Evaluation of Die Trim Morphology Made by CAD/CAM Technology

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EVALUATION OF DIE TRIM MORPHOLOGY MADE BY CAD/CAM TECHNOLOGY

By

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ABSTRACT

EVALUATION OF DIE TRIM MORPHOLOGY MADE BY CAD/CAM TECHNOLOGY

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Purpose: The purpose of this vitro study was to evaluate the accuracy of the morphology of digitally trimmed dies in comparison with the subgingival contour of a prepared tooth to be restored with a single crown.

Materials and Methods: 20 human extracted teeth, 10 incisors and 10 molars were disinfected, mounted on dentoforms. The teeth were prepared for a single all ceramic restoration. Digital impressions of the preparations were made using the 3M Lava COS. With the data, the SLA models were fabricated with removable dies. The prepared tooth and the corresponding dies were then compared with the Rhino software.

Results: Three different parameters were tested angle, length and volume to compare the accuracy of the digital die to the subgingival morphology of the prepared teeth. Paired t test was used to compare the teeth to their corresponding dies. For the angle analysis of CAD/CAM die trim morphology, the incisor group demonstrated significant difference at the BL surfaces. On the contrary, the molar group showed significant difference at the MD surfaces. For the evaluation of length and volume of CAD/CAM die trim morphology, the incisor group showed significant difference at zone D of both BL and MD surfaces. However, significant differences at zone C and D of BL surfaces and all zones of MD surfaces was noticed in the molar group.

Conclusions: Within the limitations of this study, the following conclusion was made: Incisor group - the CAD/CAM (SLA) dies were bigger in the Zone D in both BL and MD direction. Molar group – the CAD/CAM dies were bigger in all the zones in both BL and MD direction. The angle measurements showed the teeth had a tendency to be more narrow and flat while the SLA dies were more concave.

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Pratiksha Agrawal, B.D.S.

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CHAPTER I

INTRODUCTION

Traditionally, a cast-die system has been used to produce fixed dental prostheses in the laboratory.[1] However, intraoral digital scans are now being used with increasing frequency. The digital information from these scans are used to create virtual casts and cast-die systems. In either case, accurate die trimming is a critical step in the fabrication of a fixed dental prostheses.[2]

Direct fabrication of patterns in the mouth for extra and intra-coronal restorations is possible; however, the procedure is inconvenient for the patient, difficult to accomplish well, requires additional time at the chair, and is nearly impossible to do in some situations. Therefore, cast-die systems were developed to overcome the challenges of direct pattern fabrication. A cast-die system is necessary to replicate the clinical situation so that this information can be transferred to the laboratory. A die is a working replica of a single tooth or several teeth.[2]

An ideal die possesses certain requirements. For example, it should reproduce fine details and sharp margins and possess good color contrast with other materials like inlay wax or porcelain. The die material should not interact with impression materials and it should undergo minimal dimensional change upon setting. Usually, die materials expand upon setting and compensates for the polymerization shrinkage of impression materials. Die materials should remain stable over time. Desirable mechanical properties such as high strength and abrasion resistance are important. A high strength die reduces the likelihood of accidental breakage, and abrasion resistance allows carving of a wax pattern without damage to the die. Finally, die materials must be economical and easy to use.

After an intraoral impression is made and cast in stone, the dies must be prepared or trimmed to remove unnecessary information prior to manufacture of a cast restoration. The trimmed region is usually soft tissue, but may be a reproduction of the retraction cord, blood or saliva. Trimming of this excess material will help visualize the prepared finish line on the die. Die trimming areas are divided into three parts: (1) marginal zone; (2) body; and (3) the base. The marginal zone is the area which extends from the finish line to 3-5 mm apically. This zone is the most critical die trimming area, as it determines emergence profile and contour of the restoration made on the die. The body is the connection between the marginal zone and the base. The third part is the dies base, which is the most apical extent of the die and it determines the stop point of the die when placed on the cast.[3]

The conventional die trimming technique is a two-stage procedure. The first stage is the gross reduction of the die. The second stage is the fine reduction near the margins of the preparation using hand instruments, under magnification and high illumination. This technique has been used by dental technicians for a long time.[2, 4]

Accurate die fabrication is very important because an over-trimmed marginal zone may produce a large and over-contoured restoration. However, an under-trimmed marginal zone will produce a restoration with a flat and straight contour. Therefore, die trimming must attempt to reproduce the sub-gingival contour of teeth being restored in order to achieve an appropriate emergence profile.The term “emergence profile” was first used in 1977 by Stein and Kuwata to describe tooth and crown contours as they traversed soft tissue and rose toward the contact area interproximally and height of contour facially and lingually. Emergence profile is defined as the contour of a tooth or restoration, such as a crown on a prepared tooth or dental implant abutment, as it relates to the adjacent tissues.[5]

In 1989, B. M. Croll defined emergence profile as the portion of axial tooth contour extending from the base of the gingival sulcus past the free gingival margin into the oral environment. Croll said that emergence profile is the most crucial link between tooth form and gingival health. The emergence profile is important for giving a prepared look to a restoration, maintaining gingival health, preventing plaque retentive areas, and facilitating maintenance of oral hygiene. Clinical longevity of prostheses may be directly related to proper coronal contours. This involves integrating periodontal and prosthodontic principles during the fabrication of the prostheses, such as, properly locating the restoration margin so that it will not violate the biologic width.[6]

CHAPTER II

LITERATURE REVIEW

1. Dies

Many different materials are used for fabrication of dies, for example: Type 4 dental stone (high strength), Type 5 dental stone (high strength and high expansion), and resin materials such as epoxy and polyurethane. Some die materials are amenable to electroplating with copper or silver, producing more durable dies. Metals and metal sprays have been used, as well as, flexible materials for making interim restorations.

Various die trimming systems are available in the market like working casts with removable dies (Straight dowel pin, Curved dowel pin, Di-lok tray, Pindex system), or working casts with separate dies (DVA model system, Zeiser model system). There are many studies in the literature that have evaluated and compared the advantages and disadvantages, and accuracy of various die systems. Following is a review of some of the available die materials and die systems.

History of Dies and Die materials in dentistry

1. Die Materials

Sverker Toreskog et al (1966) conducted a comparative study of the pertinent properties for die materials. They evaluated dimensional stability, hardness, detail duplication, compatibility and abrasion resistance of 8 classes of die materials. The evaluated materials included stone (Silky Rock (+ water), Glastone (+ water), Kryptex (silico phosphate cement), Diamond Die Material, Micra Die, Perma Rock and Devcon); F2 (epoxy resin); Cerrolow 136, silver plated-metallized with silver powder; copper plated-metallized with silver powder; and copper plated-metallized with bronze. It was concluded that no one material proved to be superior in all properties. The stones were superior from the standpoint of dimensional accuracy but their abrasion resistance was low. All of the dies, with the exception of those made from stone or low-fusing alloy, were undersize at the cervical margin of the simulated full cast crown preparation. The dies made from the ceramic material, silico-phosphate cement, one of the resins and by electrodeposition were superior in abrasion resistance. The surface of the electroplated dies, the ceramic material, stones and silico-phosphate cement provided excellent duplication of detail. Differences were observed in the compatibility of certain die materials and rubber impression products as compared to the duplication produced when the die material was poured against an inert surface. [7]

James A. Stackhouse (1970) conducted a study concerning the accuracy of stone dies as affected by the dimensional changes in rubber impressions. He also tested difference in accuracy using three different techniques: (1) technique I – relief area; (2) technique II – perforated; and (3) technique III – simultaneous double mix. The three silicones tested were Plastosil, Elasticon and Lastic 55 and the thiokol was Permlastic. The authors concluded more uniform dies were produced from silicone than from mercaptan rubber. Perforated tray technique caused the dies to be undersized in diameter, the other two techniques. Relief area and simultaneous double mix were not significantly different from each other. Bench setting caused the stone dies to be shorter in length and thicker in diameter.[8]

Crispin et al conducted 2 studies (1984). The purpose of the first study was to determine the acceptability of silver-plated dies and the time required for initial plating of dies made from the 4 groups of elastomers with the use of standard or modified plating techniques. Acceptable silver-plated dies were obtained from Permlastic and Impregum. and condensation-reaction silicones with Xantopren-Optosil. From the polyvinylsiloxane group, Reprosil and President produced acceptable dies. The technique modification studied was not effective for Citricon and President. The surface quality of silver-plated dies and the consistency of plating varied with materials. They in general concluded silver-plated dies may be less accurate than stone dies.[9]

The second study by Crispin et al used clinically applicable techniques to test the marginal accuracy of castings made on stone and silver-plated dies fabricated from 4 groups of elastomeric impression materials. Accuracy of crowns fabricated on the silver-plated dies were statistically as accurate as that of crowns fabricated on stone dies in all cases and significantly more accurate in some instances. Silver-plated dies fabricated from Reprosil produced more accurate crowns than all other dies tested. Acceptable crown margins were obtainable from either stone or silver-plated dies when judged by clinical criteria.[9, 10]

Jack D. Gerrow et al (1998) conducted an in vitro study to compare the surface detail reproduction of 7 flexible die material systems used in combination with 7 elastomeric impression materials. Flexible die materials have been advocated for making interim crowns and indirect composite acrylic resin inlays. This is another compatibility study looking at different impression material and die material combinations. They concluded that dies made with Impregum F from Extrude Light impressions reproduced better surface detail than the control dies (elastomeric material with type IV dental stone). Reproduction of surface detail on dies made with Agarloid/Imprint, Proof/Extrude medium, or Agarloid/Impregum F impression/die combinations were similar to the surface detail reproduction on the control dies. Certain combinations like Impregum F impressions were incompatible with Blu-Mousse, Impregum F, or Imprint used as die materials and should not be used to fabricate flexible dies. Polyvinyl siloxane impressions were incompatible with polyvinyl siloxane dies unless a separator was used. When a separator was used, the surface detail reproduction was not as good as the control die system.[11]

Brian Kenyon et al (2005) compared the linear dimensional accuracy and the handling characteristics of 7 die materials. They looked at conventional Type IV dental stone, Type V dental stone, resin impregnated Type IV dental stone, epoxy resin, polyurethane resin, copper plated and Bis-acryl composite resin. It was determined that Type IV resin-impregnated dental stone and copper-plated dies most closely approximated the dimensions of the master die. Conventional Types IV and V dental stone dies exhibited setting expansion within the range of acceptability for gypsum. Epoxy resin die materials demonstrated shrinkage. Polyurethane dies displayed a combination of linear expansion and shrinkage. Bis-acryl composite resin dies had excessive shrinkage.[12]

Rosario Prisco et al (2008) conducted a study to determine if retarding the setting reaction during polymerization and altering the base-to-catalyst ratio can be recommended for resinous die materials to reduce the inaccuracy. A Blue Star Type E epoxy resin die material was tested. It was concluded that alteration of the base-to-catalyst ratio did not improve its dimensional accuracy, instead the material exhibited higher contraction variability across all tested groups. This shrinkage could significantly affect the dimension of the master cast.[13]

2. Die Systems

Gerald T Nomura et al (1980) evaluated the accuracy, fit, detail registration and Knoop hardness of 3 commercially available resin die systems (Pandent, Epoxydent and Precision) and compared them with die stone (Vel-Mix). They tested the difference between full coverage crown and mesio-occlusal-distal preparation dies. It was concluded that complete crown epoxy resin dies were undersized and mesio-occlusal-distal onlay epoxy resin dies were accurate. Detail duplication of epoxy resin dies was comparable to die stone; however, hardness values of epoxy resin were less than that of die stone.[14]

M. Myers and J.H. Hembree (1982) conducted a study on the relative accuracy of 4 removable die systems (brass dowel pin, Plastipin, J-pin, and Logix Model System). They investigated vertical shift and the horizontal shift of the dies and concluded that Plastipin exhibited least amount of horizontal shift and the brass dowel pin exhibited greatest shift in both directions though the difference was not statistically significant.[15]

3. Die hardener

Habib et al (1983) evaluated the effects of an application of cyanoacrylate on die stone, to include changes in the dimension, surface hardness, and numbers of layers of cyanoacrylate that can be safely applied. They concluded the application of one coat of cyanoacrylate adhesive on the surface of trimmed and marked dies increases the surface hardness and scratch resistance, will not appreciably change the dimensions of the die, and renders the margin marking more permanent. The use of hardener instead of water is recommended for mixing Type IV dental stone.[16]

4. Die trimming

Aaron G. Segal et al (1984) presented an alternative method to trimming a die. The technique described use of a dead soft wax, such as boxing or carding wax, flowed onto the gingival surface of the impression and around the prepared teeth. This allowed tooth structure gingival to the finish line in the impression to remain on the die. Trimming could be nearly eliminated, and the root surface remaining on the die facilitated the development of proper axial contours on the restoration.[17]

Richard J Windhorn in (1998) described a similar technique of flowing wax onto the gingival surface of the impression around the prepared teeth followed by pouring a cast. The difference was he utilized the technique not to fabricate the die but to make a solid cast that would aid the technician with perfecting the interproximal contacts of fixed prostheses.[18]

V. Diego (1992) described a technique to protect the finish line of die stone during trimming. The technique recommended the use of sticky wax around the margins of the preparation to make a protective thick cap during trimming. This was a simple and inexpensive technique that can be used by dentists and technicians in protecting the margins of the dies.[19]

II. CAD/CAM – Computer aided designing/Computer aided machining

For many years, researchers have investigated the dimensional accuracy, size, marginal accuracy, surface detail, and compatibility between the different impression materials and die materials. However, there are few studies that have investigated the dimensional and anatomical accuracy of digitally trimmed dies. Though popularity of digital dentistry is growing, research and scientific evidence in the digital field is lacking. Therefore, the purpose of this research is to evaluate the accuracy of digitally trimmed dies using the 3M Lava COS in comparison with the subgingival contour of a tooth prepared for restoration with a complete all-ceramic crown.

CAD/CAM – History

Computer Aided Design/Computer Aided Manufacturing (CAD/CAM) was first employed for the aviation and automotive manufacturing industries in the 1960's and was first utilized in the field of dentistry on an experimental level approximately 10 years later. The first CAD/CAM system for dentistry was the Sopha system which was developed by Francois Duret of France in 1984. [20] It consisted of an optical scanner that acquired a digital impression of the prepared tooth, a computer with the necessary software to design a restoration and finally a numerically controlled milling machine that produced the designed restoration. Dr. Mormann was the developer of the first commercial CAD/CAM system. In 1985, his team performed the first chairside inlay using a combination of their optical scanner and milling device. They called the device CEREC, an acronym for Computer Assisted Ceramic Reconstruction. At about the same time, Dr. Andersson developed the Procera (now known as Nobel Procera, Nobel

Biocare, Zurich, Switzerland) method of manufacturing high-precision dental crowns in 1983.

There are many different imaging/milling systems available in market today, for example:

1.	**CEREC – by Sirona Dental System GMBH (DE)**
2.	iTero – by CADENT LTD (IL)
3.	E4D – by D4D TECHNOLOGIES, LLC (US)
4.	Lava™ COS – by 3M ESPE (US)
5.	IOS FastScan – by IOS TECHNOLOGIES, INC. (US)
6.	DENSYS 3D – by DENSYS LTD. (IL)
7.	DPI-3D – by DIMENSIONAL PHOTONICS INTERNATIONAL, INC. (US)
8.	3D Progress – by MHT S.p.A. (IT) and MHT Optic Research AG (CH)
9.	directScan – by HINT - ELS GMBH (DE)
10.	trios – by 3SHAPE A/S (DK)

Four products are more commonly used for digital impressions in the dental office, they are the CEREC AC, iTero, E4D Dentist and the Lava COS systems. The CEREC and the E4D can be combined with in-office design and milling whereas the iTero and Lava COS are only reserved for data/image acquisition. In-office milling allows for same day insertion of restorations.

Table 1 shows comparison between these 4 major systems.

	CEREC	E4D	iTero	LAVA COS
Full-arch	Yes	No	Yes	Yes
Powder	Yes	Yes	No	Yes
In-Office Milling	Yes	Yes	No	No
Connectivity to Labs	Yes	No	Yes	Yes
In-Office Designing	Yes	Yes	No	No
Bridge	3 unit	No	Full	Yes
Focal Distance	Focuses automatically	Distance constant using 2 rubber feet	Any	15 mm

Lava Chairside Oral Scanner

The Lava™ Chairside Oral Scanner (COS) was created at Brontes Technologies in Lexington, Massachusetts, and was acquired by 3M ESPE (St. Paul, MN) in October 2006. The product was officially launched in February 2008. The Lava COS system consists of a mobile cart containing a central processing unit, a touch screen display, and a scanning wand. The Lava COS camera contains a highly complex optical system comprised of 22 lens systems and 192 blue light emitting diode cells. The Lava COS wand has a 13.2-mm wide tip and weighs 390 grams.

The Lava COS. introduced an entirely new method of capturing 3D data based on the principle of active wavefront sampling with structured light projection. This scanning method has been named “3D-in-Motion technology”. The Lava system uses the triangulation or sampling principle of imaging, and typically applies one angled cone of light to capture a single image. The single rotating aperture allows projection of images at several positions which in turn increases the spatial resolution and enhances the measurement sensitivity. The Lava COS is a 3D video system that captures 20 3D frames per second, which are registered in real time. After the scanning process a post processing cycle recalculates the registration and compensates potential errors. Triangulation/sampling scanners require teeth to be coated with scanning powder that contains titanium oxide.

Once the scan is signed off the data is sent wirelessly to 3M where the technician reviews and synthesizes the images before creating a model. A Lava COS physical model is fabricated using stereolithography, an additive fabrication process building the model one layer at a time.[21]

3M Lava COS – Literature review

Andreas Syrek et al (2010) conducted an in vivo study to compare the fit of all-ceramic crowns fabricated from intraoral digital impressions using the Lava Chairside Oral Scanner (Lava COS; 3M ESPE), with the fit of all-ceramic crowns fabricated from conventional 2 step silicone impressions. The results showed a median marginal gap in the conventional impression group of 71 microns and in the digital impression group 49 microns. It was concluded that crowns produced from intraoral scans possessed a significantly better marginal fit than crowns produced from silicone impressions. Marginal discrepancies in both groups were within the limits of clinical acceptability. Crowns from intraoral scans tended to show better interproximal contact area quality. Crowns from both groups performed equally well with regard to occlusion.[22]

Paul Seelbach et al (2013) conducted an in vitro study to compare the accuracy of complete ceramic crowns obtained from Lava Chairside Oral Scanner COS (3M ESPE, St. Paul, Minn.), CEREC AC with Bluecam (Sirona, Bensheim, Germany), and iTero (AlignTechnology, San Jose, Calif.) with conventional elastic impressions. They concluded that internal fit and accessible marginal inaccuracy of the crowns made by digital impressions is comparable to the crowns made by conventional impressions. The digital impression technique can be considered as a clinical alternative to conventional impressions for fixed dental prostheses.[23]

Thorsten Grunheid et al (2014) aimed to assess accuracy, scan time, and patient acceptance of chairside oral scanner (Lava COS; 3M ESPE, St Paul, Minn) compared with alginate impressions when used for full-arch scans in the orthodontic setting. Intraoral scans (Lava COS; 3M ESPE, St Paul, Minn) and alginate impressions were made on 15 patients. Based on survey results, 73% of the patients preferred impressions because they were “easier” or “faster,” and 27% preferred the scan because it was “more comfortable”. The casts made from alginate impressions and cast made using the intraoral scanner were digitally superimposed to assess accuracy; it was concluded that digital models produced from intraoral scans can be as accurate as those made from alginate impressions.[24]

Sebastian Patzelt et al (2014) conducted an in vitro study using 3 different intraoral scanners. The scanners were the Lava Chairside Oral Scanner COS (3M ESPE, St. Paul, Minn.), CEREC AC with Bluecam (Sirona, Bensheim, Germany), and iTero (Align Technology, San Jose, Calif.). A single abutment (scenario 1) was digitalized, as well as, a short-span fixed dental prosthesis (scenario 2), and a complete arch prosthesis preparation (scenario 3). They measured the durations of each procedure for each scenario. Data was compiled and contrasted with the procedure duration for 3 conventional impression materials. The mean total procedure duration for making digital impressions were: scenario1, 5 minutes 57 seconds; scenario2, 6 minutes 57 seconds; and scenario3, 20 minutes 55 seconds. The mean total procedure durations for making conventional impressions for S1 and S2 ranged between 18 minutes 15 seconds and 27 minutes 25 seconds, S3 ranged between 21 minutes 25 seconds and 30 minutes 25 seconds. time measurements for each scanner for the hardware startup, software setting, powdering or coating (if required by the manufacturer), scanning of the abutments, scanning of the antagonists, bite registration scan and data processing and for the conventional impressions summing the manufacturers provided working times for the adhesive, impression material, antagonist impression material, bite registration material and disinfectant. The authors found that computer-aided impression making was significantly faster for all tested scenarios. This suggests that computer-aided impression making might be beneficial in establishing a more time-efficient work flow.[25]

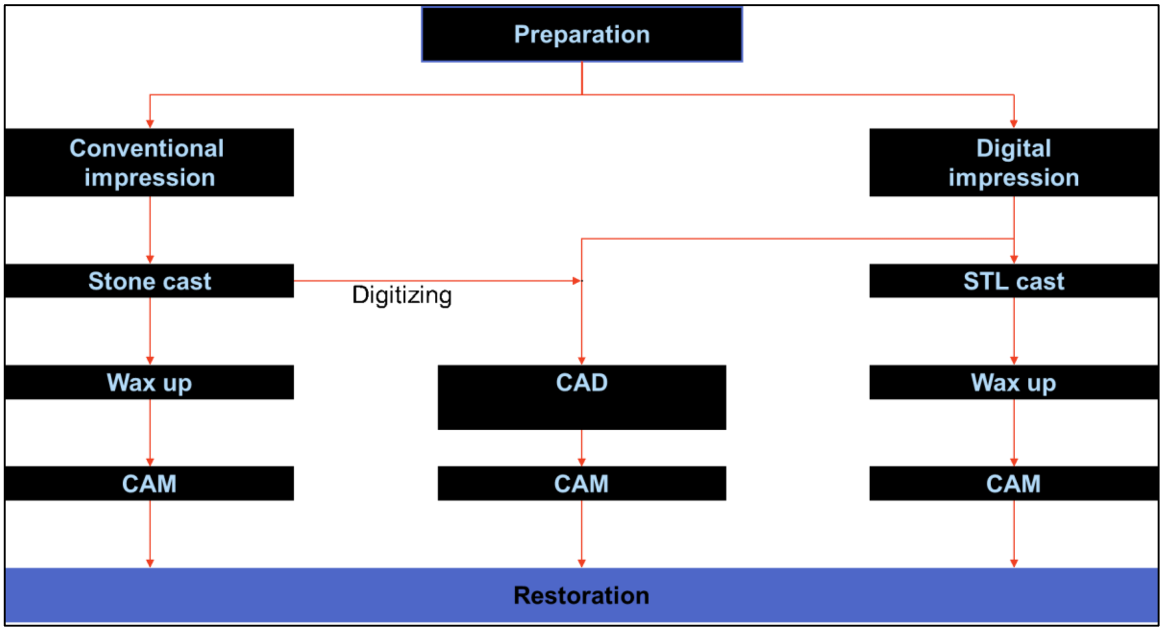
In another study, Sebastian Patzelt et al (2014) determined the accuracy of CAD/CAM generated dental casts based on intraoral scanner data. The mean trueness values of Lava Chairside Oral Scanner COS (3M ESPE, St. Paul, Minn.), CEREC AC with Bluecam (Sirona, Bensheim, Germany) and iTero (AlignTechnology, San Jose, Calif.) were looked at. All of the casts showed an acceptable level of accuracy; however, the SLA-based casts (CEREC AC with Bluecam and Lava Chairside Oral Scanner COS) seemed to be more accurate than milled casts (iTero).[26]

Jan-Frederick Guth et al conducted an in vitro study to determine the accuracy of digital models obtained by direct and indirect data capturing. Twelve datasets were generated using: (1) the Lava Chairside Oral Scanner (COS); (2) by digitizing polyether impressions (IMP); and (3) by scanning the referring gypsum cast by the Lava Scan ST laboratory scanner (ST) at a time. Using inspection software, these datasets were superimposed by a best fit algorithm with the reference dataset. Within the limitations of this in vitro study, the direct digitalization with Lava COS showed statistically significantly higher accuracy compared to the conventional procedure of impression taking and indirect digitalization. [27]

Robert G. Nedelcu et al in 2014 conducted an in vitro study comparing the scanning accuracy and precision in 4 intraoral scanners. The scanners were the 3M Lava COS, Cerec AC/Bluecam, E4D, and iTero. Models were fabricated in 3 materials (polymethyl methacrylate [Telio CAD], titanium, and zirconia) and reference scanned with an industrial optical scanner. Each reference model was scanned 10 times. An additional 10 scans were performed, in which the Telio CAD reference model was coated with an excessive amount of powder to assess any effect of oversaturating the surface. Data were evaluated using 3-dimensional analysis with “3D compare” software commands (3D compare analysis) regarding standard, mean, and maximum deviations, with subsequent statistical analysis. The 3M Lava COS, Cerec AC/Bluecam, and iTero generally displayed similar results regarding deviations. Maximum deviations, however, increased by several factors for the non-coating scanners (iTero and E4D). Significant differences were found between coating and non-coating scanners. There are specific scanning errors for the system using parallel confocal microscopy (iTero) for translucent material (Telio CAD) body materials. Specific areas of sizable deviation for E4D using laser triangulation technology was explained by the scanner design and non-coating technology. Excessive coating shows no negative effect.[28]

Eneko Solaberrieta et al in 2016 conducted an in vitro study to determine the requirements, quantity, and dimensions of the virtual occlusal record procedure in order to locate the mandibular casts 3-dimensional (3D) spatial position in reference to its corresponding maxillary cast on a virtual articulator. An industrial 3D scanner (ATOS Compact Scan 5M; GOM GmbH) was used to digitize the casts and to obtain their virtual occlusal records. They concluded the combination of left and right lateral occlusal records was the most convenient. Additionally, the minimum optimum dimension for a virtual occlusal record was 12×15 mm.[29]

Figure 1: An overview of current dental CAD/CAM systems using for the fabrication of crown-bridge restorations.



Today, there are many different systems and scanners available in the market. Currently, there are no laboratory or clinical studies that have assessed accuracy of digital die trimming. Therefore, the purpose of this study will be to evaluate the accuracy of digitally trimmed dies made using the 3M lava COS in comparison with the subgingival contour of a extracted tooth to be restored with a full coverage all-ceramic crown.

Two null hypotheses will be considered. First, there will be no difference between the original tooth morphology and the die made using CAD/CAM technology. In addition, it is hypothesized there will be no difference between anterior and posterior teeth.

CHAPTER III

MATERIAL AND METHODS

A power analysis was performed and it was determined for a difference of 95% that a sample size of 20 specimens would be sufficient to test the hypotheses with a power of 80% and medium effect size.

Twenty extracted human teeth (10 maxillary incisors and 10 molars) were utilized in this study. The teeth were cleared of adherent material by scrubbing with detergent and water, followed by immersion in 5.25% sodium hypochlorite solution for 10 minutes. The teeth were stored in distilled water until mounted. The teeth were mounted on an endodontic dentoform (ModuPro Endo; Acadental) using Aquasil easy mix putty (Dentsply Caulk). The coronal one third of the root was covered with Durabase (Dental Mfg. Co), which simulated the gingiva. Each tooth was mounted in its respective position in the dentoform. One dentoform simulated a patient with a single crown preparation. Two groups were made: Incisor group - with maxillary Incisors to be prepared; and Molar group with 11 molars to be prepared.

Figure 2: Mounted incisor teeth in the dentoform

Figure 3: Mounted molar teeth in the dentoform

Each tooth was prepared to receive a single all-ceramic restoration. Preparations were made with a total convergence angle of 10-20 degrees, incisal reduction or occlusal reduction of 2 mm, uniform axial reduction of 1.5mm, and a deep chamfer for the facial and a chamfer for the lingual finish lines. All finish lines were placed 1 mm supra-gingival. All crown preparations were done by one experienced prosthodontist.

Figure 4: The prepared incisor tooth with titanium oxide spray applied before impression making

Figure 5: The prepared molar tooth with titanium oxide spray applied before impression making

Twenty digital impressions were made using the Lava™ Chairside Oral Scanner (COS) (3M ESPE, St. Paul, Minn.) digital intra-oral scanning system. 3M Lava requires a light powder coating (titanium oxide), which was applied with a battery-operated device (Lava COS Powder Sprayer; 3M). During the scan, a pulsating blue light is emitted from the wand head and an on-screen image of the teeth appears instantaneously. The “stripe scanning” was completed as the wand was returned to scanning the occlusal of the starting tooth. Once the scan was confirmed, a quick scan of the rest of the arch was obtained. If there were holes in the scan and in areas where data was critical, the operator scanned that specific area and the software then patched the hole. The buccal surfaces on one side of the dentoform was lightly powdered, and a scan of the occluding teeth was captured. The maxillary and mandibular scans are then digitally articulated on the screen.

Figures 6: The completed maxillary scan

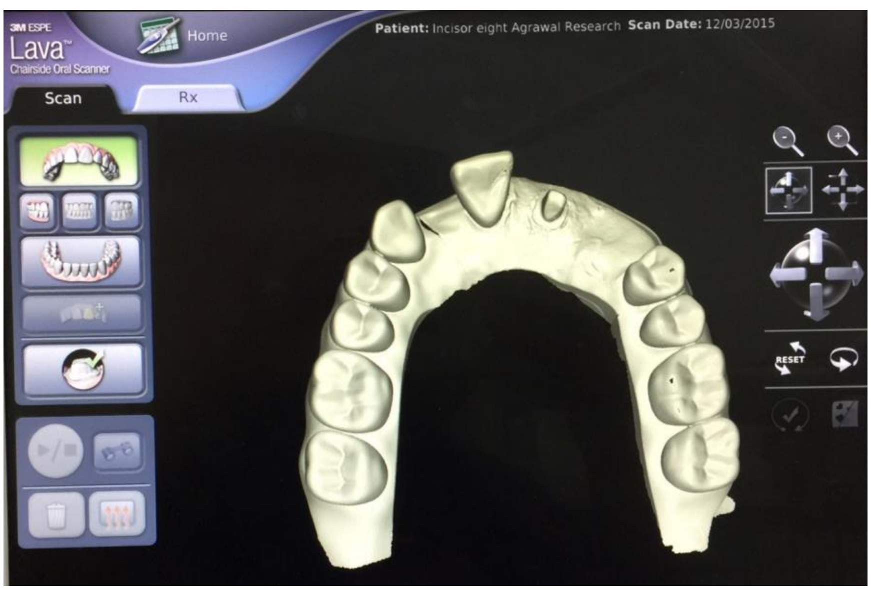


Figure 7: The completed mandibular scan

Figure 8: The bite registration scan

Figure 9: An anterior view of both arches in occlusion

After digital impressions and the bite registration were captured, data was transferred to the 3M laboratory for fabrication of 20 SLA casts. The dies for the preparations were digitally trimmed and the SLA casts with the dies were returned from the laboratory to make measurements.

Figure 10: The SLA cast with the trimmed die

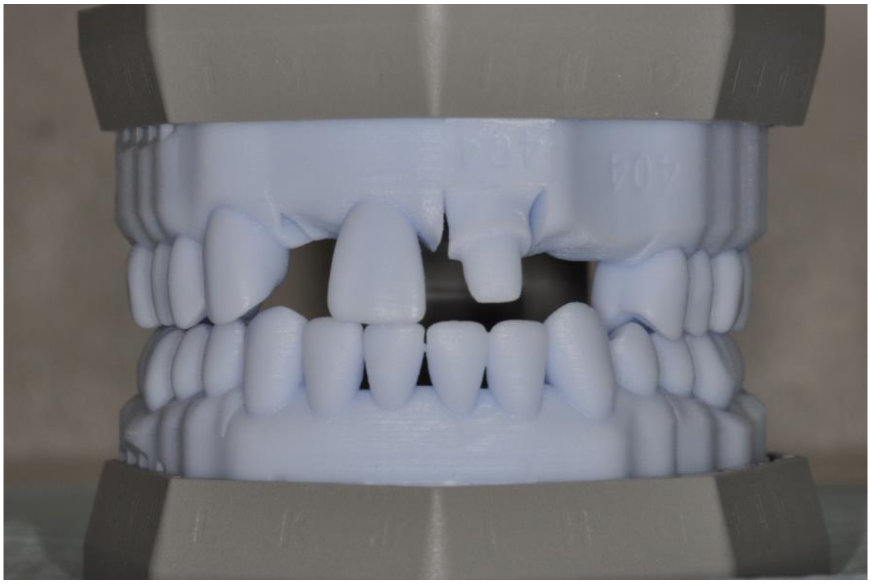


Figure 11: The SLA cast with the trimmed die

After all the casts were fabricated, the teeth were removed from the dentoforms and the dies from the SLA models. The prepared tooth and the digitally fabricated die corresponding to the preparation were then digitized by using the 3D lab scanner (D8100, 3 shape) in order to produce STL files.

Figure 12: The prepared tooth and SLA die

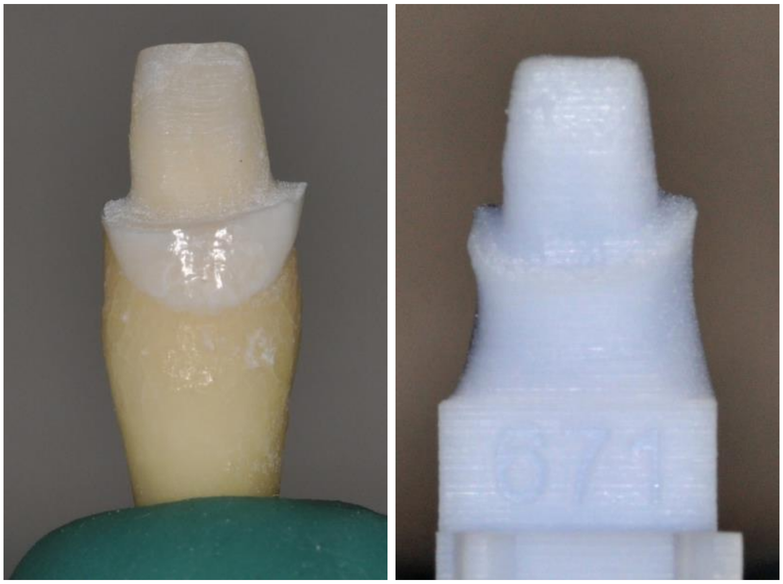


Figure 13: The prepared tooth and SLA die

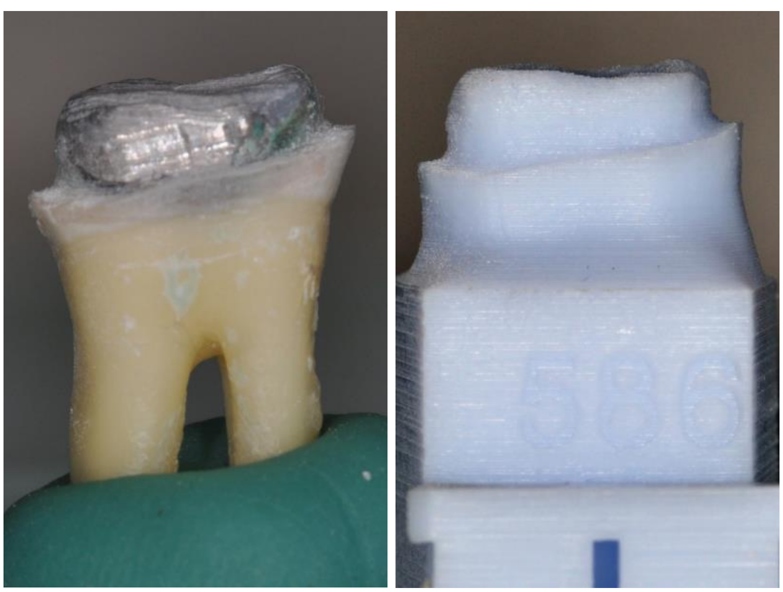


Table 2: The tooth number and the corresponding model number

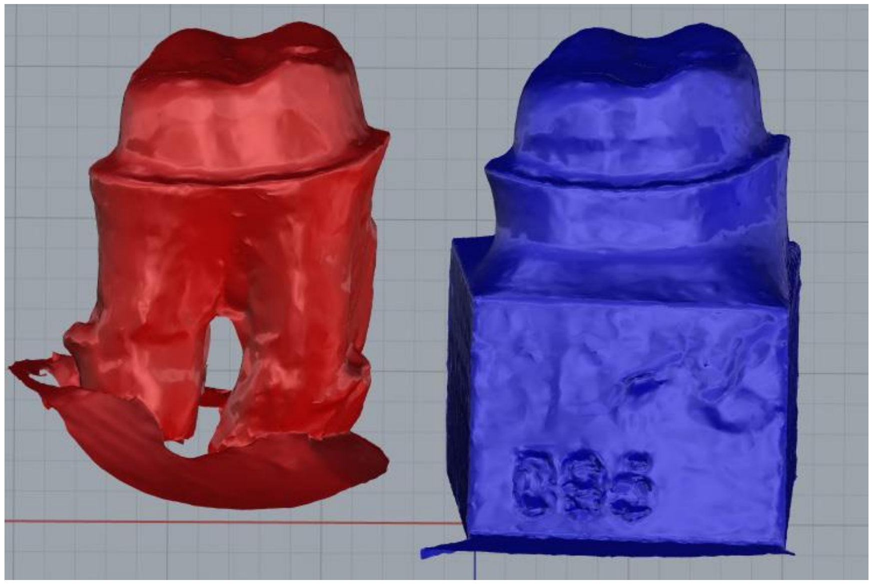
Incisor Number	Model Number	Tooth Number
I1	578674	#9
I2	573915	#9
I3	626341	#9
I4	626457	#9
I5	626564	#9
I6	626671	#9
I7	634535	#9
I8	634857	#9
I9	635144	#9
I10	647404	#9

Table 3: The tooth number and the corresponding model number

Molar Number	Model Number	Tooth Number
M1	574087	#18
M2	574095	#30
M3	573808	#3
M4	573949	#14
M5	573956	#30
M6	573964	#3
M7	574079	#18
M8	578690	#3
M9	609586	#30
M10	609693	#3
M11	579193	#30

Using the Rhino program (Rhino 5; McNeel North America), each prepared tooth and the SLA model die were compared. The root surface area between the finish line and 2mm below the finish line were then compared to the subgingival morphology to determine the accuracy. Statistical analyses were performed to compare the Volumes (Total, Bucco-Lingual, Mesio-Distal), Distances and Angles of Prepared teeth and SLA models.

Figure 14: The STL file images of the prepared tooth with its corresponding die



Three different parameters Volume, Length and Angle were tested and compared between the teeth and the SLA die. The difference in volume were tested in 4 zones named A, B, C, and D; the 4 zones were made by sectioning the tooth at 5 levels. Zone A is an area between the lowest point on the margin of the preparation to the second level at 0.5mm, B zone extended from 0.5mm to 1mm, C zone from 1mm - 1.5mm, and D zone 1.5mm – 2mm. The bucco-lingual (BL) and mesio-distal (MD) volumes were also calculated by sectioning the zones in BL and MD areas. The volume was measured for both Incisors and Molars.

Figure 15: The sections and the zones A B C and D

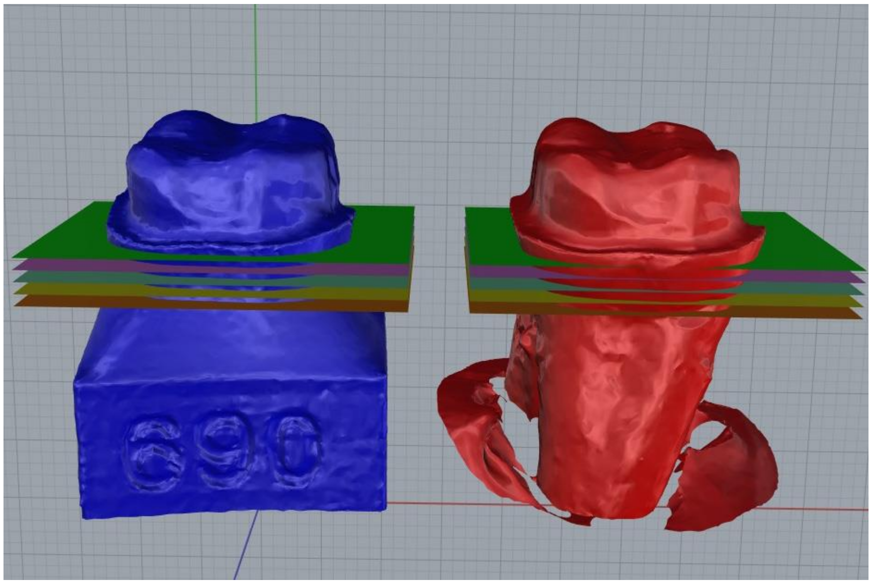


Figure 16: The sections and the zones A B C and D

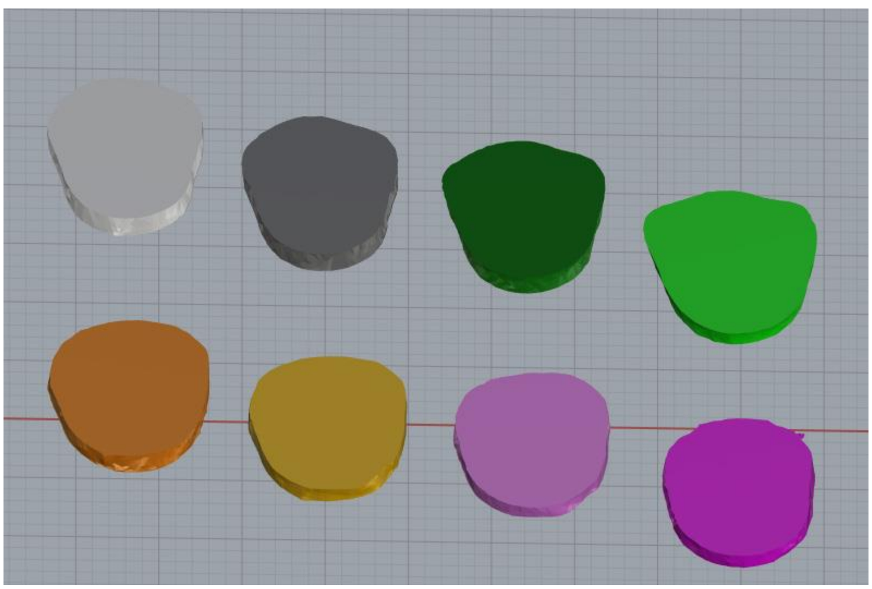


Figure 17: The 4 zones Model – zone A – black, zone B – gray zone, C – green zone, D – cyan and Tooth –zone A – orange, zone B – gold, zone C – pink, zone D – magenta from the interproximal aspect

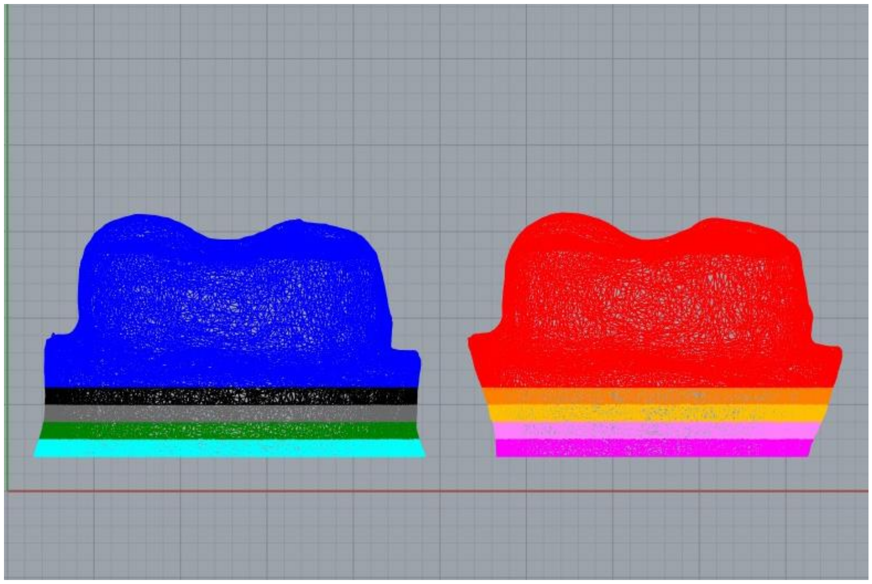


Figure 18: The same 4 A B C and D zones from the buccal aspect

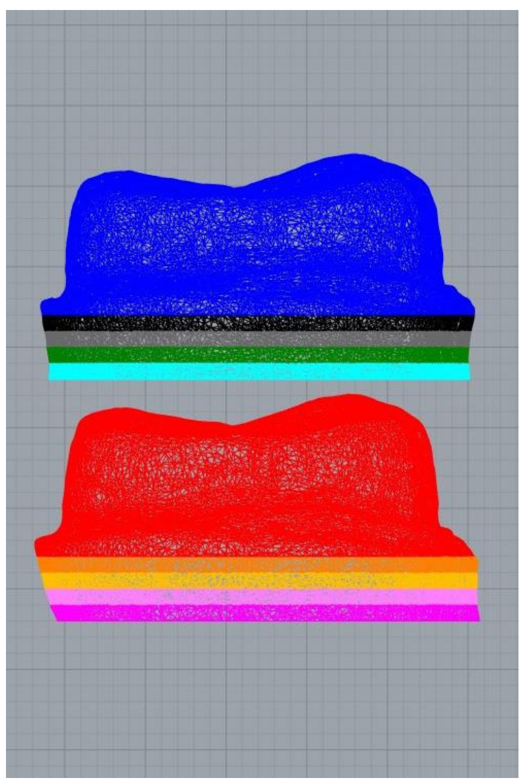
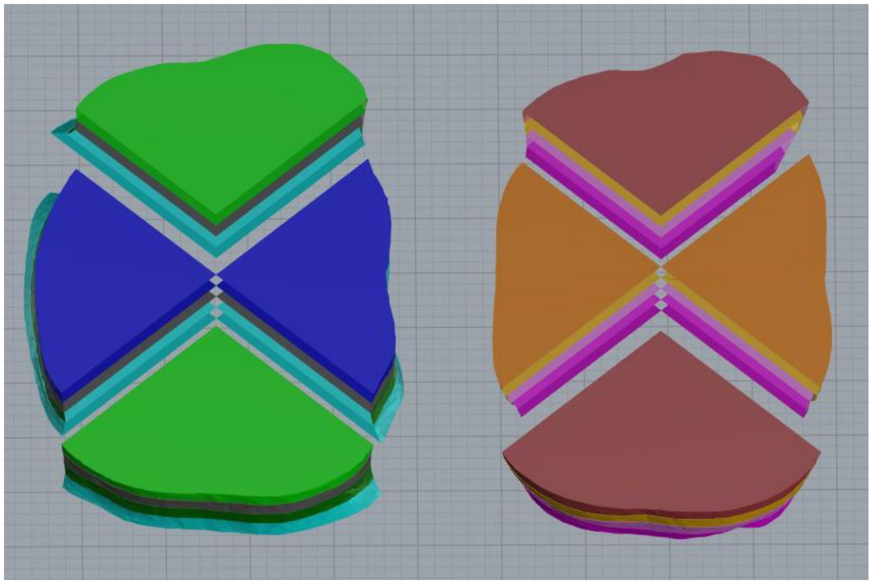
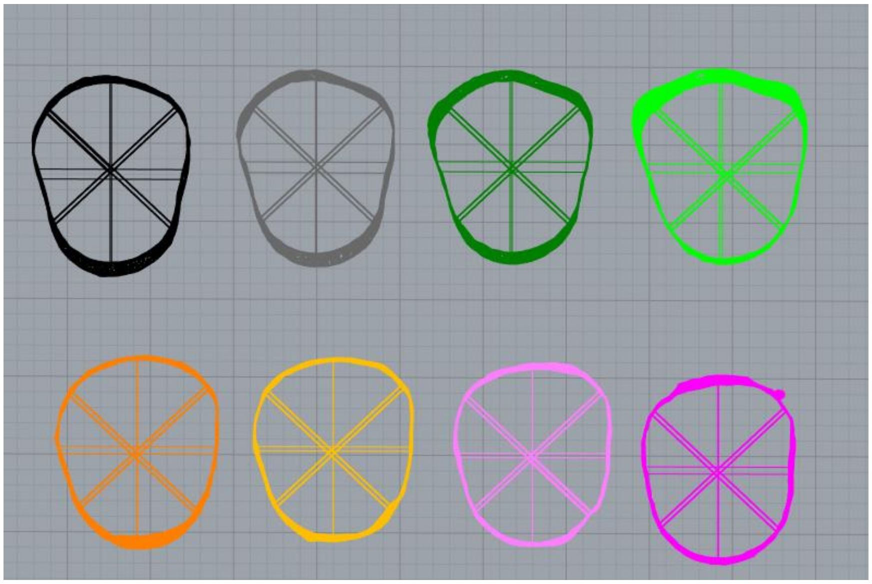


Figure 19: The bucco-lingual and the mesio-distal sections



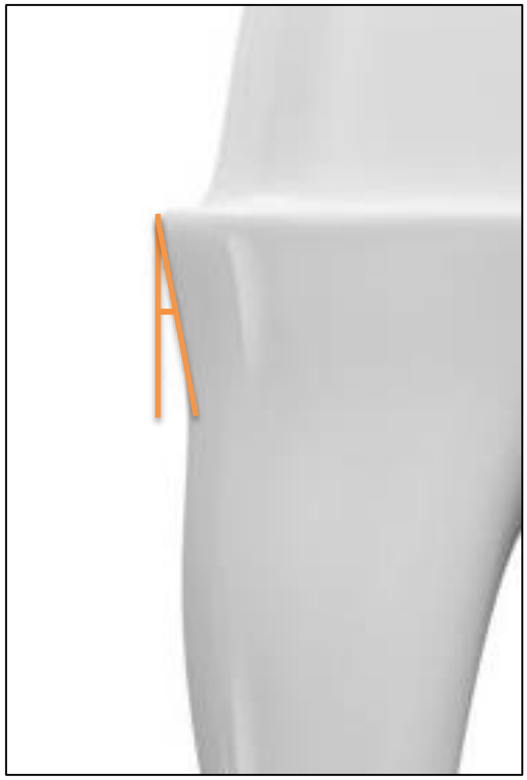
The second parameter tested was length. The BL and the MD length was measured for zones A, B, C, and D. The length was measured at the upper and the lower surface of each zone and an average was obtained for each zone. The lengths were compared between teeth and SLA model and measured for both incisors and molars.

Figure 20: The zones for length measurement



The third parameter tested was the angle formed between the perpendicular line drawn from the highest point at the margin and the line drawn on the surface of the tooth die at 1mm on four different surfaces - Buccal(B), Lingual(L) and (Mesial and Distal called Left and Right surfaces). The angle was measured using MB Ruler - the triangular screen ruler 5.3 (Markus-Brader) positioned on 4 different surfaces. The angle difference was compared between the prepared teeth and the SLA dies for both incisors and molars.

Figure 21: A schematic representation of an angle measurement



Statistical Analysis

One examiner (P.B.) collected all the data for angle, length and volume. These measurements were recorded in a spreadsheet (Excel 2013, Microsoft). All statistical computations were done in IBM SPSS Statistics 23.

Statistical analyses were performed to compare the volumes, length and angles of prepared teeth and SLA models using paired t-test, at the bucco-lingual (BL) and mesio-distal (MD) surfaces. Based on the Q-Q plots, no significant departure from normal distributions was observed, p-values were adjusted by Bonferroni correction to address the multiplicity of hypotheses testing with familywise error rate controlled of 0.05.

CHAPTER IV

RESULTS

Angle analysis in degree (^{0})

Table 4: shows the mean and standard deviations for angle comparison measured on four surfaces – buccal, lingual, mesial and distal for both teeth and SLA models, and for incisors and molars. In the incisor group, statistically significant difference was noted on bucco-lingual surfaces between the teeth and the SLA models (P value<0.05) whereas for the molar group there was a statistically significant difference in mesio-distal surfaces (P value<0.05)

		Incisors		Molars	
		Mean (°)	SD	Mean (°)	SD
Bucco-Lingual (BL)	Teeth (B)	-3.3[a]	8.39	-10.9	9.86
	SLA (B)	7.8[a*]	3.36	-9.7	5.71
	Teeth (L)	-3.2[b]	13.87	-11.5	8.99
	SLA (L)	-21.4[b*]	5.38	-10.1	6.09
Mesio-Distal (MD)	Teeth (M)	-4.5	7.25	-11.5[c]	8.20
	SLA (M)	-3.9	3.60	-3. 5[c*]	2.42
	Teeth (D)	-11.3	8.07	-15.1[d]	5.19
	SLA (D)	-7.4	3.83	-8.2[d*]	5.34

Note: * indicates the statistical significant difference between same alphabets superscripted

Length measured in millimeter (mm)

Table 5: shows the mean and standard deviations for length comparison measured at Zone A, B, C, and D for both teeth and SLA models. The table also shows the numbers for both incisors and molars. In the incisor group statistically significant difference was noted in Zone D for both bucco-lingual and mesio-distal surfaces between the teeth and the SLA models (P value<0.05) whereas for the molar group there was statistical significant difference in Zone C and D for bucco-lingual (P value <0.05) and Zone A, B, C, and D for mesio-distal surfaces (P value <0.05)

Zone			Incisors		Molars	
			Mean (mm)	SD	Mean (mm)	SD
BL	A	Teeth	6.33	.83	10.08	1.77
		SLA	6.38	.86	10.19	1.47
	B	Teeth	6.26	.73	9.76	1.86
		SLA	6.24	.84	9.96	1.50
	C	Teeth	6.19	.60	9.42^{c}	1.98
		SLA	6.21	.87	9.99^{c*}	1.43
	D	Teeth	6.10^{a}	.48	9.14^{d}	2.12
		SLA	6.43^{a*}	.77	10.28^{d*}	1.40
MD	A	Teeth	5.30	.76	8.87^{e}	.96
		SLA	5.36	.82	9.49^{e*}	1.11
	B	Teeth	5.22	.77	8.65^{f}	.95
		SLA	5.34	.83	9.47^{f*}	1.13
	C	Teeth	5.16	.78	8.37^{g}	.86
		SLA	5.41	.87	9.58^{g*}	1.21
	D	Teeth	5.11^{b}	.77	8.17^{h}	.83
		SLA	5.58^{b*}	.89	9.81^{h*}	1.27

Note: * indicates the statistical significant difference between same alphabets superscripted

Volume (mm^3)

Table 6: shows the mean and standard deviations for volume comparison measured at Zone A, B, C, and D for teeth and SLA models. The table also shows the numbers for both incisors and molars. In the incisor group statistically significant difference was noted in Zone D for both bucco-lingual (P value<0.05) and mesio-distal surfaces (P value<0.05) between the teeth and the SLA models whereas for the molar group there was statistical significant difference in Zone C and D for bucco-lingual (P value<0.05) and Zone A, B, C, and D for mesio-distal surfaces (P value<0.05)

Volume			Incisors		Molars	
			Mean (mm^3)	SD	Mean (mm^3)	SD
BL	A	Teeth	7.50	1.91	21.43	7.10
		SLA	7.72	2.10	21.88	6.30
	B	Teeth	7.54	1.69	20.74	6.63
		SLA	7.60	1.89	21.30	6.09
	C	Teeth	7.14	1.62	19.78 ^{c}	6.37
		SLA	7.60	1.88	21.26 ^{c*}	6.04
	D	Teeth	7.10 ^{a}	1.13	18.73 ^{d}	6.46
		SLA	8.28 ^{a*}	1.93	22.76 ^{d*}	5.89
M D	A	Teeth	5.64	1.14	17.67 ^{e}	3.72
		SLA	6.38	1.82	19.85 ^{e*}	4.96
	B	Teeth	5.64	1.22	16.82 ^{f}	3.32
		SLA	6.32	1.81	19.29 ^{f*}	4.20
	C	Teeth	5.50	1.29	15.90 ^{g}	3.00
		SLA	6.48	1.91	19.70 ^{g*}	4.36
	D	Teeth	5.44 ^{b}	1.28	15.02 ^{h}	2.72
		SLA	7.00 ^{b*}	2.09	21.02 ^{h*}	4.77

Note: * indicates the statistical significant difference between same alphabets superscripted.

CHAPTER V

DISCUSSION

The comparison of die trim morphology made by CAD/CAM technology was investigated. The present study was designed to test the accuracy of the die trimmed using the Lava COS scanner to the root morphology of the prepared tooth. Three different parameters were tested the angle, volume and length. The null hypotheses was rejected as there is statistically significant difference between the CAD/CAM generated dies and the corresponding prepared teeth in both incisor and molar groups.

An over-contoured restoration has margin overhangs at the edge of the tooth, food and bacterial plaque can accumulate along the margins, leading to inflammation and caries. Also, the overcontoured restorations in many studies have found to be more detrimental to the surrounding tissue than an undercontoured/flat crown.[30, 31] Perel conducted a study on dogs and stated overcontour produced inflammation whereas undercontour did not.[31] Parkinson did a study on 50 restorations (25 cast metal and 25 PFM crowns). He found that there was an increase in faciolingual dimension in the final restorations and that the plaque index was significantly higher for both the PFM and full cast metal crowns versus control teeth. The less axial accentuation of prominences on full crown restorations, the less the quantity of plaque.[32] Hence, importance should be given to developing a normal contour to the restoration. In 1969, Kraus et al gave the anatomic theory which stated anatomic or biological concept of a tooth contour are important and that stimulated natural, healthy, self-protecting teeth.[33] The clinical implication being that an area 2-3 mm below the finish line determines the emergence profile of a final restoration. Emergence profile plays a key role in development of a life-like final restoration and maintenance of gingival health. For this reason, clinicians and technicians attempt to capture and replicate tooth subgingival morphology below the finish line of the preparation. Gingival retraction materials such as retraction cords, lasers, retraction paste and other methods enable clinicians to capture the critical area below the finish line. Laboratory technicians have given importance to trimming the dies at the marginal zone, area the 2-3 mm below the finish line; however, until now there have been no studies evaluating the accuracy of die trimming morphology made using CAD/CAM technology, compared with the subgingival tooth surfaces. Robert Nedelcu et al conducted a study to compared accuracy of casts made with different intraoral scanners and casts poured by conventional impression techniques.[28] Segal et al (1984) and Diego (1992) placed huge importance on capturing and maintaining the 2 mm marginal zone on a die, by purposing different die trimming techniques to maintain this critical area.[17, 19] They reasoned that it was necessary for development of an ideal emergence profile restorations/crowns and would mimic the cervical third of the unprepared tooth. This study took into account this concept and applied it to CAD/CAM trimmed dies.

With respect to angle values for Incisors, there were statistically significant differences on the buccal and lingual surfaces. The buccal surface angle of the SLA dies had positive value (7.8°) compared with negative value (-3.3°) of the teeth. In addition, the lingual surface angle (-21.4°) of the SLA dies demonstrated the very large values difference compared with the teeth (-3.2°). For this difference of incisors, the certain angulation of maxillary anterior teeth should be taken into consideration (Figures 22 and 23). Andrews et al discussed the six keys for normal occlusion, the six keys being molar relationship, crown angulation - the mesio-distal tip, crown inclination (labio-lingual or bucco-lingual inclination), rotations, tight contacts and occlusal plane. He explained that the maxillary central and lateral incisors have a natural labio-lingual inclination which may be different in individuals which might be a reason for the difference noted between the prepared teeth and the SLA model dies.[34]

Figure 22: Ange difference in bucco-lingual direction between teeth and SLA model

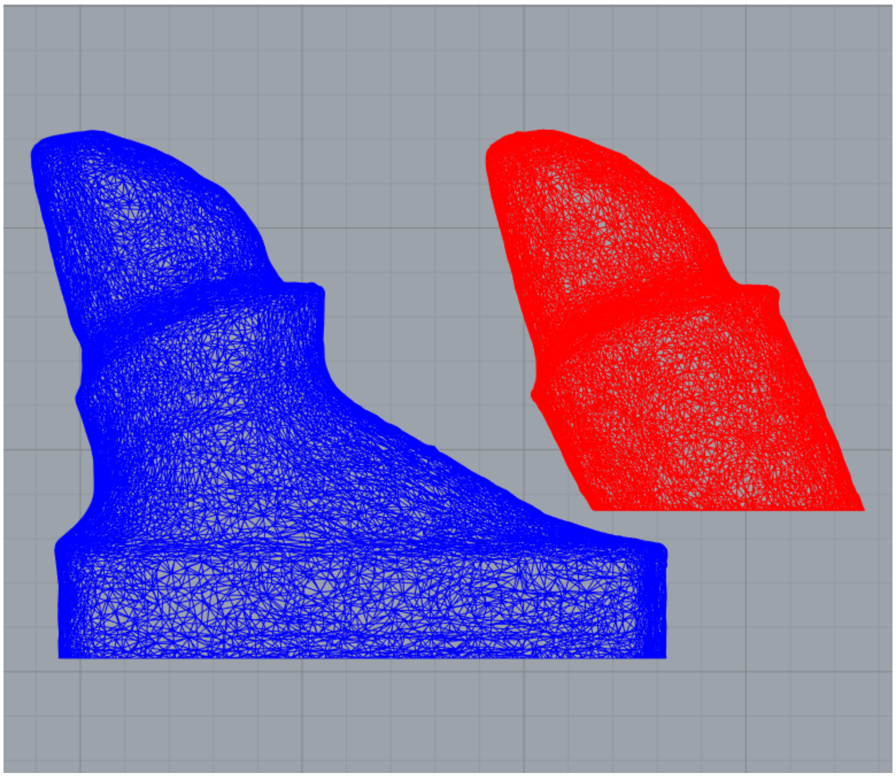
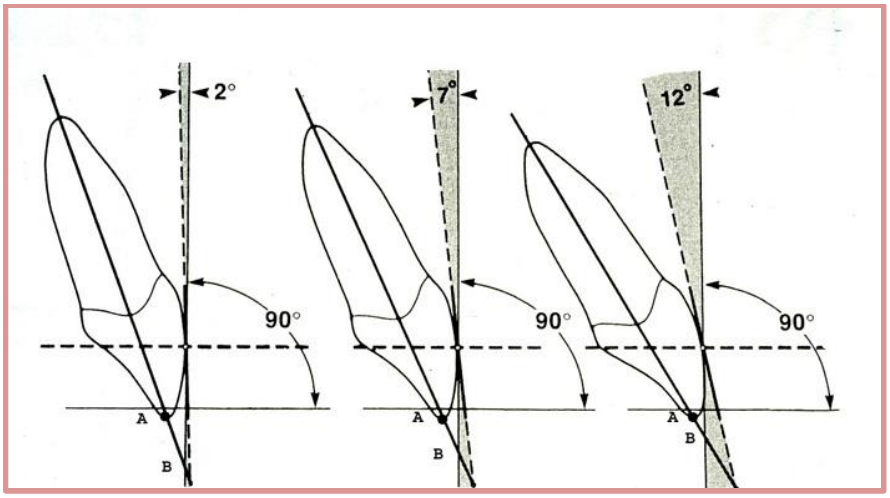


Figure 23: Andrews article showing the natural inclination in maxillary anterior teeth

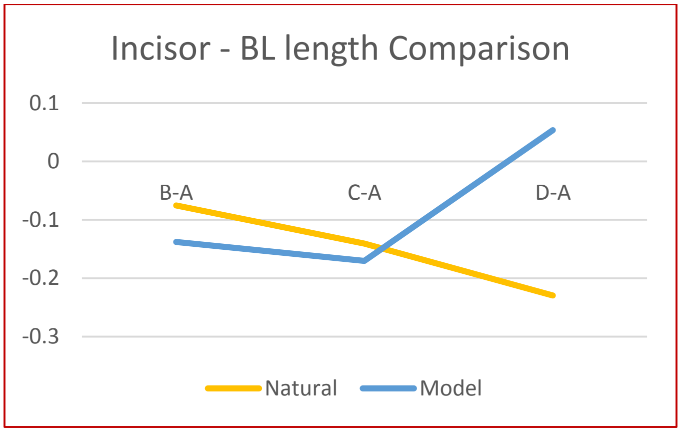


While the maxillary anterior teeth have certain angulation towards labial direction, the SLA dies were trimmed parallel to the long axis of the tooth, which could produce large different angle values at the buccal and lingual surface compared with the teeth subgingival morphology.

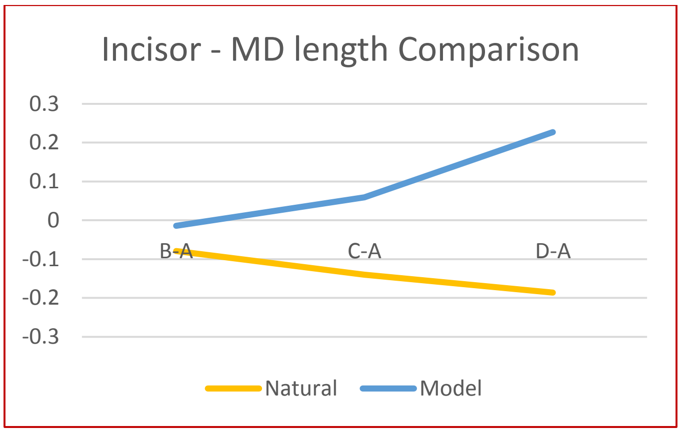
On the other hands, molars have the different angulation patterns, such as curve of Spee and curve of Wilson. Due to curve of Spee, the mandibular molars have the tendency to tilt toward mesial direction. The present study showed only MD surfaces of molars had significant difference, which can be explained by the curve of Spee.[34]

With regards to length for incisors, statistically significant differences were found in zone D bucco-lingually (BL) and mesio-distally (MD) wherein the length values of SLA dies were greater than the values of the prepared tooth. Graphs 1 and 2 shows the trend line for the BL length changes: the graph shows the value difference between the length of the certain zone and the length of zone A. The prepared teeth became narrower, while SLA dies became greater in zones D after zone C.

Graphs 1: Bucco-Lingual length changes between zones: Incisors

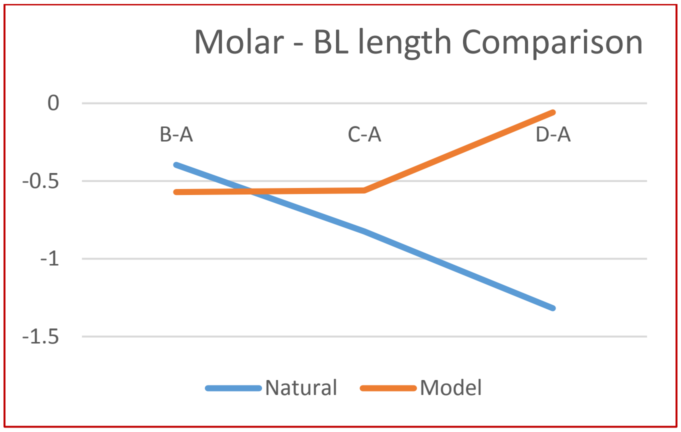


Graphs 2: Mesio-Distal length changes between zones: Incisors

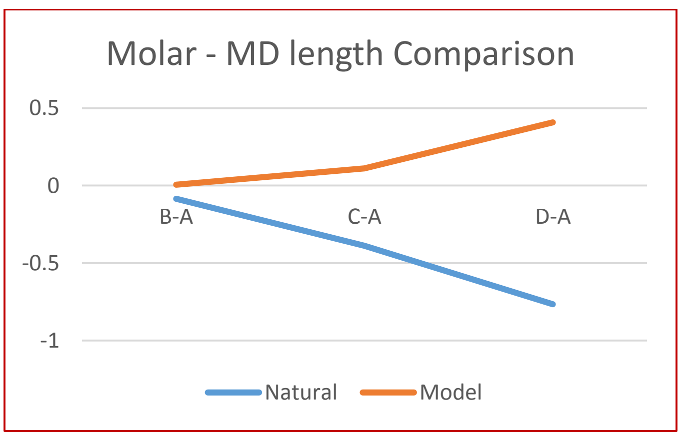


In terms of the length of molars, there was statistically significant difference in the zones C and D at BL surfaces wherein the SLA model is greater than the prepared tooth. Graph 3 indicates the trend line for the BL length of molars; the prepared teeth became narrower while the SLA dies become bigger in zones C and D. There was statistically significant difference in all four zones mesio-distally wherein the SLA model is bigger than the prepared tooth. The trend line Graph 4 for the MD length shows that the prepared tooth becomes narrower compared to the SLA model where the trend is similar to teeth in Zones A and B but changes to become bigger in Zones C and D.

Graphs 3: Bucco-Lingual length changes between zones: Molars



Graphs 4: Mesio-Distal length changes between zones: Molars

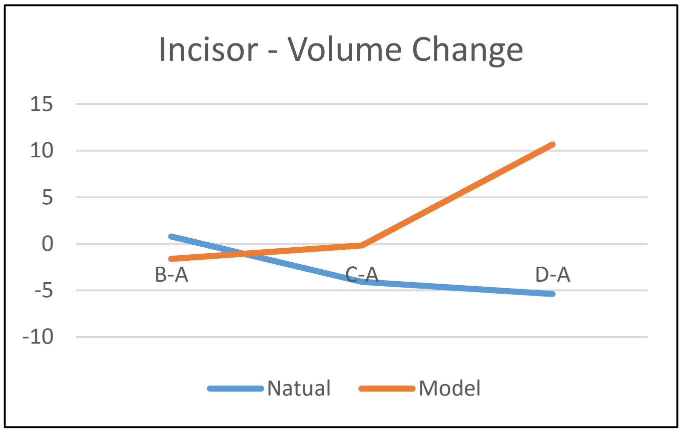


Note: B-A: value difference between the length of zone A and zone B; C-A: value difference between the length of zone A and zone C: D-A: value difference between the length of zone A and zone D

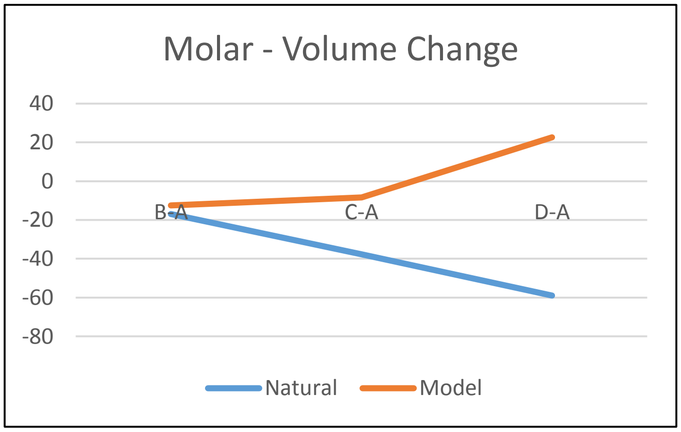
For the total volume of the incisors, there was statistically significant difference for zones C and D wherein the SLA model was greater in volume than the prepared tooth.

Graphs 5 and 6 demonstrates the trend line, which shows that the prepared teeth becomes narrower , compared to the SLA model where the volume decreases from zone A to B but increases from zone C to D.

Graphs 5: The total volume change between zones: Incisors



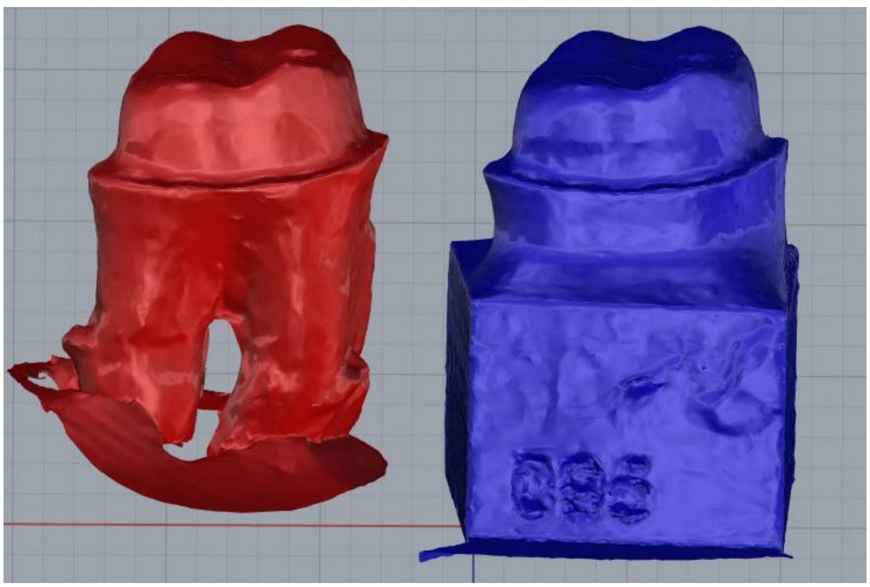
Graphs 6: The total volume change between zones: Molars



Note: B-A: value difference between the total volume of zone A and zone B; C-A: value difference between the total volume of zone A and zone C: D-A: value difference between the total volume of zone A and zone.

The trend line shows that volume values showed similar trends as the bucco-lingual and mesio-distal lengths. The volume and length data emphasized on the fact that natural teeth are more flat in profile and the corresponding SLA die is more concave which might clinically imply that the final restorations made of these dies would be overcontoured. In addition, furcation involvement should be taken into consideration for the molars as the dies do not account for the taper and narrow area of furcation.

Figure 24: The SLA die is not trimmed considering the furcation which can be appreciated between the mesial and the distal roots of the mandibular molar



One of the reason why the BL volume of the SLA dies was larger than the volume of the prepared tooth was the SLA dies did not consider the furcation involvement in molars, which could affect the proposed restoration contour and the periodontal maintenance associated with the contour.

There are several limitations of this research with respect to methods, material, and technology used. Future scope for research in this topic would be the repeat the same study and add a third group of dies made using the conventional impression technique and die trim technology, then comparing the accuracy between teeth, stone dies and CAD/CAM dies. Also, final crowns could be fabricated on these dies and compared to the unprepared corresponding tooth and more definitive conclusions could be derived regarding the relation between the over/under trimming a die and over/under contouring a restoration. The current study used only incisors and molar teeth the study could possibly be repeated with premolars and canines and evaluate the possibility of difference depending on the location and anatomy of the teeth more precisely. The current study used only the Lava COS the results cannot be directly applied to other systems so there is a scope to repeat the same study with different scanning systems.

CHAPTER VI

CONCLUSIONS

Within the limitations of this study, the following conclusions have been drawn:

1. For the angle analysis of CAD/CAM die trim morphology, the incisor group demonstrated significant difference at the BL surfaces. On the contrary, the molar group showed significant difference at the MD surfaces.
2. For the evaluation of length and volume of CAD/CAM die trim morphology, the incisor group showed significant difference at zone D of both BL and MD surfaces. However, significant differences at zone C and D of BL surfaces and all zones of MD surfaces was noticed in the molar group.

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APPENDIX A

Statistical Tables –

1. **Angle**

T-Test (Incisors)

Paired Samples Statistics

		Mean	N	Std. Deviation	Std. Error Mean
Pair 1	TB0.5	-5.000	10	7.7028	2.4358
	MB0.5	6.300	10	4.4234	1.3988
Pair 2	TB1	-3.300	10	8.3938	2.6543
	MB1	7.800	10	3.3599	1.0625
Pair 3	TL0.5	-3.400	10	16.1603	5.1103
	ML0.5	-20.400	10	5.1897	1.6411
Pair 4	TL1	-3.200	10	13.8708	4.3863
	ML1	-21.400	10	5.3790	1.7010
Pair 5	TMDA0.5	-2.600	10	6.2929	1.9900
	MMDA0.5	-6.200	10	3.1198	.9866
Pair 6	TMDA1	-4.500	10	7.2457	2.2913
	MMDA1	-3.900	10	3.6040	1.1397
Pair 7	TMDB0.5	-11.200	10	8.7788	2.7761
	MMDB0.5	-8.500	10	4.1966	1.3271
Pair 8	TMDB1	-11.300	10	8.0698	2.5519
	MMDB1	-7.400	10	3.8355	1.2129

Paired Samples Correlations

		N	Correlation	Sig.
Pair 1	TB0.5 & MB0.5	10	.245	.496

Pair 2	TB1 & MB1	10	.053	.885
Pair 3	TL0.5 & ML0.5	10	.685	.029
Pair 4	TL1 & ML1	10	.472	.168
Pair 5	TMDA0.5 & MMDA0.5	10	.599	.067
Pair 6	TMDA1 & MMDA1	10	.308	.386
Pair 7	TMDB0.5 & MMDB0.5	10	.160	.659
Pair 8	TMDB1 & MMDB1	10	.269	.453

		Paired Differences			
		Mean	Std. Deviation	Std. Error Mean	95% Confidence Interval of the Difference Lower
Pair 1	TB0.5 - MB0.5	-11.3000	7.8888	2.4947	-16.9433
Pair 2	TB1 - MB1	-11.1000	8.8751	2.8065	-17.4488
Pair 3	TL0.5 - ML0.5	17.0000	13.1572	4.1607	7.5879
Pair 4	TL1 - ML1	18.2000	12.2819	3.8839	9.4141
Pair 5	TMDA0.5 - MMDA0.5	3.6000	5.0816	1.6069	-.0351
Pair 6	TMDA1 - MMDA1	-.6000	7.0269	2.2221	-5.6268
Pair 7	TMDB0.5 - MMDB0.5	-2.7000	9.1049	2.8792	-9.2133
Pair 8	TMDB1 - MMDB1	-3.9000	7.9505	2.5142	-9.5875

Paired Samples Test

		Paired Differences: 95% Confidence Interval of the Difference Upper	t	df	Sig. (2-tailed)
Pair 1	TB0.5 - MB0.5	-5.6567	-4.530	9	.001
Pair 2	TB1 - MB1	-4.7512	-3.955	9	.003
Pair 3	TL0.5 - ML0.5	26.4121	4.086	9	.003
Pair 4	TL1 - ML1	26.9859	4.686	9	.001
Pair 5	TMDA0.5 - MMDA0.5	7.2351	2.240	9	.052
Pair 6	TMDA1 - MMDA1	4.4268	-.270	9	.793
Pair 7	TMDB0.5 - MMDB0.5	3.8133	-.938	9	.373
Pair 8	TMDB1 - MMDB1	1.7875	-1.551	9	.155

T-Test (Molars)

Paired Samples Statistics

		Mean	N	Std. Deviation	Std. Error Mean
Pair 1	TB0.5	-12.545	11	8.1408	2.4545
	MB0.5	-11.818	11	5.6182	1.6939
Pair 2	TB1	-10.909	11	9.8636	2.9740
	MB1	-9.727	11	5.7112	1.7220
Pair 3	TL0.5	-10.545	11	8.2142	2.4767
	ML0.5	-10.455	11	6.5324	1.9696
Pair 4	TL1	-11.455	11	8.9929	2.7115
	ML1	-10.091	11	6.0902	1.8363
Pair 5	TMDA0.5	-10.818	11	8.4359	2.5435
	MMDA0.5	-3.636	11	2.6560	.8008
Pair 6	TMDA1	-11.545	11	8.2020	2.4730
	MMDA1	-3.455	11	2.4234	.7307

Pair 7	TMDB0.5	-14.455	11	6.8317	2.0598
	MMDB0.5	-9.636	11	5.9879	1.8054
Pair 8	TMDB1	-15.091	11	5.1856	1.5635
	MMDB1	-8.182	11	5.3445	1.6114

Paired Samples Correlations

		N	Correlation	Sig.
Pair 1	TB0.5 & MB0.5	11	.153	.653
Pair 2	TB1 & MB1	11	-.125	.715
Pair 3	TL0.5 & ML0.5	11	.470	.144
Pair 4	TL1 & ML1	11	.498	.119
Pair 5	TMDA0.5 & MMDA0.5	11	.608	.047
Pair 6	TMDA1 & MMDA1	11	.248	.462
Pair 7	TMDB0.5 & MMDB0.5	11	-.049	.885
Pair 8	TMDB1 & MMDB1	11	-.080	.815

		Paired Differences			
		Mean	Std. Deviation	Std. Error Mean	95% Confidence Interval of the Difference
					Lower
Pair 1	TB0.5 - MB0.5	-.7273	9.1552	2.7604	-6.8778
Pair 2	TB1 - MB1	-1.1818	11.9985	3.6177	-9.2425
Pair 3	TL0.5 - ML0.5	-.0909	7.7260	2.3295	-5.2813

Pair 4	TL1 - ML1	-1.3636	7.9658	2.4018	-6.7152
Pair 5	TMDA0.5 - MMDA0.5	-7.1818	7.1389	2.1525	-11.9778
Pair 6	TMDA1 - MMDA1	-8.0909	7.9556	2.3987	-13.4355
Pair 7	TMDB0.5 - MMDB0.5	-4.8182	9.3040	2.8052	-11.0687
Pair 8	TMDB1 - MMDB1	-6.9091	7.7389	2.3334	-12.1082

Paired Samples Test

		Paired Differences			
		95% Confidence Interval of the Difference			
		Upper	t	df	Sig. (2-tailed)
Pair 1	TB0.5 - MB0.5	5.4233	-.263	10	.798
Pair 2	TB1 - MB1	6.8789	-.327	10	.751
Pair 3	TL0.5 - ML0.5	5.0995	-.039	10	.970
Pair 4	TL1 - ML1	3.9879	-.568	10	.583
Pair 5	TMDA0.5 - MMDA0.5	-2.3859	-3.337	10	.008
Pair 6	TMDA1 - MMDA1	-2.7463	-3.373	10	.007
Pair 7	TMDB0.5 - MMDB0.5	1.4323	-1.718	10	.117
Pair 8	TMDB1 - MMDB1	-1.7100	-2.961	10	.014

2. Length

T-Test (Incisors)

Paired Samples Statistics

		Mean	N	Std. Deviation	Std. Error Mean
Pair 1	Teeth BL A	6.3308	9	.82873	.27624
	Model BL A	6.3787	9	.85535	.28512
Pair 2	Teeth BL B	6.2556	9	.72908	.24303
	Model BL B	6.2410	9	.83540	.27847
Pair 3	Teeth BL C	6.1899	9	.59682	.19894
	Model BL C	6.2085	9	.81609	.27203
Pair 4	Teeth BL D	6.1011	9	.47784	.15928
	Model BL D	6.4323	9	.77119	.25706
Pair 5	Teeth MD A	5.3007	9	.75778	.25259
	Model MD A	5.3558	9	.82388	.27463
Pair 6	Teeth MD B	5.2215	9	.76723	.25574
	Model MD B	5.3413	9	.82835	.27612
Pair 7	Teeth MD C	5.1605	9	.77622	.25874
	Model MD C	5.4147	9	.87027	.29009
Pair 8	Teeth MD D	5.1143	9	.77114	.25705
	Model MD D	5.5828	9	.89088	.29696

Paired Samples Correlations

		N	Correlation	Sig.
Pair 1	Teeth BL A & Model BL A	9	.985	.000
Pair 2	Teeth BL B & Model BL B	9	.932	.000
Pair 3	Teeth BL C & Model BL C	9	.877	.002
Pair 4	Teeth BL D & Model BL D	9	.884	.002
Pair 5	Teeth MD A & Model MD A	9	.894	.001

Pair 6	Teeth MD B & Model MD B	9	.887	.001
Pair 7	Teeth MD C & Model MD C	9	.883	.002
Pair 8	Teeth MD D & Model MD D	9	.883	.002

		Paired Differences			
					95% Confidence Interval of the Difference
		Mean	Std. Deviation	Std. Error Mean	Lower
Pair 1	Teeth BL A - Model BL A	-.04794	.14702	.04901	-.16095
Pair 2	Teeth BL B - Model BL B	.01456	.30628	.10209	-.22087
Pair 3	Teeth BL C - Model BL C	-.01861	.40940	.13647	-.33330
Pair 4	Teeth BL D - Model BL D	-.33128	.41462	.13821	-.64998
Pair 5	Teeth MD A - Model MD A	-.05511	.36997	.12332	-.33949
Pair 6	Teeth MD B - Model MD B	-.11983	.38417	.12806	-.41513
Pair 7	Teeth MD C - Model MD C	-.25422	.40888	.13629	-.56851
Pair 8	Teeth MD D - Model MD D	-.46844	.41889	.13963	-.79043

Paired Samples Test

	Paired Differences	t	df	Sig. (2-tailed)

		95% Confidence Interval of the Difference			
		Upper			
Pair 1	Teeth BL A - Model BL A	.06506	-.978	8	.357
Pair 2	Teeth BL B - Model BL B	.24998	.143	8	.890
Pair 3	Teeth BL C - Model BL C	.29608	-.136	8	.895
Pair 4	Teeth BL D - Model BL D	-.01257	-2.397	8	.043
Pair 5	Teeth MD A - Model MD A	.22927	-.447	8	.667
Pair 6	Teeth MD B - Model MD B	.17546	-.936	8	.377
Pair 7	Teeth MD C - Model MD C	.06007	-1.865	8	.099
Pair 8	Teeth MD D - Model MD D	-.14646	-3.355	8	.010

T-Test (Molars)

Paired Samples Statistics

		Mean	N	Std. Deviation	Std. Error Mean
Pair 1	Teeth BL A	10.0846	11	1.76651	.53262
	Model BL A	10.1868	11	1.47102	.44353
Pair 2	Teeth BL B	9.7593	11	1.86018	.56086
	Model BL B	9.9561	11	1.49778	.45160
Pair 3	Teeth BL C	9.4216	11	1.97509	.59551
	Model BL C	9.9922	11	1.43002	.43117
Pair 4	Teeth BL D	9.1374	11	2.11914	.63895
	Model BL D	10.2846	11	1.40469	.42353
Pair 5	Teeth MD A	8.8728	11	.96194	.29003
	Model MD A	9.4890	11	1.11154	.33514
Pair 6	Teeth MD B	8.6542	11	.94862	.28602
	Model MD B	9.4656	11	1.12862	.34029
Pair 7	Teeth MD C	8.3726	11	.86117	.25965
	Model MD C	9.5781	11	1.20705	.36394
Pair 8	Teeth MD D	8.1655	11	.82981	.25020
	Model MD D	9.8150	11	1.27251	.38368

Paired Samples Correlations

		N	Correlation	Sig.
Pair 1	Teeth BL A & Model BL A	11	.987	.000
Pair 2	Teeth BL B & Model BL B	11	.976	.000
Pair 3	Teeth BL C & Model BL C	11	.948	.000
Pair 4	Teeth BL D & Model BL D	11	.876	.000
Pair 5	Teeth MD A & Model MD A	11	.924	.000
Pair 6	Teeth MD B & Model MD B	11	.891	.000
Pair 7	Teeth MD C & Model MD C	11	.841	.001
Pair 8	Teeth MD D & Model MD D	11	.778	.005

		Paired Differences			
		Mean	Std. Deviation	Std. Error Mean	95% Confidence Interval of the Difference Lower
Pair 1	Teeth BL A - Model BL A	-.10215	.39487	.11906	-.36742
Pair 2	Teeth BL B - Model BL B	-.19686	.51464	.15517	-.54261
Pair 3	Teeth BL C - Model BL C	-.57059	.76862	.23175	-1.08696
Pair 4	Teeth BL D - Model BL D	-1.14723	1.11742	.33691	-1.89792
Pair 5	Teeth MD A - Model MD A	-.61627	.42945	.12948	-.90478
Pair 6	Teeth MD B - Model MD B	-.81141	.51556	.15545	-1.15777

Pair 7	Teeth MD C - Model MD C	-1.20545	.67173	.20253	-1.65673
Pair 8	Teeth MD D - Model MD D	-1.64941	.81552	.24589	-2.19729

Paired Samples Test

		Paired Differences			
		95% Confidence Interval of the Difference			
		Upper	t	df	Sig. (2-tailed)
Pair 1	Teeth BL A - Model BL A	.16312	-.858	10	.411
Pair 2	Teeth BL B - Model BL B	.14888	-1.269	10	.233
Pair 3	Teeth BL C - Model BL C	-.05422	-2.462	10	.034
Pair 4	Teeth BL D - Model BL D	-.39653	-3.405	10	.007
Pair 5	Teeth MD A - Model MD A	-.32777	-4.760	10	.001
Pair 6	Teeth MD B - Model MD B	-.46505	-5.220	10	.000
Pair 7	Teeth MD C - Model MD C	-.75418	-5.952	10	.000
Pair 8	Teeth MD D - Model MD D	-1.10153	-6.708	10	.000

3. **Total Volume**

T-Test (Incisor)

Paired Samples Statistics

		Mean	N	Std. Deviation	Std. Error Mean
Pair 1	TA	13.413222222222222	9	3.389702744260099	1.129900914753366
	MA	14.093888888888888	9	3.864938953089830	1.288312984363277

Pair 2	TB	13.500777777777780	9	3.081955052307617	1.027318350769206
	MB	13.914888888888887	9	3.640536685862554	1.213512228620852
Pair 3	TC	12.958444444444444	9	2.948099562053117	.982699854017706
	MC	14.074777777777777	9	3.737837468971123	1.245945822990374
Pair 4	TD	12.812111111111111	9	2.491244239554025	.830414746518008
	MD	15.279000000000003	9	3.973800951230446	1.324600317076815

Paired Samples Correlations

		N	Correlation	Sig.
Pair 1	TA & MA	9	.921	.000
Pair 2	TB & MB	9	.985	.000
Pair 3	TC & MC	9	.956	.000
Pair 4	TD & MD	9	.948	.000

	Paired Differences				
				95% Confidence Interval of the Difference	
	Mean	Std. Deviation	Std. Error Mean	Lower	Upper

Pair 1	TA - MA	-.68066666666666665	1.51522663321365 9	.50507554440455 3	-1.845372960651522	.484039627318191
Pair 2	TB - MB	-.41411111111110 8	.81095891456417 9	.27031963818806 0	-1.037469314598309	.209247092376093
Pair 3	TC - MC	-1.116333333333333 33	1.258559394704913	.41951979823497 1	-2.083747722861086	-.148918943805581
Pair 4	TD - MD	-2.466888888888889 2	1.797429028115188	.59914300937172 9	-3.848515146075758	-1.085262631702027

Paired Samples Test

		t	df	Sig. (2-tailed)
Pair 1	TA - MA	-1.348	8	.215
Pair 2	TB - MB	-1.532	8	.164
Pair 3	TC - MC	-2.661	8	.029
Pair 4	TD - MD	-4.117	8	.003

T-Test (Molar)

Paired Samples Statistics

		Mean	N	Std. Deviation	Std. Error Mean
Pair 1	TA	39.106000000000000	11	9.843355403519674	2.967883322872012

	MA	41.731727272727270	11	10.497172744038359	3.165016668320059
Pair 2	TB	37.561454545454550	11	8.716721635610906	2.628190460663127
	MB	40.596000000000000	11	9.394416054231364	2.832523016034227
Pair 3	TC	35.685636363636360	11	7.849252388256187	2.366638641513345
	MC	40.963727272727276	11	9.463782627373782	2.853437824771149
Pair 4	TD	33.745999999999995	11	7.495492832362660	2.259976122158655
	MD	43.787090909090914	11	9.701624239832682	2.925149769140176

Paired Samples Correlations

		N	Correlation	Sig.
Pair 1	TA & MA	11	.952	.000
Pair 2	TB & MB	11	.975	.000
Pair 3	TC & MC	11	.947	.000
Pair 4	TD & MD	11	.879	.000

		Paired Differences				
		Mean	Std. Deviation	Std. Error Mean	95% Confidence Interval of the Difference: Lower	95% Confidence Interval of the Difference: Upper
Pair 1	TA - MA	-2.62572727272727268	3.209214143397387	.96761447141372 2	-4.781706670228344	-.469747875226192

Pair 2	TB - MB	-3.034545454545444	2.140514067397660	.645389274548686	-4.472562371822608	-1.596528537268281
Pair 3	TC - MC	-5.278090909090913	3.228000633659957	.973278811352687	-7.446691242480855	-3.109490575700973
Pair 4	TD - MD	-10.041090909090919	4.741287007860742	1.429551820769174	-13.226330861874434	-6.855850956307403

Paired Samples Test

		t	df	Sig. (2-tailed)
Pair 1	TA – MA	-2.714	10	.022
Pair 2	TB – MB	-4.702	10	.001
Pair 3	TC – MC	-5.423	10	.000
Pair 4	TD – MD	-7.024	10	.000

4. **Bucco-lingual and mesio-distal Volume**

T-Test (Incisors)

Paired Samples Statistics

		Mean	N	Std. Deviation	Std. Error Mean
Pair 1	TA_BL	7.50467	9	1.907106	.635702
	MA_BL	7.71633	9	2.095804	.698601
Pair 2	TB_BL	7.54478	9	1.692488	.564163
	MB_BL	7.59711	9	1.886084	.628695

Pair 3	TC_BL	7.13633	9	1.624514	.541505
	MC_BL	7.59644	9	1.877397	.625799
Pair 4	TD_BL	7.10078	9	1.125495	.375165
	MD_BL	8.28078	9	1.933770	.644590
Pair 5	TA_MD	5.63556	9	1.135637	.378546
	MA_MD	6.37756	9	1.815509	.605170
Pair 6	TB_MD	5.64256	9	1.222653	.407551
	MB_ND	6.31856	9	1.810269	.603423
Pair 7	TC_MD	5.50456	9	1.288500	.429500
	MC_ND	6.47811	9	1.909663	.636554
Pair 8	TD_MD	5.43689	9	1.276632	.425544
	MD_MD	6.99822	9	2.091474	.697158

Paired Samples Correlations

		N	Correlation	Sig.
Pair 1	TA_BL & MA_BL	9	.910	.001
Pair 2	TB_BL & MB_BL	9	.958	.000
Pair 3	TC_NL & MC_BL	9	.874	.002
Pair 4	TD_BL & MD_BL	9	.916	.001
Pair 5	TA_MD & MA_MD	9	.712	.031
Pair 6	TB_MD & MB_MD	9	.572	.108
Pair 7	TC_MD & MC_MD	9	.489	.181
Pair 8	TD_MD & MD_MD	9	.541	.133

		Paired Differences			
		Mean	Std. Deviation	Std. Error Mean	95% Confidence Interval of the Difference
					Lower
Pair 1	TA_BL - MA_BL	-.211667	.870454	.290151	-.880757
Pair 2	TB_BL - MB_BL	-.052333	.555617	.185206	-.479419
Pair 3	TC_BL - MC_BL	-.460111	.911179	.303726	-1.160505
Pair 4	TD_BL - MD_BL	-1.180000	1.010425	.336808	-1.956681
Pair 5	TA_MD - MA_MD	-.742000	1.284153	.428051	-1.729087
Pair 6	TB_MD - MB_MD	-.676000	1.496714	.498905	-1.826476
Pair 7	TC_MD - MC_MD	-.973556	1.702643	.567548	-2.282323
Pair 8	TD_MD - MD_MD	-1.561333	1.764991	.588330	-2.918026

Paired Samples Test

		Paired Differences 95% Confidence Interval of the Difference Upper	t	df	Sig. (2-tailed)
Pair 1	TA_BL - MA_BL	.457424	-.730	8	.487
Pair 2	TB_BL - MB_BL	.374752	-.283	8	.785
Pair 3	TC_NL - MC_BL	.240283	-1.515	8	.168
Pair 4	TD_BL - MD_BL	-.403319	-3.503	8	.008
Pair 5	TA_MD - MA_MD	.245087	-1.733	8	.121
Pair 6	TB_MD - MB_ND	.474476	-1.355	8	.212
Pair 7	TC_MD - MC_ND	.335211	-1.715	8	.125
Pair 8	TD_MD - MD_MD	-.204641	-2.654	8	.029

T-Test (Molars)

Paired Samples Statistics

		Mean	N	Std. Deviation	Std. Error Mean
Pair 1	TA_BL	21.43282	11	7.095169	2.139274
	MA_BL	21.88136	11	6.302548	1.900290
Pair 2	TB_BL	20.74036	11	6.633205	1.999987
	MB_BL	21.30164	11	6.094115	1.837445
Pair 3	TC_BL	19.78245	11	6.365794	1.919359
	MC_BL	21.26318	11	6.039708	1.821040
Pair 4	TD_BL	18.72645	11	6.464173	1.949022
	MD_BL	22.76455	11	5.894535	1.777269
Pair 5	TA_MD	17.67318	11	3.719011	1.121324
	MA_MD	19.85036	11	4.962079	1.496123
Pair 6	TB_MD	16.82109	11	3.316027	.999820
	MB_MD	19.29436	11	4.195267	1.264921
Pair 7	TC_MD	15.90318	11	3.002771	.905370

	MC_MD	19.70055	11	4.364780	1.316031
Pair 8	TD_MD	15.01955	11	2.719026	.819817
	MD_MD	21.02255	11	4.767632	1.437495

Paired Samples Correlations

		N	Correlation	Sig.
Pair 1	TA_BL & MA_BL	11	.980	.000
Pair 2	TB_BL & MB_BL	11	.987	.000
Pair 3	TC_BL & MC_BL	11	.967	.000
Pair 4	TD_BL & MD_BL	11	.910	.000
Pair 5	TA_MD & MA_MD	11	.907	.000
Pair 6	TB_MD & MB_MD	11	.950	.000
Pair 7	TC_MD & MC_MD	11	.901	.000
Pair 8	TD_MD & MD_MD	11	.890	.000

	Paired Differences			
				95% Confidence Interval of the Difference
	Mean	Std. Deviation	Std. Error Mean	Lower

Pair 1	TA_BL - MA_BL	-.448545	1.565123	.471902	-1.500009
Pair 2	TB_BL - MB_BL	-.561273	1.164296	.351049	-1.343458
Pair 3	TC_BL - MC_BL	-1.480727	1.617561	.487713	-2.567420
Pair 4	TD_BL - MD_BL	-4.038091	2.673865	.806201	-5.834418
Pair 5	TA_MD - MA_MD	-2.177182	2.232266	.673054	-3.676839
Pair 6	TB_MD - MB_MD	-2.473273	1.474626	.444616	-3.463940
Pair 7	TC_MD - MC_MD	-3.797364	2.106795	.635223	-5.212728
Pair 8	TD_MD - MD_MD	-6.003000	2.656616	.801000	-7.787739

Paired Samples Test

		Paired Differences 95% Confidence Interval of the Difference Upper	t	df	Sig. (2-tailed)
Pair 1	TA_BL - MA_BL	.602919	-.951	10	.364
Pair 2	TB_BL - MB_BL	.220912	-1.599	10	.141
Pair 3	TC_BL - MC_BL	-.394035	-3.036	10	.013
Pair 4	TD_BL - MD_BL	-2.241764	-5.009	10	.001
Pair 5	TA_MD - MA_MD	-.677525	-3.235	10	.009
Pair 6	TB_MD - MB_MD	-1.482606	-5.563	10	.000
Pair 7	TC_MD - MC_MD	-2.381999	-5.978	10	.000
Pair 8	TD_MD - MD_MD	-4.218261	-7.494	10	.000