DIMENSIONAL CHANGE OF DENTURE PMMA PROCESSED TO CAD/CAM PRODUCED DENTURE BASES

A Thesis

by

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Submitted to the Office of Graduate and Professional Studies of
Texas A&M University
In partial fulfillment of the requirements for the degree of

MASTER OF SCIENCE

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May 2019

Major Subject: Oral Biology

ABSTRACT

Purpose: The purpose of this study was to carry out a three-dimensional analysis of the processing distortion that occurs when acrylic resin and teeth are processed onto two types of CAD/CAM denture bases. Previous studies used analog methods of measurement, and have not examined CAD/CAM denture base distortion after processing.

Materials and Methods: Ten milled and printed denture bases were fabricated on an edentulous cast, the intaglio surface scanned, and then a second processing step with acrylic resin and teeth was performed to finish fabrication of complete dentures. The samples were scanned a second time after the second processing step and then both pre- and post-processed STL files of the intaglio surface were compared with the original design file by digital file superimposition to record distortion in twelve anatomic regions.

Results: Both milled and printed denture bases had statistically significant changes ($p<.001$) after processing. Milled denture bases had an average deviation from the design file before processing of -82.5 µm and -2.3 µm after. Printed denture bases had an average deviation from the design file before processing of -100.2 µm and 23.3 µm after. Comparison between denture base groups showed a significant difference ($p<.05$) in distortion; milled denture bases distorted less than printed denture bases.

Conclusions: There was a significant difference in denture bases after processing regardless of fabrication method, with more distortion seen in printed denture bases. This difference, while statistically significant, may not be clinically significant. The area of the smallest distortion after processing was the posterior palatal seal for both milled and printed denture bases. The area of

greatest distortion after processing for the printed bases was the tuberosity region, for the milled bases the mid palate region exhibited the greatest value of distortion.

DEDICATION

To my beloved wife, Amanda who loves and believes in me despite my eccentricities and quirks.

To my beloved parents, Scott and Karen, who raised me from a strong-willed child to be a thinker, tinkerer, and good citizen.

To my beloved brother, Scotty, who knows no sadness and is the most virtuous of us all.

To my Lord, who created me from before there was time, and watches over every moment.

ACKNOWLEDGEMENTS

I would like to thank my committee chair and program director, Dr. Seok-Hwan Cho, for his expertise, direction, and mentorship, as well as Dr. William Nagy and Dr. David Murchison, for their guidance and support throughout the course of this research project.

I would like to also thank Dr. Elias Kontogiorgos and Dr. Emet Schneiderman for their statistical expertise. I also extend gratitude to the technicians and engineers who provided assistance during this project, including Mrs. Maribel Mendiola and Mr. David Jordan, for their help with fabricating and processing of the denture bases.

NOMENCLATURE

CAD	Computer Aided Design
CAM	Computer Aided Manufacture
STL	Standard Tessellation Language
PMMA	Poly-methyl-methacrylate
DLP	Digital Light Projection

CONTRIBUTORS AND FUNDING SOURCES

Contributors

This work was supported by a thesis committee consisting of Dr. Seok-Hwan Cho, committee chair, of the Department of Restorative Sciences; Dr. William Nagy of the Department of Restorative Sciences; and Dr. David F. Murchison, of the Department of Diagnostic Sciences.

The data analysis was provided by Dr. Elias D. Kontogiourious and Dr. Emet Schneiderman.

All other work conducted for the thesis was completed by the student independently.

Funding Sources

Graduate study was supported by a research grant from Texas A&M University, and from the College of Dentistry.

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INTRODUCTION

In complete denture prosthodontics, the denture base is the portion that makes up the tissue bearing surface and the material that supports and holds the denture teeth. Denture bases have undergone many changes and a long evolution in dental history, beginning with crude wooden denture bases found in Japan from the sixteenth century, to ivory, gold, porcelain, vulcanite rubber, and chrome cobalt.[1] In modern prosthodontics, the denture base material most commonly found today is poly-methyl-methacrylate (PMMA), which is an acrylic resin consisting of a liquid and powder component. The liquid constituents include unreacted monomers of methacrylate and inhibitors such as hydroquinone to prevent premature polymerization before mixing; the powder component is comprised of previously polymerized spheres of PMMA polymers in solid form, and an initiator such as benzoyl peroxide to activate the polymerization reaction by contributing free radicals that begin the cascade of electron transfers.[2] Acrylic resin denture bases can be fabricated to match an anatomical denture bearing surface in a variety of methods: chemically activated; heat initiated, which includes traditional pack and press, compression molded, and poured; light activated; and CAD/CAM methods which include either milling from a pre-polymerized 'puck' of heat initiated acrylic resin, or printing with light initiated acrylic resin by a stereolithography (SLA) printer.

Of importance to all denture base materials, but certainly not exhaustive, are the following properties: accuracy of fit, strength, flexibility, color stability, water sorption, ability to be repaired, bond strength to denture teeth, and biocompatibility.[3] Of principle concern is the accuracy of fit. Denture principles such as retention, stability, and support depend on accuracy of fit. Acrylic resins shrink after polymerization, which is a disadvantage of this material. Milled denture bases from prepolymerized pucks of acrylic resin have been introduced to compensate for conventional fabrication distortion of acrylic resins. The conventional method of processing complete dentures involves boiling out wax from a trial denture that has been invested in stone in a denture flask, then packing heat-cured acrylic resin into the resultant cavity to form the denture base and teeth bearing surface. The denture flask is placed into a water bath set at a certain temperature to initiate the polymerization reaction of the acrylic resin, and left for nine hours to complete the curing cycle.

Milled denture bases have been shown to be more accurate than traditional methods,[4] have better retention,[5] have less fungal adherence,[6] and less shifting of teeth after processing.[7] Even as early as 1994, printing of denture bases with a SLA printers, which initiates polymerization with precise application of visible light, was introduced.[8] The advantages of printing denture bases are less expense, less material used, and more end-point consumer availability than larger milling units used for puck milling. However, very little is known and published on the material properties and accuracy of fit of printed acrylic resins. Printed denture bases have been shown in previous studies to be more accurate with a digital light projection (DLP) type printer than milled for both maxillary and mandibular denture bases.[9,10] DLP printers, while utilizing the same UV light that SLA printers use, are faster at prototyping because they cure an entire print layer at one time.[11,12] However, milling workflows include the incorporation of teeth into the denture base, yielding a finished prosthesis. Printed dentures must be printed in their individual component pieces, the base and the teeth, then luted together using an acrylic resin or printing resin.

An alternate workflow that deviates little from traditional denture fabrication protocols is to incorporate the use of a pre-processed denture base. Described by Graser, the technique involves fabricating a denture base without teeth and supporting resin, then trying in the denture base at the interocclusal records appointment.[13] The wax occlusion rim is added to the pre-processed denture base, and appointments proceed as normal. A second processing step is required in which heat initiated PMMA that makes up the remainder of the denture base is processed with the teeth onto the original preprocessed denture base. The processed denture base is immersed for a few minutes in a boiling tank to evacuate the wax from the stone mold, pressure is applied in the denture flask with a mixture of heat cured acrylic resin to 3000 pounds per square inch, and the flask assembly is placed in a curing unit with a long curing cycle of nine hours at 165 degrees Fahrenheit. There are several tradeoffs with this technique. Advantages include increased early patient confidence in the fit of the prosthesis, which is psychologically important to outcomes; increased stability, retention, and support of the occlusion rim, which improves the quality of the interocclusal record.[14] and as a diagnostic tool to help evaluate the necessity of implants from an earlier stage in the denture process. Some studies have shown that a second processing step produces very little distortion to the denture base when using heat activated processed denture bases, such as compression molded and injection molding.[18,19] The disadvantages to this technique are more time required of the technician and more expense to the prosthodontist.

With the incorporation of CAD/CAM technology into dental practice, a processed CAD/CAM denture base becomes more feasible as part of a routine workflow, where a denture base is fabricated with CAD/CAM techniques and then the traditional heat initiated acrylic resin is processed onto the denture with the teeth. This technique, first described by McDonough and Ramos[15], has several major advantages. There is a higher degree of customization allowed than with a purely milled or printed workflow; teeth can be moved in wax during the trial denture appointment, and new interocclusal records made. Custom tinting of the denture during the half-flask stage can also be performed. The dental technician does not need to have extensive CAD/CAM software and milling solutions; the definitive cast can be sent to a centralized milling or printing center to produce denture bases by using existing mills with pucks or printers with acrylic resins that can be interchanged. Carving a posterior palatal seal in the stone cast, which is needed for retention[16] and to compensate for shrinkage of the acrylic resin in the palate area during polymerization,[17] is not required for CAD/CAM denture bases due to the lack of stress relaxation after deflasking and polymerization shrinkage. Finally, the accuracy of the CAD/CAM method can be incorporated into a traditional and familiar workflow. Potential disadvantages of this workflow include the lack of evidence of shear bond strength of heat activated acrylic resins to CAD/CAM denture bases, which may be affected by the chemical differences between the acrylic ether of the printed denture bases and the PMMA resin used for the second processing step. Another disadvantage is the difficulty of color matching of the denture base with the processed acrylic resin; milled denture bases are similar to traditional denture base colors, but printed denture bases usually come from the manufacturer in one color that doesn't match particularly well with either conventional chemical or heat cured denture base acrylic resins.

However, very little is known about what happens to CAD/CAM denture bases undergoing a second processing procedure. In addition, previous analog methods of measurement did not employ as many measurement points as in a contemporary technique that relies on optical scanning and superimposition upon an original digital design file.[18,19]. Therefore, the purpose of this study was to measure distortion of milled and printed denture bases after processing, by using a three-dimensional spatial mapping software measurement that digitally captures the intaglio surface before and after the processing step. The hypothesis is that there will be a difference in the denture base before and after processing, and that there will be a difference between printed and milled denture bases after processing. The null hypotheses are that there is no difference in each type of denture base before and after processing, and that there is no difference in the amount of distortion between milled and printed denture bases after processing.

MATERIALS AND METHODS

Specimen Fabrication

An edentulous maxillary stone cast that closely replicates an American Board of Prosthodontics type A patient was chosen as the anatomical basis for the denture base. The cast was scanned with a lab scanner (D900; 3shape) with an accuracy of 7 microns (μm) and a digital

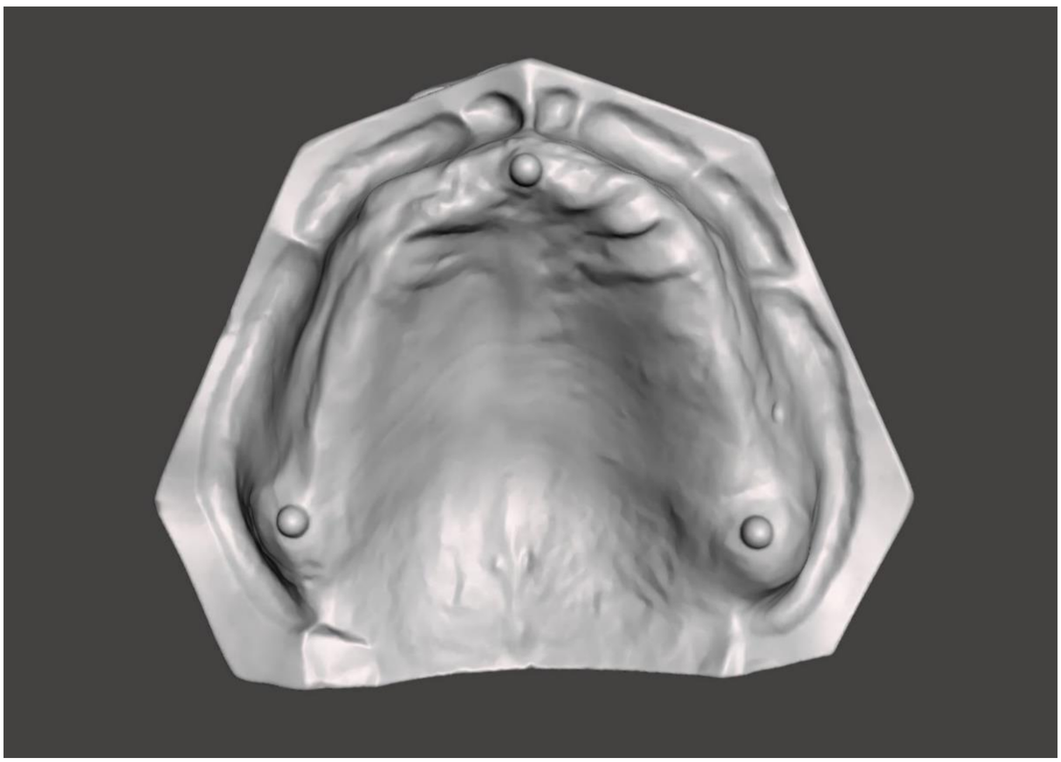

Figure 1 Digitized definitive cast showing alignment spheres

standard tessellation language (STL) model was acquired (Figure 1). The digital cast was then sent to the denture base designer who also manufactures the milled denture bases (AvaDent). A denture base with a uniform thickness of 2-3 mm was digitally designed and ten milled

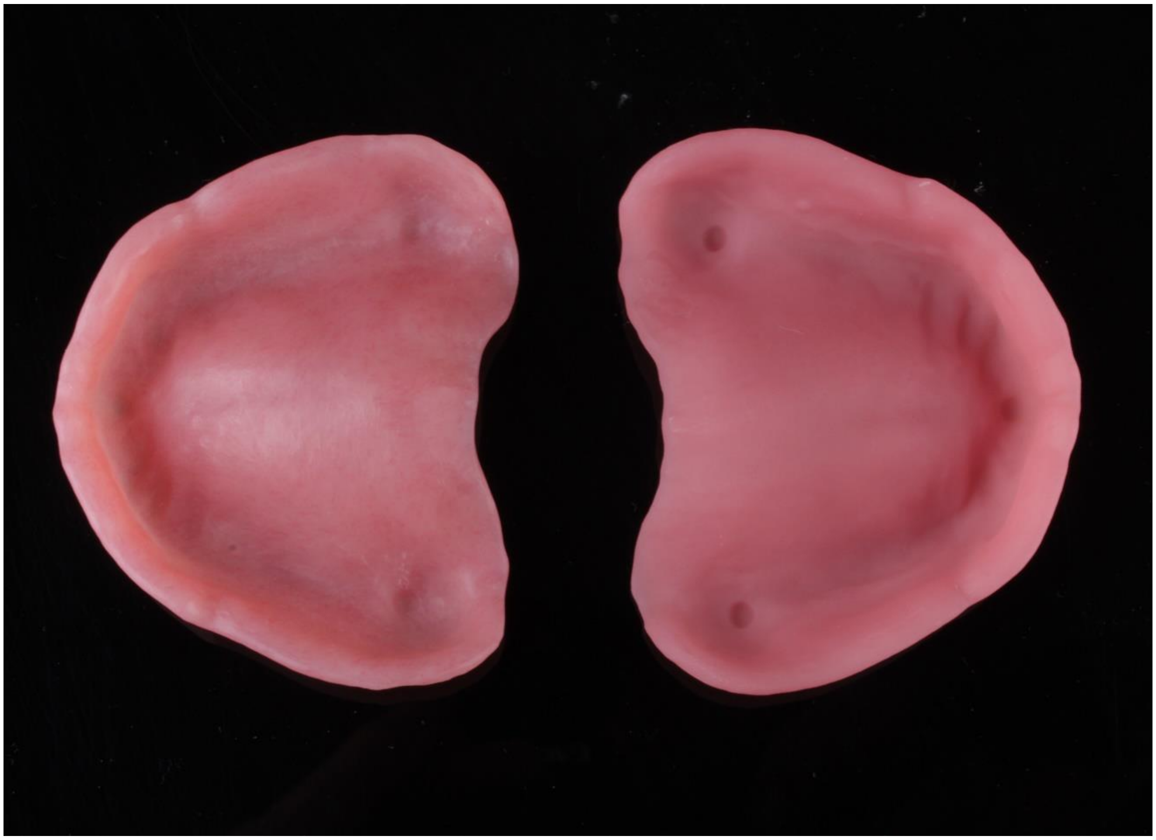

Figure 2 Milled (left) and printed (right) denture base intaglio surfaces.

specimens were fabricated from a pre-cured puck of PMMA (Lucitone 199; Dentsply Sirona). The same design STL file was also sent to the 3D print manufacturer (MedCad) and ten printed denture bases were fabricated by an SLA printer (Envisiontec Vida; Envisiontec) with denture base resin (E-denture 3D+; Envisiontec).

Before-Processing Data Acquisition

Specimens were scanned as received from the manufacturers (Figure 2) after applying a coating of CAD powder (CAD spray; Whip Mix) to generate an STL file of the intaglio surface with an optical light scanner (D2000; 3Shape).

Acrylic Addition to Denture Bases – 'Processing'

A trial tooth setup was performed on one denture base with denture teeth (Nobilium) and base plate wax (base plate wax; Pearson) (Figure 3). A putty positioning matrix was then made of the completed trial denture setup and then was used to duplicate tooth positions and wax to each denture base. The trial dentures, composed of denture base, occlusion rim, and teeth were flasked and processed by conventional methods, according to McDonough and Ramos,[15] which involves the following steps. The intaglio surface was invested with improved dental stone (Microstone;

Figure 3 Tooth setup on denture base in wax.

Whip Mix) and then embedded into the first addition of stone in the lower half of the denture flask. After the stone had set, a liquid foil separator was applied to the stone and then a second stone pour was added into the upper half of the flask and left to set. The flasks were boiled out for seven minutes and separated. Wax was then flushed from the cameo surface of the denture

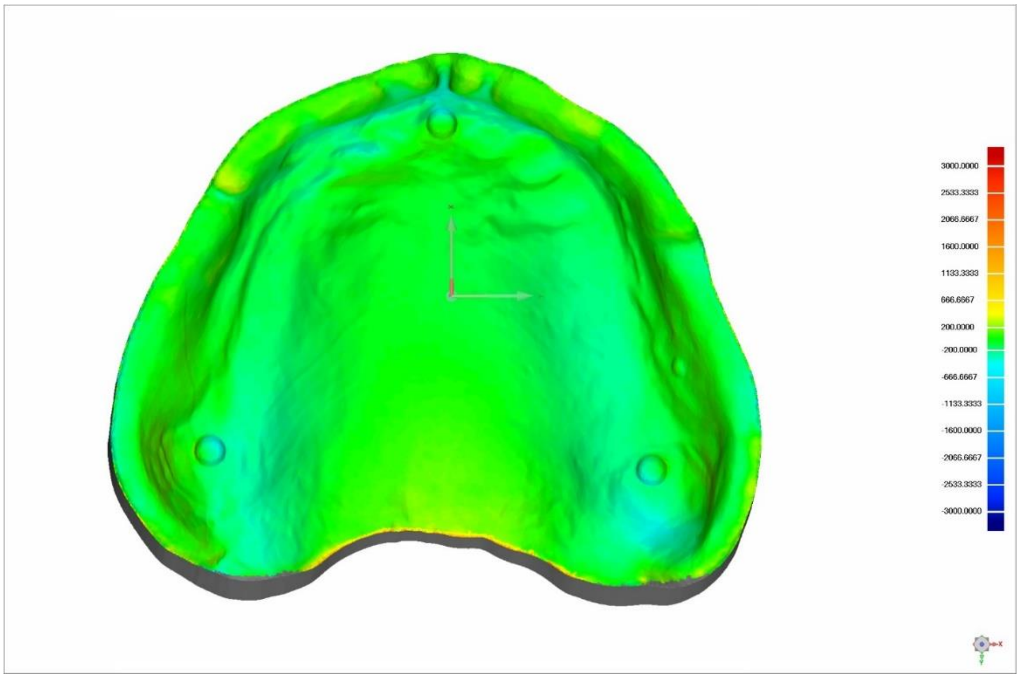

Figure 4 Printed denture base intaglio surface processing distortion

base, and from the intaglio surface of the invested denture teeth with clean boiling water (Figure 4). Heat activated denture base acrylic (Lucitone 199; Dentsply Sironia) was mixed following manufacturer instructions and placed into the denture flask and onto the denture base to adapt the teeth to the CAD/CAM denture base. The flask was pressed to 3000 psi and then transferred to the flask press, which was then placed into a 3 stage curing unit (Hanau curing unit; Whip Mix,) for 9 hours. After curing, the dentures were devested and stone removed from intaglio and cameo surfaces using a pneumatic hammer. No air abrasion was used to remove any stone particulates. Rotary instruments were used to finish and polish the cameo surface of the finished prosthesis.

After-Processing Data Acquisition and Data Analysis

The definitive dentures with resin and teeth processed to the denture bases were then resprayed with CAD spray, rescanned in the same scanner, and a digital STL file was generated of the intaglio surface of the denture base. Both STL files were then incorporated into an analysis program (Geomagic Control; 3D Systems, Morrisville) and a best fit analysis, using a tolerance of zero, was run to superimpose the pre- and post-processed denture base scans against the digital design file. Superimposition of pre- and post-processed denture base scans with the digital design file was accomplished as a reference in order to make standardized measurements between scans, perform statistical analysis, and create color mapped zones to show visual differences (Figure 4,5). Color mapped zones, which are visual depictions in color gradients of numerical data, were set at 200 µm brackets, where one bracket corresponded to one distinct color. Annotations were created in twelve anatomic locations (Figure 6) on each denture base, and any deviation from the denture base file and the denture base was measured for both pre- and post-processed denture bases. These included canine, premolar, tuberosity, posterior palatal seal,

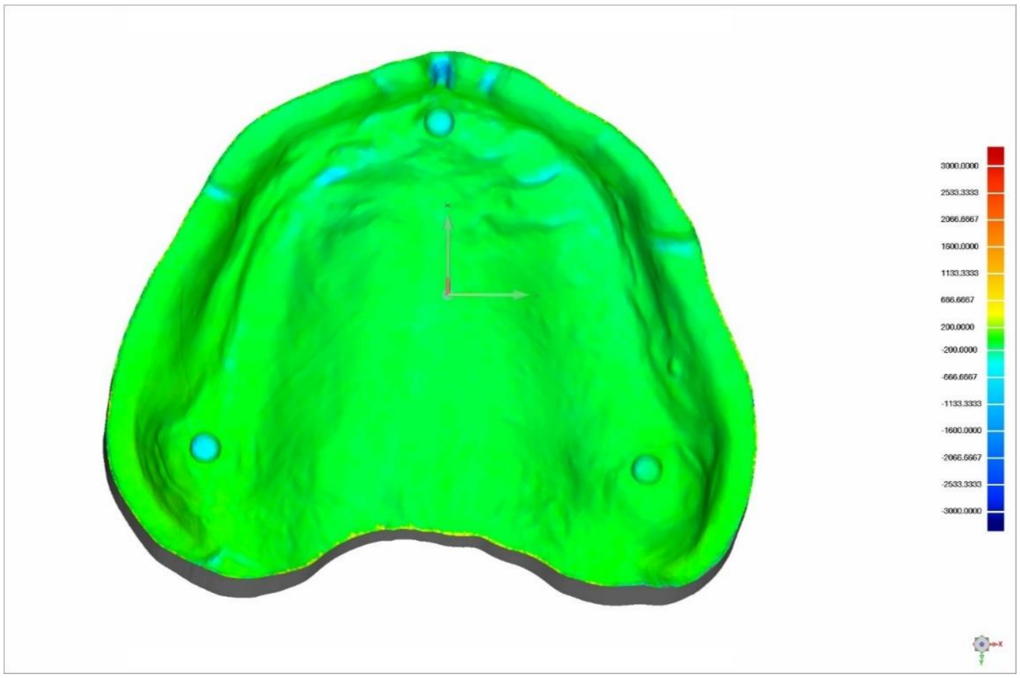

Figure 5 Milled denture base intaglio surface processing distortion.

and mid-palate locations bilaterally; and, mid palatal raphe and rugae unilaterally. Three 3 mm spheres on the cameo surface of each denture base were aligned to a marked clear overhead projector sheet on the computer screen that allowed standardization between samples of the annotation locations. The annotations created had a diameter of 3 mm in the shape of a circle, and measured hundreds of points within the circle to compute an average deviation from the denture base in one of the selected anatomical regions of the intaglio surface. A positive measurement indicated that the denture base deviated into the soft tissue (impingement), and a negative measurement means that the denture base deviated away from the soft tissue (gap). Values of deviation in the positive range show as yellow, orange, and red; values of deviation in the negative range show as cyan, blue, and dark blue. The differences in fit deviation in the twelve anatomical regions was recorded.

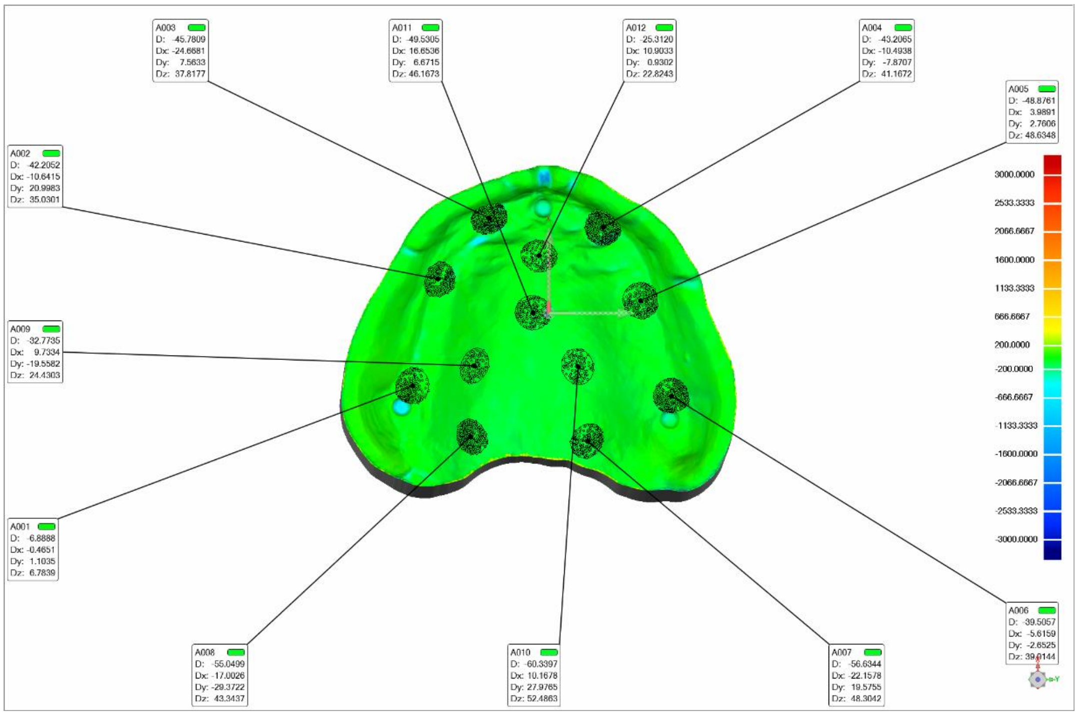

Figure 6 Anatomic regions measured in milled denture specimen.

Statistical Analysis

A paired t-test was conducted to compare the deviations before and after processing (α=.001). An unpaired t-test was performed to compare the before and after differences for each denture base type, to determine if there was a difference between the amount of distortion in milled and printed denture bases (α=.05).

RESULTS

Table 1 shows the deviation values before and after procession of each group. There was a statistically significant difference between before and after processing for both milled and printed denture base groups ($p<.0001$). The average deviation from the original design file in the printed denture bases was -100.2 µm before processing, and 23.3 µm after processing. The average deviation from the original design file in the milled denture bases was -82.5 µm before processing, and -2.3 um after processing.

Table 2 demonstrates the values of distortion change by denture processing for each group. Comparing the difference of the means with an unpaired t-test shows a statistically significant difference ($p<.0174$) between two groups. The mean distortion of printed denture bases was 123.5 µm after processing (SD=49.7 µm), and 80.2 µm after processing (SD=15) for milled denture bases, a 43.3 µm difference.

A qualitative difference between milled and printed denture bases can be seen in Figures 5 and 6. A low difference is represented by green coloration; higher positive differences are represented by yellow, orange, and red colors, while higher negative differences are represented by progressively darkening shades of blue.

Figure 6 shows the distortion analysis by 12 different locations for milled and printed denture groups. The area of highest distortion after processing was the mid palate (average deviation 160 µm) for milled denture bases and the tuberosity region for printed denture bases (average deviation 292 µm). The area of lowest distortion after processing was the posterior palatal seal for milled (average deviation 10 um) as well as for printed denture bases (average deviation 43 µm).

Table 1. Descriptive statistics for paired t-test of milled and printed denture bases before and after processing.

	Milled (n=10)		Printed (n=10)	
	Before Processing	After Processing	Before Processing	After Processing
Mean distance (µm)	-82.5	-2.33	-100.2	23.3
Standard Deviation (µm)	6.3	15	16.5	47.4

Table 2 Descriptive statistics for milled and printed denture base processing distortion

	Milled (n=10)	Printed (n=10)
Mean distance (µm)	80.2	123.5
Standard deviation (µm)	15.9	49.7

DISCUSSION

The present study evaluated the distortion of the milled and printed denture bases after processing heat activated compression molded acrylic resin and denture teeth. There was a statistically significant difference of distortion values between before and after processing for both milled and printed denture base groups. In addition, there were statistically significant differences of the deviation values by denture processing between milled denture bases and printed denture bases. Thus, the null hypotheses were all rejected. For milled and printed denture bases, the values after processing were both positive (80.2 and 123.5 µm), indicating the denture base deviation impinged into the soft tissue. The results of the present study demonstrated that definitive milled and printed dentures after a second processing step might not be seated completely in the mouth because of some degree of distortion. In terms of comparison between milled and printed denture bases, heat and pressure could result in more distortion in the printed denture bases than milled denture bases. Because milled denture bases were made from prepolymerized pucks of PMMA, milled denture bases might be less influenced by the heat and pressure during the multiple steps in denture processing.[7]

Qualitative analysis in the form of heat maps, which are representations of data in the form of a map where data values are represented as colors, are also helpful in visualizing areas exhibiting distortion (Figure 5 and 6). The scale used in the comparison program was set at 200 µm per group, where each group is shown visually by a color. Figure 7 shows an example of a milled denture base studied with its selected anatomic areas marked. These regions visually demonstrate which of areas have higher and lower deviations from the design file. In printed denture bases, the area of highest distortion after processing was in the tuberosity region, and the lowest after processing was in the posterior palatal seal. The higher deviation could be explained by the fact that there is more variance in the surface topography in the tuberosity region of a denture base; more volumetric shrinkage might occur at the tuberosity region in a printed denture base that has not been subjected to the heat and pressure associated with a previous flasking. However, the posterior palatal seal area was not influenced by the denture processing of the printed denture bases because posterior palatal seal areas in dentures are fairly flat in shape, and pressure from the flask assembly would be perpendicular to the widest portion of the denture base, which may stabilize the denture base during processing. In milled denture bases, the area of highest distortion after processing was in the mid palate, and the area of lowest distortion was also in the posterior palatal seal, presumably for the same reasons at seen in printed groups. Both printed and milled denture bases showed the posterior palatal seal area was the least distorted area in the present study. Goodacre et al[4] indicated that this was one of the advantages of the milled dentures, which do not require additional cast carving on the posterior palatal seal area due to adequate adaptation. Conventional denture processing method usually require physical carving in stone of the posterior palatal seal area in order to compensate for the distortion of heat activated compression molded PMMA during processing.[16, 17] Al-Hanbali et al found similar results but with lowest distortion in the palate area of heat activated acrylic resin denture bases [20]

Some studies have looked to correlate accuracy of fit and retention by measuring the force needed to displace a maxillary denture.[21] However, the difficulty of assessing distortion acceptability remains because each patient is different in terms of anatomy, soft tissue thickness, and soft tissue compressibility, all of which affect the fit, retention, and overall success of a denture base. There have been very few studies that assign a numerical value to distortion of pre-processed denture bases after denture processing; most of these involve analog measurements using landmarks on the intaglio surface,[19] or a standardized puck that is dimensionally measured.[20] No previous study has used the digital measurement techniques employed in this study that examine thousands of points to make such robust averages.

The average distortion found in the present study could be compared with the clinical acceptability threshold of fixed restorations on natural teeth.[21] Thus, the clinical significance of the present study is that the distortion caused by denture processing of milled and printed denture bases may not be clinically significant, because both techniques displayed very minimal distortion values. A clinician can send a definitive denture impression to a laboratory and it can either scan or send the definitive cast to a design and milling or printing center for fabrication of the CAD/CAM denture base. The laboratory technician can then receive the final denture bases and fabricate working casts to place occlusion rims on the cameo surface of the denture bases to perform interocclusal records. This workflow has been described for milled dentures[15] but has not been described for printed denture bases. Printed denture bases have the advantage of being able to be produced in office or in a dental laboratory that has a compatible printer; no specialized milling equipment is needed.

There are a few limitations of the present study. There are no established guidelines for the amount of distortion deemed clinically acceptable on such a precise scale; there are only comparisons between different fabrication methods and not a standard agreed upon measurement. Another limitation to this study is that compression molded acrylic resin denture bases, which are the conventional fabrication method for the workflow used in this study, were not used as a comparison; only CAD/CAM produced denture bases were. The superimposition of different STL files, though very accurate, cannot always be perfect. A potential for future study and a better design may be to have metal spheres embedded into the denture base, so that after a second processing step, the spheres would not change. In the present study design, superimposition was performed by a simple best fit regression using the entire denture base, which can potentially cause some areas to be superimposed more accurately than others. A future direction of study in this area should focus on heat activated compression molded denture base distortion after a second processing step as this would serve as a control group to contrast with CAD/CAM denture bases. Also, due to a dramatically different anatomical topography, it is unknown how a mandibular denture base would perform under the same conditions.

CONCLUSIONS

Within the limitation of this in vitro study, the following conclusions were drawn:

1. There was a significant difference of distortion values after denture processing for both milled and printed denture bases. Between the two groups, the printed denture base showed more deviation than the milled denture after processing. This difference, while statistically significant, may not be clinically significant.
2. The area of the smallest distortion after processing was the posterior palatal seal for both milled and printed denture bases. The area of greatest distortion after processing for the printed bases was the tuberosity region, for the milled bases the mid palate region exhibited the greatest value of distortion.

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