Evaluation of trueness in a denture base fabricated by using CAD-CAM systems and adaptation to the socketed surface of denture base: An in vitro study

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RESEARCH AND EDUCATION

Evaluation of trueness in a denture base fabricated by using CAD-CAM systems and adaptation to the socketed surface of denture base: An in vitro study

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ABSTRACT

Statement of problem. Computer-aided design and computer-aided manufacturing (CAD-CAM) systems are increasingly used to fabricate removable complete dentures. However, comparisons and analyses of the trueness and adaptation of the socketed surface of denture bases produced by milling (MIL) and digital light processing (DLP) are lacking.

Purpose. The purpose of this in vitro study was to evaluate and compare the trueness and socketed surface adaptation of denture bases fabricated by using additive and subtractive manufacturing.

Material and methods. Based on a denture base standard tessellation language (STL) file, a total of 15 denture bases were produced by using DLP (horizontal and vertical direction) and MIL. The intaglio and cameo surfaces of the fabricated denture bases were scanned with a dental scanner. The scanned intaglio and cameo surfaces were overlapped with the corresponding reference denture base STL file for trueness evaluation. In addition, the ridge lap STL file of the diagnostic tooth arrangement, in which reverse normal was performed, was superimposed on the socketed surface of the denture base of all groups to evaluate adaptation.

Results. The root mean square (RMS) values of trueness and adaptation showed statistically significant differences ($P<.05$). For the trueness RMS value of the intaglio surface of the denture base, the MIL-denture base (MDB) group had the lowest value of 150 ±6 μm, whereas the vertical denture base (VDB) of the DLP group was the largest with 328 ±4 μm. For the trueness RMS value of the cameo surface, the MDB group was the lowest with 50 ±1 μm, whereas the VDB group was the largest with 334 ±24 μm. For the adaptation RMS value of the socketed surface of the denture base, the MDB group was the lowest with 44 μm, whereas the VDB group was the largest with 117 ±2 μm.

Conclusions. Within the limits of this in vitro study, the MDB group showed better trueness and socketed surface adaptation than the DLP groups (HDB and VDB). (J Prosthet Dent 2020;■:■-■)

A removable complete denture manufacturing process with computer-aided design and computer-aided manufacturing (CAD-CAM) has been in use for over 20 years, and studies have been conducted on its clinical performance and accuracy.[1-6] Digital removable complete dentures have advantages over the conventional process, including reduced patient visits and treatment cost. In addition, by reducing the manufacturing process, errors that may occur during this process can be reduced, improving the quality of the prostheses. The stored digital data can be used for future treatment, with duplicate dentures being easily produced. In addition, material cost and processing time can be reduced.[4-6] Typically, the artificial tooth and the denture base are CAD-CAM processed separately and then assembled.[2-9] As a result, space between the artificial teeth and the socket in the denture base may be insufficient, resulting in errors in tooth displacement because of a premature contact and interference in the bonding process.[3,5,8] However, 2-colored blocks with artificial teeth and denture base color have been

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Clinical Implications

In fabricating a removable complete denture base with a CAD-CAM system, the trueness and socketed surface adaptation depend on the processing method. Among the tested methods, milling showed the best results.

developed, making it possible to manufacture a 1-piece denture through subtractive manufacturing.[10,11]

The current 2-piece manufacturing method is achieved by subtractive manufacturing and additive manufacturing after designing artificial teeth and denture bases by using a CAD software program.[2-9] Subtractive manufacturing creates an object by removing material from a prepolymerized block of acrylic resin based on an image of a digital file with a milling tool. Additive manufacturing creates a series of cross-sectional slices based on an image of a digital file and polymerizes the selected material layer-by-layer to create the definitive object.[12-17]

Subtractive manufacturing uses a polymethyl methacrylate (PMMA) block prepolymerized under high-temperature and high-pressure conditions; therefore, the definitive prosthesis is not subject to shrinkage as a postpolymerization process is not required.[3,5,12] However, accessing undercut areas is difficult because of limitations in the milling bur size and machining axis.[4,5,12] Among additive manufacturing methods, DLP can be used to manufacture with higher surface detail and in undercut areas. However, in the DLP method, ultraviolet or visible light sources are repeatedly used to irradiate a nonpolymerized resin liquid, and the polymerization contraction of the definitive prosthesis may increase because of an additional photopolymerization step.[4,18-20] In addition, this may affect the accuracy of the 3D objects according to the build direction.[13,19,21,22]

Deformation during processing can lead to inaccuracies in the border and posterior palatal areas of the removable complete denture. In addition, the denture may require selective grinding because of deformations to adjust the occlusal vertical dimension, resulting in nonanatomic teeth.[5] The accuracy of a removable complete denture produced with the CAD-CAM system should be evaluated according to the International Standards Organization (ISO) 12836.[23] Previous studies have evaluated the denture base for the trueness of the intaglio surface of the denture bases and tissue surface adaptation.[4,24] However, few studies have evaluated the trueness of the cameo and intaglio surfaces of the denture base and adaptation of the socketed surface.

Therefore, the purpose of this in vitro study was to evaluate and analyze the trueness of denture bases produced according to the DLP (horizontal and vertical direction) and milling (MIL) methods and the adaptation of the socketed surface of denture bases. The null hypotheses were that no difference would be detected in the trueness of the denture base produced according to the DLP and MIL methods and that no difference would be detected in the adaptation of the socketed surface of denture bases.

MATERIAL AND METHODS

The flow chart of the protocol of this study is presented in Figure 1. A maxillary edentulous model (EDE1001; Nissin) was selected as the master model for the fabrication of a maxillary removable complete denture. The selected master model was replicated as a stone cast by using a silicone material (Deguform; DeguDent GmbH). A digital cast was obtained by scanning the duplicated stone cast with a dental digital scanner (D700 Scanner; 3Shape A/S) with an accuracy of 20 μm.

A removable complete denture was designed on the digital cast with a CAD software program (3Shape Dental System; 3Shape A/S), and the denture base and diagnostic tooth arrangement were saved separately as standard tessellation language (STL) files. The denture base STL file was selected as reference data to evaluate the trueness of the denture base. In addition, to evaluate the adaptation of the denture base socket, it was saved by performing reverse normal after editing to leave only the ridge lap of the diagnostic tooth arrangement with a 3D analysis program (Geomagic Verify 2015; Geomagic GmbH). The reverse normal was performed because the opposite side of the ridge lap coincides with the bottom of the socketed surface of the denture base.

Based on previous research, a power analysis was conducted to estimate the required sample size,[4] assuming 3 test groups, an effect size of 2.16, and type I and type II error probabilities of 0.05 and 0.95, respectively. As a result, 3 per group were required for 9 specimens in total, and the actual power calculated was 0.99. Therefore, the sample size was determined to be 5 per group.

In additive manufacturing, the denture base STL file was uploaded to the software program (FlashDLPrint; Flashforge) of the DLP equipment. The support location was set differently according to the DLP build direction setting. For the horizontal direction, the supports were attached to the intaglio surface of the denture base, whereas for the vertical direction, the supports were attached to the labial area of the cameo surface of the denture base. The layer thickness was set to 100 μm.[4,19] Five horizontal denture bases (HDBs) and vertical denture bases (VDBs) were output by using DLP equipment (Bio3D L12_PRO; NextDent) with an accuracy of 62 μm and gingival-colored resin liquid (NextDent Base;

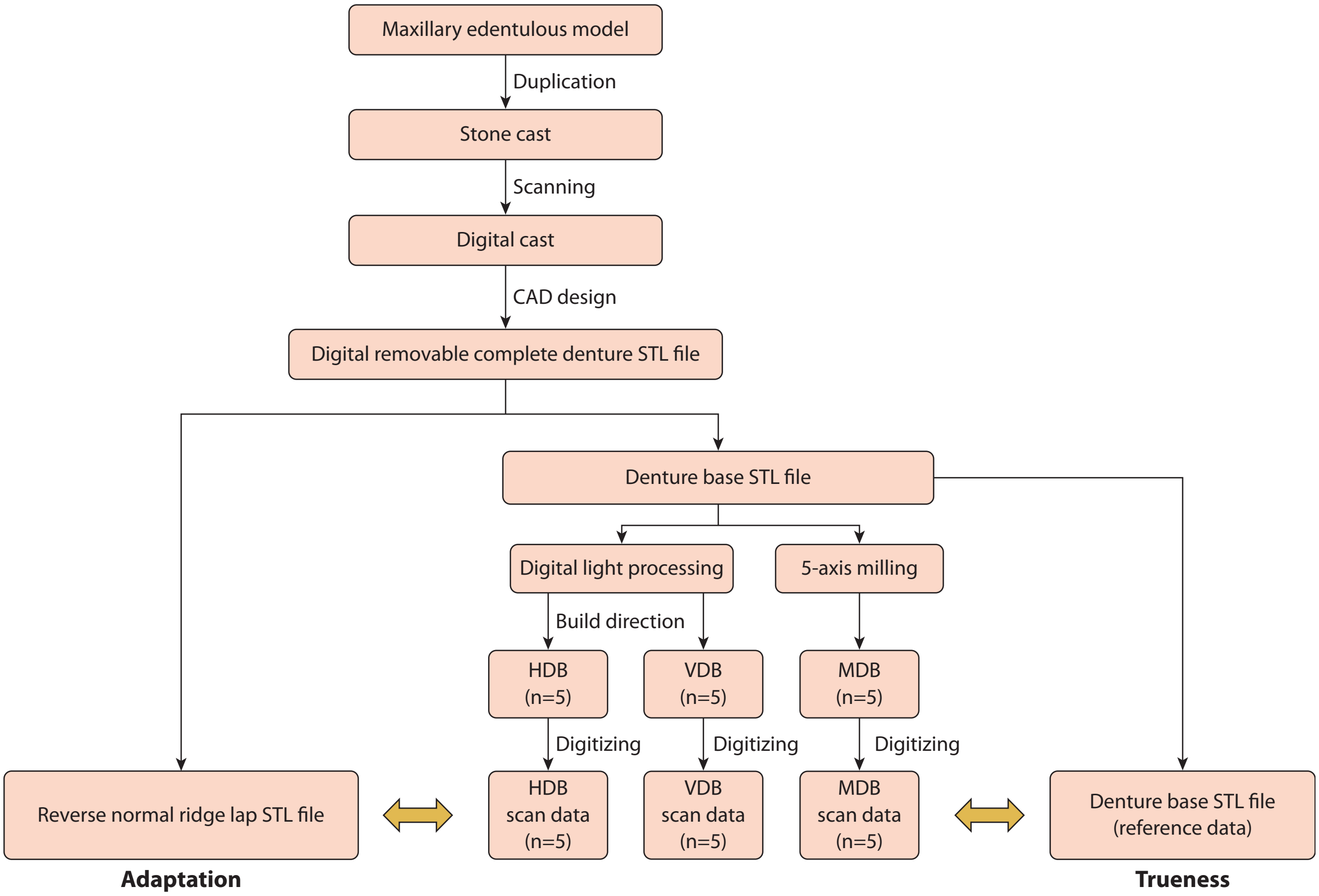

Figure 1. Research protocol. CAD, computer-aided design; HDB, horizontal denture base; MDB, milled denture base; STL, standard tessellation language; VDB, vertical denture base.

NextDent). The printed denture bases were rinsed in an ultrasonic bath with isopropyl alcohol for 10 minutes. Thereafter, the postpolymerization process was performed by using an ultraviolet polymerization unit (LC 3DPrint Box; Bio3D), and the support was removed.

In the case of subtractive manufacturing, 5 MIL-denture bases (MDBs) were produced based on denture base STL files by using a 5-axis milling machine (CAM5-S1; VHF) with an accuracy of 3 μm and a gingival-colored PMMA block (HUGE PMMA Block-Pink; Huge Dental Material).

To evaluate trueness and adaptation, the intaglio and cameo surfaces of the denture bases of the 3 groups (HDB, VDB, and MDB) fabricated with the CAD-CAM system were scanned and digitized with a dental scanner. For digital removable complete denture scanning, a scan spray (EZ scan; Alphadent) with an average particle size of 3 μm and a blue light scanner (Identica blue; Medit) with an accuracy of 10 μm were used to improve the accuracy of the scan. The STL files of the 3 digitized groups (HDB, VDB, and MDB) were uploaded to a 3D analysis program (Verify; Geomagic GmbH).

The trueness of the 3 groups (HDB, VDB, and MDB) was evaluated by overlapping the STL file and reference denture base STL file (Figs. 2, 3). In the case of trueness, they were autoaligned when overlapping, followed by best-fit alignment. The adaptation was evaluated by superimposing the ridge lap STL file of the diagnostic tooth arrangement in which reverse normal was performed onto the socketed surface of the denture bases for all specimens (Figs. 4, 5). In the adaptation evaluation, when overlapping, the alignment was transformed to set the standardized insertion direction, and the n point was set based on the middle point of each of the ridge laps. Thereafter, best-fit alignment was performed. Root mean square (RMS) was used for quantitative analysis, and a color difference map was used for visual deviation analysis. The nominal and critical deviation in the visual deviation analysis were set to ±50 and 300 μm, respectively.[4,19]

A statistical software program (IBM SPSS Statistics, v25.0; IBM Corp) was used to analyze the obtained quantitative data, and the statistical significance of the mean and standard deviations of the surface deviation (RMS and positive and negative mean) were tested.

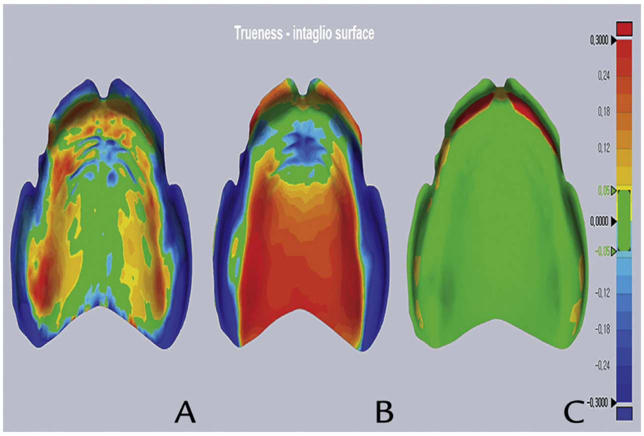

Figure 2. Visual deviation analysis of trueness of intaglio surface of denture base manufactured with CAD-CAM system. A, Horizontal denture base. B, Vertical denture base. C, Milling denture base. Tolerance limit denoted in green. Positive error denoted by yellow to red. Negative error denoted from cyan to blue. CAD-CAM, computer-aided design and computer-aided manufacturing.

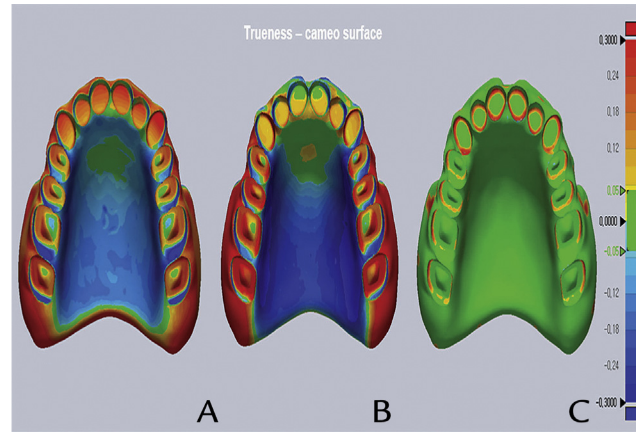

Figure 3. Visual deviation analysis of trueness of cameo surface of denture base manufactured with CAD-CAM system. A, Horizontal denture base. B, Vertical denture base. C, Milling denture base. Tolerance limit denoted in green. Positive error denoted by yellow to red. Negative error denoted from cyan to blue. CAD-CAM, computer-aided design and computer-aided manufacturing.

The Kolmogorov-Smirnov and Shapiro-Wilk tests did not satisfy the normality test ($P<.05$). Therefore, the nonparametric Kruskal-Wallis test was performed, the mean values of the 3 groups (HDB, VDB, and MDB) were compared, and significant differences were analyzed ($\alpha=.05$). The Mann-Whitney U Test was performed by applying the significance level adjusted by the Bonferroni method for post hoc analysis.

RESULTS

The trueness of the intaglio and cameo surface of the denture base produced with the CAD-CAM system and the adaptation of the socketed surface of the denture base were evaluated, and the statistical analysis showed statistically significant differences ($P<.05$). In addition, the RMS values of trueness and adaptation were lowest in the MDB group and highest in the VDB group (Tables 1 and 2). Postanalyses of trueness of the intaglio and cameo surfaces of the denture base revealed no significant difference between the HDB and VDB groups with additive manufacturing ($P=.231$), and no significant difference was found between the HDB group with additive manufacturing and the MDB group with subtractive manufacturing ($P=.231$). However, a significant difference was found between the VDB and MDB groups ($P=.001$).

Postanalyses of the adaptation at the socketed surface of the denture base showed significant differences only between the VDB and MDB groups ($P=.001$). No significant difference was found between the MDB and HDB groups ($P=.231$) nor between the HDB and VDB groups ($P=.231$).

In visual deviation analysis, color-coded 3D surface deviation maps were used to visually evaluate the trueness of the intaglio and cameo surface of the denture base and the adaptation of the socketed surface of denture base. Yellow to red indicated a positive deviation area, blue indicated negative deviation, and green indicated a range within tolerance.

In the analyses of the trueness of the intaglio surface of denture bases made with the CAD-CAM system, the HDB group with additive manufacturing generally showed negative deviation color at all border areas and all deviation colors overall at the palatal area. The VDB group showed a negative and positive deviation color in the posterior border and palatal area, respectively. The MDB group showed a positive deviation color in the anterior area of the alveolar ridge crest, where the undercut was most severe (Fig. 2).

In the analysis of the trueness of the cameo surface of the denture base, the HDB and VDB groups with additive manufacturing generally showed positive and negative deviation color in the outer and inner regions, respectively. In the MDB group, there was a positive deviation color in the areas where the supports were located and at the edges of the denture base socket (Fig. 3).

In the adaptation analysis at the socketed surface of the denture base, the HDB and VDB groups showed all deviation colors. The MDB group was generally within the tolerance range but showed negative deviation at the edges of the denture base socket (Fig. 5). In addition, in the horizontal direction, the HDB was manufactured in 1 hour 20 minutes, whereas in the vertical direction, the VDB was produced in 2 hours 40 minutes. The MDB was milled by subtractive manufacturing in 3 hours 40 minutes.

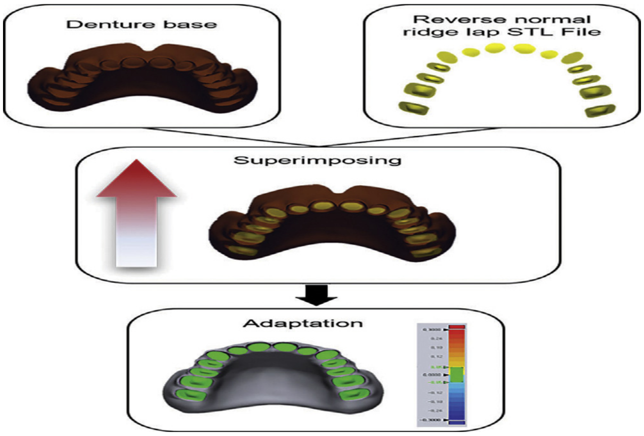

Figure 4. Three-dimensional evaluation method of adaptation between socketed surface of denture base manufactured with CAD-CAM system and reverse normal ridge lap of diagnostic tooth arrangement. CAD-CAM, computer-aided design and computer-aided manufacturing; STL, standard tessellation language.

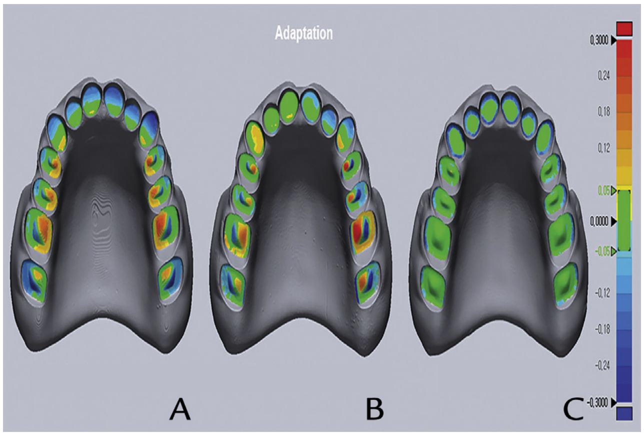

Figure 5. Visual deviation analysis of adaptation between socketed surface of denture base manufactured with CAD-CAM system and reverse normal ridge lap of diagnostic tooth arrangement. A, Horizontal denture base. B, Vertical denture base. C, Milling denture base. Positive deviation (yellow to red) indicates gap with sockets, whereas negative deviation (cyan to blue) indicates premature contact with sockets; tolerance limit below 50 μm (green). CAD-CAM, computer-aided design and computer-aided manufacturing.

DISCUSSION

In the trueness and adaptation results of this in vitro study, a statistically significant difference was found, depending on the build direction (horizontal and vertical), in the denture base group produced with the additive manufacturing technique and the denture base group produced with subtractive manufacturing. Therefore, all null hypotheses were rejected (Tables 1 and 2).

In this study, trueness and adaptation were evaluated by using a 3D analysis method. A digitizing device with an accuracy of 10 μm was used to minimize the errors that may have occurred during scanning of the denture base, and a scan spray with an average particle size of 3 μm was applied to minimize light reflection.[4,25] In the case of the denture base manufactured according to the lamination direction of additive manufacturing, the time required to manufacture the VDB group was 1 hour and 20 minutes longer than that for the HDB group. The increased production time was because the number of layers to be manufactured increased with the increasing height of the object output along the z-axis.[19,26]

In the quantitative analysis, the mean, SD, and 95% CI values for trueness of the intaglio and cameo surface were higher for HDB and VDB than those for MDB (Table 1). In addition, during visual deviation analysis of the intaglio surface, errors were detected in all 3 groups (Fig. 2). In the case of the DLP group (HDB and VDB), a negative deviation was detected in the border area, whereas a positive deviation was detected in the palatal area. This error occur because of centripetal shrinkage toward the center of the object.[19,27] In addition, for VDB, a larger positive deviation was observed in the posterior area of the palatal area, an error caused by sagging in the posterior area away from the platform.[18,21,27] In addition, MDB showed a large positive deviation, mainly in the anterior area of the alveolar ridge crest. This was because of a limitation in the diameter and machining axis of the milling bur; therefore, it is considered to be an error caused by the inability to reproduce the most severe part of the undercut.[4,12]

In the visual deviation analysis of the cameo surface, the DLP group (HDB and VDB) generally showed a positive outside error and a negative inside error (Fig. 3). This error was from dimensional distortion caused by the curl and warpage phenomena, as the new layer is polymerized on the previously polymerized layer during the 3D printing output process.[26-28] In addition, for VDB, a color range within tolerance was observed on the labial surface, and it was judged that there were few errors because it was close to the support position.[22] In the case of MDB, a positive deviation was found mainly in the region where the support was located and at the edges of the denture base socket. This error can be attributed to the inability to reproduce sharp edges and protrusions because of the diameter of the milling bur and the limited machining axis.[12,29]

In the case of adaptation of the socketed surface of denture base, the mean, SD, and 95% CI values were smaller for MDB than those for HDB and VDB (Table 2). In the visual deviation analysis of the socketed surface of denture base, the positive deviation suggests that the ridge lap of the diagnostic tooth arrangement is below the bottom of the socketed surface of denture base (Fig. 5). Conversely, the negative deviation suggests that the ridge lap of the diagnostic tooth arrangement is above the bottom of the socketed surface of denture

Table 1. Trueness root mean square values of denture base according to CAD-CAM system (μm).

	HDB Group		VDB Group		MDB Group		
Trueness	Mean ±SD	95% CI	Mean ±SD	95% CI	Mean ±SD	95% CI	P*
Intaglio surface	228 ±10[ab]	215-241	328 ±4[a]	324-333	150 ±6[b]	143-157	.002
Cameo surface	207 ±8[ab]	197-216	334 ±24[a]	303-364	50 ±1[b]	49-52	.002

CAD-CAM, computer-aided design and computer-aided manufacturing; CI, confidence interval; HDB, horizontal denture base; MDB, milled denture base; SD, standard deviation; VDB, vertical denture base. Values followed by different superscript letters indicates statistical significance based on Mann-Whitney U test with Bonferroni correction (significant $P<.05/3=0.017$). *Analyzed by Kruskal-Wallis test (α=.05).

Table 2. Adaptation root mean square values between socketed surface of denture base according to CAD-CAM system and reverse normal ridge lap of diagnostic tooth arrangement (μm).

	HDB Group		VDB Group		MDB Group		
Adaptation	Mean ±SD	95% CI	Mean ±SD	95% CI	Mean ±SD	95% CI	P*
Fitting area	107 ±5[ab]	101-112	117 ±2[a]	114-119	44[b]	43-44	.002

CAD-CAM, computer-aided design and computer-aided manufacturing; CI, confidence interval; HDB, horizontal denture base; MDB, milled denture base; SD, standard deviation; VDB, vertical denture base. Values followed by different superscript letter indicates statistical significance based on Mann-Whitney U test with Bonferroni correction (significant $P<.05/3=0.017$). *Analyzed by Kruskal-Wallis test (α=.05).

base.[4] The socketed surface of the HDB and VDB groups generally showed all deviation colors, which is attributed to dimensional distortion and centripetal shrinkage caused by the curl and warpage phenomena.[19,26-28] Comparatively, the anterior socketed surfaces of the VDB group were within the tolerance range, in contrast with HDB, and showed small errors because they were close to the support position.[22] The socketed surface of the MDB group showed a negative deviation at the edges of the socket, which is an error caused by the limitations of the milling bur diameter and machining axis.[12,29]

Limitations of the present study included that, in the DLP printer method of additive manufacturing, the denture base was printed in the horizontal (vertical direction based on z-axis) and vertical directions (horizontal direction based on z-axis) based on the platform to exclude various angles.[13] The socketed surface of the denture base manufactured with the CAD-CAM system overlapped with the ridge lap of the diagnostic tooth arrangement performed reverse normal to objectively evaluate adaptation. The layer thickness setting of DLP was set to 100 μm to prevent accumulation of errors due to more layers.[17,19,26,28] Alharbi et al[13] reported that this affects the compressive strength and mechanical properties of a 3D output and depends on the build direction, whereas Park et al[17] reported that this affected accuracy of the prosthesis depending on the build direction and layer thickness. In addition, the build direction can affect the degree of polymerization shrinkage by affecting the shape of a layer. Therefore, in a future study, it is necessary to evaluate the accuracy of denture bases manufactured at various angles in the build direction and then evaluate the compressive strength.[13] Furthermore, the accuracy of a denture base fabricated with various layer thicknesses should be evaluated.[19]

Another limitation of this study was that different milling equipment and 3D printing equipment could not be secured and that the study was conducted with a small sample size. Additionally, in the case of adaptation evaluation, this study explains the result of the cross-section of the bottom of the socketed surface overlapping the ridge lap, but not of the whole surface area of the socket. Therefore, in future studies, the number of specimens should be increased, reliability should be secured by using a variety of equipment, and studies on the insertion direction should be conducted according to specific adjustable parameters (the coupling depth, the coupling angle, the adhesive space, and the esthetics of the interdental gingiva) built into the 3Shape software workflow.

CONCLUSIONS

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

1. A CAD-CAM digital denture base is more appropriate for MDB than for the DLP group (HDB and VDB).
2. From the viewpoint of production time and accuracy in additive manufacturing, the lamination direction of the DLP should be set in the horizontal direction rather than the vertical direction when producing a denture base.

REFERENCES

1. Wimmer T, Gallus K, Eichberger M, Stawarczyk B. Complete denture fabrication supported by CAD/CAM. J Prosthet Dent 2016;115:541-6.
2. Lin WS, Harris BT, Pellerito J, Morton D. Fabrication of an interim complete removable dental prosthesis with an in-office digital light processing three-dimensional printer: a proof-of-concept technique. J Prosthet Dent 2018;120:331-4.
3. Yamamoto S, Kanazawa M, Iwaki M, Jokanovic A, Minakuchi S. Effects of offset values for artificial teeth positions in CAD/CAM complete denture. Comput Biol Med 2014;52:1-7.
4. Hwang HJ, Lee SJ, Park EJ, Yoon HI. Assessment of the trueness and tissue surface adaptation of CAD-CAM maxillary denture bases manufactured using digital light processing. J Prosthet Dent 2019;121:110-7.
5. Wang C, Shi Y-F, Xie P-J, Wu J-H. Accuracy of digital complete dentures: a systematic review of in vitro studies. J Prosthet Dent 27 February 2020. doi:10.1016/j.prosdent.2020.01.004. [Epub ahead of print].
6. Bidra AS, Taylor T, 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.
7. Kalberer N, Mehl A, Schimmel M, Müller F, Srinivasan M. CAD/CAM milled versus rapidly-prototyped (3D-printed) complete dentures: an in vitro evaluation of trueness. J Prosthet Dent 2019;121:637-43.
8. Yamamoto S, Kanazawa M, Hirayama D, Nakamura T, Arkida T, Minakuchi S. In vitro evaluation of basal shapes and offset values of artificial teeth for CAD/CAM complete dentures. Comput Biol Med 2016;68:84-9.
9. Han W, Li Y, Zhang Y, Lv Y, Zhang Y, Hu P, et al. Design and fabrication of complete dentures using CAD/CAM technology. Medicine (Baltimore) 2017;96:e5435.
10. AvaDent Digital Dental Solutions. Available at: https://lmtmag.com/services/avadenttrade-digital-dentures. Accessed August 12, 2020.

11. Ivotion Denture System. Available at: https://www.ivoclardigital.com/en/laboratory/material/removable-prosthetics. Accessed August 12, 2020.
12. Kim CM, Jeon JH, Kim JH, Kim HY, Kim WC. Three-dimensional evaluation of the reproducibility of presintered zirconia single copings fabricated with the subtractive method. J Prosthet Dent 2016;116:237-41.
13. Alharbi N, Osman R, Wismeijer D. Effects of build direction on the mechanical properties of 3D-printed complete coverage interim dental restorations. J Prosthet Dent 2016;115:760-7.
14. Liu Q, Leu MC, Schmitt SM. Rapid prototyping in dentistry: technology and application. Int J Adv Manuf Technol 2006;29:317-35.
15. Miyazaki T, Hotta Y, Kunii J, Kuriyama S, Tamaki Y. A review of dental CAD/CAM: current status and future perspectives from 20 years of experience. Dent Mater J 2009;28:44-56.
16. van Noort R. The future of dental devices is digital. Dent Mater 2012;28:3-12.
17. Park GS, Kim SK, Heo SJ, Koak JY, Seo DG. Effects of printing parameters on the fit of implant-supported 3D printing resin prosthetics. Materials (Basel) 2019;12:2533.
18. Katheng A, Kanazawa M, Iwaki M, Minakuchi S. Evaluation of dimensional accuracy and degree of polymerization of stereolithography photopolymer resin under different postpolymerization conditions: an in vitro study. J Prosthet Dent 13 May 2020. doi: 10.1016/j.prosdent.2020.02.023. [Epub ahead of print].
19. You SM, You SG, Kang SY, Bae SY, Kim JH. Evaluation of the accuracy (trueness and precision) of a maxillary trial denture according to the layer thickness: an in vitro study. J Prosthet Dent 20 February 2020. doi: 10.1016/j.prosdent.2019.12.014. [Epub ahead of print].
20. Bass L, Meisel NA, Williams CB. Exploring variability of orientation and aging effects in material properties of multi-material jetting parts. Rapid Prototyp J 2016;22:826-34.
21. Jin MC, Yoon HI, Yeo IS, Kim SH, Han JS. The effect of build angle on the tissue surface adaptation of maxillary and mandibular complete denture bases manufactured by digital light processing. J Prosthet Dent 2020;123:473-82.
22. Alharbi N, Osman RB, Wismeijer D. Factors influencing the dimensional accuracy of 3D-printed full-coverage dental restorations using stereolithography technology. Int J Prosthodont 2016;29:503-10.
23. International Organization of Standardization. ISO 12836. Dentistry-digitizing devices for CAD/CAM systems for indirect dental restorations: test methods for assessing accuracy. Geneva: ISO; 2015. Available at: https://www.iso.org/obp/ui/#iso:std:iso:12836:ed-2:v1:en.
24. Goodacre BJ, Goodacre CJ, Baba NZ, Kattadiyil MT. Comparison of complete denture base adaptation between CAD/CAM and conventional fabrication techniques. J Prosthet Dent 2016;116:249-56.
25. Wang W, Yu H, Liu Y, Jiang X, Gao B. Trueness analysis of zirconia crowns fabricated with 3-dimensional printing. J Prosthet Dent 2019;121:285-91.
26. Favero CS, English JD, Cozad BE, Wirthlin JO, Short MM, Kasper FK. Effect of print layer height and printer type on the accuracy of 3-dimensional printed orthodontic models. Am J Orthod Dentofacial Orthop 2017;152:557-65.
27. Patzelt SB, Bishti S, Stampf S, Att W. Accuracy of computer-aided design/computer-aided manufacturing-generated dental casts based on intraoral scanner data. J Am Dent Assoc 2014;145:1133-40.
28. Khoshkhoo A, Carrano AL, Blersch DM. Effect of build orientation and part thickness on dimensional distortion in material jetting processes. Rapid Prototyp J 2018;24:1563-71.
29. Alharbi N, Alharbi S, Cuijpers VM, Osman RB, Wismeijer D. Three-dimensional evaluation of marginal and internal fit of 3D-printed interim restorations fabricated on different finish line designs. J Prosthodont Res 2018;62:218-26.

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