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## CLINICAL RESEARCH

# Fit and retention of complete denture bases: Part I – Conventional versus CAD-CAM methods: A clinical controlled crossover study

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Retention, along with stability and support, is a principal element ensuring adequate complete denture (CD) function. Retention depends on anatomic features such as the size, shape, and resilience of the edentulous ridges and also on the adequate extension and fit of the denture base to the denture bearing tissues.<sup>1</sup> The intimate contact between the base and the underlying tissues enables the establishment of physical forces created by a thin and homogenous salivary film and the development of a negative pressure created by a hermetic intaglio and peripheral seal.<sup>1</sup> The combination of these forces creates resistance against the vertical displacement of the denture base.<sup>1</sup> The fit and retention of a denture base can therefore be influenced by the impression

## ABSTRACT

**Statement of problem.** Clinical evidence is sparse on whether dentures fabricated by computer-aided design and computer-aided manufacturing (CAD-CAM) methods afford superior fit and retention when compared with those fabricated conventionally.

**Purpose.** The purpose of this clinical controlled crossover study was to evaluate the peak retention force and fit of CAD-CAM manufactured (3D-printed and milled) maxillary complete denture bases and conventional heat-polymerized bases (control).

**Material and methods.** Twenty participants with edentulous maxillary arches were recruited. Impressions were made with a border-molded custom tray, and the resulting definitive cast was scanned. The conventional base was manufactured on the definitive cast with a hook and a 45-degree platform with a central notch and 2 lateral notches. The scan of the definitive cast was used for the fabrication of a milled and a printed base. The platform and hook position on the conventional base were transferred digitally to the milled and printed bases. All bases were scanned. A traction dynamometer was orientated into the notches, and retention was evaluated in the post dam and tuberosity areas. Scans were imported into a comparison software program which matched scans to their corresponding reference and performed a 3-dimensional comparison. The Friedman and Wilcoxon tests were used to compare between groups (confidence interval: 95%,  $\alpha=.05$ ).

**Results.** Nineteen participants with a mean  $\pm$ standard deviation age of 64.1  $\pm$ 14.7 years completed all clinical sessions. No significant difference in peak retention was measured between milled (MB1), printed (PB1), and conventional (CB) bases in the post dam (CB: 12.44  $\pm$ 9.62 N, PB1: 16.08  $\pm$ 15.28 N, MB1: 14.52  $\pm$ 17.07 N) and right tuberosity area (CB: 8.99  $\pm$ 7.82 N, PB1: 11.28  $\pm$ 9.57 N, MB1: 11.99  $\pm$ 12.10 N). In the left tuberosity area, peak retention was lower for CB (10.03  $\pm$ 8.39 N) than PB1 (14.98  $\pm$ 14.72 N) and MB1 (13.55  $\pm$ 15.53 N;  $P=.05$ ). Compared with the definitive cast, the fit of the conventional base (0.18  $\pm$ 0.01 mm) was closer than the printed (0.21  $\pm$ 0.03 mm) and milled bases (0.21  $\pm$ 0.02 mm) ( $P<.001$ ).

**Conclusions.** The CD bases manufactured by CAD-CAM techniques provided retention and fit similar to that of conventionally manufactured bases and can therefore be considered suitable techniques. (J Prosthet Dent 2022;■:■-■)

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## Clinical Implications

Printing or milling can be used instead of conventional methods of fabricating dentures, providing the advantages of digitized dentistry.

material and technique used to capture the tissue anatomy and also by the method of fabrication of the denture base and the accuracy of its intaglio surface.

The trueness of CD bases fabricated by milling, injection molding, and pack-and-pressing from a single reference model has been reported to be statistically similar and within a clinically acceptable range.<sup>2</sup> However, other studies have reported a more uniform adaptation to the cast of bases produced with computer-aided design and computer-aided manufacturing (CAD-CAM) methods when compared with bases fabricated by conventional techniques.<sup>3-5</sup> Since the palate depth and arch form can influence denture fit by inducing different shrinkage patterns of conventionally fabricated bases, manufacturing procedures without polymerization shrinkage might be advantageous in some anatomic situations.<sup>6</sup>

Additive manufacturing (3-dimensional (3D)-printing) can also be used to fabricate CDs. To date, the technique has mostly been recommended for creating custom impression trays and evaluation prostheses.<sup>7,8</sup> The trueness of 3D-printed compared with milled CDs was reported to be significantly inferior when compared with that of the master model, but the reported trueness was within the clinically acceptable range.<sup>9</sup> Denture bases processed by 3D-printed digital light have been reported to have improved surface adaptation ( $\leq 100 \mu\text{m}$ ) compared with milled and pack-and-pressed denture bases.<sup>10</sup> A recent clinical crossover trial investigating the clinician and patient evaluation of milled and 3D-printed dentures reported some inferiority of the 3D-printed dentures in terms of different clinical outcomes.<sup>11</sup>

A recent systematic review of *in vitro* studies on the accuracy of digital dentures concluded that the denture base adaptation ranged between 0.058 and 0.29 mm and was within the acceptable clinical range, with an improvement in adaptation occurring after storage in saliva for 21 days; however, a consensus on the threshold of clinical acceptability for the adaptation of a denture base is lacking.<sup>12,13</sup> The superiority of 1 fabrication method has not been established for all aspects; nevertheless, using CAD-CAM methods has the advantage of preserving a digital record that can be valuable for older adults.<sup>14</sup>

The clinical significance of deviations in fit between conventional and CAD-CAM fabrication needs to be determined in a clinical environment to address the

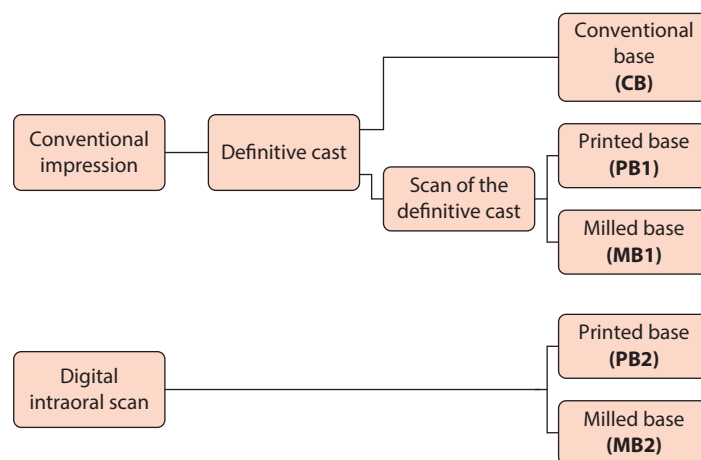
anatomic variability and to evaluate whether the alleged improved fit results in improved retention. Different methods have been used to determine the retention of denture bases, yet none can fully reproduce the reality of a denture in use.<sup>15-17</sup> The retention of milled and heat-polymerized bases has previously been evaluated clinically, with milled bases being reported to have higher retention than conventionally fabricated bases.<sup>18,19</sup> When the retention and adaptation of milled and printed denture bases were compared, better fit values were reported for printed bases; however, this did not translate into higher retention forces.<sup>20</sup> To date, there has been little clinical evidence to determine whether a particular fabrication method provides both the superior fit and retention of CDs.

The objectives of this study were to clinically compare the peak retention force and fit of complete denture bases, printed and milled versus a conventionally manufactured control, and to investigate whether retention and fit vary after storage in saliva. The null hypothesis was that the retention force of denture bases would not be affected by the fabrication method or by storage in saliva. Secondary outcomes included the fit and subjective patient perception of the different bases.

## MATERIAL AND METHODS

Approval for conducting this study was obtained from the local ethical committee (2018-02042). Patients attending the university clinics of dental medicine of the University of Geneva for either a recall or receiving treatment were recruited. The inclusion criteria were being 18 years or older, being edentulous in the maxillary arch, and being willing to participate and sign the informed consent. Participants having undercuts of more than 2 mm in the maxillary ridge were excluded, as were those with a flabby ridge, papillary hyperplasia, noticeably poor neuromuscular control, hyposalivation, general health, or other issues rendering repeated appointments difficult.<sup>21,22</sup> Undercuts were measured clinically with a graduated probe (PCP-12; Hu-Friedy). Hyposalivation was determined as an unstimulated salivary flow rate of less than 0.1 mL/min.<sup>23,24</sup>

A conventional definitive impression with a border-molded custom tray was made for each participant. The technique and materials used are detailed in Part II.<sup>25</sup> A definitive cast was poured in dental stone from the conventional impression and was considered as the reference cast for future analyses. It was scanned with a calibrated laboratory scanner (Iscan D103i; Imetric 3D SA) and saved in standard tessellation language (STL) format.<sup>26</sup> An experienced dental laboratory technician carved the post dam area on the definitive cast and used a modified polymethylmethacrylate (PMMA) resin (Ivoclar High Impact; Ivoclar AG) to fabricate the



**Figure 1.** Denture bases fabricated for each participant.

conventional base (CB) by injection molding (Ivoclar technique; Ivoclar AG). A platform was designed with a 45-degree inclination and a central and 2 diagonally placed notches. A dislodging force could therefore be applied via a dynamometer connected to a hook and orientated into the notches, thus ensuring the application of force in the same direction, simulating the dislodging force applied when clinically testing denture retention. The dental laboratory technician produced the platform on the external surface of the CB, which was subsequently scanned and sent to a manufacturing center. The platform design along with the exact location was reproduced on all CAD-CAM bases for the same participant. The base shape was designed on the STL file of the scanned reference cast using a software program (AvaDent; Global Dental Science Europe BV), and 2 denture bases were manufactured from PMMA resin, 1 printed (PB1) (NextDent; Vertex-Dental BV) and 1 milled (MB1) (AvaDent Denture Base Puck; Global Dental Science Europe BV). The prostheses were finished and polished according to the standard technique used by each manufacturer. Additionally, another impression technique was evaluated; the corresponding results are reported separately in Part II<sup>25</sup> (Fig. 1).

A visual analog scale (VAS) questionnaire was created inquiring about taste, smell, fit sensation of the base, pain on insertion and removal, and the smoothness of the bases (Appendix 1, available online). Participants were trained to use this type of questionnaire by means of an exercise sheet. Participants were blinded to the type of base they were evaluating.

Participants were invited to a total of 4 clinical appointments. Screening according to the inclusion and exclusion criteria and the preliminary impression were carried out during the first clinical appointment. The definitive impressions were made in the second appointment. The retention of the denture bases was evaluated during the third appointment and assessed in a



**Figure 2.** Retention testing platform with dynamometer hook.

predetermined random sequence ([www.randomizer.org/](http://www.randomizer.org/)). Each base was inserted in the mouth and left for 1 minute for proper seating and the formation of a salivary film between the base and the mucosa. During this time, participants were asked to answer the VAS questionnaire for each respective base. The dislodging forces were recorded with a digital traction dynamometer (Imada Digital Force Gauge; Imada Co), which was hooked onto the base and orientated into the central notch to oppose the retentive force of the post dam area and into the right and left notches to oppose the left and right tuberosities (Fig. 2). The dynamometer continuously displayed the dislodging forces in Newtons and registered the peak force. A total of 3 measurements were made for each area by the same investigator (S.M.), with a resting time of 1 minute between each measurement. The highest value was recorded as the peak retention force and used for the analysis. The same procedure was applied for all test bases. In the laboratory, all bases were subsequently sprayed with an antiglare scanning spray (Helling 3D Scan Spray; Helling GmbH), and the intaglio surface, including the peripheral border, was digitized by the

**Table 1.** Participant demographics

|                                   |                 |
|-----------------------------------|-----------------|
| Mean age $\pm$ SD (yr)            | 64.1 $\pm$ 14.7 |
| Sex N (%)                         | —               |
| Total                             | 19 (100)        |
| Women                             | 7 (36.8)        |
| Men                               | 12 (63.2)       |
| Prosthetic Diagnostic Index N (%) |                 |
| Type A                            | 15 (78.9)       |
| Type B                            | 2 (10.5)        |
| Type C                            | 1 (5.3)         |
| Type D                            | 1 (5.3)         |
| Mean USFR $\pm$ SD (mL/min)       | 0.87 $\pm$ 0.72 |

N, number; SD, standard deviation; USFR, unstimulated salivary flow rate.

same investigator (Y.I.) with the laboratory scanner. The bases were then stored in artificial saliva in an individual container for 14 days.<sup>2</sup> After the storage period, at the fourth appointment, the bases were retested with the same protocol in a randomly allocated order. Participants were asked to complete an identical second questionnaire. All bases were scanned for a second time, and the files were imported into a comparison software program (Geomagic Control X 2020; 3D systems) for analysis of fit; deviations from the reference were reported in mm.

The primary outcome being retention force, a power analysis was conducted based on the retention comparison between milled and conventional bases.<sup>18</sup> The difference in retention was used to determine an effect size (E) for the present study of 19.910 with a standard deviation of the change in outcome  $S(\Delta)$  of 29.960. According to this analysis, a sample size of 18 would detect a significant difference (Type I error=0.05, power test 1 –  $\beta$ =.8, two-sided test). To account for dropouts, a total of 20 participants were recruited.

Statistical analyses were performed with a statistical software program (IBM SPSS Statistics, v24.0; IBM Corp). Kolmogorov–Smirnov tests were used to assess the normality distribution of the continuous variables “fit” and “retention” in each group. Friedman tests were used to compare the fit values and peak retention forces among conventional, printed, and milled bases in each zone. For each patient, the mean peak retention force was calculated for the overall 3 areas and was also analyzed statistically as overall mean peak retention force. Wilcoxon tests were used to compare the fit and retention forces, as well as VAS scores before and after storage in saliva for 2 weeks ( $\alpha$ =.05).

## RESULTS

Nineteen participants with a mean  $\pm$ standard deviation age of 64.1  $\pm$ 14.7 years completed all sessions; 1 dropped out for medical reasons. Participant characteristics including edentulous ridge classification with the Prosthetic Diagnostic Index and unstimulated salivary flow rate (USFR) are detailed in Table 1.<sup>27,28</sup>

**Table 2.** Peak retention forces of bases fabricated from conventional impressions before and after storage in saliva, expressed in N (mean  $\pm$ SD; median [IQR])

| Traction Area  | CB   | PB1   | MB1   | P*   |
|----------------|--|---|---|------|
| PD             |  |   |   |      |
| Pre            | 12.44 $\pm$ 9.62;<br>8.72 [10.73]                            | 16.08 $\pm$ 15.28;<br>10.01 [14.5]                            | 14.52 $\pm$ 17.07;<br>6.89 [7.58]                             | .368 |
| Post           | 11.65 $\pm$ 11.89 <sup>a</sup> ;<br>9.34 [8.93] <sup>a</sup> | 16.26 $\pm$ 15.22 <sup>b</sup> ;<br>8.84 [21.29] <sup>b</sup> | 14.57 $\pm$ 13.71 <sup>b</sup> ;<br>7.12 [24.2] <sup>b</sup>  | .016 |
| P <sup>†</sup> | .112   | .983  | .983  | —    |
| LT             |  |   |   |      |
| Pre            | 10.03 $\pm$ 8.39 <sup>a</sup> ;<br>6.12 [14.33] <sup>a</sup> | 14.98 $\pm$ 14.72 <sup>b</sup> ;<br>6.84 [22.2] <sup>b</sup>  | 13.55 $\pm$ 15.53 <sup>b</sup> ;<br>6.20 [20.69] <sup>b</sup> | .050 |
| Post           | 10.57 $\pm$ 7.77;<br>7.69 [12.98]                            | 13.26 $\pm$ 14.88;<br>7.64 [11.2]                             | 14.26 $\pm$ 15.51;<br>5.70 [14.13]                            | .368 |
| P <sup>†</sup> | .906   | .305  | .586  | —    |
| RT             |  |   |   |      |
| Pre            | 8.99 $\pm$ 7.82;<br>6.06 [10.62]                             | 11.28 $\pm$ 9.57;<br>8.15 [9.03]                              | 11.99 $\pm$ 12.10;<br>5.90 [13.61]                            | .179 |
| Post           | 12.53 $\pm$ 12.83;<br>8.26 [14.32]                           | 12.63 $\pm$ 12.03;<br>7.41 [10.38]                            | 11.96 $\pm$ 12.36;<br>7.10 [5.77]                             | .431 |
| P <sup>†</sup> | .446   | .744  | .616  | —    |

CB, conventional base; IQR, interquartile range; LT, left tuberosity; MB1, milled base 1; PB1, 3D-printed base 1; PD, post dam; Post, after storage in saliva; Pre, before storage in saliva; RT, right tuberosity; SD, standard deviation. Different lowercase letters indicate significant difference ( $P$ <.05). \*Friedman test. <sup>†</sup>Wilcoxon test.

**Table 3.** Average fit of bases to reference cast before and after storage in saliva, expressed in mm (mean  $\pm$ SD; median [IQR])

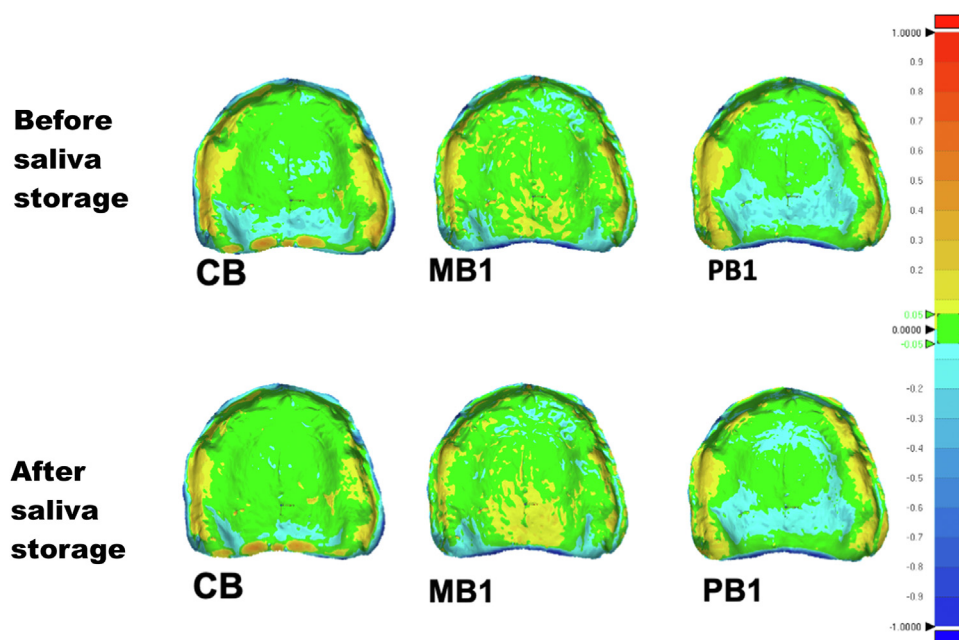
| Traction Area  | CB  | PB1   | MB1   | P*    |
|----------------|---|---|---|-------|
| Pre-saliva     | .18 $\pm$ 0.1 <sup>†</sup> ; .18 [0.02] <sup>†</sup>  | .20 $\pm$ 0.03 <sup>†</sup> ; .20 [0.02] <sup>†</sup> | .21 $\pm$ 0.02 <sup>†</sup> ; .20 [0.03] <sup>†</sup> | <.001 |
| Post-saliva    | .18 $\pm$ 0.05 <sup>†</sup> ; .17 [0.02] <sup>†</sup> | .23 $\pm$ 0.10 <sup>†</sup> ; .20 [0.03] <sup>†</sup> | .23 $\pm$ 0.09 <sup>†</sup> ; .21 [0.05] <sup>†</sup> | <.001 |
| P <sup>†</sup> | .107  | .028  | .021  | —     |

CB, conventional base; IQR, interquartile range; MB1, milled base 1; PB1, 3D-printed base 1; SD, standard deviation. \*Friedman test. <sup>†</sup>Wilcoxon test. <sup>‡</sup>Significant ( $P$ <.05).

The peak retention forces of the denture bases are reported in Table 2. Overall, the fabrication method did not influence retention, except at the left tuberosity, where CB had reduced retention. After storage in artificial saliva, the only difference was found in the post dam, with CB having reduced retention. CAD-CAM bases presented similar retention. CB (10.49  $\pm$ 8.13 N; 6.97 N [12.18]), PB1 (14.11  $\pm$ 12.65 N; 7.55 [16.61]), and MB1 (13.35  $\pm$ 14.67 N; 6.60 [8.71]) had similar overall mean peak retentive forces (Friedman;  $P$ =.150).

The mean fit for CB, MB1, and PB1 are reported in Table 3, indicating a fit close to the reference cast measured for all bases, with CB presenting the best fit, irrespective of storage in saliva (Friedman;  $P$ <.001). Printed and milled bases demonstrated an equally precise fit, with an improved fit after storage in saliva (Wilcoxon; PB1:  $P$ =.028; MB1:  $P$ =.021). The color maps displaying the fit of the different bases are shown in Figure 3.

The average VAS scores of the assessed outcomes in the subjective evaluation of the denture bases are reported in Table 4. Overall, participants evaluated all bases favorably, irrespective of the fabrication method and the



**Figure 3.** Color maps representative of base fit to reference. *Blue* indicates negative deviations and *yellow* positive deviations (mm).

storage in saliva. Only for surface smoothness did the CB score more favorably than other fabrication methods (Wilcoxon;  $P=.009$ ).

## DISCUSSION

The CAD-CAM fabrication methods evaluated in this study have become popular in recent years for complete dentures, but with limited evidence as to whether CAD-CAM methods are clinically better than their conventional counterpart. As the overall retentive force was not influenced by the manufacturing method, the null hypothesis concerning retention was not rejected. However, the null hypothesis concerning fit was rejected, as the CB presented with a better fit than CAD-CAM bases.

In the present study, the overall retentive force was not influenced by the manufacturing method. However, bases fabricated via a milling technique had higher peak retention than those fabricated conventionally in crucial areas like the post dam ( $P=.016$ ), a finding consistent with those of previous clinical research.<sup>18</sup> The retentive values, however, are difficult to compare, as the direction of the pulling forces differed between studies, the present design yielding forces which were generally lower than those obtained with a solely vertical pulling.<sup>18</sup> The absence of polymerization shrinkage of milled bases, the decreased polymerization shrinkage for printed bases, as well as improved fit, have been described as the factors contributing to higher retention compared with CBs.<sup>4,13,20</sup> These factors may explain the similar performance of the CAD-CAM bases even in the absence of a post dam. Significant differences were not found

between the retention of MBs and PBs, not consistent with the findings of a previous study that reported increased retention for milled bases.<sup>20</sup> The differences in the methodology of pulling forces and the variabilities present in the printing process may explain the contradictory findings.

Limitations of the testing methods included assessing retention with a unidirectional force which does not reproduce the complexity of the clinical situation with masticatory dislodging forces. The study design assessed only the retentive potential of the denture base given by base adaptation against the tissues. Hence, other important retentive factors such as occlusal scheme and patient's adaptive neuromuscular control were not considered.<sup>1</sup> A strength of the methodology, however, was the placement of the platform at the center of the base, which has been considered the most appropriate location for pulling the bases to evaluate retention.<sup>18,20</sup>

CB presented with a better fit than CAD-CAM bases. Although statistically significant, detected differences were small, around 0.02 mm, with an overall difference in fit of 0.2 mm on the whole intaglio surface compared with their corresponding reference. This small difference does not appear to be clinically relevant, as the retention and patients' evaluation of fit were similar. All groups presented with a precise fit, with small variability in the results. The better fit of CB may be because the base was manufactured directly on the definitive cast, while MB1 and PB1 were fabricated from the scan. While laboratory scanners have been shown to have a high trueness of up to 1  $\mu\text{m}$ , they may still have precision errors.<sup>26</sup>

**Table 4.** Visual analog scale scores of participants' subjective evaluation (mean  $\pm$ SD; median [IQR])

| Score         | CB                        | PB1                       | MB1                       |
|---------------|---------------------------|---------------------------|---------------------------|
| Taste         |                           |                           |                           |
| Pre           | 99.6 $\pm$ 1.2; 100 [0]   | 99.7 $\pm$ 1.2; 100 [0]   | 99.6 $\pm$ 1.2; 100 [0]   |
| Post          | 99.1 $\pm$ 2.8; 100 [0]   | 98.2 $\pm$ 6.9; 100 [0]   | 98.8 $\pm$ 3.6; 100 [0]   |
| Smell         |                           |                           |                           |
| Pre           | 99.6 $\pm$ 1.3; 100 [0]   | 99.6 $\pm$ 1.2; 100 [0]   | 99.6 $\pm$ 1.2; 100 [0]   |
| Post          | 99.6 $\pm$ 1.8; 100 [0]   | 99.7 $\pm$ 1.1; 100 [0]   | 99.8 $\pm$ 1.3; 100 [0]   |
| Fit sensation |                           |                           |                           |
| Pre           | 91.3 $\pm$ 15.2; 100 [10] | 93.3 $\pm$ 15.0; 100 [5]  | 87.3 $\pm$ 19.1; 97 [20]  |
| Post          | 88.9 $\pm$ 24.9; 100 [10] | 83.9 $\pm$ 29.4; 98 [20]  | 88.2 $\pm$ 24.2; 100 [15] |
| Comfort       |                           |                           |                           |
| Pre           | 96.2 $\pm$ 11.7; 100 [0]  | 92.5 $\pm$ 16.4; 100 [5]  | 91.6 $\pm$ 18.4; 100 [7]  |
| Post          | 98.3 $\pm$ 3.5; 100 [2]   | 97.1 $\pm$ 7.5; 100 [2]   | 98.4 $\pm$ 4.3; 100 [1]   |
| Smoothness    |                           |                           |                           |
| Pre           | 97.9 $\pm$ 5.0*; 100 [2]* | 88.6 $\pm$ 15.1; 100 [28] | 90.6 $\pm$ 18.0; 100 [11] |
| Post          | 95.7 $\pm$ 9.7; 100 [1]   | 86.6 $\pm$ 23.8; 100 [28] | 89.3 $\pm$ 16.5; 100 [20] |

CB, conventional base; IQR, interquartile range; MB1, milled base 1; PB1, 3D-printed base 1; Pre, before storage in saliva; Post, after storage in saliva; SD, standard deviation. \*Significant ( $P=$ .009).

A difference in fit was not detected between printed and milled denture bases, contradicting a previous *in vitro* study that reported a better fit of milled dentures compared with printed ones.<sup>9</sup> This difference may be attributed to the rapid advancement in 3D-printing and postprocessing techniques, which may have significantly improved since previous studies. The fit values for the entire intaglio surface were lower than those previously detected, probably because of the differences in methodology used to calculate differences between scan tests and references.<sup>9</sup> Moreover, the present clinical study was consistent with previous *in vitro* studies that reported excellent fit for milled bases.<sup>2-5,9,14</sup>

Storage in artificial saliva did not affect fit or retention, independently of the manufacturing method, indicating minimal volume change from water absorption. Insufficient retention immediately after CD delivery is a common postinsertion problem.<sup>29</sup> The stability after storage in saliva shows that the increase in retention after a few days of CD wearing may result from tissue compression under occlusal load, a factor which was not investigated in this study. Furthermore, artificial saliva was used, and the CD was not stored at mouth temperature.

The ease of fabrication and the reproducibility of the milling method along with the improved mechanical properties are making this technique the new standard in denture fabrication.<sup>14</sup> Dentures fabricated by 3D-printing represent an interesting additive technique, with reduced material waste and good detail reproduction.<sup>12</sup> Less sophisticated and expensive equipment is required for 3D printing compared with milling machines, as well as accelerated production time. Printed dentures may help meet the need for quality prosthetic devices at a reasonable cost.<sup>12</sup> However, this technology still has some

limitations, with different factors influencing the printed end results, including the technology used, light intensity, number of layers, angle of printing, shrinking, and amount of supporting structures and postprocessing.<sup>12</sup> The results of the present study indicate that 3D-printing may be a good technique for fabricating CDs. However, a recent clinical study reported inferior results compared with milled denture bases regarding the time and cost of prosthodontic aftercare.<sup>11</sup> Moreover, the quality and esthetic outcomes of 3D-printing for a complete CD still need further investigation, as esthetic results seem inferior compared with other fabrication methods.<sup>30</sup>

Although some differences were recorded in retention or fit, participants were not able to perceive any difference in the fit sensation of different bases. This finding was not consistent with that of a previous clinical study where participants evaluated milled dentures more favorably than conventional ones.<sup>31</sup> However, these evaluations are difficult to compare, as participants were previously aware that a newer technique was being assessed and were not be blinded to the type of prosthesis they were evaluating.<sup>31</sup> When participant and clinician were blinded, their evaluations of dentures fabricated by both techniques were comparable.<sup>11</sup> To date, patient evaluation of the complete process of CAD-CAM fabrication, including functional parameters, satisfaction and esthetics, is still insufficient. The cost-efficiency and time needed for fabrication, including adjustment sessions, should be evaluated from the patient perspective. The possibility for a trade-off between less esthetic outcomes and more cost-efficient dentures should be further investigated.

## CONCLUSIONS

Based on the findings of this clinical controlled crossover study, the following conclusions were drawn:

1. The CAD-CAM complete denture bases provided retention and fit similar to that of the conventionally manufactured ones.
2. All 3 techniques appear to be suitable denture manufacturing methods.
3. Storage in saliva did not affect the retention or fit of denture bases, and patient evaluations of the different bases were favorable for all evaluated techniques.
4. The use of CAD-CAM techniques can therefore be used for fabricating bases with results similar those of conventional methods. Moreover, they provide numerous advantages of digitized dentistry.

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