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RESEARCH AND EDUCATION

Comparison of denture base adaptation between CAD-CAM and conventional fabrication techniques

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ABSTRACT

Statement of problem. Currently no data comparing the denture base adaptation of CAD-CAM and conventional denture processing techniques have been reported.

Purpose. The purpose of this in vitro study was to compare the denture base adaptation of pack and press, pour, injection, and CAD-CAM techniques for fabricating dentures to determine which process produces the most accurate and reproducible adaptation.

Material and methods. A definitive cast was duplicated to create 40 gypsum casts that were laser scanned before any fabrication procedures were initiated. A master denture was made using the CAD-CAM process and was then used to create a putty mold for the fabrication of 30 standardized wax festooned dentures, 10 for each of the conventional processing techniques (pack and press, pour, injection). Scan files from 10 casts were sent to Global Dental Science, LLC for fabrication of the CAD-CAM test specimens. After specimens for each of the 4 techniques had been fabricated, they were hydrated for 24 hours and the intaglio surface laser scanned. The scan file of each denture was superimposed on the scan file of the corresponding preprocessing cast using surface matching software. Measurements were made at 60 locations, providing evaluation of fit discrepancies at the following areas: apex of the denture border, 6 mm from the denture border, crest of the ridge, palate, and posterior palatal seal. The use of median and interquartile range was used to assess accuracy and reproducibility. The Levine and Kruskal-Wallis analysis of variance was used to evaluate differences between processing techniques at the 5 specified locations (α=.05).

Results. The ranking of results based on median and interquartile range determined that the accuracy and reproducibility of the CAD-CAM technique was more consistently localized around zero at 3 of the 5 locations. Therefore, the CAD-CAM technique showed the best combination of accuracy and reproducibility among the tested fabrication techniques. The pack and press technique was more accurate at 2 of the 5 locations; however, its interquartile range (reproducibility) was the greatest of the 4 tested processing techniques. The pour technique was the most reproducible at 2 of the 5 locations; however, its accuracy was the lowest of the tested techniques.

Conclusions. The CAD-CAM fabrication process was the most accurate and reproducible denture fabrication technique when compared with pack and press, pour, and injection denture base processing techniques. (J Prosthet Dent 2016;116:249-256)

Complete dentures can be fabricated using several different processes. The goal of each technique is to produce a prosthesis that exhibits intricate mucosal adaptation resulting in good retention, stability, and support with minimal fabrication distortion.

Three popular denture processing techniques are compression molding, pouring a fluid resin, and injection molding. Compression molding in a conventional flask (pack and press) has been used for decades and is the most widely used technique. The fluid resin (pour) technique became popular because of decreased processing time. However, by increasing the speed of processing, undesirable features such as prosthetic denture teeth shift during processing, air entrapment, and poor bonding between denture base and teeth have been identified.[1,2] The injection molding technique was first described by Prior in 1942 and commercialized in 1970 by Ivoclar. It incorporates characteristics of both pack and press and pour processing, combining the benefits of heat processing with the decreased time of the pour

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Clinical Implications

CAD-CAM fabricated dentures provided the most consistent denture base adaptation.

technique. This technique led to a decrease in cost and increased accuracy and stability of the denture bases.[3-5]

Dentures undergo distortion during processing,[3,6-10] which can be as much as 0.45% to 0.9% linear distortion.[11,12] This distortion is a cause of decreased adaptation of the denture base to the mucosa.

A new technique for denture fabrication has emerged with computer-aided design and computer-aided manufacturing (CAD-CAM), through the use of prepolymerized blocks of polymethyl methacrylate (PMMA), computer software, and 5-axis milling. CAD-CAM dentures have become a rapidly expanding part of the dental market.[13,14]

CAD-CAM dentures offer several potential benefits to both the clinician and the patient. Dentures have traditionally required 5 appointments involving many hours of the dentist's, technician's, and patient's time. CAD-CAM dentures can be completed in as few as 2 appointments, saving considerable time. Patient records are digitized and stored by the manufacturing company. Hence, should a patient lose or fracture a complete denture, a new and identical replacement prosthesis can be fabricated expeditiously without having to make new clinical records.[13,14]

A variety of methods have been used to evaluate the amount and location of dimensional change that occurs during denture processing. These have included 2-dimensional and 3-dimensional measurements with differing degrees of complexity. Recently, the use of laser and contact scanners has become a popular way to measure denture base deformation.[15] With the use of these technologies, scanned files can be superimposed and analyzed using advanced computer software. Studies have demonstrated the validity of these evaluation methods.[15-18] To date, no research has been published comparing the processing distortion of traditional techniques and the CAD-CAM fabrication technique.

The purpose of this study was to compare the denture base adaptation of pack and press, pour, injection, and CAD-CAM techniques of fabricating dentures to determine which process produces the most accurate and reproducible prostheses. The null hypothesis was that no differences in processing deformation would be found among the 4 techniques with regard to accuracy and reproducibility.

MATERIAL AND METHODS

An edentulous maxillary definitive cast was fabricated with morphology closely resembling an American College of Prosthodontists (ACP) Type A classification of residual ridge morphology.[19] The definitive cast included 3 metal spheres, 1 located on the crest of the ridge over each tuberosity and 1 on the anterior crest of the ridge at the midline. These spheres were used to precisely overlay a measurement guide after scans of the cast and denture base were superimposed to ensure measurements were made at the same locations.

The definitive cast was duplicated using silicone based duplication material (Vivid Image; Pearson Dental), and 40 stone casts were made using a Type IV scannable dental stone (FujiRock OptiXscan; GC America Inc) (Fig. 1A). Ten casts were assigned to each of the following 4 fabrication techniques: pack and press (Lucitone 199; Dentsply Intl), pour (Lucitone Fas-Por; Dentsply Intl), injection (Ivobase; Ivoclar Vivadent AG), and CAD-CAM milled (AvaDent; Global Dental Science, LLC) (Table 1). Assuming a large effect size, based on previously reported findings, a sample size of approximately 10 is needed to have 80% power to detect a difference between groups. Therefore, a sample size of 10 was determined to be appropriate. A pilot study was completed to verify methodology and accuracy of measurements before initiating this study. Each stone cast was labeled and allowed to dry for 24 hours before scanning. Scanning was completed in a temperature (70°F) and humidity (30%) controlled room using a Dental Wings iSeries scanner outputting a stereolithography (STL) file.

A master complete denture was designed using AvaDent software (Global Dental Science, LLC) and fabricated by milling the denture base from prepolymerized PMMA resin and bonding denture teeth (Ivostar; Ivoclar Vivadent AG) into the milled base (Fig. 1B). This definitive denture was then used to create a polysiloxane putty mold (Lab Putty; Coltène/Whaledent Inc) for use in fabricating standardized dentures for the other 3 techniques.

For the pack and press, pour, and injection molding techniques, denture teeth were placed into the putty mold and molten baseplate wax was injected into the mold to create standardized wax dentures with identical thicknesses and tooth position (Fig. 1C). A total of 30 wax dentures were fabricated, 10 for each of the following traditional techniques: pack and press, pour, and injection. For the CAD-CAM dentures, each of the specimens was fabricated from a separate scan of each of the 10 stone casts assigned to that group. Scanned files were sent to Global Dental Science for fabrication using the same computer-aided design as the master complete denture, thus keeping thicknesses and tooth positions the same across all fabrication techniques.

All completed dentures were hydrated for 24 hours, then lightly coated with anti-glare spray (3-D laser scanning anti-glare spray; Helling) with an average particle size of 2.8 μm, and the intaglio surface of each

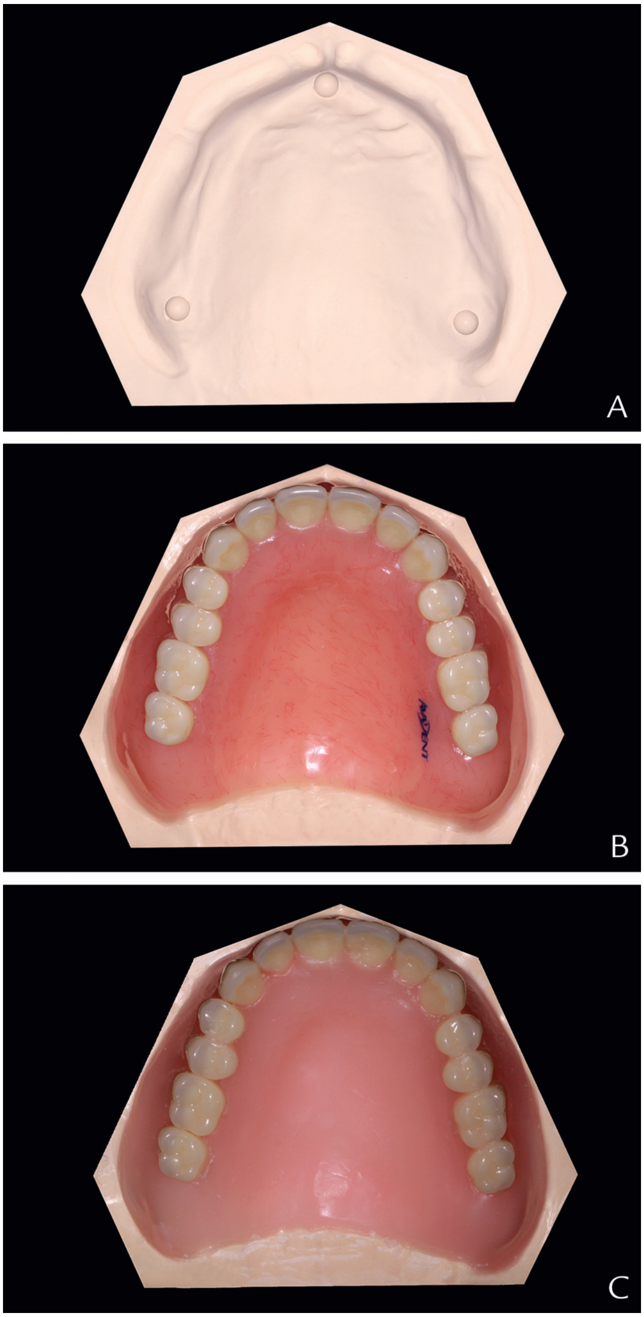

Figure 1. A, Cast with American College of Prosthodontists Type A residual ridge morphology. B, Master complete denture used to create putty mold. C, Festooned wax denture made from putty mold.

denture was scanned using the Dental Wings iSeries scanner (Fig. 2), outputting an STL file for each denture's intaglio surface. The STL file of each denture was superimposed on the STL file of the corresponding preprocessing cast using surface matching software (Geomagic Control 2014; 3D Systems). Using this software, measurements were made at 60 points for each of the 40 dentures using an overlay guide to verify the location of the 60 measurements (Fig. 3). In addition, color surface maps were created to visually display the adaption of the denture base with the cast. The surface matching and measurements provided the basis for evaluation of fit discrepancies in the following areas: apex of the denture border, 6 mm from denture border, crest of the ridge, palate, and posterior palatal seal.

To determine whether the differences between each processing technique were statistically significant, the Kruskall-Wallis analysis of variance was conducted. This analysis compared each of the processing technique measurements by location and determined whether the difference was significant. The standard error of repeated measurements was 0.002 mm.

An analysis of mean ranks of distortion among the processing techniques stratified by the 5 locations of interest was conducted using the Kruskal-Wallis procedure. Post hoc comparisons were adjusted for multiple testing. Statistical analysis using the Levene test was used to determine whether homogeneity of variance existed among the processing techniques. All tests of hypotheses were 2-sided (α=.05).

Table 1. Products used, processing method, abbreviation, and manufacturer information

Product	Processing Method	Abbreviation	Manufacturer
Lucitone 199	Compression and heat	Pack and press	Dentsply Intl
Lucitone Fas-Por	Fluid resin	Pour	Dentsply Intl
Ivobase Hybrid	Compression, heat, injection	Injection	Ivoclar Vivadent Inc
AvaDent	CAD-CAM	CAD-CAM	Global Dental Science

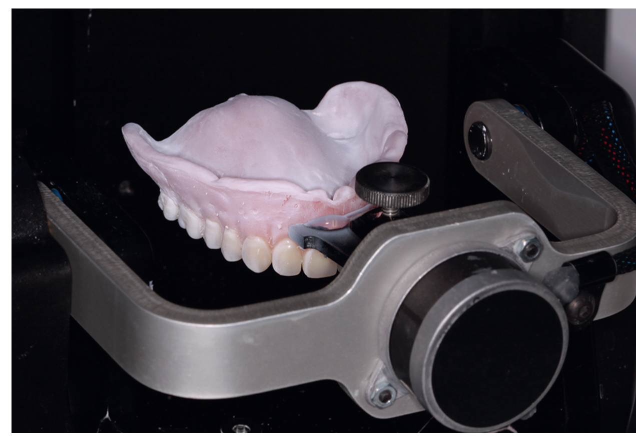

Figure 2. Denture placed in Dental Wings iSeries scanner.

RESULTS

The results of this study led to the rejection of the null hypothesis and confirmed that variations in processing deformation among the 4 processing techniques do occur. Color maps of the surface matching differences

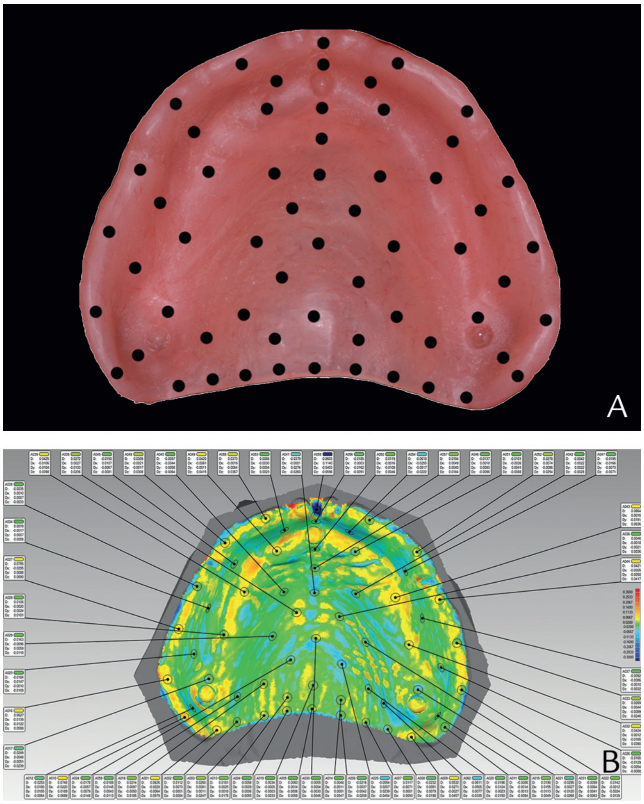

Figure 3. A, Intaglio surface showing 60 measurement points. B, Geomagic Control Software with 60 measurement points.

among the 4 techniques and the casts on which they were fabricated are shown in Figure 4. Areas that are yellow to red in color indicate impingement of the denture base with the cast. Areas that are blue in color indicate space between the denture base and cast. The ideal denture would show a color map that was entirely green, giving a measurement value of 0, which would represent no processing deformation and ideal adaptation of the denture base to the cast. Of the 4 techniques evaluated, the CAD-CAM technique demonstrated the most uniform distribution of adaptation, while the pack and press technique showed the least uniform distribution of adaptation.

Descriptive statistics including mean, median, and standard deviation values are shown in Table 2. Boxplots were constructed to demonstrate the observations for each processing technique within each location (Fig. 5). The Levene test revealed statistically significant differences in variance among the 4 processing techniques at each of the 5 locations ($P<.05$). The ranking based on accuracy (median values) and reproducibility (interquartile range) are listed in Table 3 for all 5 locations.

Both the accuracy (median distortion) and the reproducibility (interquartile range; IR) results for each technique are listed in Table 3 for all 5 locations. For both accuracy and reproducibility, the closer the value is to 0, the more accurate and reproducible the technique performed.

The difference at the apex of the denture border between CAD-CAM and pack and press was not statistically significant ($P>.05$). However, CAD-CAM distortion was observed to be statistically lower compared with injection ($P<.001$) and pour ($P<.001$). When pack and press was compared with injection and pour, a statistically significant difference was found ($P<.05$, $P<.01$, respectively). When injection was compared with pour, there was not a significant difference ($P>.05$).

For the location 6 mm from the denture border, comparing CAD-CAM denture fit with pack and press, injection, and pour, a statistically significant difference was found (all $P<.01$). When pack and press was compared with pour, a statistically significant difference was found ($P<.01$). However, there were no significant differences between pack and press and injection or injection and pour (both $P>.05$).

Evaluation based on adaptation at the crest of the ridge showed the following variation: when pack and press was compared with CAD-CAM and pour, a statistically significant difference was found ($P<.05$, $P<.01$, respectively). In comparing pack and press with injection, the difference was not considered statistically significant ($P>.05$). When CAD-CAM was compared with injection and pour, a statistically significant difference was found ($P<.05$, $P<.01$, respectively). When injection was compared with pour, a statistically significant difference was found ($P<.05$).

When evaluating the distortion from the palate, the following was found: comparing CAD-CAM with pack and press, injection, and pour, a significant difference was found ($P<.05$, $P<.01$, $P<.01$, respectively). Pack and press showed a significant difference when compared with injection and pour ($P<.01$, $P<.01$). Injection, when compared with pour, showed a statistically significant difference ($P<.01$).

Evaluation of distortion based on the posterior palatal seal area resulted in the following: comparing pack and press with CAD-CAM did not show a statistically significant difference ($P>.05$). Pack and press, when compared with injection and pour, showed a statistically significant difference ($P<.01$, $P<.01$, respectively). CAD-CAM, when compared with injection and pour, showed a statistically significant difference ($P<.01$, $P<.01$, respectively). Injection, when compared with pour, did not show a significant difference ($P>.05$).

To summarize the ranking results from the median and interquartile range, the CAD-CAM technique's median and interquartile range values were more consistently localized around zero at 3 of the 5 locations. Therefore, the CAD-CAM technique showed the best combination of accuracy and reproducibility among the tested processing techniques. The pack and press

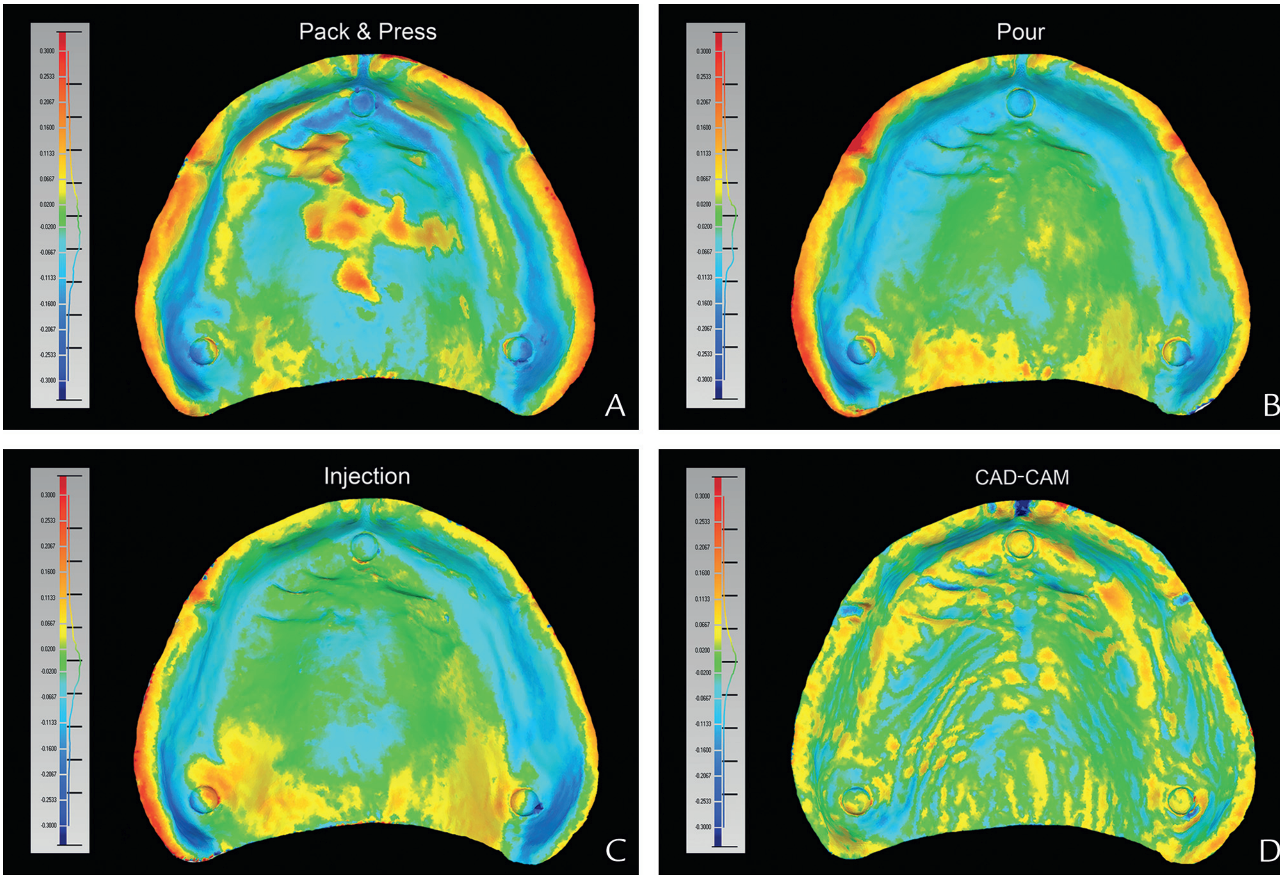

Figure 4. A, Color map of surface adaptation of pack and press technique. Yellow to red indicates impingement of denture base with cast. Blue indicates space between denture base and cast. Green indicates denture base in contact with cast. B, Color map of surface adaptation of pour technique. C, Color map of surface adaptation of injection technique. D, Color map of surface adaptation of CAD-CAM technique.

technique produced median results comparable with CAD-CAM at the apex of the denture border and the posterior palatal seal area; however, its interquartile range (reproducibility) was the largest of the 4 tested processing techniques.

DISCUSSION

Previous research has shown that dentures deform during processing, leading to diminished retention, stability, and support.[3,6-10] This decrease in retention, stability, and support has adverse consequences for the patient's comfort and it increases the clinician's chair time because of required adjustments. Denture processing techniques have been developed and improved over time in an attempt to decrease these dimensional distortions while increasing productivity for the dental laboratory. With each new technique, denture fabrication has evolved, streamlining the process and promising improved results. Finding a balance between minimal processing distortions, biocompatibility, esthetics, and adaptation is the ultimate goal. The results of this study indicate that the newest processing technique, CAD-CAM, offers a desirable balance of minimal fabrication distortion and consistently better adaptation.

The color maps shown in Figure 4 represents an average sample from the 10 specimens for each of the processing techniques tested. The color maps revealed the varying degrees of adaptation that were produced by the 4 processing techniques. While no processing technique produced a color map that was entirely green, it is evident that CAD-CAM produced the most uniform adaptation of the denture base to the cast, and statistical analysis of the measurements confirmed this finding. Visual analysis of the color maps show the following order of adaptation: CAD-CAM performed best, followed by injection and pour, which showed similar results, and pack and press showed the least uniform adaptation.

The results of the Kruskal-Wallis analysis of variance at 3 locations (6 mm from denture border, crest of ridge, and palate) showed results that require some interpretation. The results from the 3 locations appear to conflict with the results from the median values. It is important to

Table 2. Mean, standard deviation, and median values by location

	Technique			
Results by Location	**Pack and Press**	**Pour**	**Injection**	**CAD-CAM**
Apex of denture border				
Mean	0.0202[a,b]	0.0447[e]	0.0383[f]	0.0215
Standard Deviation	0.0816[a,b]	0.0447[e]	0.0400[f]	0.0331
Median	0.0219	0.0477	0.0374	0.0168
6 mm from denture border				
Mean	-0.0364[a,b,c]	-0.0737[e]	-0.074[f]	-0.006
Standard Deviation	0.0928[a,b,c]	0.0343[d]	0.054[f]	0.0358
Median	-0.0653	-0.0636	-0.0557	-0.0037
Crest of ridge				
Mean	-0.0167[a,c]	-0.0295[d,e]	-0.008[f]	0.0087
Standard Deviation	0.0787[a,b,c]	0.0356	0.0455	0.0344
Median	-0.0019	-0.0418	-0.0208	0.0076
Palatal				
Mean	0.0012[a,b,c]	0.0288[d,e]	0.0172[f]	-0.0061
Standard Deviation	0.0628[a,b,c]	0.033[e]	0.0358[f]	0.0251
Median	0.0035	0.0266	0.0087	-0.0029
Posterior palatal seal				
Mean	-0.008 [a,b]	0.0381[e]	0.0347[f]	-0.0002
Standard Deviation	0.0648[a,b,c]	0.0435[e]	0.0369[f]	0.024
Median	-0.0009	0.0434	0.038	0.0023

Statistically significant difference found between the following: [a]*P*<.05 for pack and press and pour; [b]*P*<.05 for pack and press and injection; [c]*P*<.05 for pack and press and CAD-CAM; [d]*P*<.05 for pour and injection; [e]*P*<.05 for pour and CAD-CAM; [f]*P*<.05 for injection and CAD-CAM.

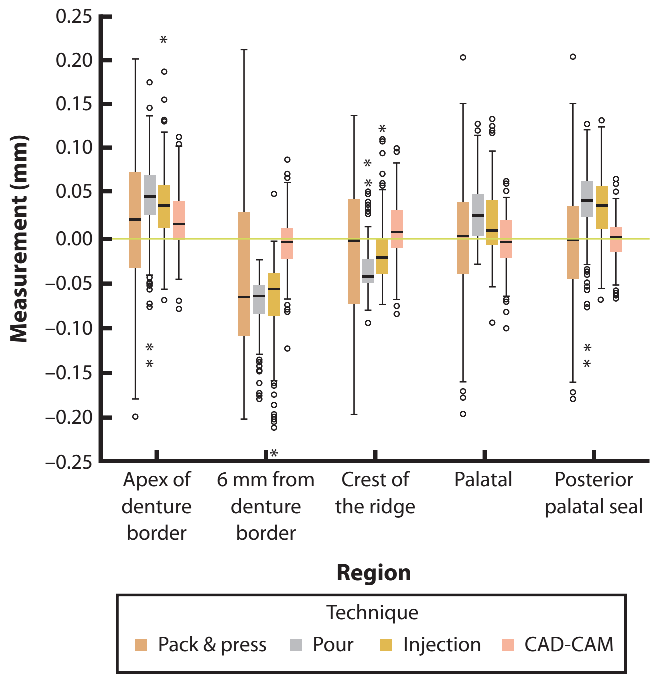

Figure 5. Performance by location. Bold, black horizontal line within each box represents median value. Red horizontal line at zero represents ideal contact with cast.

consider that the Kruskal-Wallis analysis is based on all measurements and does not represent a median value. The median generalizes the results, and the Kruskal-Wallis analysis takes each measurement and compares it with that same measurement point from the other processing techniques. Because of this difference, the determination of a difference being statistically significant will not always match the difference between median values. One example is at the crest of the ridge location, where pack and press and injection did not show a statistically significant difference but where their median values appeared to be significant.

The mean and median data are important in demonstrating the ability of the 4 processing techniques to produce a denture with accurate and uniform adaptation. Of equal or greater importance is the distribution or range of measurements recorded.[3] Those values represent the reproducibility of the technique to create a well-adapted denture base each time a denture is processed using that specific technique. In order to evaluate which technique performed best, it is important to look at the accuracy and reproducibility of the processing techniques. The ability of the processing techniques to produce a denture that is accurate, creating a median value close to zero and to be reproducible, creating the smallest interquartile range possible, determines the best processing technique.

Table 3. Accuracy and reproducibility of processing ranking based on location

Rank of Accuracy: Proximity to Zero (Median)	**Rank of Reproducibility (Interquartile Range)**
Apex of denture border	
1. CAD-CAM (0.017)	1. CAD-CAM (0.042)
2. Pack and press (0.022)	2. Pour (0.046)
3. Injection (0.037)	3. Injection (0.048)
4. Pour (0.048)	4. Pack and press (0.106)
6 mm from denture border	
1. CAD-CAM (-0.004)	1. Pour (0.032)
2. Injection (-0.056)	2. CAD-CAM (0.034)
3. Pour (-0.064)	3. Injection (0.049)
4. Pack and press (-0.065)	4. Pack and press (0.137)
Crest of ridge	
1. Pack and press (-0.002)	1. Pour (0.026)
2. CAD-CAM (0.008)	2. Injection (0.039)
3. Injection (-0.021)	3. CAD-CAM (0.041)
4. Pour (-0.042)	4. Pack and press (0.116)
Palate	
1. CAD-CAM (-0.003)	1. CAD-CAM (0.030)
2. Pack and press (0.004)	2. Pour (0.046)
3. Injection (0.009)	3. Injection (0.049)
4. Pour (0.027)	4. Pack and press (0.081)
Posterior palatal seal	
1. Pack and press (-0.001)	1. CAD-CAM (0.027)
2. CAD-CAM (0.002)	2. Pour (0.039)
3. Injection (0.038)	3. Injection (0.046)
4. Pour (0.043)	4. Pack and press (0.080)

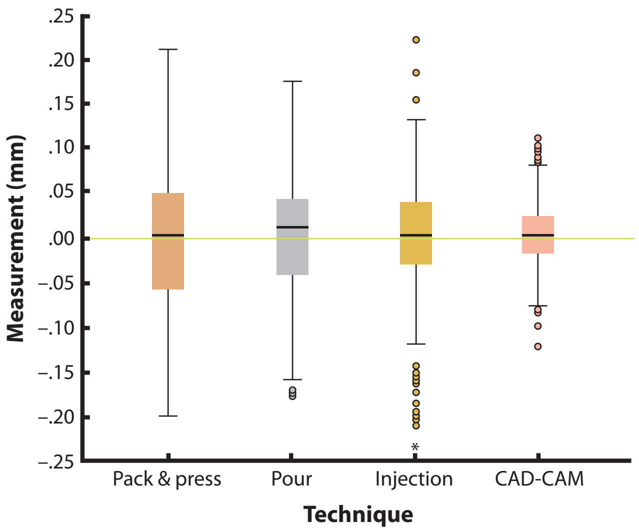

Figure 6. Overall results comparing processing techniques.

CAD-CAM had the narrowest distribution of dimensional distortion, which was located closest to zero and therefore was the most reproducible technique as shown in Figure 6. Injection was the second most reproducible technique followed by pour. Pack and press had the largest range, which is in agreement with previously published articles comparing pack and press with both pour and injection processing techniques in terms of volumetric changes during processing.[3,5,8,16]

While all measurements were small, ranging from -0.241 mm to 0.224 mm, the combination of some areas that impinged on the mucosa and others that were out of contact with the mucosa creates an environment where sore spots are more likely to occur and retention may be compromised. However, determining at what threshold a measurement of distortion becomes clinically significant is not possible. In addition, the differences in median values are small and the clinical significance is unknown.

Causes of the differences in the contact shown in the color maps and the initial contact found clinically could be attributed to multiple variables. First of all, the use of software to superimpose scanned data provides ideal superimposition, a technique not used in many of the previous studies. Another cause could be the protocol used in this study. This protocol involved immersing the dentures in water for 24 hours before making the measurements so as to represent the ultimate base fit obtained after a patient wears a denture and it becomes completely hydrated.[10,20,21] A third possibility was the strict adherence to the manufacturers' processing protocol used in this study. Finally, the palatal form and thickness of the denture base are a few factors that can affect distortion; the palatal thickness used in this study was 2 to 3 mm.[10] These variables were kept consistent for all processing techniques in this study.

Injection and pour processing techniques demonstrated both negative and positive aspects in their accuracy and reproducibility. With regard to accuracy, injection consistently performed better than the pour technique; however, both were outperformed by CAD-CAM. The reproducibility of these processing techniques both outperformed pack and press at all locations. The pour technique outperformed CAD-CAM at 6 mm from the denture border and the crest of the ridge. The findings of this study suggest both injection and pour are viable processing techniques for fabricating dentures. However, the use of the pour technique can result in undesirable features such as prosthetic tooth shift during processing, air entrapment, and poor bonding between the denture base and teeth.[1]

Previous studies that evaluated the adaptation of denture bases relied on physical measurements. In this study, using surface matching and best-fit algorithms to adapt the denture base and the cast as closely as possible allowed digital measurements to be recorded. One limitation to any study evaluating denture adaptation in vitro is how to correlate the results in vivo. No experimental protocol exists that accurately reproduces soft tissue compression. In this study, the technique that consistently provides the closest adaptation of the denture base to the cast was judged to be the best. The cast is a representation of the patient's anatomy based on the clinician's impression making ability. The more accurately the denture fits the cast, the less distortion the denture underwent during processing. Future in vitro and in vivo studies are needed to compare different palatal forms, base thicknesses, varying lengths of water immersion, and tooth movement for their effect on all the processing techniques tested in this study.

CONCLUSIONS

The CAD-CAM fabrication process was found to be the most accurate and reproducible denture fabrication technique when compared with pack and press, pour, and injection denture base processing techniques. CAD-CAM produced the most accurate adaptation at the apex of the denture border, 6 mm from the denture border, and the palate. Based on the median values, the pack and press process was most accurate at the crest of the ridge and posterior palatal seal areas, but it was the least reproducible of the tested fabrication techniques.

CAD-CAM was the most reproducible technique at the apex of the denture border, palate, and posterior palatal seal areas. The pour technique was the most reproducible at 6 mm from the denture border and crest of the ridge.

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