A COMPARISON OF CROWN MARGINAL FIT FABRICATED USING DIGITAL
AND CONVENTIONAL METHODS

by

Jonathan Ng

BMed.Sc., The University of Alberta, 2005
Doctor of Dental Surgery, 2007

A THESIS SUBMITTED IN PARTIAL FULFILLMENT OF
THE REQUIREMENTS FOR THE DEGREE OF

MASTER OF SCIENCE

in

THE FACULTY OF GRADUATE AND POSTDOCTORAL STUDIES
(Craniofacial Science)

THE UNIVERSITY OF BRITISH COLUMBIA
(Vancouver)

August 2013
© Jonathan Ng, 2013
Abstract

**Purpose.** The aim of this study was to determine and compare the marginal fit of crowns fabricated using digital and conventional methods.

**Materials and Methods.** A maxillary right second bicuspid, set in a typodont (Frasaco, Greenville, N.C., USA), was prepared for a ceramic crown. The maxillary typodont was then digitized, using a 3Shape D700 lab scanner (3Shape Inc., New Jersey, N.Y., USA) and the digital file was used to mill a replica of the maxillary arch out of a monolithic block of yttria-stabilized zirconia, to serve as master model. Digital impressions of the prepared maxillary right second bicuspid were recorded using a 3M LAVA C.O.S. scanning unit. Scan files were exported as .STL files and e-mailed to the dental lab. Files were inputed (Core3dcentres®; Las Vagas, Nevada, USA) into a digital design workflow for digital articulation, digital wax-up, and design of the final crown. Fifteen crowns were produced by 5-axis milling IPS e.max® CAD (Ivoclar Vivadent, Liechtenstein) lithium disilicate glass-ceramic blocks. An additional fifteen IPS e.max® Press (Ivoclar Vivadent, Liechtenstein) lithium disilicate glass-ceramic crowns were produced using a conventional impression and laboratory fabrication methods. The original zirconia die was removed from the zirconia master model for evaluation of crown margins. Circumferential marginal gap measurements were taken at eight measurement locations: mesial, distal, buccal, palatal, and associated line angles. The marginal gap measurements were made to determine the vertical component of marginal gap, according to the definition of marginal fit.
Results. A total of 240 images (2 groups, 15 crowns per group, 8 sites per crown) were recorded and measured. The overall mean vertical gap measurement for the digitally made crowns was $48 \pm 25 \mu m$, which was significantly smaller than that for the conventionally made ones $(74 \pm 47 \mu m)$.

Conclusion. The fully digital fabrication methodology provides a better fitting crown margin than the conventional methodology.
Preface

This research project was conducted under the direct supervision Dr. Chris C.L. Wyatt and Dr. N. Dorin Ruse. The committee members included Dr. Chris Wyatt, Dr. Dorin Ruse and Dr. Caroline Nguyen.

Aurum Ceramic Dental Laboratories of Calgary, Alberta, Canada fabricated the standardized zirconia master model by digital design, 5-axis milling and finishing. Dental impressions for both the conventional and digital group were done in collaboration with Dr. David Alfaro with equal contribution for impressions. After all impressions, Dr. Jonathan Ng did all subsequent measurements and data collection independently.

This study did not include the use of any human subjects, animals or bio-hazardous material. Therefore, there was no need for approval from the UBC Research Ethics Board.
Table of Contents

Abstract........................................................................................................................................... ii
Preface................................................................................................................................................ iv
Table of Contents ............................................................................................................................... v
List of Tables ........................................................................................................................................ vii
List of Figures ..................................................................................................................................... viii
Glossary ............................................................................................................................................. ix
Acknowledgments .......................................................................................................................... x
Dedication .......................................................................................................................................... xii

Chapter 1: Introduction .................................................................................................................. 1

1.1 Tooth Preparation......................................................................................................................... 1

1.1.1 Assessment of Fit....................................................................................................................... 3

1.2 The Conventional Method ........................................................................................................ 4

1.2.1 Impression................................................................................................................................. 5

1.2.1.1 Conventional Impression Materials ...................................................................................... 5

1.2.1.2 Tray Selection and Adhesives............................................................................................... 11

1.2.1.3 Disinfection of the Impression............................................................................................... 14

1.2.1.4 Transportation of the Impression to the Dental Laboratory................................................. 15

1.2.2 Pouring Dental Impressions to create Casts........................................................................ 17

1.2.2.1 Gypsum Stone......................................................................................................................... 18

1.2.3 Crown Fabrication.................................................................................................................... 19

1.3 The Digital Method..................................................................................................................... 20
List of Tables

Table 1  Results of vertical marginal gap measurement (Mean ± SD; in µm) and statistical analysis

.................................................................................................................................................................................. 42
List of Figures

Figure 1 – Images captured using a digital SLR (Single Lens Reflex) camera attached to a 40X stereomicroscope. Master die held in place using affixed holder…………………………33

Figure 2 – Image example of marginal gap - Digital group……………………………………34

Figure 3 – Image example of marginal gap – Conventional group…………………………35

Figure 4 – Photograph of a (0.5) mm increment caliper taken at the same focal length as marginal gap photographs for use in calibration…………………………………………36

Figure 5 – Calibration of image measurement software using a photograph of a (0.5) mm increment caliper taken at the same focal length and input into IMAGE J software………37

Figure 6 – Photo of marginal gap measurement……………………………………………………38

Figure 7 – Enlarged photo of marginal gap…………………………………………………………39

Figure 8 – Box plots of the results of marginal gap measurements…………………………………………………………………………………………………………………………………..43

Figure 9 – Marginal chipping defect…………………………………………………………………44
### Glossary

<table>
<thead>
<tr>
<th>Term</th>
<th>Definition</th>
</tr>
</thead>
<tbody>
<tr>
<td>CEREC</td>
<td>Chair-side Economical Restorations of Esthetic Ceramics</td>
</tr>
<tr>
<td>IMPRESSION</td>
<td>a negative likeness or copy in reverse of the surface of an object; an</td>
</tr>
<tr>
<td></td>
<td>imprint of the teeth and adjacent structures for use in dentistry</td>
</tr>
<tr>
<td>SYNERESIS</td>
<td>Losing water</td>
</tr>
<tr>
<td>IMBIBITION</td>
<td>Gaining water</td>
</tr>
<tr>
<td>CMOS</td>
<td>Complementary metal oxide semiconductor</td>
</tr>
</tbody>
</table>
Acknowledgments

I wish to extend my gratitude and appreciation to the following individuals whose support and guidance contributed to the successful completion of this project.

To Dr. Chris C.L. Wyatt, professor and chair of the Division of Prosthodontics and Dental Geriatrics, Director of the Graduate Prosthodontics Program and Director of the Geriatric Dentistry Program, University of British Columbia, my supervisor. I extend my deepest gratitude for his leadership, support and guidance over the course of this project, the completion of my graduate program and career mentorship.

To Dr. N. Dorin Ruse, Professor and Chair of the Department of Biomaterials, University of British Columbia, my co-supervisor. I express my sincerest thankfulness for the advice, guidance, and knowledge gained from his willingness to share his extensive experience in research and writing. I thank him for his understanding and direction throughout the course of this project as well as my training.

To Dr. Caroline Nguyen, Assistant Professor, Department of Oral Health Sciences, University of British Columbia and member of my research committee. I thank her for her support and direction in planning for this project as well as her esteemed knowledge in the area of Maxillofacial Prosthodontics that has been helpful for the planning and focus of this project.
To my parents, David and Kathleen Ng, for their lifelong support, wisdom and direction. The sacrifices that they have made allowed me to pursue the aspirations and desires for my life and my career.

To my dearest wife and soul mate, Alicia Ng, I thank her for her unending love and kindness that has been with me through this entire process with love and support. It was through her thoughtfulness and understanding that helped me during this process.

To my beautiful and precious son, Noah Aiden Ng, who was born during the final year of this project and has been a significant inspiration. I could not imagine going through this without him.
Dedication

Dedicated to my dearest wife and life partner, Alicia Ng as well, our first son, Noah Aiden Ng.
Chapter 1: Introduction

If a tooth experiences extensive decay, fracture, or is functionally or esthetically compromised, a laboratory-fabricated crown is often required. A clinically acceptable crown should accurately fit the prepared tooth. The conventional approach to crown fabrication involves an accurate impression of the prepared tooth which is then poured with gypsum to form a cast replica of the preparation. A wax-up of the crown is created and invested in dental stone, then the wax is burned out to create the space necessary for the casting of the crown. The fabricated crown must restore the missing tooth structure and be well fitting; this requires that each of the steps involved be performed with accuracy. Digital technology has and continues to develop as an available means to performing the many steps of crown fabrication. However, what is unknown is the accuracy of crown fit of the digital technology, and is it any better than the conventional technology?

1.1 Tooth Preparation

According to Shillingburg¹, the design and preparation of a restoration is governed by five principles:

1) The preservation of tooth structure
2) Retention and resistance
3) Structural durability
4) Preservation of the periodontium
5) Marginal integrity
These principles provide for the fabrication of a predictable restoration. The importance of these principles cannot be overlooked as all are interrelated and violation of any one factor can lead to unfavorable outcomes. Proper retention and resistance are determined by an adequate amount of total occlusal convergence (between 10-20°), height of the preparation (3mm minimum for anterior teeth and 4mm minimum for posterior teeth) and ratio of the preparation width to height (0.4 minimum). This will ensure an adequate amount of reduction while maximizing the preservation of tooth structure. The structural durability can be determined by the amount of remaining tooth structure and the need for foundation restorations may be required to augment missing hard tissue. If the preparation encroaches into unfavorable locations of the periodontium, the preparation is said to violate the biologic width, which is defined by Gargiulo as the dentogingival junction consisting of the epithelial attachment and the connective tissue attachment. When this region is interrupted, the resultant inflammatory response that may occur, lead to loss of hard and soft tissue that support the tooth. Placement of a finish line should be ideally on enamel and above the crest of the gingiva as subgingival restorations has been described as a major etiological factor in periodontitis.

Finally, the survival of a restoration is determined by its ability to withstand the oral environment, which requires that the margins be closely adapted to the cavosurface finish line. Finish line configuration is determined largely by the requirements of the restorative material and can include the following designs: chamfer, heavy chamfer, shoulder, radial shoulder, shoulder with bevel and the knife-edge finish line. In the case of the all-ceramic restoration, the use of a shoulder finish line with a uniform width of approximately 1mm is
used as the gingival finish-line which provides a flat seat that resists forces directed in the axial direction.$^8$

### 1.1.1 Assessment of Fit

The marginal integrity of a dental prosthesis can determine longevity and predictability and its measurement requires accurate assessment and quantification of marginal parameters so as to differentiate fit from misfit. Holmes et al. defined geometrically the relation of the cavosurface finish line to the prosthesis margin and defined fit in terms of “misfit”, categorized into eight variables: internal gap, marginal gap, vertical marginal discrepancy, horizontal marginal discrepancy, overextended margin, underextended margin, absolute marginal discrepancy and seating discrepancy.$^9$ Fit has been defined in both *in vitro* and *in vivo* studies as the marginal discrepancy, either vertically or horizontally.$^{10}$ This gap is important because the amount of space will determine the amount of possible cement dissolution. Margin inaccuracy could lead to the accumulation of plaque and bacteria,$^{11}$ the dissolution of luting material,$^{12}$ and/or the introduction of unfavorable inflammation of the periodontal tissues.$^5$ As described by McLean and Von Fraunhofer, clinically acceptable marginal gap are those that are $\leq 120$ μm.$^{13}$ However, according to the American Dental Association (ADA) Specification No. 8, the marginal fit of cemented restoration should be in the range of 25-40 μm to allow for luting cement thickness,$^{14}$ however, this range is seldom achievable.$^{15}$
Both destructive and non-destructive methods have been used to assess the fit of crown prostheses. The most commonly cited destructive technique is the cementing of the prosthesis followed by sectioning of the die-crown complex. The section is then evaluated under magnification for marginal as well as internal gap. Other methods use a silicone medium to impress and indicate the amount of space available between the prosthesis and the die; this technique is advantageous as it may be utilized in both in vitro and in vivo setting. Lastly and most recently, the photographic technique has become popular and uses digital photography at an angle parallel to the focal plane of the microscope positioned perpendicular to the die and prosthesis. The digital image is measured based on pixel numbers in comparison to a standardized image.

1.2 The Conventional Method

The conventional methodology of crown fabrication requires the securing of a negative replica of the dentition with a stable recording medium, such as a polyvinyl siloxane elastomeric impression material. Numerous steps in the process are required and include: the use of a custom acrylic tray, application of adhesives, attention to setting time and distortions upon removal from the oral cavity and disinfection of the impression. Most often, the impression is sent to a commercial dental laboratory by courier which subjects an impression to significant variation in temperature, notwithstanding the variable amount of transportation time between securing an impression and pouring the dental cast. The type of gypsum chosen, water-to-powder proportions, and how the impression was handled before pouring, directly affects the quality and outcome of the gypsum cast. Once the gypsum cast
is made, die-hardener, and die-spacer are applied\textsuperscript{28}, then, a full-contour wax-up, high
temperature burnout, and casting\textsuperscript{29}. As a whole, numerous steps lead to possible variability in
the marginal fit of the crown to the tooth.

1.2.1 Impression

1.2.1.1 Conventional Impression Materials

The essential first step of the crown fabrication process involves the impression. As stated by
Rudd et al.\textsuperscript{30}, it is “axiomatic that accurate impressions are a prime requisite for forming
accurate casts”. As such, it is the impression that is critical first step in the process of
prosthesis fabrication which cannot be overlooked.

According to the Glossary of prosthodontics terms, an impression is “a negative likeness or
copy in reverse of the surface of an object; an imprint of the teeth and adjacent structures for
use in dentistry”\textsuperscript{31}. The use of conventional impressions requires a number of individual
steps, the risk of error increasing with an increase in the number of steps involved.
Ultimately, the effect that each procedural step has upon the resultant product needs to be
accounted for and provisions made to minimize error.

In 1937, Sears was the first to describe the use of hydrocolloids for the making of a dental
impression\textsuperscript{32}. Still routinely used today, the hydrocolloid impression is a versatile material
available in two varieties, the reversible (agar) and irreversible (alginate) hydrocolloid. The
agar (reversible) variety of hydrocolloid has been shown to be more accurate in reproducibility while the alginate (irreversible) hydrocolloids are slightly less accurate, but are more easily manipulated. Reversible hydrocolloid is more complex as its use requires water-cooled trays necessary for the maintenance of a workable phase and therefore their use in everyday practice is limited\textsuperscript{33}. In the 1980’s, attempts were made to maximize the favorable qualities of both of these materials by fabricating a single combined system\textsuperscript{33,34}. However, interface connection between the two types was reported to be unfavorable as it was purely mechanical and not chemical. Moreover, its dimensional stability was also questionable. The conventional single method irreversible hydrocolloid, which requires very little special equipment and has a clinically insignificant average inaccuracy of 0.104% has widely been accepted as the hydrocolloid of choice for clinical dentistry\textsuperscript{34}. However, the stability of water molecules within alginate is highly variable and is determined heavily by surrounding humidity. As a result, alginates are unstable and are constantly undergoing syneresis (losing water) or imbibition (gaining water), resulting in weight loss / gain and dimensional change over time\textsuperscript{35}. The relative inaccuracies and noted dimensional change can be as high as 1\% by 5 days of delayed pouring\textsuperscript{36}. Still, alginate has retained its place as a diagnostic tool and in some specific dental procedures such as acrylic prostheses; however, overall, alginate has been eclipsed in fixed prosthodontics by more accurate materials.

The introduction of elastomeric impression materials further revolutionized the securing of dental impressions. Polysulfide and silicone materials are two types of elastomeric materials routinely used today. Polysulfide material is a slower setting material, which is odorous and difficult to handle and exists as a two-paste system of a base and an accelerator\textsuperscript{37}. The base
contains polysulfide polymer, titanium dioxide, zinc sulfate, copper carbonate or silica, while
the accelerator is comprised of lead dioxide, sulfur and magnesium stearate. Polysulfide
material is hydrophilic and makes a detailed impression in the presence of moisture.
However, these impressions can imbibe water if stored in inappropriate humidity\textsuperscript{38}. As there
are some unfavorable characteristics of polysulfide materials, most particularly the setting
time being long, silicone materials have been used preferentially\textsuperscript{37}. Despite this, polysulfide
material is still sometimes used as it has a higher propensity to capture significantly greater
detail and accuracy then hydrocolloids\textsuperscript{39}. This is because elastomeric materials yield much
less curing or thermal contraction, creep, water sorption and desorption\textsuperscript{40}.

Addition-polymerization silicones such as polyvinyl siloxane, is another elastomeric
material. They consist of a base (polymethyl hydrogen siloxane co-polymer) and accelerator
(vinyl-terminated poly-dimethyl siloxane). Although all elastomers experience contraction
from a reduction of spatial volume during cross-linking, the addition of siloxane and vinyl
groups occurs with minimal dimensional change, with no byproducts\textsuperscript{22}. Polyvinyl siloxane
has been shown to have the smallest dimensional change with a reduction of volume as low
as 0.1-0.05\textperthousand\textsuperscript{22}. Careful handling of this material requires the clinician to be cautious of
sulfur compounds contained in latex products. This may inhibit the platinum catalyst that is
used in the reaction process, leading to potential distortion of the impression or the inability
for the setting reaction to complete. Preparation and soft tissue area should be done prior to
impression making with 2\% solution of chlorohexidine to remove any contaminants
introduced during preparation.
Polyether, another elastomeric material, has dimensional accuracy that is comparable to that of polyvinyl siloxane. However, because of its stiffness, it is has made it difficult to remove, particularly in the case of full arch impressions. Polyether is hydrophilic and thus after the setting reaction, imbibition of water can cause swelling of the impression material leading to inaccuracies. Polyether exists as a base and catalyst and contains fillers, plasticizers and triglycerides. The setting reaction occurs when aziridine-terminated polyether chains concatenate as a result of the aziridine ring opening and are lengthened by cross-linking to form a polyether rubber. Setting time is favorable and similar in length as that of polyvinyl siloxane.

Comparing elastomeric materials has been inconclusive. Comparative studies have been unable to unequivocally advocate a single material. Certain studies have indicated superior dimensional accuracy of one material over another, while others have indicated that there is no difference at all. An in vitro study comparing polyether, addition silicone and agar, indicated polyether and hydrocolloid as less dimensionally stable then polyvinyl siloxane material. However, the test conditions were moist, which fails to recognize the difference in polyether and hydrocolloid materials as hydrophilic, while polyvinyl siloxane material as hydrophobic. In contrast, Peuzfeldt and Asmussen determined elastomeric material to be superior in dimensional accuracy with up to 39-130 µm space discrepancy between two dies while hydrocolloids had up to 44-188 µm discrepancy. These authors determined that polyvinyl siloxane material was superior to polyethers. Then, Herring et al. determined that as long as a custom tray was used and impressions were immediately poured, the relative
dimensional accuracies showed no statistical difference between impression materials in the production of an accurate gypsum cast.

The dimensional accuracy of impression materials depends on multiple factors. There is variation in dimensional stability, elastic recovery, polymerization shrinkage and time dependent shrinkage. Numerous studies have indicated that polyvinyl siloxane is the most accurate\textsuperscript{43, 44}, and presents the least amount of time dependent dimensional change\textsuperscript{45}. Eames\textsuperscript{43} studied the percentage change that occurs for polyether, polyvinyl siloxane and polysulfide impression materials at 30 minutes and 24 hours and showed that for all impression materials there was an increase in percentage change between 30 minutes and 24 hours except for polyether which showed a decrease in dimensional change at 24 hours compared to 30 minutes, a difference that was however not statistically significant. Overall, the percentage change for polysulfide was the least stable while polyvinyl siloxane showed better dimensional stability at 24 hours. Nonetheless, it was shown that at 30 minutes, all the tested materials showed an approximate average of 0.2 % change and thus it was suggested that pouring time within 30 minutes would be favorable regardless of material used\textsuperscript{43}. Dimensional change was shown in a study to be the greatest in the dimension of height, where polyvinyl siloxane has the least (0.04 %) and polysulfide had the greatest (0.45 %) at 1 hour\textsuperscript{46}. In the same study, Johnson and Craig determined that repeated pouring was also a major factor in notable cast difference and found that polyvinyl siloxane material showed 0.18 % larger diameter second pour posts while polyether produced 0.1 % decrease in diameter between pours\textsuperscript{46}. The dimensional stability of various rubber based impression materials in decreasing order is: addition silicones, polyether, polysulfide and condensation
silicone with typical dimensional change after 24hours in 50 % humidity of 0.05 %, 0.1 %, 0.2 % and 0.5 %, respectively\textsuperscript{47}. Studies confirm that polyvinyl siloxane material is the most stable elastomer available and that other materials, such as polysulfide rubber, display a poor time dependent level of accuracy, as indicated by progressive increase in die diameter with time\textsuperscript{48} \textsuperscript{49}.

The polymerization reaction, involving cross-linking and rearrangement of bonds within and between polymer chains can lead to contraction. Distortion can also occur if the material does not elastically recover when removed from undercuts, which augment the dimensional changes that occur during setting\textsuperscript{47}. As a result of such factors, permanent deformation is used to quantify, as a percentage, the amount of change or deviation from the actual that occurs in a given impression material. Polyvinyl siloxane material has the lowest permanent deformation with a range of 0.05-0.4 %, while polythers have a 1-2 % deformation and polysulfide material has the highest degree with up to 6 % permanent deformation\textsuperscript{47}. Polyvinyl siloxane has therefore become the gold standard impression material, with the most predictable handling, ease of use, long-term stability, wettability, least sensitive to pouring time and has the overall highest accuracy\textsuperscript{50} \textsuperscript{22}. The international standard for dental elastomeric impression material states that an impression material must be able to reproduce a line 0.020 mm in width, for which polyvinyl siloxane is able to\textsuperscript{22}. Materials of very low viscosity have the ability to reproduce lines as small as 1-2 µm\textsuperscript{51}.
1.2.1.2 Tray Selection and Adhesives

In general, there are two types of trays available for making dental impressions: a custom fabricated tray, or the pre-fabricated stock tray. Custom trays are most often fabricated on a duplicate of the specific patient oral anatomy, while a stock tray is a generically fitted tray with various pre-fabricated sizes. When using irreversible hydrocolloid impression material, a study comparing the accuracy of various tray types showed that a rim lock tray provided better accuracy in the width and length of an arch than perforated trays and custom fabricated trays; however, trays with perforated holes were shown to be more advantageous for obtaining height, such as in a situation of a deep palatal vault. When making impressions with silicone materials, stock trays were shown to be less accurate then custom trays. Thus, the use of stock trays is limited to certain indications where accuracy is not a primary concern. Burton et al. indicated that in the case of agar and alginate, a disposable stock tray is equal in maintaining dimensional accuracy to a reusable stock tray. This is not true when using elastomeric materials and, therefore, the use of stock trays is not indicated for elastomeric impression materials. When using elastomeric materials, a custom tray is indicated with a recommended 3 mm thickness between the soft/hard tissue and the tray internal surface. Similarly, Valderhaug et al. recommended a (2 to 4) mm material thickness, suggesting, however, that as long as stock trays are able to adhere to these limitations then there is no need to use custom trays, which are costly and time consuming. Conversely, Eames et al. using polyether, determined that material bulk is ideal at 2 mm and that any deviation will contribute to inaccuracies as this specific thickness allows for support
while still being able to deform and rebound during removal to yield the least amount of dimensional discrepancy\textsuperscript{43}.

Advocates against the use of custom trays cited concerns regarding the use of auto polymerizing acrylic resin that could lead to human exposure to the toxic monomer components. Furthermore, these types of trays require fabrication at least 24 hours in advance because of 7\% linear shrinkage during this time with residual shrinkage expected for even up to 180 days\textsuperscript{56}. Urethane dimethacrylate light cured material has been suggested for use as a superior alternative because it offers high stiffness (elastic modulus) and is stable immediately after cure without harmful chemicals\textsuperscript{27}.

Regardless of custom or stock tray, it is imperative that an adhesive be utilized to minimize dislodgment of the impression material from the tray on removal of the impression intraorally\textsuperscript{52}. However, proper technique indicates that tray adhesive must be allowed proper drying time, which can be between 5 minutes to 48 hours depending on manufacturers’ recommendations\textsuperscript{27}. As such, careful attention must be taken prior to making any impression. Before any dental impression is made, the requirements include thoughtful material selection, the material carrier or tray type and the method of maintaining good retention through the use of various tray designs and tray adhesive.

The dimensional accuracy of impressions shows variation when different types of trays are used. The type of tray selected depends on the material used for making the dental impression. As described by Mendez\textsuperscript{52}, impressions made with irreversible hydrocolloids
show dimensional change with any type of tray used. They achieve the greatest accuracy in
the length and width of an arch when used with trays that are perforated, are most accurate in
the height of the palatal vault when used with non-perforated trays, and their dimensional
changes were not found to be clinically significant. However, with the use of hydrocolloid
materials, it is the bulk of material that is the most crucial factor for determining accuracy. A
study showed that an optimum bulk is needed to provide accuracy, for which a uniform
distribution of material that is (3.20 to 6.35) mm in thickness is needed\textsuperscript{30}. In the case of
elastomeric materials, a custom acrylic tray has been shown to be best suited\textsuperscript{50}. Similar to
hydrocolloid materials, the bulk of elastomeric materials is a crucial factor determining the
accuracy of the impression. In the case of elastomeric impression materials, a uniform bulk
between (1.5 to 2.5) mm in thickness has been suggested to provide the greatest accuracy\textsuperscript{37}
\textsuperscript{57}. With the use of an acrylic custom tray that provides this uniform space, it can be expected
that as little as 0.2 % change will occur in the first 30 minutes and up to 0.3 % change if
poured at 24 hours\textsuperscript{57}. However, custom fabricated acrylic resin trays inherently possess (0.08
to 0.4) % dimensional change in the first 24 hours, with 90 % of all shrinkage occurring in
the first (8-10) hours\textsuperscript{47}.

When elastomeric materials are used, it is crucial that adhesion of the material to the tray be
obtained in order to obtain an accurate impression. At least 0.44 MPa of bond strength is
required to sufficiently withstand stresses induced during removal of an impression\textsuperscript{58}. The
time allowed for the drying of the adhesive is also of great importance. Dixon et al.
determined that optimal and highest adhesive bond strength was obtained for custom trays of
any material with 48 hour adhesive drying time, while a 10 minute drying time exhibited
significantly lower mean adhesive bond strength\textsuperscript{21}. The material from which the custom tray is fabricated is also very important as it affects the adhesive bond strength, with urethane dimethacrylate material exhibiting higher adhesive bond strength than polymethylmethacrylate material\textsuperscript{59 21}.

1.2.1.3 Disinfection of the Impression

There are many sources of contamination in the mouth, including saliva, plaque, food particles and sometimes blood, all of which can contain pathogenic organisms\textsuperscript{60}. Disinfection of materials that have been exposed to the oral environment concerns anyone who handles these materials, including laboratory technicians. Suggested disinfection methods include surface disinfectants, submersion disinfection and the incorporation of disinfecting solution into the impression material mixture. The latter involves mixing 20 \% aqueous solution of 0.2 \% chlorhexidine gluconate with alginate mixtures to eliminate the need for any additional surface disinfectant. Limited investigation of this method has shown it to have no effect on the accuracy when compared to the same impressions without the use of incorporated disinfectant\textsuperscript{61}. Its use is not widely accepted and has not become routine practice for impression making. Most commonly used is surface disinfection, either by spraying or by immersion. There are potential consequences that disinfectants could have on impression materials, which will ultimately affect the outcome of a gypsum cast. Immersion of alginate impressions in disinfectants has been shown to result in significant imbibition at the early stages of gelation, which leads to a less than ideal surface quality of casts. For hydrophilic polyether and hydrocolloid impression materials, spray disinfection is suggested over
immersion disinfection as complete submersion will cause moisture absorption, leading to unfavorable dimensional change, particularly when immersion is longer than 15 minutes\textsuperscript{62}. Sporicidin and sodium hypochlorite spray disinfectants can be used for alginate impressions for (10 to 30) minutes, but not exceeding 60 minutes, without adverse effects on surface quality of stone casts\textsuperscript{60}. Polyvinyl siloxane can be subjected to immersion disinfection and has shown accurate dimensional stability when submerged for 30 minutes and even up to 16 hours in various disinfectants, whereas polyether and hydrocolloids were distorted\textsuperscript{22, 63}. As true sterilization requires all and total elimination of all microorganisms and spores, this would necessitate intense chemical or heat treatments. Since all dental impression disinfection methods are not of this nature, impressions are considered to be disinfected and not sterilized\textsuperscript{22}.

\subsection*{1.2.1.4 Transportation of the Impression to the Dental Laboratory}

Transportation subjects the impression to significant variations in temperature. The effects of temperature change on the accuracy of elastomeric impression materials are of particular importance since most impressions are transported from a dental office to a dental laboratory. Various climates subject impressions in some areas to temperatures close to freezing while areas of warmer climate can reach temperatures exceeding 40°C.

Dental impressions are sent to a dental laboratory via ground or air courier services, which could subject them to potentially extreme temperature changes. Corso et al.\textsuperscript{25} determined that because elastomeric impression materials have a high coefficient of thermal expansion, even
removal from the oral environment could result in distortion. It was determined that there was significant thermal expansion and contraction that occurred when an impression was heated to 40 °C or cooled to 4 °C. The study showed that when polyvinyl siloxane was heated to 40 °C, there was contraction of the material by 0.0014 mm, while an expansion of 0.0027 mm was noted when cooled for 24 h to 4 °C, compared to baseline measurement of impressions stored at mouth temperature. A waiting period of at least 24 h is recommended to minimize error. Sandrik and Sarna, determined that the intraoral temperature when the mouth is open in a relaxed state was 35 °C ± 1 °C which is the temperature at which the impression is set64. This is congruent with reports that an improvement in accuracy could be achieved if an impression was heated to body temperature before pouring65. Jorgensen discovered this as well in determining that when an elastomeric impression was reheated to body temperature, inaccuracy was reduced by approximately one seventh of the inaccuracy of an impression at room temperature of 22 °C66. Dimensional changes that occur with temperature fluctuations in the impression can influence the outcome of the cast, which, as a representation of the original preparation, will influence the accuracy of the final product. Minimizing the compounding effect of dimensional changes at the impression stage requires proper account of the expected expansion and/or contraction for given temperature conditions. An impression should therefore be either stabilized to within the range of body temperature before pouring, or a calculated accommodation of the amount of change that is expected in an impression needs to be made if it is stored at any temperature other then body temperature.
1.2.2 Pouring Dental Impressions to create Casts

The amount of time that elapses between securing the dental impression and pouring of a gypsum stone significantly affects quality and result. A hydrocolloid impression is dimensionally stable if poured within 30 minutes. However, Tan et al.\textsuperscript{60} argued that this was not the case as the gelation reaction continues extraorally beyond the initial setting phase. The pouring of a hydrocolloid impression within 10 minutes of removal from the mouth showed poor surface quality of stone casts when compared to those kept in 100 \% relative humidity for (30 to 60) minutes\textsuperscript{60}. Schleier et al.\textsuperscript{67} showed that storage in 100 \% relative humidity allowed for less then 78 \(\mu\)m of linear change, which is considered within clinically acceptable limits.

Elastomeric materials are significantly more stable than hydrocolloid materials\textsuperscript{68}. Immediately following the securing of the impression, continued polymerization has been shown to occur, and thus the highest accuracy has been reported with impressions that are poured immediately\textsuperscript{69}. Although different elastomeric materials exhibit varying degrees of stability, they exhibit only clinically insignificant changes should delay between securing an impression and the actual pouring of the dental cast occur. Polyether impressions are very stable in air once setting has completed but should not be left in contact with moisture. The material is hydrophilic and is subject to water absorption that leads to inaccuracies if stored in excess humidity. As inherent humidity variations in different climates may be unavoidable, it is suggested that polyether impressions be poured within one day\textsuperscript{27}. Conversely, Luebke et al. found that polyether displays no clinically relevant dimensional
change when poured at 15 minutes, at 24 hours and even at one full week\textsuperscript{70}. Polyvinyl siloxane impression material has been shown to be the most dimensionally stable for up to 720 hours (30 days), without clinically significant dimensional changes\textsuperscript{27}.

Some of the main factors affecting dimensional stability of impressions are thermal fluctuations, polymerization shrinkage and loss of volatile products\textsuperscript{25}. Loss of volatile products may alter the accuracy and setting of the gypsum products, while polymerization shrinkage and thermal changes affect the size and dimensional stability of the impression.

1.2.2.1 Gypsum Stone

Gypsum stone undergoes thermal changes such as setting expansion, which have been shown to vary depending on type of impression material that it is poured into. Gypsum casts poured into stiffer materials such as the elastomeric impression materials, showed less dimensional inaccuracy than those poured into hydrocolloid impressions. This is due to the higher stiffness of elastomeric materials, which resists dimensional change that can occur during stone setting, thereby increasing accuracy\textsuperscript{71}. Others have investigated hydrocolloids and determined that these materials can often exhibit varying levels of compatibility with different gypsum stones. Morrow et al.\textsuperscript{72} investigated gypsum products and their compatibility with various hydrocolloid materials and determined that different combinations affected surface quality and ability to reproduce a clear 0.025 mm line with accuracy. It was determined that certain combinations produced better surface duplication than others due to moisture content and chemical interactions\textsuperscript{72}. The dimensional accuracy of impression
materials that are hydrophilic are affected by the exothermic setting reaction and by the water content of gypsum products. When using hydrophilic materials, such as polyether and surfactant-incorporated polyvinyl siloxane elastomeric material, this can be a concern, as suggested by a study by Walker et al. who reported that the mean percentage expansion of polyether in the presence of moisture was 0.049 % over 24 hours, while surfactant-incorporated hydrophilic polyvinyl siloxane material showed 0.065 % shrinkage over the same time interval\textsuperscript{73}. Although a significant difference was noted between the two groups, both materials exhibited dimensional accuracy within the acceptable ADA specification standard No.19, i.e. \( \leq 0.5 \% \) change over 24 hours\textsuperscript{73 74}. Additionally, it has been shown that dental gypsum crystal size is between 15 µm and 25 µm, as such limiting the ability of the material to produce detail more accurate than 20 µm, while epoxy resin and polyurethane resin used in the fabrication of digital impression casts, can produce detail as small as 1 to 2 µm\textsuperscript{75}.

1.2.3 Crown Fabrication

The final stage is the fabrication of the fixed single unit dental prosthesis (crown) utilizes the cast produced from the conventional impression. The lost-wax technique of prosthesis fabrication requires a full contour wax duplicate of the proposed crown. Once ideally contoured, the waxed crown is invested in a phosphate bonded investment material. The wax must be removed by high temperature burnout where variation in temperature and variation in time for initial set has shown to affect dimensional accuracy of a finished product. Wax
used should ideally remain dimensionally stable and ridged until eliminated from the investment, however, inlay waxes have been shown to expand as much as 0.7 % when heated by 20 °C, and contract by 0.35 % when cooled from oral temperature to 25 °C. Expansion of dental investment also plays a significant role in the fit of a final prosthesis. Dootz et al. determined that the total expansion of phosphate bonded investment material is (1.6 to 2.1) %, which is used to compensate for the shrinkage of alloy, however, depending on the type of alloy or in the case of pressed all-ceramic materials, the expected investment expansion may not adequately compensate for dimensional changes in the final material. Once burned out, a negative space remains within the investment into which a heated ingot of ceramic material is pressed into leading to the molten matrix taking the shape of the space once occupied by the waxed duplicate. Once completed, the crown may be either layered with feldspathic porcelain if a cut back was done, or finished and glazed for insertion.

1.3 The Digital Method

Computer aided design / computer aided manufacturing (CAD/CAM) is increasingly being utilized by dental laboratories in the manufacturing of dental prostheses. The implementation of this digital methodology has decreased manufacturing costs by reducing technician time and material costs while increasing productivity. The use of intraoral digital scanners to create virtual impressions has allowed clinicians to eliminate the use of impression materials, identify preparation margins, check inter-occlusal space, and design prostheses.
Dr. Francois Duret first envisioned the use of digital technology in dentistry in 1973 in his thesis entitled “Empreinte optique” (“The optical impression”) \(^{80}^{81}\). In 1985, there was the integration of digital imaging, digital design, and digitally-controlled machining realized by the introduction of the Sirona CEREC1 (Chairside Economical Restorations of Esthetic Ceramics) system which allowed clinicians to obtain digital impressions, digitally design restorations, and mill ceramic materials to create inlays within their offices \(^{82}\).

The CEREC1 used a two-dimensional optical impression technique. Today, three-dimensional video capture offers a much greater image quality. The LAVA C.O.S. (3M ESPE, Lexington, USA) system is based on the use of active optical wavefront sampling \(^{83}^{84}\). The digital methodology involves the capture of an image of the prepared tooth, adjacent and opposing teeth, to create a three-dimensional data file. This file is then utilized to design the crown in the virtual realm. The transfer of digital information does not require disinfection, land transportation, or fabrication of a gypsum cast for articulation. Thus, the potential for dimensional inaccuracies could be eliminated, or at least dramatically reduced \(^{17}\). The crown is fabricated by a subtractive method 5-axis milling, utilizing an industrially fabricated block of ceramic/composite material. The combination of state of the art intraoral digital scanning and dental laboratory digital milling should provide “perfectly” fitting restorations.

1.3.1 The Digital Impression

In capturing a negative image, the digital impression secures a digital record for the purpose of designing and creating restorations \(^{84}\). The digital system offers many advantages over the
conventional method. Thus, the digital system eliminates the need for impression trays; digitized files are delivered electronically thereby eliminating the need for physical shipping which would otherwise subject a physical impression to temperature, humidity fluctuations and takes time; infection control requires a disposable single-use camera sleeve; and the digital impression is subsequently ready for design without concern for dimensional changes that are expected in the conventional workflow\textsuperscript{85}.

1.3.1.1 Digital Impression Technology

There are two types of digital manufacturing systems: the in-office systems and the in-lab systems. In-office manufacturing systems, such as the CEREC AC system and the E4D system, are capable to fabricate a final prosthesis immediately in the dental office, while in-lab systems, such as the LAVA COS and iTero CADENT, utilize chair side impressions for off-site design and manufacturing.

All systems use cameras to capture either still images or video for the collection of data points that becomes a digital image of the object. Specific image acquisition technology varies among these different systems.

- The iTero unit uses “parallel confocal imaging” where 100,000 parallel beams of red laser light at 300 different focal depths are spaced 50 µm apart to allow a depth of scan between (13 to 15) mm. This system captures approximately 3.5 million data points per arch scanned\textsuperscript{86} \textsuperscript{87} \textsuperscript{88}. Disposable sleeves and no opaque scanning powder enable direct contact with dentition.
The LAVA COS system is currently the only system on the market that captures images at a video rate. The camera wand uses 192 blue LED lights with 22 lenses. CMOS (complimentary metal oxide semiconductor) captures data from three perspectives simultaneously. Twenty three-dimensional data sets are acquired per second with each data set containing 10,000 points of information. Rendered images accumulate greater than 24 million data points captured per arch. The wand is kept 5 mm to 15 mm from the surface being captured. Titanium oxide powder is required, as blue LED systems require a fine coating for video contrast. A true three-dimensional rendering of the image is available for review, which is an option not available in any other system. For both systems, a buccal capture of occluding teeth is required for digital rendering.

CEREC AC utilizes blue LED scan technology and is only capable of a single orientation of the camera. It cannot accommodate multiple angles and compensates for this using active triangulation technology that uses reflective light to read at different angles. Reflective titanium oxide powder is required. Image capture occurs once there is no movement, thus eliminating the use of foot pedals or buttons.

The E4D system utilizes red light laser and micromirrors that oscillate at 20,000 cycles per second for the capture of a series of images. Scans are obtained from multiple angles to render the digital model. No titanium oxide coating is required. This system has the ability to scan traditional polyvinyl and polyether impressions, creating a reverse optical imprint of a
conventional impression. This is useful if a digital scan intraorally is limited, but digital data is still required. However, there are still no studies to prove the precision of this type of reverse scan as its use is still in its rudimentary stages. Both CEREC AC and the E4D system offer in-office milling units for single unit restorations.

Few studies exist that compare various digital impression systems as the systems are becoming more numerous and are constantly evolving. However, a study by Ender et al, compared two of the more widely used types of digital impression systems. Evaluation of accuracy was determined by comparing precision of full-arch scans superimposed on a reference scan of the master model. By measuring deviation from the scan of the standard model it was determined that digital impressions with the Cerec AC provided accuracy of $(49 \pm 14.2) \mu m$ while the Lava COS system provided scans with greater accuracy at $(40 \pm 14.1) \mu m$. A 2010 study, which evaluated the fit of LAVA Zirconia crowns fabricated by digital impression using the Lava COS digital scan, reported an average marginal gap of $49 \mu m$. In this study, a stereo lithographic model was fabricated as an intermediary step, which introduced an analog step into the digital process, which could have possibly acted as a source of error.

There are comparatively more studies of the CEREC systems then any other digital impression system, as they have been available longer. The results have been variable suggesting that the marginal accuracy prostheses fabricated by the CEREC system could be $49 \mu m$, $59 \mu m$, $94 \mu m$ and even up to $111 \mu m$. 
Evidence regarding the iTero system is significantly less readily available. A limiting factor of this system lies in the fact that it compiles information based on images repositioned three-dimensionally in the z-axis in increments of approximately 50 µm\(^8\). For this reason, restorations fabricated based on scanned images that are generated by the iTero system, are limited physically by this dimension\(^9\).

1.4 Summary

The conventional impression technique for the fabrication of all-ceramic crowns requires numerous steps, which include: tray selection, adhesives and disinfection, an elapsed time before pouring, temperature and humidity variations, and selection of the type of gypsum used, all of which can either individually, or as a whole contribute to the final fit of the prosthesis. The digital workflow that includes digital impression, digital design and digital manufacturing, has been suggested as a means of increasing the fitting accuracy of crowns.

The conventional impression technique for the fabrication of all-ceramic crowns has been successful in providing clinically acceptable prostheses. The introduction of the digitally captured tooth preparation, digital design and manufacturing may increase the fitting accuracy of the crown, reduce the need for uncomfortable and messy impressions, and reduce laboratory technician time. There is a lack evidence regarding the comparative accuracy of the digital technology versus the conventional one. The clinical acceptability of the digital technologies has yet to be fully explored, but the significant advantage of the crown
fabrication process completed entirely by digital means is unquestionable. The aim of this study was to assess and compare the marginal fit afforded by the digital and the conventional method.

1.5  Aim

The aim of this study was to compare the marginal fit of crowns fabricated using conventional and digital methodology.

1.6  Research Question

Is the marginal fit of crowns fabricated by the digital technology method different then that of crowns fabricated by the conventional method?

1.7  Hypothesis

The null hypothesis of this study is that there will be no difference in marginal fit of a single-unit crown manufactured by the use of technological methods, compared with those fabricated by conventional methods.
1.8 Expectations

The digital methodology involves fewer physical intermediary steps compared to the conventional method. As there is less opportunity for a compounding of errors, it is logical to expect that crowns fabricated by the fully digital methodology should be more accurate.
Chapter 2: Materials and Methods

2.1 Master Model and Crown Fabrication

The maxillary right second bicuspid, set in a maxillary typodont (Frasaco, Greenville, N.C., USA), was prepared for a ceramic crown with circumferential 1.0 mm chamfer finish line, a 2 mm functional cusp, and 1.5 mm non-functional cusp reduction, using medium grit diamond burs (Brasseler, Savannah, GA, USA). The maxillary and corresponding mandibular typodont arches were digitized with 3Shape D700 lab scanner (3Shape Inc., New Jersey, N.Y., USA). This scan was utilized with the intention of duplicating the acrylic typodont into a standardized model. Conventional standardization techniques of test dies have been reported in the literature to be made of acrylic, brass, stainless steel or other metallic substances. As a standardized die, the intension is to provide an unchanging model that will serve as starting-point for which all impressions are made from and for which all measurements can be made to. The scanning technology, which uses blue LED light and titanium oxide powder, could not be expected to perform predictably as the reflective ability of acrylic or metallic structures are not expected to represent the true clinical condition. Routinely in current dental clinical practice, zirconia implant abutments are captured using the current scanning technology, which as such, should provide a medium that is both relevant and realistic. A zirconia master model was devised from the full-arch scan of the originally prepared acrylic typodont. Used as a template, the digital file of the typodont maxillary arch was replicated by milling a solid 25mm thickness Wieland translucent yttria-stabilized zirconia block (Wieland Dental, Schwenninger, Germany). The zirconia master
model, milled from a single block of monolithic zirconia was designed to allow the inclusion of a retaining hexagonal-headed screw positioning a removable zirconia die of the prepared bicuspid. The complete arch was stained for gingival and tooth characteristics followed by glazing. The use of zirconia would allow for controlled and standardized evaluation of the crown marginal fit. The removable die remained affixed throughout all conventional and digital impressions to ensure stability, which would limit error from any movement of the die. A removable die allows the ability for direct visualization and measurement of marginal discrepancies in a reproducible and predictable manor.

Using the master model, 15 lithium disilicate crowns were produced using conventional methodology and 15 lithium disilicate crowns were produced using fully digital methodology, as detailed in the following sections.

2.2 Conventional Crown Fabrication

Maxillary custom trays were fabricated using an autopolymerized polymethylmethacrylate (Ivolen®, Ivoclar Vivadent, Liechtenstein), with three locating rests positioned distal to the maxillary right and left second molars and on the left central incisor, thus ensuring that a space of (2.0 to 2.5) mm was provided\textsuperscript{20}. The custom acrylic resin trays were then duplicated by the Ecker’s process\textsuperscript{99,100}. Each tray was stored for a period of 7 days, for the accommodation of polymerization shrinkage before impression making\textsuperscript{57}. 
Polyvinyl siloxane adhesive (DENTSPLY/Caulk, Waltham, MA, USA) was applied to each tray and allowed to dry for a period of 30 minutes\textsuperscript{101}. Polyvinyl siloxane impression material (Aquasil Ultra DENTSPLY/Caulk, Waltham, MA, USA) was loaded, using equivalent volume of base and catalyst delivered by 50/75 Imprint Dispensing dual dispensing holder (DENTSPLY/Caulk, Waltham, MA, USA), into the custom tray. The loaded tray was seated firmly and allowed to set for 5 minutes, according to manufacturer’s recommendation. Fifteen impressions were secured.

A mandibular impression was made with alginate (Kromopan, LASCOD, Florence, Italy) in a number 12 Rim-Lock stock impression tray (DENTSPLY/Caulk, Waltham, MA, USA). Each pair of maxillary PVS and mandibular alginate impressions were removed from the corresponding master models, sprayed with a surface disinfectant (CaviCide\textregistered, METREX, Orange County, CA, USA) and rinsed according to manufacturer’s specification. Each impression was then cast in American Dental Association (ADA) Certified Type IV dental stone (Silky-Rock, WHIP-MIX, Louisville, KY, USA), following manufacturer’s recommendation.

All 15 crowns were fabricated from IPS e.max\textsuperscript{®} Press (Ivoclar Vivadent, Liechtenstein) lithium disilicate glass ceramic ingots by one master technician, by full contour wax up (without cut back) for the lost wax / pressed method. Crowns were subsequently glazed and returned for evaluation.
2.3 Digital Crown Fabrication

Digital impressions were produced using the LAVA C.O.S. scanning unit (3M ESPE, Lexington, USA). Prior to each scan, the zirconia master model was thoroughly cleaned and dried before application of titanium dioxide powder, following the specifications suggested by the manufacturer. A light dusting is recommended by the manufacturer for the creation of reference points, when using blue light-emitting diode lights.

Scan files were exported as .STL files and delivered by electronic mail to 3M for data cleansing. The dental lab input files using Core3dcentres® (Las Vegas, Nevada, USA) digital design workflow software for the digital articulation, digital wax-up, and design of the final crown.

Lithium disilicate glass-ceramic blocks, IPS e.max® CAD (Ivoclar Vivadent, Liechtenstein) were used in a DMG-20 5-axis milling machine (DMG / Mori Seiki, Cypress, CA, USA) to produce 15 crowns. Crowns were subsequently glazed and returned for evaluation.

2.4 Marginal fit measurement

The zirconia die of the prepared tooth was removed from the zirconia master model and the crown placed. The marginal gap of the crown to the prepared tooth was measured at 8 locations: mesial, distal, buccal, palatal and line angles (mesial-buccal – MB, mesial-lingual
– ML, distal-buccal – DB, and distal-lingual – DL), as recommended by Bindl and Mormann\textsuperscript{95}. No cement or other medium was used to affix the crowns onto the die. The measurements were made to determine the vertical component of the marginal gap, according to the definition of marginal fit given by Holmes et al.\textsuperscript{9}. The samples were observed and photographed at 40X magnification using a Canon 5D Mark II 21-megapixel digital camera mounted onto a stereomicroscope (Figure 1, 2, 3) and calibrated using a single focal point calibration slide (Figure 4, 5), as described by Romeo et al.\textsuperscript{18}. Images were measured utilized IMAGE J software (Image J 1.32, U.S. National Institutes of Health, Bethesda, MA, USA), as described previously by others\textsuperscript{102, 103}. All measurements were made perpendicular to the crowns, to evaluate vertical marginal gap (Figure 6, 7).
Figure 1 – Images captured using a digital SLR (Single Lens Reflex) camera attached to a 40X stereomicroscope.
Figure 2 – Image example of marginal gap - Digital group
Figure 3 – Image example of marginal gap – Conventional group
Figure 4 – Photograph of a (0.5) mm increment caliper taken at the same focal length as marginal gap photographs for use in calibration
Figure 5 – Calibration of image measurement software using a photograph of a (0.5) mm increment caliper taken at the same focal length and input into IMAGE J software (Image J 1.32, U.S. National Institutes of Health, Bethesda, MA, USA)
Figure 6 – Photo of marginal gap measurement
Figure 7 – Enlarged photo of marginal gap
2.5 Sample Size Calculation

From recent published data, Syrek et al.\textsuperscript{17} determined in a similar study that the mean marginal gap (MG) of all-ceramic copings was 71 \( \mu m \) for conventionally fabricated crowns and 48 \( \mu m \) for the digitally fabricated ones. The standard deviation was determined to be 26 \( \mu m \) with at a significance level 0.05. The Standardized Difference was determined by the equation:

\[
\frac{\text{Target Difference}}{\text{Standard Deviation}} = \text{Standardized Difference}
\]

In this case, a target difference equaled the difference between the results obtained by Syrek et al.\textsuperscript{17}, and was divided by the standard deviation as follows: 22 \( \mu m \) / 26 \( \mu m \) = 0.85.

Extrapolation for the nomogram for sample size calculation and power from Altman\textsuperscript{104}, was used for the calculation of a sample size for means of equal sized groups. This determined the sample size of 15 per group.

2.6 Statistical analysis

The Statistical Package for Social Sciences (SPSS) (SPSS Inc., Chicago, Ill.) was used to analyze the results obtained in this study. The results of the measurements were analyzed using one-way analysis of variance (ANOVA) followed, if warranted, by Scheffé multiple means modified t-tests (\( \alpha = 0.05 \)). All the results were included in the analysis.
Chapter 3: Results

A total of 240 images (2 groups, 15 crowns per group, 8 sites per crown) were measured. The results of the measurements, along with the results of the statistical analysis, are summarized in Table 1 and graphically presented in Figure 8. The overall mean vertical gap measurement for the digitally produced crowns was \((48 \pm 25) \mu m\), which was significantly lower than the overall mean gap measured for the conventionally produced crowns \((74 \pm 47) \mu m\). For the conventional methodology group, there were no statistically significant differences between the different sites and the largest marginal gap measured was in the distal site. For the digital methodology group, the lingual site had a significantly lower marginal gap than the mesial, distal, and buccal sites. With the exception of the mesial and MB sites, the measurements recorded for the sites of the conventional methodology group were significantly higher than the corresponding measurements of the digital methodology group.

Some of the crown margins showed signs of marginal chipping (Figure 9). These defects occurred in both the conventional as well as the digital groups and did not appear to be more prevalent at any specific site. However, it was noted that some of the crowns showed more chipping then others, but this seemed to be the case for both the conventional as well as the digital groups.
Table 1 - Results of vertical marginal gap measurements (Mean ± SD; in µm) and statistical analysis#

<table>
<thead>
<tr>
<th>Site</th>
<th>Methodology</th>
<th>Conventional</th>
<th>Digital</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mesial</td>
<td></td>
<td>69 ± 32 a</td>
<td>62 ± 25 b</td>
</tr>
<tr>
<td>Distal</td>
<td></td>
<td>100 ± 54 a*</td>
<td>63 ± 24 b</td>
</tr>
<tr>
<td>Buccal</td>
<td></td>
<td>78 ± 50 a*</td>
<td>60 ± 16 b</td>
</tr>
<tr>
<td>Lingual</td>
<td></td>
<td>66 ± 40 a*</td>
<td>27 ± 24 a</td>
</tr>
<tr>
<td>Mesial – Buccal (MB)</td>
<td></td>
<td>53 ± 25 a</td>
<td>51 ± 29 ab</td>
</tr>
<tr>
<td>Mesial – Lingual (ML)</td>
<td></td>
<td>84 ± 63 a*</td>
<td>45 ± 25 ab</td>
</tr>
<tr>
<td>Distal – Buccal (DB)</td>
<td></td>
<td>79 ± 52 a*</td>
<td>41 ± 16 ab</td>
</tr>
<tr>
<td>Distal – Lingual (DL)</td>
<td></td>
<td>59 ± 40 a*</td>
<td>36 ± 10 ab</td>
</tr>
<tr>
<td>Total</td>
<td></td>
<td>74 ± 47 *</td>
<td>48 ± 25</td>
</tr>
</tbody>
</table>

# Small letter superscripts refer to within test group comparisons, identical superscripts identifying not significantly different results. Asterisks (*) identify significant differences (p < 0.05) between the two methodologies for the respective site.
Figure 8 - Box plots of the results of marginal gap measurements
Figure 9 – Marginal chipping defect
Chapter 4: Discussion

Crown marginal fit is critical for success of the restoration; crowns with poor fit (marginal gap) are prone to failure due to micro-leakage, cement dissolution, and dental caries. In this study, the fit of crowns was assessed based on the vertical gap measurement which was selected as the most critical factor of marginal gap (MG) while being the least susceptible to manipulation post-fabrication, as indicated by Holmes et al.\textsuperscript{9}. Horizontal discrepancies, such as crown overhangs, can be adjusted to some degree intra-orally, however, vertical MG can only be closed with luting cement, which is prone to dissolution\textsuperscript{12}. For this reason, the vertical MG has the most clinical relevance and should be regarded as the most critical in crown margin evaluation.

The mean vertical MG of lithium disilicate crowns fabricated by the fully digital methodology was significantly less than that measured in crowns fabricated by the conventional methodology. However, mean MG of both groups fell within clinically acceptable limits of marginal opening of 120 µm\textsuperscript{13}. The mean vertical MG for crowns fabricated by the digital methodology was 48 µm, which was similar to the values reported in other studies\textsuperscript{17 105 106 96}.

Measurements of the sites were not blinded and the measurements of the two groups were taken for all crowns of both groups one site at a time. The standardized zirconia die was placed into an affixed holder in the position of each of the eight locations arbitrarily.
However, at each location, the affixed die holder and the camera with microscope unit was maintained and not moved from each position until all photographs for both groups were obtained. This resulted in photographs that were taken at the same location and measurements taken from the same position on the master die. All measurements were reported, including outlying values. Nonetheless, the trends indicate that although there was variation in the different sites within the groups, as a whole, the conventional group showed consistently a statistically significantly larger marginal gap measurement than the digital group.

A recent study by Ender et al. evaluated accuracy and precision of conventional versus digital impressions, which is defined as the closeness of the digital impression image superimposed on an image of the standardized scan of the original model. The results assessed only the impression and not a final prosthesis which involves numerous additional steps, but suggest that the digital impressions are significantly less accurate than conventional impressions. Though in this study, the digital system evaluated was the CEREC AC system which was determined in another study also by Ender et al. to be significantly less true and precise under the same measurement conditions than the LAVA COS scanning system. Seelbach et al. discussed the difference in capture resolution between the two systems where the manufacturer stated voxel size of the CEREC AC is 19 µm while the LAVA COS system reports a voxel size of less than 10 µm which significantly affects the accuracy of the two systems when compared. The CEREC AC system is limited by its resolution to a degree greater than the LAVA COS system and for that reason, would refute the recent findings by Ender et al. Seelbach et al. concludes that digital impressions
allow for the fabrication of prosthetic restorations with high accuracy and can be considered an alternative to the conventional technique\textsuperscript{98}.

The use of the conventional methodology of crown fabrication has been used for decades with proven long-term results in both longevity and survival. Careful selection of materials and meticulous fabrication procedures are necessary to compensate for dimensional changes. In this study, attempts were made to control and standardize the steps involved. Each impression was accompanied by an identical and standardized written prescription that carefully outlined the specifications of materials and material handling for the fabrication of crowns. The author observed the fabrication of the crowns at the commercial laboratory to ensure that the prescription was followed. However, the impossibility of controlling all the variables, combined with propensity for human error, can result in poor marginal fit and even misfit. The use of digital methodology decreases the chances for error and should produce better fitting crowns at improved cost efficiency.

The results of this \textit{in vitro} study determined that the digital method produced crowns that had acceptable margins, and surpassed the fit of conventional fabricated crowns. The use of the digital technique of impression and crown fabrication has numerous advantages over the technique of securing a conventional impression and crown fabrication such as the elimination of the need for consideration of impression materials, tray type selection, use of adhesives, disinfection, transportation temperature changes and time elapsed before pouring, pouring temperature and gypsum choice, notwithstanding the numerous steps involved in post-impression prosthesis fabrication. Digital impressions offer added value in time savings,
cost savings, space saving, and reproducibility, nevertheless, these benefits are only realized
if accuracy is comparable to or greater then that of the conventional technique. Based on the
results obtained, the digital methodology seems to be a legitimate alternative for the
traditional methodology. However, as the clinical acceptance of a crown requires more than
simply an acceptable vertical MG, further studies are required to assess digital crown
fabrication. Future studies are needed to evaluate the accuracy of the technology in capture,
design and manufacturing of multi-unit prostheses.
Chapter 5: Conclusion

In this study, point measurements of the prosthesis fit were made use of digital mapping software. However, a volumetric measurement would perhaps yield a more complete picture of the marginal gap circumferentially. Future research in this area should consider the use of tomography or other radiographic means to measure volume of the marginal gap, which as such could include more parameters such as horizontal discrepancy.

In this study, the eight pre-determined crown/die interface locations, allowed for standardization and reproducibility, but pre-set, fixed measurement points do not account for marginal discrepancies in the non-measured locations. Whether conventionally or digitally produced, the lithium disilicate crown margins presented damage-induced vertical discrepancies, such as marginal chippings. No single crown was entirely free of discrepancy and for this reason it would be recommended that more measurement points be utilized or that a complete circumferential evaluation of the entire vertical opening be performed.

This study only investigated the vertical marginal gap, however other parameters such as horizontal gap and internal fit could be evaluated. In addition, the study focused on the fabrication of a single crown. As such, the fabrication of splinted or multiple unit prostheses could determine if there is a difference in the performance of the scanning technology or the design and fabrication steps. Thus, future studies should evaluate the use of this technology in more complex restorative procedures.
This study evaluated the relationship of the cavosurface finish line to the crown margin by evaluating marginal gap without focusing on inter- and intra-arch relationships. Occlusal contacts and proximal contact points with adjacent teeth are important factors that contribute to the acceptability of the final prosthesis, however, because these factors do not directly affect the integrity of fit both internally or at the margin, it was not considered in this study. However, future studies should be conducted which would evaluate these parameters, which contribute to the overall clinical acceptability of a final prosthesis.

The development of a new method of creating a standardized master model with the use of stained and glazed monolithic zirconia presented a more realistic approach to representing the clinical situation than the use of metallic standard models. The ability for the scanning technology to capture this material is expected to perform better than the classically utilized metallic substrates that may unpredictably reflect and capture the laser light emitted from the video camera capture units. However, future studies should be done to evaluate the ability of the scanning technology to recognize different material substrates, as well, how accurately these represent the true clinical situation.

In conclusion, given the limitations of this *in vitro* study, crowns created by digital techniques are comparable to, or better than those created by conventional techniques with respect to marginal fit.
References


82. Mörmann WH. The evolution of the CEREC system. The Journal of the American Dental Association 2006;137:7S-13S.


