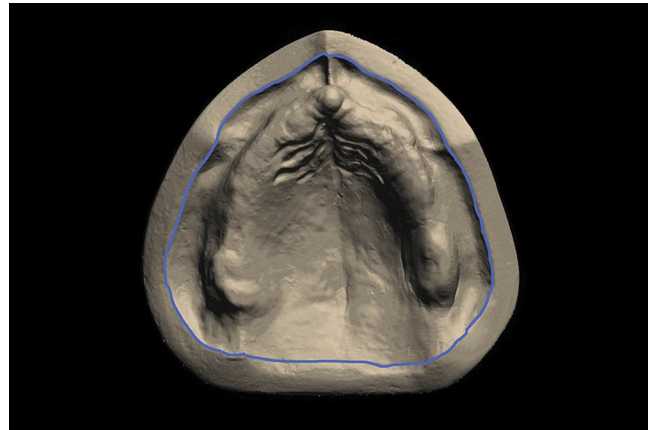

Figure 2. Scan of reference typodont with intraoral scanner. *Blue line* represents border line of specimens for superimposition.

silicone material (ADDISIL A+B 85; Bartolini Dental Group S.r.l.) poured with an autopolymerizing resin (BI CRYL COLD N; Bartolini Dental Group S.r.l).

The tester was a custom-made, steel mechanical precision device with a square support base. Three holes in the base corresponded to the 3 reference cylinders of the tray. The base supported 4 perpendicular cylinders, allowing the upper plate to slide smoothly onto the base. The upper base had 3 holes to block the typodont to its lower surface with 3 passing screws. The upper plate was loaded (49 N) to lock the typodont to the tray containing the polysulfide. This force was higher than that used clinically (approximately 10 N)[40] but did not compress the impression material because 4 polyvinyl chloride tubes were used as a mechanical stop to provide a 3-mm space. Ten polysulfide impressions were made: manual mixing time=50 seconds (mixing ratio 1:1); placing material into the tray and impression making=60 seconds; removal of the tray from the tester=15 minutes from the beginning of mixing. Because the manufacturer advises pouring an impression between 30 minutes and 8 hours after impression making and polysulfide-based materials are dimensionally stable for up to 12 hours,[41] each impression was scanned with a laboratory extraoral scanner (DScan 3; EGS S.R.L.) using a structured blue light-emitting diode (LED) after 2 hours. Ten digital casts (dREC) were obtained by activating the function "Invert Selected Normals" of a software program (DentalCad 6.2; EGS S.R.L.) (Fig. 4A, 4B).

A Type IV stone (Elite Stone; Zhermack SpA) was mixed as per the manufacturer's instructions (150 g powder, 37.5 mL water, 60-second manual mix, and 30-second vacuum mix, poured into the impressions, and removed after 45 minutes). They were immediately scanned with the laboratory extraoral scanner to obtain 10 digital casts (dEOC) (Fig. 4C). These procedures were performed in the same room under similar
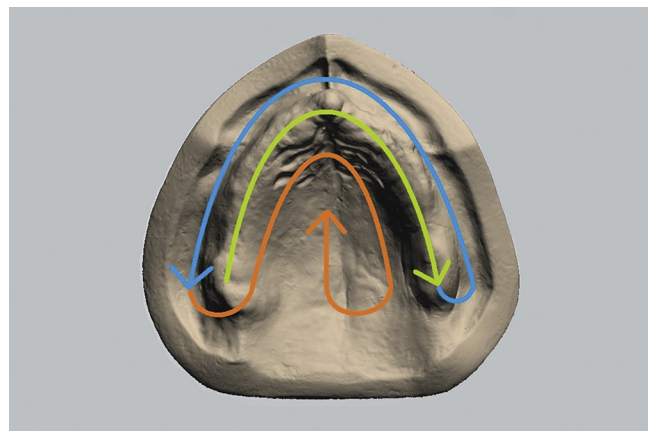
Figure 3. Scanning strategy with intraoral scanner. *Green arrow* indicates top ridge scanning. *Blue arrow* indicates scanning strategy of buccal ridge. *Orange arrow* indicates scanning strategy of palatal vault.

environmental conditions (temperature 24 °C, pressure 760 ±5 mmHg, and 50% relative humidity). The same experienced and calibrated operator (R.S.) made and poured the impressions. The 3 groups of STL files (n=10) were imported into an inspection software program (Geomagic Control X; 3D SYSTEMS) to calculate trueness and precision in μm.

All the STL files were imported into a dedicated software program (MeshLab v2016.12; ISTI-CNR) by using the dRT as a guide to cut the surplus surfaces of each digital experimental cast. The border line of specimens for superimposition was delineated at the boxing line of the native cast from which RT was obtained (Fig. 2). The dRT and every digital cast were imported into Geomagic Control X to be superimposed (Fig. 5), indicating dRT as "reference data" in the software program.[42]
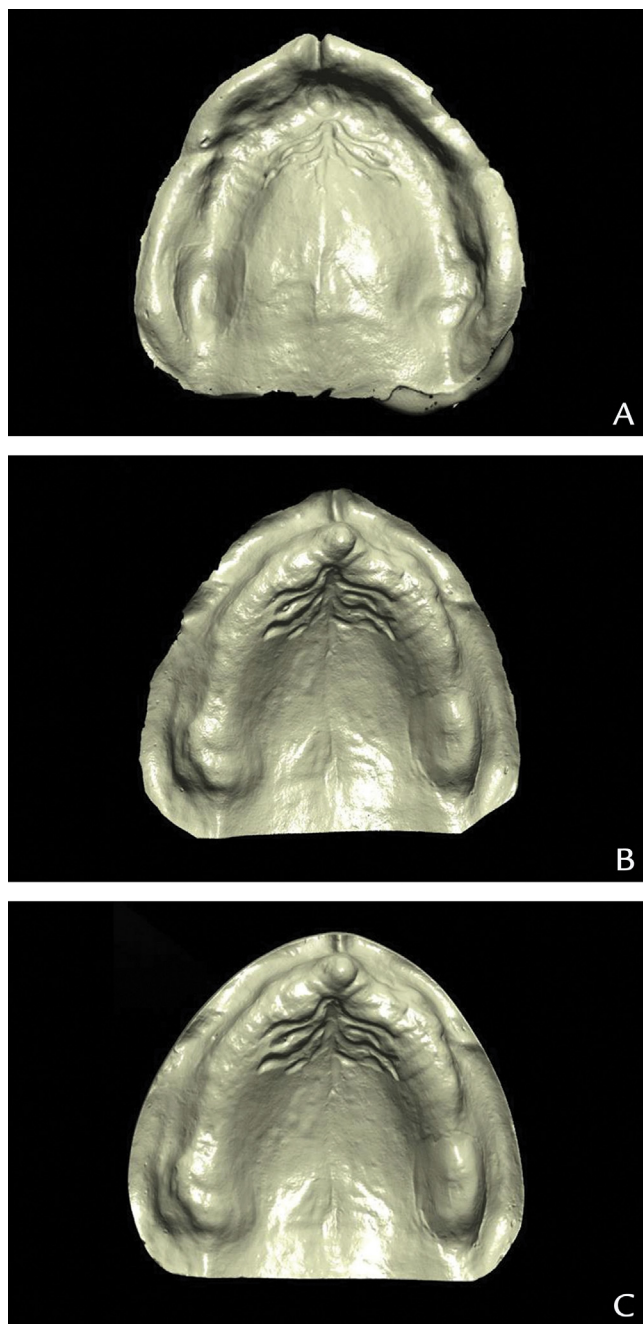
Figure 4. Scans tested. A, Scan of physical impression in polysulfide with laboratory scanner. B, Digital cast (dREC) obtained from inversion of scan of polysulfide impression. C, Scan of stone cast with laboratory scanner (dEOC). dEOC, digital extraoral scanner cast; dREC, digital reversed cast.

The 2 digital casts were superimposed in the software program by activating the function "initial alignment" and then the function "best-fit alignment," which aligned the 2 digital casts with a minimal distance between the superimposed surfaces.[43] Then, the "3D compare" function was activated, and the value of standard deviation (SD) was chosen from the "tabular view-3D compare." The SD value calculated by the software program indicated a mean between the positive and negative deviations resulting from each superimposition of the digital surfaces, and the mean of the SD values was chosen to evaluate the trueness and precision.[6,34] With this procedure, a color map was created to visualize the displacement between the superimposed digital casts (Fig. 5). For each experimental group, the trueness was calculated as the mean of the SD values resulting from the superimposition of each cast and the dRT. The precision was evaluated as the mean of the SD values recorded after the superimposition between each cast of an experimental group and the cast that recorded the best result of trueness in the same group. Therefore, all the scans of the same group were superimposed onto this selected cast, whose trueness corresponded to the actual reference value for precision.[6,34]

Statistical analysis was performed with a statistical software program (IBM SPSS Statistics, v25; IBM Corp). Both for the evaluation of trueness and precision, descriptive statistics (mean, standard error, 95% confidence intervals), and confirmatory factor analysis tests were determined. The sample size was determined to be appropriate for factor analysis by using the Kaiser-Meyer-Olkin (KMO) measure of sampling adequacy and the Bartlett test of sphericity. Thus, the KMO value should be higher than 0.500 and the chi-square value of the Bartlett test must be significant at α=.05.[44] The Shapiro-Wilk test was used to check data normality, the Levene test was run to evaluate variance homogeneity, and the 1-way ANOVA followed by the Bonferroni test or the Kruskal-Wallis and the Dunn tests were run to evaluate the statistical significance of the differences among the groups (α=.05).

RESULTS

The trueness and precision of the KMO statistic were 0.572 and 0.650, respectively, values higher than the recommended 0.500, and the Bartlett test was statistically significant both for trueness (P=.009) and precision (P=.007). The results for trueness are summarized in Table 1; mean values were not normally distributed for all groups of scans, as detected by the Shapiro-Wilk test (P<.05). The Levene test showed no homogeneity of the variances (P=.002) for the different groups. A $\log_{10}$ transformation of the data was performed because the assumptions on the normal distribution and the homogeneity of the variances were violated to evaluate differences with a 1-way ANOVA. After this transformation, the Shapiro-Wilk test detected a normal distribution (P>.05), and the Levene test reported homogeneity of the variances (P=.079). Furthermore, the Bonferroni test detected statistically significant
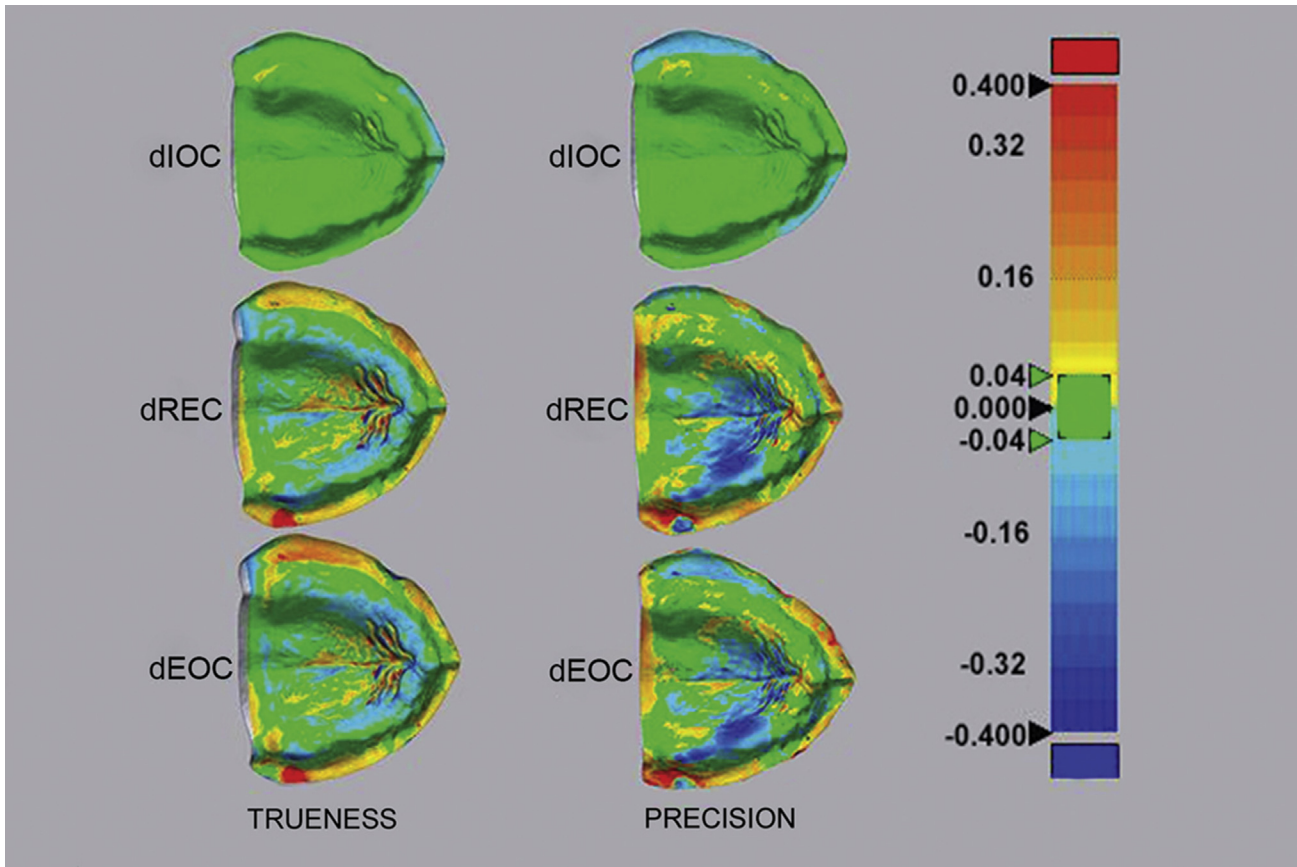
Figure 5. Evaluation of trueness and precision: Best superimposition for each group of scans. *Green areas* indicate minimum displacements of ±0.04 mm of digital cast compared with reference data. *Red areas* indicate outward displacement of +0.4 mm. *Blue areas* indicate inward displacement of -0.4 mm. dEOC, digital extraoral scanner cast; dIOC, digital intraoral scanner cast; dREC, digital reversed cast.

Table 1. Mean with 95% CI for trueness measures in μm by scanning methods

Type of Cast	Mean	Lower-Upper Bound (95% CI)	Standard Error
dIOC	48.720	37.876-59.564	4.793
dREC	249.960	121.349-378.571	56.853
dEOC	308.820	186.641-430.999	54.009

CI, confidence interval; dEOC, digital extraoral scanner cast; dIOC, digital intraoral scanner cast; dREC, digital reversed cast.

Table 2. Mean with 95% CI and actual reference values for precision measures in μm by scanning methods

Type of Cast	Mean	Lower-Upper Bound (95% CI)	Standard Error	Actual Reference Value
dIOC	46.767	29.780-63.754	7.366	32.4
dREC	271.250	94.606-447.894	74.702	97.6
dEOC	341.438	175.500-507.375	70.175	136.9

CI, confidence interval; dEOC, digital extraoral scanner cast; dIOC, digital intraoral scanner cast; dREC, digital reversed cast.

differences between the means values of dIOC and dREC (P<.001) and between dIOC and dEOC (P<.001).

The results for precision with the actual reference values are summarized in Table 2; mean values were not normally distributed for all groups of scans, as detected by the Shapiro-Wilk test (P<.05). The Levene test showed no homogeneity of the variances (P=.002) for the different groups. A $\log_{10}$ transformation of the data was performed because the assumptions on the normal distribution and the homogeneity of the variances were violated to evaluate differences with a 1-way ANOVA. After this transformation, the Shapiro-Wilk test did not detect a normal distribution (P<.05), whereas the Levene

test reported homogeneity of the variances (P=.083). The Kruskal-Wallis (P<.001) and the Dunn tests were performed with the Bonferroni correction, and statistically significant differences were detected between the means of dIOC and dREC (P=.003) and between dIOC and dEOC (P=.001). P values of post hoc comparisons are reported in Table 3.

The trueness and precision were better with the IOS than with the laboratory scanner. No significant differences were detected between scanning the polysulfide impressions or the stone casts. From the analysis of the color maps (Fig. 5), dREC and dEOC exhibited more displacement than dIOC. Particularly, outward

Table 3. Post hoc comparisons among scanning methods

Accuracy (Log$_{10}$)	Type of Scan		P
Log$_{10}$ trueness	dIOC	dREC	<.001*
		dEOC	<.001*
	dREC	dEOC	.696
Log$_{10}$ precision	dIOC	dREC	.003*
		dEOC	.001*
	dREC	dEOC	1.00

dEOC, digital extraoral scanner cast; dIOC, digital intraoral scanner cast; dREC, digital reversed cast. *Statistically significant differences (P<.05).

displacements were detected at the buccal vestibule up to 400 μm, and inward displacements were observed at the palatal vault and on the top of the edentulous crest up to 320 μm.

DISCUSSION

The null hypothesis that no difference would be found in the trueness and precision among the various scanning typologies tested was rejected because statistically significant differences were detected between the means of dIOC and dREC (trueness: P<.001; precision: P=.003) and between dIOC and dEOC (trueness: P<.001; precision P=.001). The evaluation of trueness and precision obtained with different digitization techniques showed that scanning the typodont directly with an IOS (dIOC) was more accurate in terms of trueness and precision, with statistically significant differences compared with the reverse scans of the physical impression (dREC) and with the scans of the stone casts (dEOC), both with a laboratory scanner. These results could be explained by the absence of material distortions when direct scanning with an IOS, particularly the negative effects of both polysulfide[25,26] and stone[20-24] deformation on the final accuracy.

Although significant differences were detected, because of the experimental and comparative nature of the present investigation, the clinical impact of these differences may be small. The findings suggest no difference for trueness and precision in scans performed with a laboratory scanner among the polysulfide impressions and the corresponding stone casts, in spite of the mean of the polysulfide impressions showing values of trueness and precision better than the stone casts. Moreover, the tested IOS has better trueness and precision than conventional impression making for recording the test cast, notwithstanding the limitations of a solid object. However, using an IOS in the oral cavity causes passive and excessive displacements of soft tissues, making the definition of the denture borders inaccurate.[7,8,10,12]

Limitations of the present investigation included its in vitro design with a solid polyurethane typodont. Factors, in particular, the temperature, humidity, optical features, resilience, and mobility of soft tissues, related to the intraoral anatomic limitations and to the oral environment were not taken into account. Moreover, the experimental impressions were made at room temperature, making them more accurate than clinical impressions because of the absence of the thermal contraction of the impression materials from the intraoral to room temperature.[45] Further experimental studies with a larger number of specimens should be made to confirm the outcomes of the present investigation.

CONCLUSIONS

Based on the findings of this in vitro study, the following conclusions were drawn:

1. Direct scanning of a solid typodont of a completely edentulous maxilla with an IOS produced better trueness and precision than indirect digitization of both polysulfide impressions and stone casts with an extraoral laboratory scanner.
2. With the extraoral laboratory scanner, no significant differences in trueness and precision were detected between the scans of the polysulfide impressions and of the corresponding stone casts on the reference typodont.

REFERENCES

1. Bilgin MS, Baytaroğlu EN, Erdem A, Dilber E. A review of computer-aided design/computer-aided manufacture techniques for removable denture fabrication. Eur J Dent 2016;10:286-91.
2. Bidra AS, Taylor TD, Agar JR. Computer-aided technology for fabricating complete dentures: systematic review of historical background, current status, and future perspectives. J Prosthet Dent 2013;109:361-6.
3. AlHelal A, AlRumaih HS, Kattadiyil MT, Baba NZ, Goodacre CJ. Comparison of retention between maxillary milled and conventional denture bases: a clinical study. J Prosthet Dent 2017;117:233-8.
4. McLaughlin JB, Ramos V Jr, Dickinson DP. Comparison of fit of dentures fabricated by traditional techniques versus CAD/CAM technology. J Prosthodont 2019;28:428-35.
5. Bonnet G, Batisse C, Bessadet M, Nicolas E, Veyrune JL. A new digital denture procedure: a first practitioners appraisal. BMC Oral Health 2017;17:155.
6. Zarone F, Ruggiero G, Di Mauro MI, Spagnuolo G, Ferrari M, Sorrentino R. Accuracy of three impression materials on the totally edentulous maxilla: in vitro/in silico comparative analysis. Materials (Basel) 2020;13:515.
7. 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: 264-8.
8. Lo Russo L, Salamini A. Single-arch digital removable complete denture: a workflow that starts from the intraoral scan. J Prosthet Dent 2018;120:20-4.
9. Lo Russo L, Salamini A. Removable complete digital dentures: a workflow that integrates open technologies. J Prosthet Dent 2018;119:727-32.
10. Goodacre CJ, Garbacea A, Naylor WP, Daher T, Marchack CB, Lowry J. CAD/CAM fabricated complete dentures: concepts and clinical methods of obtaining required morphological data. J Prosthet Dent 2012;107:34-46.
11. Chebib N, Kalberer N, Srinivasan M, Maniewicz S, Perneger T, Müller F. Edentulous jaw impression techniques: an in vivo comparison of trueness. J Prosthet Dent 2019;121:623-60.
12. Unkovskiy A, Wahl E, Zander AT, Huettig F, Spintzyk S. Intraoral scanning to fabricate complete dentures with functional borders: a proof-of-concept case report. BMC Oral Health 2019;19:46.
13. International Organization for Standardization. ISO 5725-1. Accuracy (trueness and precision) of measurement methods and results. Part 1: general principles and definitions. Berlin: International Organization for Standardization; 1994. Available at: http://www.iso.org/iso/home.html.
14. Sim JY, Jang Y, Kim WC, Kim HY, Lee DH, Kim JH. Comparing the accuracy (trueness and precision) of models of fixed dental prostheses fabricated by digital and conventional workflows. J Prosthodont Res 2019;63:25-30.

15. 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.
16. Jeong ID, Lee JJ, Jeon JH, Kim JH, Kim HY, Kim WC. Accuracy of complete-arch model using an intraoral video scanner: an in vitro study. J Prosthet Dent 2016;115:755-9.
17. Peng L, Chen L, Harris BT, Bhandari B, Morton D, Lin WS. Accuracy and reproducibility of virtual edentulous casts created by laboratory impression scan protocols. J Prosthet Dent 2018;120:389-95.
18. Sorrentino R, Gherlone EF, Calesini G, Zarone F. Effect of implant angulation, connection length, and impression material on the dimensional accuracy of implant impressions: an in vitro comparative study. Clin Implant Dent Relat Res 2010;12:63-76.
19. Calesini G, Zarone F, Sorrentino R, Micarelli C, Fabianelli A, Papacchini F, et al. Effect of 2 impression techniques on the dimensional accuracy of working implant prosthesis models: an in vitro study. J Craniofac Surg 2014;25:822-7.
20. Eames WB, Wallace SW, Suway NB, Rogers LB. Accuracy and dimensional stability of elastomeric impression materials. J Prosthet Dent 1979;42:159-62.
21. Gonçalves FS, Popoff DA, Castro CD, Silva GC, Magalhães CS, Moreira AN. Dimensional stability of elastomeric impression materials: a critical review of the literature. Eur J Prosthodont Restor Dent 2011;19:163-6.
22. Valderhaug J, Fløystrand F. Dimensional stability of elastomeric impression materials in custom-made and stock trays. J Prosthet Dent 1984;52:514-7.
23. Chai J, Takahashi Y, Lautenschlager EP. Clinically relevant mechanical properties of elastomeric impression materials. Int J Prosthodont 1998;11:219-23.
24. Re D, De Angelis F, Augusti G, Augusti D, Caputi S, D'Amario M, et al. Mechanical properties of elastomeric impression materials: an in vitro comparison. Int J Dent 2015;2015:428286.
25. Heshmati RH, Nagy WW, Wirth CG, Dhuru VB. Delayed linear expansion of improved dental stone. J Prosthet Dent 2002;88:26-31.
26. Gujjarlapudi MC, Reddy SV, Madineni PK, Ealla KK, Nunna VN, Manne SD. Comparative evaluation of few physical properties of epoxy resin, resin-modified gypsum and conventional type IV gypsum die materials: an in vitro study. J Contemp Dent Pract 2012;13:48-54.
27. Oda Y, Matsumoto T, Sumii T. Evaluation of dimensional stability of elastomeric impression materials during disinfection. Bull Tokyo Dent Coll 1995;36:1-7.
28. Kamble SS, Khandeparker RV, Somasundaram P, Raghav S, Babaji RP, Varghese TJ. Comparative evaluation of dimensional accuracy of elastomeric impression materials when treated with autoclave, microwave, and chemical disinfection. J Int Oral Health 2015;7:22-4.
29. Thouati A, Deveaux E, Iost A, Behin P. Dimensional stability of seven elastomeric impression materials immersed in disinfectants. J Prosthet Dent 1996;76:8-14.
30. Thota KK, Jasthi S, Ravuri R, Tella S. A comparative evaluation of the dimensional stability of three different elastomeric impression materials after autoclaving - an invitro study. J Clin Diagn Res 2014;8:48-50.
31. 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;111:186-94.
32. Kim JH, Kim KB, Kim WC, Kim JH, Kim HY. Accuracy and precision of polyurethane dental arch models fabricated using a three-dimensional subtractive rapid prototyping method with an intraoral scanning technique. Korean J Orthod 2014;44:69-76.
33. Nedelcu R, Olsson P, Nyström I, Rydén J, Thor A. Accuracy and precision of 3 intraoral scanners and accuracy of conventional impressions: a novel in vivo analysis method. J Dent 2018;69:110-8.
34. Imburgia M, Logozzo S, Hauschild U, Veronesi G, Mangano C, Mangano FG. Accuracy of four intraoral scanners in oral implantology: a comparative in vitro study. BMC Oral Health 2017;17:92.
35. Mangano FG, Veronesi G, Hauschild U, Mijiritsky E, Mangano C. Trueness and precision of four intraoral scanners in oral implantology: a comparative in vitro study. PLoS One 2016;11:e0163107.
36. Rameez M, Razi SS, Farhan F, Kumar B, Rashid H. Clinical implications of elastomeric impression materials used for complete denture construction. Dent Med Res 2018;6:19-23.
37. Rubel BS. Impression materials: a comparative review of impression materials most commonly used in restorative dentistry. Dent Clin North Am 2007;51:629-42.
38. Giordano R. Impression materials: basic properties. Gen Dent 2000;48:51-6.
39. Passamonti G. Relationship between the two arches and its effect in the diagnosis and treatment of complete denture prosthesis. Quintessence Int Dent Dig 1979;10:37-51.
40. Chopra S, Gupta NK, Tandan A, Dwivedi R, Gupta S, Agarwal G. Comparative evaluation of pressure generated on a simulated maxillary oral analog by impression materials in custom trays of different spacer designs: an in vitro study. Contemp Clin Dent 2016;7:55-60.
41. Gonçalves FS, de Freitas Oliveira W, Soares LA, Cario HL, da Mota AS, Popoff DAV, et al. Impression materials and storage time influence on cast models accuracy. Int J Exp Dent Sci 2013;2:18.
42. Mandelli F, Gherlone E, Gastaldi G, Ferrari M. Evaluation of the accuracy of extraoral laboratory scanners with a single-tooth abutment model: a 3D analysis. J Prosthodont Res 2017;61:363-70.
43. Marani R, Reno V, Nitti M, D'Orazio T, Stella E. A modified iterative closest point algorithm for 3D point cloud registration. Comput Aided Civil Infrastruct Eng 2016;31:515-34.
44. Harper D, Kim JO, Mueller CW. Introduction to factor analysis: what it is and how to do it. Contemp Sociol 1980;9:562.
45. Kim KM, Lee JS, Kim KN, Shin SW. Dimensional changes of dental impression materials by thermal changes. J Biomed Mater Res 2001;58:217-20.

Corresponding author:
Dr Gennaro Ruggiero
Division of Prosthodontics and Digital Dentistry
Department of Neurosciences
Reproductive and Odontostomatological Sciences
University "Federico II" of Naples
Via Pansini, 5, Naples 80131
ITALY
Email: gennaro_ruggiero@hotmail.it