Comparison of Anterior Denture Teeth Arrangements Made with the Tooth Mold Template and Definitive Computer-Aided Design & Computer-Aided Manufacturing Complete Removable Dental Prostheses

Jose Antonio Sierra
Marquette University

COMPARISON OF ANTERIOR DENTURE TEETH ARRANGEMENTS MADE WITH THE TOOTH MOLD TEMPLATE AND DEFINITIVE COMPUTER-AIDED DESIGN & COMPUTER-AIDED MANUFACTURING COMPLETE REMOVABLE DENTAL PROSTHESES

By

Jose Antonio Sierra D.D.S

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ABSTRACT

COMPARISON OF ANTERIOR DENTURE TEETH ARRANGEMENT MADE WITH THE TOOTH MOLD TEMPLATE AND DEFINITIVE COMPUTER-AIDED DESIGN & COMPUTER-AIDED MANUFACTURING COMPLETE REMOVABLE DENTAL PROSTHESES

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Introduction: There is a dearth of information in the refereed literature regarding esthetics of CAD/CAM complete removable dental prostheses (CRDPs). The purpose of this study was to investigate and compare the anterior denture teeth arrangement made with the medium-size anterior tooth mold template to CAD/CAM complete removable dental prostheses fabricated with bonded denture teeth and milled teeth.

Material and methods: Poly-vinyl siloxane impression were made of an edentulous maxillary model and selected for use as the patient template. The edentulous model was mounted on a semi-adjustable articulator. Definitive impressions and jaw relation records were made according to the manufacturer's protocol. Digital mock-ups of the denture tooth arrangement were received by the manufacturer and confirmed prior to processing. Ten CRDPs were generated; subgroups of 5 units were made and divided into 2 groups. One-half of the CRDPs were made by bonding manufactured denture teeth onto denture base milled from pre-polymerized PMMA pucks, while the other half were made by milling denture teeth directly.

For comparison, a Canon 70D camera mounted on a tripod was used for photographic documentation. All photos were taken during the same day. Reference markers placed on the edentulous model were used to orient and measure photos using Photoshop CS4. Data was collected in the X-plane and the Y-plane and compared with the tooth mold template. Data were statistically analyzed by Mann-Whitney U and Wilcoxon signed-rank tests (α=.05)

Results: No statistical difference was found when CAD/CAM CRDPs milled and bonded were compared. The tooth mold template represented the position of the central incisors on the milled teeth and bonded teeth CRDPs. The inter-canine distance was found to be 5 mm narrower on the CRDPs than the tooth mold template. The canines on the CRDPs were 1 to 2 mm incisal when compared to the tooth mold template.

Conclusions: Tooth arrangements in bonded and milled CAD/CAM CRDPs did not accurately reproduce the tooth mold template's measurements in terms of intercanine distance and position. There was no significant difference between tooth position on the milled and bonded CAD/CAM CRDPs

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CHAPTER 1

INTRODUCTION

The estimated prevalence of complete edentulism in 2020 will be 37.9 million adults; a 10% decline in age specific population has also been reported.[1] Though the rate of edentulism continues to drop, the increase in population has created more need than ever before.[1,2] Yoshida et al. reported that oral health has an impact of the quality of life (QOL) of the elderly (>65 years) and is significantly decreased in the edentulous elderly population.[3] In that study, several factors were analyzed such as eating, verbal communication, physical comfort, loneliness, job and hobbies, meaningfulness (as it pertains to their lives), social life, and economic problems.[3] Other authors found patient satisfaction was greatly correlated to the dental appearance.[4-7] Furthermore, a pleasing dental appearance has been related to a satisfying psychological comfort.[7-10]

Conventional fabrication of complete removable denture prostheses (CRDPs) has been shown to be clinically predictable for almost a century.[11] The conventional method presents with some limitations: 1. number of patients visits, 2. high treatment costs due to multiple visits, 3. Dental laboratory expense, 4. lack of intimate fit between the denture base and the edentulous ridge due polymerization shrinkage, and 5. difficulty in recreating a duplicate denture.[12,13] While computer aided design/computer aided manufacture (CAD/CAM) fabrication of CRDPs has its own limitations, there are several advantages that CAD/CAM fabricated dentures have over the traditional method: 1. reduced number of patient visits, 2. superior strength and fit of dentures due to use of prepolymerized acrylic resin blocks for milling, 3. reduction microorganism adherence in dentures, 4. reduced cost for the patients and dentists, and 5. duplication of the dentures is easier and more accurate due to stored digital data.[12-16] The key differences in CAD/CAM fabrication of CRDPs when compared to conventional fabrication methods include the lack of a trial arrangement appointment. One manufacturer specially recommends that clinicians may go directly from the impression/records appointment to insertion of the definitive prostheses.[30]

The purpose of this study was to investigate and compare linear measurements associated with the anterior denture teeth arrangement made with the medium-size anterior tooth mold template (Global Dental Science LLC, Scottsdale, AZ) to the CAD/CAM complete removable dental prostheses (CRDPs) fabricated with bonded denture teeth and CAD/CAM CRDPs milled teeth. The clinical implication of the study was to provide dental professionals with clinical information about the accuracy and precision of the medium-size anterior tooth mold template (Global Dental Science, Scottsdale, AZ) with this specific CAD/CAM CRDP fabrication technology.

CHAPTER 2

REVIEW OF THE LITERATURE

Complete removable dental prosthesis has been a common dental procedure to treat edentulous patients throughout history. The earliest appearance of maxillary and mandibular CRDPs was approximately 1500 in Switzerland. These early CRDPs were carved from an ox's femur and tied together at the posterior phalanges to form a hinge. These dentures were considered to be cosmetic rather than functional since the dentures typically were fabricated directly over carious teeth.[17] Modern dental prosthesis in more modern times were introduced by Matthias Gottfried Purmann in his *Wundarzenei* of 1684, as cited by Guerini.[17] In 1839, Charles Goodyear created Vulcanite and later used the material to create denture bases in 1855. During the same year, aluminum casting was explored as a potential means of fabricating denture bases. In 1870, an aluminum casting machine was created that allowed for denture bases to be made of aluminum in combination with vulcanite and prosthetic teeth.[17,19] Vulcanite was later replaced by acrylic resin polymers, which were first introduced as denture base materials in 1937.[17,18] In 1937, Wright found that methyl methacrylate resin (Vernonite) met the requirements for an ideal base material.[18,19] Although methyl methacrylate resin is far from an ideal denture base material it possesses superior properties when compared with Vulcanite. Some of the concerns with Vulcanite denture bases had limitations associated with physical characteristics such porosity, absorbency, opacity and lifeless appearance.[17-19] Furthermore, vulcanite was difficult to fabricate, technique sensitive and provided lab equipment complexity.[17-19]

Since its introduction, polymethyl methacrylate (PMMA) has been the most commonly used resin employed to make removable dental prostheses.[18,19] Conventional denture processing with PMMA consists of investing/flasking dentures and master casts with plaster/stone into flasks; boil out to soften and remove the wax the denture is covered with plaster/stone and placed in boiling water for 5-10 minutes), elimination of the wax from the resultant molds, packing the resin (packing the acrylic resin into the mold, removing excess and re-packing), and curing the acrylic resin (polymerization of acrylic resin in a water bath heated to approximately 162 degrees F where the flask is submerged).[20]

Denture resin may be polymerized by using several different methods. Nishii was the first to report on using microwave energy in 1968 to polymerize denture resins.[15,21] The discrepancies between processed denture bases and the stone casts were less when using microwave energy was used for polymerization when compared with the hot water bath method was used. However, no difference was noted between the microwave method (500 watts, 3 minutes) and the conventional hot water bath method when the standard protocol (74^{o} C, 8 hours) was followed. [22-24] Peyton found there was no difference in polymerization shrinkage as long as the temperature wascontrolled.[19]

Digital technology was initially used in dentistry during the 1950s. In 1957, the world's first CAM software program, named PRONTO, was developed by Dr. Patrick J. Hanratty. As a result, Hanratty is referred to as the father of CAD/CAM technology.[15, 25] PRONTO became commercially available in the late 1960s. In the early 1980s, Andersson introduced CAD/CAM technology for use with fabricating titanium crowns clinically.[15] Andersson went on to develop the CAM portion of the fabrication process by combining spark erosion and copy milling.[15] In 1983, Procera (Nobel Biocare, Kloten, Switzerland) was created for CAD fabrication processes. The first CAD/CAM Procera crown made from a computer file instead of from a conventional stone die was made in 1990.[15] In 1994, Maeda et al were the first to report in English the use of computer-aided technology to fabricate complete dentures.[15,26] In 1997, a report by Kawahata et al investigated digital duplication of existing dentures and milling them by use of a computerized numerical control (CNC) machine which used a subtractive manufacturing method.[15,27] Subtractive manufacturing is milling a workpiece from a blank puck via CNC machine.[40] The CAM software translates the information to a CAD model where removal or subtraction of material was performed via milling instruments. In 2008, Sun et al investigated 3D laser scanning of edentulous casts, occlusion rims, digital tooth arrangements and created virtual flasks for denture processing. The dentures were fabricated through rapid prototyping technology, 3D printed or additive layer manufacturing, which created physical flasks and dentures. Teeth were inserted onto the denture bases and conventional laboratory procedures were used to fabricate complete dentures.[15, 29] In 2012, Goodacre investigated scanning silicone impressions, interocclusal records, and developed virtual tooth arrangements. The denture bases were CNC milled from a block of acrylic resin followed by manual bonding of denture teeth into precut openings in the bases.[15,30] It has been reported that pre-polymerized acrylic resin provided superior fit and strength compared to conventionally processed acrylic resin denture bases.[12] Since the pre-polymerized acrylic resin was milled from previously processed resin, it was considered to be more accurate and eliminated the need for a posterior palatal seal in maxillary complete dentures.[31] Limitations with this fabrication process included obtaining optimal or accurate occlusal vertical dimension (OVD) records, maxillomandibular relationship record (MMRR), evaluating lip support without the benefit of maxillary occlusion rims, evaluating maxillary incisal edge position, establishing mandibular occlusal plane, and obtaining patient input and esthetic consent. Additionally, materials and laboratory costs were higher than traditional methods.[12, 32]

Conventional CRDPs have been traditionally fabricated over five clinical appointments.[15] One appointment may be dedicated to each step, or several steps can be combined during an appointment. The steps have been identified as follows: examination and preliminary impressions, definitive impressions, maxillomandibular relationship records, wax denture trial evaluations, and CRDP insertion.[15] Even though the conventional protocol was considered predictable and successful, [26] there are certain disadvantages associated with it. Some of these disadvantages include:

1) the number of patient visits including post-insertion visits; 2) high treatment costs due to multiple patient visits; 3) dental laboratory expenses; 4) lack of intimate fit between denture bases and edentulous ridges due to polymerization shrinkage; and 5) difficulty in creating duplicate dentures.
2) In addition to these disadvantages, several authors have also noted 1) the increase in aging population and resultant increased demand for CRDPs, 2) A shortage of dental laboratory technicians in the US created greater difficulty for clinicians in obtaining the services of competent complete denture laboratory technicians.[27,29,33]

There are multiple advantages associated with CAD/CAM fabrication of CRDPs including:

1) the number of patient visits has been reported to be significantly reduced[16] 2) superior strength and fit of dentures due to use of pre-polymerized acrylic resin blocks for milling; 3) reduced potential for CAD/CAM dentures to harbor micoorganisms[12, 30] 4) reduced costs for patients and dentists; 5) replication of CADCAM dentures is easier due to the fact that all of the data for fabricating the dentures have been digitized and easily stored. .[27, 29, 33]

A significant difference between the CAD/CAM fabricated dentures and conventional dentures is the fabrication process and use of PMMA. The conventional denture curing method uses PMMA by mixing the polymer power and monomer into a dough state and then placing the resin into a mold. The denture flask was submerged into a water bath; the resin was cured 162^{o}F for 8 hours.[20] The CAD/CAM fabricated complete dentures are made from a pre-polymerized PMMA, PMMA blocks with a subtractive manufacturing process recesses that correspond to the location of the treatment planned teeth are milled into the blocks of resin/denture bases; The conventional method had reported volumetric shrinkage of 7-8% while the CAD/CAM method reported no shrinkage in the PMMA pucks nor any values have been reported.[30,34]

In contrast with conventional CRDPs, CAD/CAM CRDPs where clinicians have multiple choices in selecting tooth molds for patients, CAD/CAM CRDPs use a medium-size tooth mold template for the anterior denture teeth setup.[16,30,33] The tooth mold template is an outline of six anterior teeth on an sticker provided by the company to establish midline, cementoenamel junction, intercanine distance and incisal edge position.[30] (Figure 7) This template tab may be used as an alternative to a traditional wax denture try-in. After the clinical procedures for this CAD/CAM protocol, the denture bases are CNC milled from a gingival colored blocks of acrylic resin. After the denture bases have been milled, they are prepared for insertion of the denture teeth. The denture teeth are then manually bonded into the precut openings on the bases. [30,35] Furthermore, this medium-size tooth mold template may be used to make a monolithic milled CRDP where tooth shapes and positions are taken from a digital library and milled into the denture bases.[35]

However, few studies of CAD/CAM CRDPs have been reported, and fewer studies have analyzed the accuracy of the tooth mold template used in this process. According to this manufacturer (Global Dental Sciences, Scottsdale, AZ, USA), clinicians prescribing this type of CAD/CAM CRDPs, use a tooth mold template in order to record the midline, incisal edge positions, teeth size, and gingival heights of the anterior teeth. Several authors have discussed that development of optimal esthetics is a significant factor in CRDP success.[5-11] Authors have often correlated patient's psyche to denture success.[5-11] Since teeth are an important part of dental/facial esthetics, it is important to evaluate the accuracy of this tooth mold template for proposed tooth setups. This is a distinct limitation of this particular protocol whereby clinicians either have to spend additional money for white try-in dentures (and an additional clinical appointment) or proceed directly from the records appointment to insertion of the definitive dentures without a wax try-in.

Following the review of the literature, it was determined that esthetics of CAD/CAM CRDPs is an area without a lot of information, Hence, the null hypothesis for this thesis is there will be no difference when comparing the position of the medium-size anterior tooth template and bonded or milled denture teeth in the finished CRDP groups.

CHAPTER 3

MATERIALS AND METHODS

Data were acquired and a power analysis was performed in order to determine the number of specimens required to complete this study. As a result of the power analysis, a collection of 10 CRDPs were assembled and used as test specimens. The CRDPs were fabricated per the protocol established by AvaDent (Global Dental Sciences, Scottsdale, AZ).

Two trial bases and occlusal rims were made on the maxillary and mandibular models. Average lengths were used to identify the location of the occlusal aspects of the occlusion rims: 22 mm for the maxillary cuspids; 18 mm for the mandibular cuspids.[20](Figure 2 and 3) The maxillary edentulous model and occlusal rim was placed on a Hanau remounting record plate (Whip Mix, Louisville, KY). An arbitrary maxillomandibular relation record was made and the mandibular model was mounted. (Figure 4 and 5) Two custom trays were made on B-3 series maxillary and mandibular edentulous models (Farasco, Greenville, NC) simulated patient template (Fig. 1). Border molding of the edentulous models were made with polyvinyl siloxane (PVS) heavy body impression material and a definitive impression made with a PVS light body wash impression (AvaDent Impression Material, Global Dental Sciences, Scottsdale, AZ) (Figures 8 and 9). Maxillary and mandibular Anatomic Measuring Devices (AMDs) were used to record the OVD, MMRR, and assess the smile design. AvaDent Adhesive was applied to the AMD, and border molding was completed by applying AvaDent Border Molding material (AvaDent Impression Material, Global Dental Sciences, Scottsdale, AZ) to the intaglio surface of the AMD, and positioning them onto the edentulous models. The AMDs were completely seated onto the edentulous models, centered on the edentulous model midline, and horizontally positioned parallel to the mandibular ridge. (Figure 6) The occlusal vertical dimension was maintained with the central tracing pin set to 40mm. A notch was made in the mandibular record base for the central tracing pin to identify the arbitrary position regarding vertical dimension and centric jaw relationships. The medium size tooth mold template sticker was attached to anterior plastic arch to identify the maxillary dental midline and incisal edge position. (Figure 7) Additional interocclusal registration material was flowed between the maxillary and mandibular AMDs to interlock and record the maxillomandibular relationship. The impressions and AMDs were shipped to AvaDent (Global Dental Sciences, Scottsdale, AZ) where they were scanned by a Dental Wings scanner (Dental Wings Inc., Montreal, QC, CA). All of the information in the impressions was digitized. The maxillomandibular relationships and the proposed tooth locations were identified and made by the investigator. After all of the scans were completed, a designer used a proprietary computer software to make a tentative virtual tooth arrangement which was sent to the investigator via email for evaluation. (Figure 10 and 11) The selection of the 22 E mold from Dentsply Portrait IPN (Dentsply Sirona, York, PA) was made for use with the bonded teeth group. The monolithic milled teeth were taken from a scanned 22 E tooth mold library (Global Dental Science, Scottsdale, AZ) and milled from a PMMA tooth colored puck.

Figure 1. Maxillary Edentulous Model

Figure 2. Maxillary Record Base and Occlusal Rim

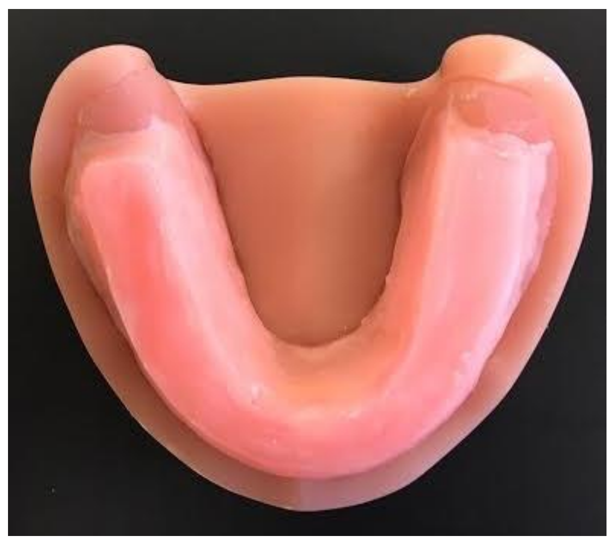

Figure 3. Mandibular Record Base and Occlusal Rim

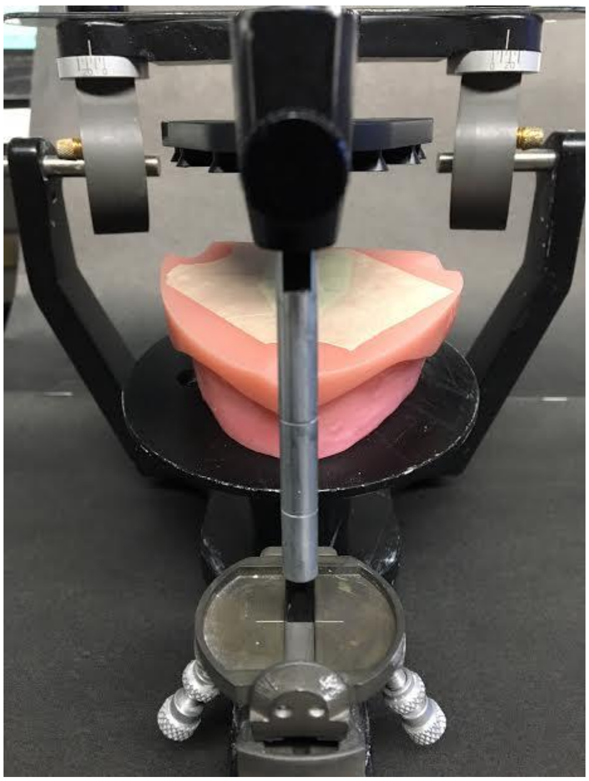

Figure 4. Arbitrary Mounting Index with Wax Occlusal Rim and Model (Frontal view)

Figure 5. Arbitrary Mounting Index with Wax Occlusal rim and Model (Sagittal view)

Figure 6. AMD Record with Bite Registration Occlusal (Frontal view)

Figure 7. AMD Record with Tooth Mold Template

Figure 8. Maxillary Definitive Impression

Figure 9. Mandibular Definitive Impression

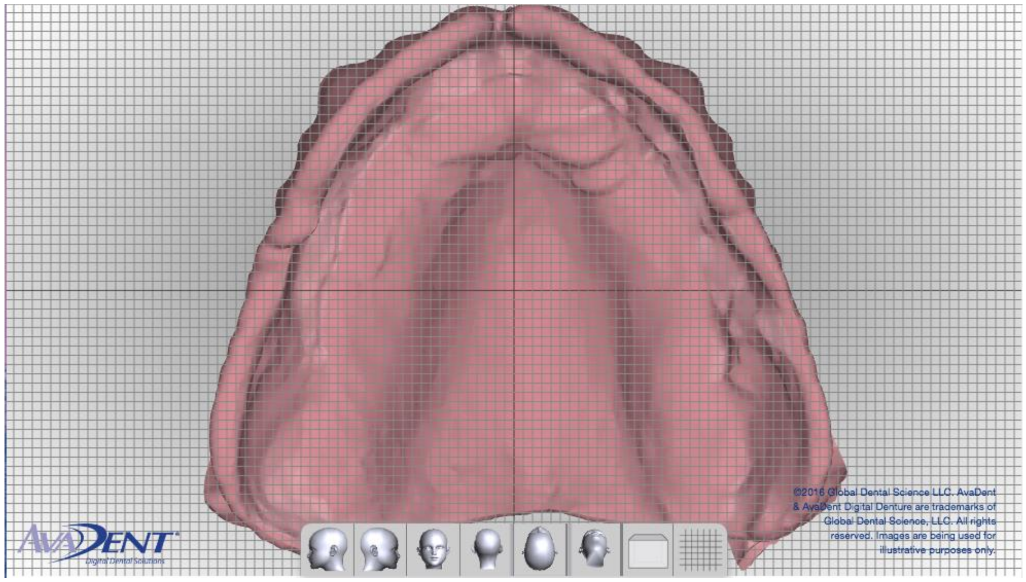

Figure 10. Digital Maxillary Intaglio Surface of CRDP

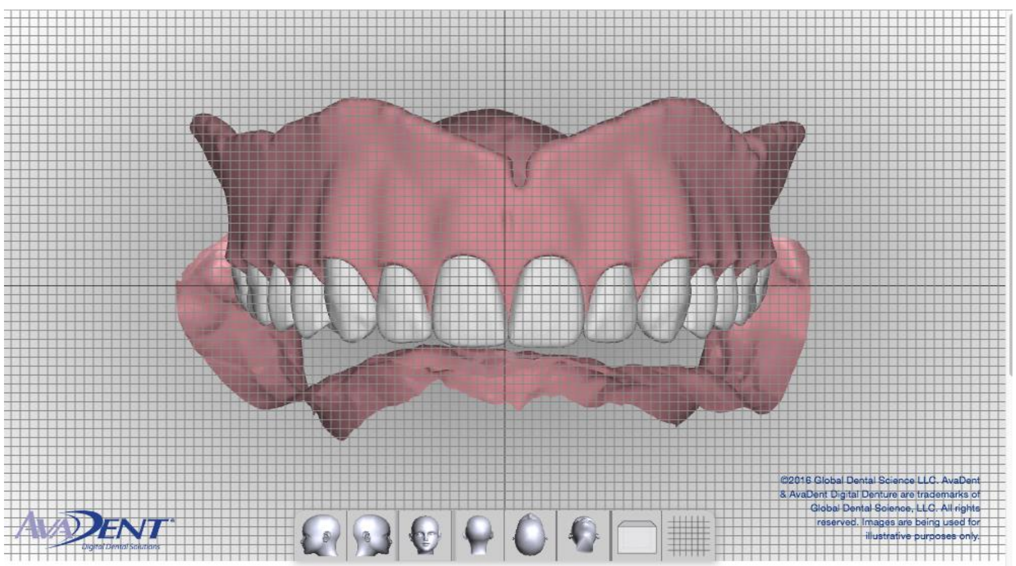

Figure 11. Digital Maxillary Teeth Arrangement (Frontal view)

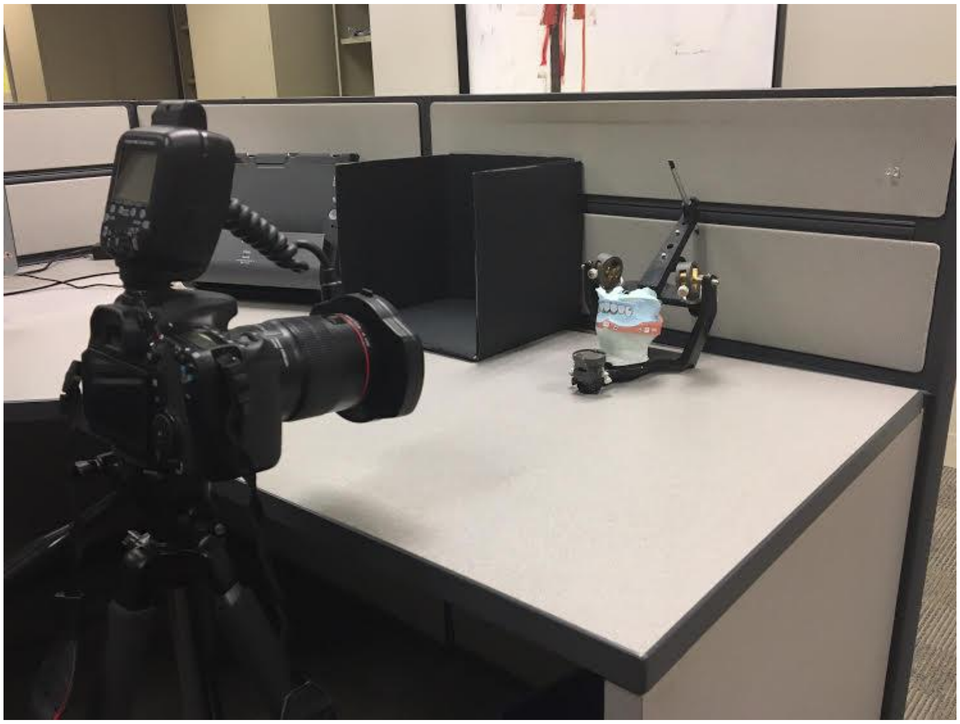

Figure 12. Studio set-up

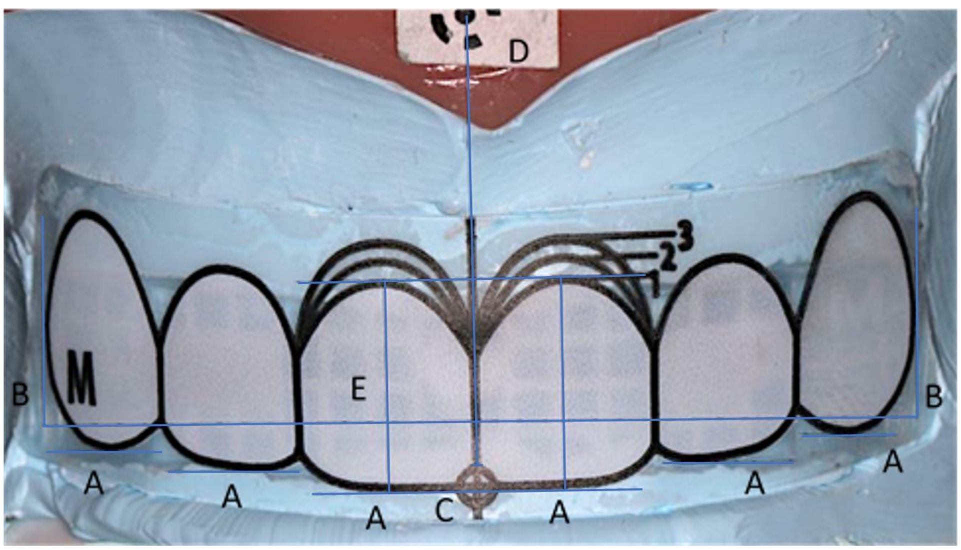

Figure 13. Reference Lines for Measurements. A. horizontal reference lines associated with the Maxillary Incisal Edges. B. Inter-canine distance (Mid Labial Lobe). C. Midline – X- axis. D. Midline – Y- axis E. Central Incisor Length

Figure 14. Photoshop Example of a Milled Maxillary CRDP with a Tooth Mold Template; the template was superimposed onto the CRDP. In this case, the anterior teeth were monolithic milled.

All CRDP models were photographed in one day by one investigator. (Figure 12) All CRDP models were measured digitally via Photoshop (Adobe Photoshop CS4, Adobe Systems Incorporated, San Jose, CA) (Fig 14). Markers were placed on the edentulous model for guidance in superimposition of photos. The CRDP models were prepared where the anterior tooth mold templates were used to arrange the teeth digitally. A single examiner conducted all measurements.

Ten linear dimensions were measured on each model in the computer in two planes (X and Y) all measurements were recorded to the nearest 0.01 mm. The measurements were made three times, and recorded. The average measurements were determined and used in the data analysis. The following dimensions were selected for measurement:

X plane:

a. Inter-canine distance – the distance between maxillary canines at their height of contour in the cervical third and compared between tooth mold template and CRDP models (Figure 13, B).

b. Midline – The point between teeth 8 and 9 on the tooth mold template midline and compared to CRDP models (Figure 13, C).

Y plane:

a. Midline – measured as the distance between the averages of the incisal embrasures of cross marks on the tooth mold template to the reference point of the edentulous model. (Figure 13, D).

b. Horizontal reference line – measured as the distance between the tooth outlines of tooth mold template to incisal edge of milled teeth 6, 7, 8, 9, 10, and 11. (Figure 13, A).

c. Central incisal length - measured as the distance between the tooth molds template incisal edges to the greatest height of cervical outline of the maxillary right or left central incisor. Tooth outline #1 was selected for use. (Figure 13, E).

Data were statistically analyzed by Mann-Whitney U and Wilcoxon signed-rank tests. Variable differences between the two tested groups were analyzed with the Mann-Whitney U test. Variable differences between each group and the TMT were tested with the Wilcoxon signed-rank test. All statistical analyses were completed using a statistical package (SPSS Statistics version 23, IBM). The level of statistical significance (α) was set at .05. Sample size was calculated to detect differences with 80% power and effect size d=1.775 (G*Power 3.1.9.2; Erdfelder, Faul & Buchner).

CHAPTER 4

RESULTS

A data analysis was made using relative values when comparing tooth mold template to the CRDP models. The relative values considered negative and positive values for determining the position of the teeth. There was a statistically significant difference found between teeth numbers 6 and 11 of the TMT – horizontal reference lines and teeth numbers 6 and 11 of the CAD/CAM CRDPs. In addition, the canines on the TMT were found to be positioned more incisally, 1.43 mm (tooth 11) and 2.20 mm (tooth 6) when compared with the position of milled teeth. Finally, the canines on the TMT were found to be positioned more incisally, 1.18 mm (tooth 11) and 2.39 mm (tooth 6) when compared with the position of bonded teeth. The median difference, in relative values, between TMTs and CRDPs are found in Table 1.

There was a statistically significant difference found between teeth numbers 7 milled denture tooth and bonded denture tooth. However, there was no statistically difference for tooth number 10 milled denture tooth and bonded denture tooth when compared to TMT – horizontal reference lines. In addition, the lateral incisors on the TMT were found to be positioned more incisally, 0.18 mm (tooth 10) and 0.72 mm (tooth 7) when compared with the position of milled teeth. Finally, the lateral incisors on the TMT were found to be positioned more incisally, 0.04 mm (tooth 10) and 0.85 mm (tooth 7) when compared with the position of bonded teeth. The median differences, in relative values, between TMTs and CRDPs are found in Table 1.

There was a statistically significant difference found between teeth numbers 9 milled denture tooth and bonded denture tooth. There was statistically significant difference found on tooth number 8 milled denture tooth. However, there was no statistically difference for tooth number 8 bonded denture tooth when compared to TMT – horizontal reference lines. In addition, the central incisors on the TMT were found to be slightly positioned incisally 0.08 mm (tooth 8) and 0.07 mm (tooth 9) when compared with the position of milled teeth. Finally, the central incisors on the TMT were found to be positioned more incisally, 0.14 mm (tooth 8) and 0.49 mm (tooth 9) when compared with the position of bonded teeth. The median differences, in relative values, between TMTs and CRDPs are found in Table 1

The inter-canine distances (ICC) differed between TMT and the CAD/CAM CRDP models. The CRDP milled denture teeth was 5.06 mm and for the bonded denture teeth ICC distances was 5.15 mm. In both instances, the inter-canine distance was found to be narrower than the TMT inter-canine distance (Table 1).

The milled denture teeth midline-X, distance between8 and 9, median analyzed to 0.12 mm positioned towards the left of the TMT midline. The bonded teeth midline-X, distance between 8 and 9, median analyzed to 0.44 mm positioned towards the left of the TMT midline (Table 1).

The milled denture teeth midline-Y, was 0.48 mm apical when compared to the TMT midline-Y. The bonded teeth midline-Y, was 0.27 mm apical to the TMT midline-Y.

The median analyzed for the central incisor length was 0.36 mm (bonded denture teeth) and 0.57 mm (milled denture teeth). There was no difference found between the sets of central incisor lengths (Table 1).

When the CRDP–milled denture teeth and CRDP–bonded denture teeth were compared, there was a statistical difference regarding the incisal position of tooth 9 ($P<.008$). Overall, the milled denture teeth and the bonded denture teeth CRDPs were found to be accurate representations of one another (Table 3).

There were statistical differences when the TMT was compared to the milled and bonded denture teeth groups. However, the incisal edge of tooth 10 and the midline - X showed no statistical difference between the milled denture teeth group when compared to the TMT. Furthermore, there were no statistical differences noted between the incisal edges of teeth numbers 8 and 10 within the bonded denture teeth group. (Table 4)

Table 1. Descriptive statistics showing median in mm measured from TMT (interquartile range) for each group.

	Relative Values	
Group	**Milled**	**Bonded**
Incisal (cusp tip) - 6	2.20 (1.26)	2.39 (0.23)
Incisal (edge) - 7	0.72 (0.25)	0.85 (0.09)
Incisal (edge) - 8	0.08 (0.02)	0.14(0.30)
Incisal (edge) - 9	0.07 (0.02)	0.49 (0.22)
Incisal (edge) - 10	0.18 (0.51)	0.04 (0.20)
Incisal (cusp tip) - 11	1.43 (0.61)	1.18 (0.17)
ICC	-5.06 (0.89)	-5.15 (0.13)
Midline-X	-0.12 (0.57)	-0.44 (0.22)
Midline-Y	-0.48 (0.59)	-0.27 (0.42)
CIL-8	-0.57 (0.25)	-0.36 (0.16)

Table 2.	Relative Values	
	Wilcoxon signed-rank	Wilcoxon signed-rank
	Difference between	Difference between
	Median and TMT	Median and TMT
	Milled	Bonded
Incisal (cusp tip) - 6	.043*	.043*
Incisal (edge) – 7	.043*	.043*
Incisal (edge) - 8	.041*	.109
Incisal (edge) - 9	.042*	.043*
Incisal (edge) - 10	.223	.109
Incisal (cusp tip) - 11	.043*	.043*
ICC	.043*	.043*
Midline-X	.345	.043*
Midline-Y	.043*	.043*
CIL	.043*	.043*
***statistically significant difference (p <.05)**		

Table 3.	Relative Values
	Mann-Whitney U Test
	Difference between
	Milled and Bonded
Incisal (cusp tip)- 6	.690
Incisal (edge) -7	.056
Incisal (edge)-8	.690
Incisal (edge)-9	.008*
Incisal (edge)-10	.310
Incisal (cusp tip) -11	.151
ICC	.310
Midline-X	.151
Midline-Y	.222
CIL	.056
***statistically significant difference (p <.05)**	

CHAPTER 5

DISCUSSION

After completing the experiment and the subsequent statistical analysis of the data, it was determined that the null hypothesis could be rejected. The results of this study indicate that a significant difference exists between the inter-canine widths and incisal gingival positions of the teeth between the groups. However, when comparing the inter-canine distances between the milled denture teeth group (5.06; $p = 0.310$) and the bonded denture teeth group (5.15, $p = 0.310$) CRDPs were compared, there were no statistical differences according to the Mann-Whitney U test. This suggests that CAD/CAM dentures are accurate and reproducible within the study. (Table 2)

The results of this study corroborate the results of Kanazawa and Yamamoto who found discrepancies in tooth position. Kanazawa and Yamamoto evaluated the fabrication of a CRDP using a CAD/CAM system.[36,37] Cone Beam Computed Tomography (CBCT) was used to scan and measure the position of the denture teeth on the CRDPs. Kanzawa mentioned the tendency to underestimate actual values of measurement were 94.4% with a difference of less than 0.1.[36] There was a tooth position deviation from the master 3D data of approximately 0.10 mm for the polished buccal surface.[36,37]However, there was no follow-up information regarding this measurement. The position of the occlusal surfaces demonstrated less accuracy with maximum tooth position deviations that averaged t 0.88 mm and average deviations were reported to be 0.50 mm.[36]

Yamamoto analyzed CAD/CAM recesses whereby denture teeth were bonded by resin cement (self-curing resin, UNIFAST III; GC, Tokyo, Japan) into the offset recesses of 0.00 (control), 0.10, 0.15, 0.20, and 0.25 mm. The central incisor (CI), canine (C), premolar (PM) and molar (M) denture teeth were bonded to each offset recesses. Offset recesses were milled into the denture bases to provide additional space into the tooth outline of the denture bases. The bonded denture teeth were scanned via CBCT and digitally analyzed. The control group without offset recesses reported distance measurements for the teeth as follows: CI to be 0.29 mm, C 0.25mm, PM 0.21mm, and M 0.15 mm with maximum deviations of 1.24 mm, 1.16 mm, 0.95 mm, and 0.62 mm respectively. The increased offset recesses led to more accurate tooth position.[37] Although Yamamoto recognized dimensional change of the data caused by partial volume effect in CBCT, there was no margin of error provided in the study.[37]

Dental professionals and patients can identify unpleasant dental aesthetics when there are errors of 1.5-2 mm when evaluating crown lengths and 3–4 mm regarding crown widths. By incorporating Kokich's findings into this study, this may help in determining a successful outcome in patient's acceptance. [38]

According to Goodacre, a comparison of the intaglio surface of CAD/CAM CRDPs fit to the master casts was made from were found to be very accurate. (.002 - .017mm) In Goodacre's study, the casts and dentures were measured with laser scanners at the apex of the denture border, 6mm from denture border, crest of ridge, palate and posterior palatal seal. The following measurements were found: 0.017 mm, - 0.004 mm, 0.008 mm, -0.003 mm, and 0.002 mm respectively.[31] He further stated that post palatal seals would not be required in CAD/CAM CRDPs since, classically, post palatal seals were meant to offset the 7-8% volumetric shrinkage associated with heat polymerized PMMA.[34]

The investigator in this study assumed that each denture would fit well on the edentulous model. However, in order to complete seat the CRDPs onto the edentulous model, it was necessary to make minor adjustments on the alveolar ridge of the edentulous model to allow fitting of the CAD/CAM CRDPs due to their accuracy. Fit checker (vinyl polyether silicone, GC America, Alsip, IL) was applied to the intaglio of each surface CRDP, firmly pressed by hand onto the edentulous model. Incomplete seating was identified with the fit checker and the alveolar ridges were adjusted as needed. Complete seating of the CRDPs onto the edentulous models was confirmed visually at the depths of the vestibules and hard palate. Accuracy of the fit checker was noted to be 0.1mm with a Boley gauge.

Hanau's hypothesis of "resilient and like effect" described tissue adaptation potentially how volumetric shrinkage could induce a change in occlusal relationships and post-operative adjustments[39] The study, the soft tissue on the edentulous model is rigid, according to the manufacturer, no volumetric shrinkage occurred since the CRDPs were made of pre-polymerized PMMA and milled with a 10 μm accuracy.[40]

CAD/CAM fabrication processes may be classified as hard machining or soft machining methods depending on the materials milled. Hard machining has been used for metal, dense sintered zirconia and composite resin while the soft machining has been used with pre-sintered zirconia. Hard machining requires strong cutting forces and power to remove material efficiently. The cutting power conducts thermal energy and raises the temperature of the milling instrument; this generally reduces the effectiveness and longevity of the burs.[40] It has also been noted that there was potential for error CAD/CAM machining milling instrument fatigue resulting in imprecise cutting dimensions of teeth or space in the acrylic resin dentures for future tooth placement.[36]

Another potential source of error in the current study was the volumetric shrinkage of the impression materials and prior to digital scans.[30] The reduction in volume has been noted to be due to the polymerization process or handling with latex gloves containing zinc diethyl dithiocarbamate. The zinc compound has been described as being an accelerator for latex, by reacting to the platinum catalyst in the polyvinyl siloxane. This would delay or total inhibition of polymerization of polyvinyl siloxane as low as 0.1 – 0.05%.[20, 41] Furthermore, lower viscosity materials such as light bodied polyvinyl siloxane showed greatest change (0.02-.05%) due to lower filler content.[20, 41]

The pre-polymerized condensed state of PMMA fabrication process used in this specific CAD/CAM protocol to mill CRDPs has less porosity in when compared to conventionally manufactured methods.[14,3014] Porosity within denture bases has been attributed to the boiling point of the PMMA monomer (100.8^{o} C or 213.4^{o} F) which is higher than water. If the temperature during polymerization rises above the boiling point of the residual monomer, then production of bubbles occurs. Porosity may occur in the thickest portion of the denture.[42] Furthermore, residual monomer is considered to be hydrophilic and a fast diffuser, movement of molecules from a region of high concentration to low concentration, that may cause tissue irritation, hypersensitivity, or allergic reactions.[20] However, if the CRDPs are boiled in a flask at 100^{o} C for at least 1 hour, the monomer content decreases to 0.2– 0.5 % which is considered clinically acceptable. [20]

CAD/CAM milled acrylic resin has less residual monomer remaining after processing and is more hydrophobic than the conventional acrylic resins. This may be the reason why CAD/CAM processed denture bases are more hygienic and more suitable for the patients. The State University of New York at Buffalo compared between CAD/CAM acrylic resin, Lucitone 199 (Dentsply Sirona, York, PA, USA) and Diamond D (Keystone Industries, Gibbstown, NJ, USA) where the acrylic resin discs were submerged in human saliva at 37^{o} C for 30 minutes. Subsequently, C. albicans was incubated on the dentures discs for 1 hour and maintained at 37^{o} C. The specimens are washed in sterile phosphate-buffered saline, physiologic pH ~7.4, by dipping them 10 times in the solution. The adhered cells that remained on the sample surface were evaluated using a microscope and determined the number of cells per area unit. The authors reported that conventional dentures retained 5-8% C. albicans while CAD/CAM retained 2%.[30]

Adherence of denture teeth onto milled PMMA resin originated from conventional denture processing methods. One of the methods used by the manufacturer of the CAD/CAM dentures used in this study was to mill solid pre-polymerized PMMA pucks with recesses that corresponded to the planned positions of the denture teeth and use a bonding agent to attach the teeth into the recesses milled into the denture bases. This method has multiple limitations associated with it including routinely used since methacrylate resin teeth may detach due to various factors such as: inadequate chemical or mechanical preparation of the tooth surfaces, presence of porosities at the base-tooth interface, impurities, processing inconsistencies, and water sorption of the resin and differences in their coefficient of thermal expansions.[20] Some considerations to prevent debonding of denture teeth from denture bases included the use of mechanical and/or chemical modifications to the acrylic resin material. The use of sandblasting and/or making diatoric holes in the cervical surface area has been shown to increase micromechanical retention between the denture teeth and denture base.[20] The use of chemical bonding with 4-META (4-methacryloxyethyl trimellitic anhydride) promoted bonding of highly cross-linked methacrylate teeth to resin bases.[20] Another method for bonding resin teeth to chemically active denture resin includes softening the necks of artificial denture teeth with a mixture of methylene chloride and methyl methacrylate monomer for 5 minutes.[20] The recesses of the denture bases per this manufacturer's protocol were milled for precise fitting of the denture teeth into the recesses. If chemical bonding has been performed, adjustments to the necks of the teeth would be necessary to provide space for the chemical bonding agent.[37] This would possibly lead to tooth displacement when bonded teeth were evaluated.[37] The milled teeth have been designed from a library of scanned teeth, milled, and within a PMMA puck that contains tooth and pink color PMMA combined. Furthermore, the position of teeth for CAD/CAM milled and bonded denture teeth in this study were not significantly different when compared to one another and in some measures to the tooth mold template.

Saponaro clinically evaluated clinical use of conventional fabricated CRDPs and CAD/CAM fabricated CRDPs in patients and noted several types of complications. The following clinical complications were noted: lack of retention (8 of 48 patients), occlusal vertical dimension discrepancy (4 of 48 patient), incorrect centric relationship (3 of 48 patients), poor esthetic outcome (3 of 48 patients), post-insertion adjustments visits (16 of 48 required 1 post-insertion visit; 14 of 48 required 2 visits; and 14 of 48 required 3 or more visits), and remake of CAD/CAM CRDPs (5 of 48 participants). Saponaro reported the remake of the CRDPs into conventional methods were due to maxillary midline deviated, excessive gingival display and an allergic reaction to the dentures.[43] Saponaro reported the mean number of appointments to deliver CAD/CAM fabricated CRDPs was 2.38 and the number of post-insertion appointments was 2.12.[43] Drago reported the results of a clinical study where post-insertion visits in CRDPs were compared based on the type of impression materials used in making the definitive impressions for CRDPs. One method consisted of a traditional technique (custom impression trays border molded with gray modeling plastic impression); the second method consisted of modifying the impression protocol that included (custom impression trays border molded with heavy-body vinyl polysiloxane impression material). The definitive wash impressions were made with light-body vinyl polysiloxane impression material. The study found there was no significant difference between the two techniques regarding the average number of adjustment visits with each technique is 2.68.[44] Bidra reported 3.3 denture adjustments visits with CAD/CAM CRDPs.[32]

Some of the imitations associated with the current study are that a Z-plane (anterior to posterior) evaluations was not performed. This was made difficult because it was problematic when trying to establish a consistent Z plane reference point for all CRDPs. Finally, it is difficult to extrapolate the outcomes of a laboratory study to the clinical situation.

Future research is indicated that would analyze changes associated in the occlusal relationships in CRDPs fabricated with the AvaDent protocol. Comparison of the accuracy of maxillomandibular relationship records made using AvaDent's guidelines compared with traditional methods should also be evaluated. Lastly, the evaluation of physical properties of AvaDent CRDPs compared to conventional heat-processed dentures should also be studied in the laboratory, as well as, in patients.

CHAPTER 6

CONCLUSIONS

From this study, the following conclusions can be made:

1. The tooth mold template effectively represented the position of the central incisors onto the CRDPs with milled denture teeth and CRDPs with bonded denture teeth.
2. Inter-canine distances were found to be 5 mm narrower on both types of CRDPs than with the tooth mold template. This may be clinically significant.
3. The canine positions of 6 and 11 were found to be 1 to 2 mm incisally positioned on both CRDPs than the tooth mold template indicated. This may be clinically significant.
4. Even though statistical differences were found, there was no clinical significant differences noted when comparing CAD/CAM CRDPs with milled teeth and CAD/CAM CRDP with bonded denture teeth.

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CHAPTER 7

APPENDIX A

Incisal Cusp tip 6	Incisal Edge 7	Incisal Edge 8	Incisal Edge 9	Incisal Edge 10	Incisal Cusp tip 11	ICC	Midline X	Midline Y	CI Length
3.3	0.85	0.09	0.08	0.46	1.69	-3.66	-0.12	-0.12	-0.35
3.09	0.57	0.09	0.09	0.18	1.43	-5.1	0.02	-0.36	-0.66
1.86	0.58	0.06	0.06	0.18	1.41	-4.95	-0.32	-0.76	-0.57
2	0.72	0.08	0.06	0.41	1.65	-5.06	0.13	-0.48	-0.72
2.2	0.79	0.08	0.07	-0.33	0.72	-5.3	-0.66	-0.89	-0.52
2.29	0.86	0.3	0.53	0.04	0.98	-5.04	-0.32	-0.46	-0.46
2.48	0.83	0	0.37	0.15	1.18	-5.22	-0.36	-0.27	-0.31
2.61	0.95	0.14	0.49	0	1.19	-5.13	-0.44	-0.12	-0.36
2.34	0.85	0	0.38	0	1.14	-5.15	-0.46	-0.01	-0.32
2.39	0.79	0.29	0.66	0.25	1.26	-5.21	-0.62	-0.51	-0.49

all measurements in millimeters (mm)	Tooth Mold Template	Milled 1	Milled 2	Milled 3	Milled 4	Milled 5
Midline - Y axis (between 8 and 9)						
sample 1	22.88	22.78	21.94	22.1	22.42	22.01
sample 2	22.9	22.76	21.89	22.2	22.35	21.98
sample 3	22.89	22.77	21.92	22.1	22.45	22.02
Average	22.89	22.77	21.91667	22.13333	22.40667	22.00333
Midline - X axis (distance from midpoint to 8)						
sample 1	-0.2	0.08	0.23	-0.12	0.31	-0.46
sample 2	-0.18	0.07	0.22	-0.13	0.33	-0.45
sample 3	-0.22	0.08	0.21	-0.12	0.34	-0.47
Average	-0.2	0.076667	0.22	-0.12333	0.326667	-0.46
Canine to Canine						
sample 1	43.64	39.96	38.55	38.67	38.53	38.26
sample 2	43.6	39.99	38.5	38.65	38.59	38.4
sample 3	43.62	39.92	38.51	38.68	38.56	38.3
Average	43.62	39.95667	38.52	38.66667	38.56	38.32
Inciso-cervical length for Max CI (8)						
sample 1	10.46	9.99	9.79	9.87	9.71	10
sample 2	10.43	10.2	9.8	9.85	9.75	9.87
sample 3	10.45	10.1	9.78	9.9	9.73	9.9
Average	10.44666667	10.09667	9.79	9.873333	9.73	9.923333
Inciso-cervical length for Max CI (9)						
sample 1	10.59	9.94	9.94	9.92	9.95	9.64
sample 2	10.58	9.91	9.93	9.83	9.93	9.68
sample 3	10.58	9.93	9.98	9.87	9.91	9.7
Average	10.58333333	9.926667	9.95	9.873333	9.93	9.673333
Incisal edge length from hor ref line (6)						
sample 1	0	3.4	3.09	1.86	1.99	2.21
sample 2	0	3.2	3.089	1.87	2.01	2.19
sample 3	0	3.3	3.1	1.85	1.99	2.19
Average	0	3.3	3.093	1.86	1.996667	2.196667
Incisal edge length from hor ref line (7)						
sample 1	0	0.87	0.56	0.58	0.72	0.78
sample 2	0	0.82	0.57	0.6	0.71	0.79
sample 3	0	0.85	0.58	0.57	0.73	0.79
Average	0	0.846667	0.57	0.583333	0.72	0.786667
Incisal edge length from hor ref line (8)						
sample 1	0	0.08	0.1	0.05	0.08	0.08
sample 2	0	0.1	0.09	0.059	0.076	0.076
sample 3	0	0.1	0.089	0.06	0.078	0.078
Average	0	0.093333	0.093	0.056333	0.078	0.078
Incisal edge length from hor ref line (9)						
sample 1	0	0.08	0.1	0.06	0.06	0.07
sample 2	0	0.078	0.092	0.059	0.068	0.073
sample 3	0	0.079	0.08	0.06	0.065	0.068
Average	0	0.079	0.090667	0.059667	0.064333	0.070333
Incisal edge length from hor ref line (10)						
sample 1	0	0.45	0.17	0.175	0.41	-0.33
sample 2	0	0.46	0.18	0.176	0.42	-0.34
sample 3	0	0.46	0.176	0.174	0.4	-0.33
Average	0	0.456667	0.175333	0.175	0.41	-0.33333
Incisal edge length from hor ref line (11)						
sample 1	0	1.688	1.4	1.39	1.64	0.72
sample 2	0	1.7	1.45	1.42	1.65	0.73
sample 3	0	1.69	1.43	1.41	1.66	0.71
Average	0	1.692667	1.426667	1.406667	1.65	0.72

all measurements in millimeters (mm)	Tooth Mold Template	Bonded 1	Bonded 2	Bonded 3	Bonded 4	Bonded 5
Midline - Y axis (between 8 and 9)						
sample 1	22.88	22.46	22.63	22.77	22.94	22.38
sample 2	22.9	22.4	22.61	22.78	22.84	22.4
sample 3	22.89	22.43	22.615	22.76	22.85	22.36
Average	22.89	22.43	22.61833	22.77	22.87667	22.38
Midline - X axis (distance from midpoint to 8)						
sample 1	-0.2	-0.12	-0.15	-0.23	-0.26	-0.41
sample 2	-0.18	-0.13	-0.16	-0.25	-0.25	-0.43
sample 3	-0.22	-0.12	-0.16	-0.25	-0.28	-0.42
Average	-0.2	-0.12333	-0.15667	-0.24333	-0.26333	-0.42
Canine to Canine						
sample 1	43.64	38.51	38.3	38.47	38.44	38.39
sample 2	43.6	38.65	38.5	38.5	38.5	38.4
sample 3	43.62	38.59	38.4	38.5	38.48	38.45
Average	43.62	38.58333	38.4	38.49	38.47333	38.41333
Inciso-cervical length for Max CI (8)						
sample 1	10.46	9.99	10.1	10.07	10.12	9.95
sample 2	10.43	9.98	10.2	10.1	10.14	9.97
sample 3	10.45	9.98	10.1	10.1	10.11	9.96
Average	10.44666667	9.983333	10.13333	10.09	10.12333	9.96
Inciso-cervical length for Max CI (9)						
sample 1	10.59	10.14	10.1	10.06	10.11	9.9
sample 2	10.58	10.1	10.2	10.2	10.13	9.93
sample 3	10.58	10.2	10.2	10.3	10.12	9.94
Average	10.58333333	10.14667	10.16667	10.18667	10.12	9.923333
Incisal edge length from hor ref line (6)						
sample 1	0	2.3	2.5	2.64	2.32	2.41
sample 2	0	2.28	2.45	2.58	2.36	2.39
sample 3	0	2.3	2.48	2.6	2.35	2.38
Average	0	2.293333	2.476667	2.606667	2.343333	2.393333
Incisal edge length from hor ref line (7)						
sample 1	0	0.87	0.82	0.96	0.83	0.79
sample 2	0	0.85	0.83	0.94	0.85	0.78
sample 3	0	0.85	0.83	0.95	0.86	0.8
Average	0	0.856667	0.826667	0.95	0.846667	0.79
Incisal edge length from hor ref line (8)						
sample 1	0	0.29	0	0.12	0	0.3
sample 2	0	0.31	0	0.14	0	0.28
sample 3	0	0.29	0	0.15	0	0.3
Average	0	0.296667	0	0.136667	0	0.293333
Incisal edge length from hor ref line (9)						
sample 1	0	0.39	0.37	0.49	0.41	0.66
sample 2	0	0.6	0.36	0.5	0.35	0.65
sample 3	0	0.59	0.37	0.48	0.38	0.67
Average	0	0.526667	0.366667	0.49	0.38	0.66
Incisal edge length from hor ref line (10)						
sample 1	0	0.04	0.145	0	0	0.25
sample 2	0	0.03	0.146	0	0	0.26
sample 3	0	0.04	0.145	0	0	0.24
Average	0	0.036667	0.145333	0	0	0.25
Incisal edge length from hor ref line (11)						
sample 1	0	1.015	1.16	1.19	1.16	1.24
sample 2	0	0.98	1.2	1.2	1.14	1.28
sample 3	0	0.95	1.18	1.18	1.12	1.26
Average	0	0.981667	1.18	1.19	1.14	1.26

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