COMPARISON OF THE ACCURACY OF DIGITAL MODELS OBTAINED FROM SCANS OF IMPRESSIONS VERSUS DIRECT INTRA-ORAL SCANS

RESPICE PROSPICE

UNIVERSITY of the WESTERN CAPE

VG Dubula

MChD (Orthodontics)

2016

COMPARISON OF THE ACCURACY OF DIGITAL MODELS OBTAINED FROM SCANS OF IMPRESSIONS VERSUS DIRECT INTRA-ORAL SCANSFROM SCANS OF IMPRESSIONS VERSUS DIRECT INTRA-ORAL SCANS

BY

VUYANI GOODMAN DUBULA

Thesis submitted in partial fulfillment of the requirements for the degree of Magister Chirurgiae Dentium in Orthodontics in the Faculty of Dentistry of the University of the Western Cape.

Supervisor: PROFESSOR AMP HARRIS – HEAD OF DEPARTMENT, ORTHODONTICS, UNIVERSITY OF THE WESTERN CAPE

Co- Supervisor: DR K JOHANNES – CONSULTANT ORTHODONTIST, UNIVERSITY OF THE WESTERN CAPE

Date of submission: 2016

DECLARATION

I,…………………………………………………………………………………….declare that, **'COMPARISON OF THE ACCURACYOF DIGITAL MODELS OBTAINED FROM SCANS OF IMPRESSIONS VERSUS DIRECT INTRA-ORAL SCANS',** is my own work and that all the sources I have quoted have been indicated and acknowledged by means of references.

SIGNED…………………………………………….. DATE………………………………….

ACKNOWLEDGEMENTS

I wish to acknowledge my sincere gratitude to the following people for the assistance they gave to me in this research project (Listed in no specific order of preference).

1. Professor Harris and Dr. Johannes for their continued support and guidance in the writing of this mini thesis
2. Professor Myburgh and the Community Dentistry department for their guidance on how to go about writing the thesis.
3. Professor Maritz for the help with statistical analysis
4. Dr. Smit and Dr. Ramphoma for their continued support whenever I needed them
5. Ms. November for her support to the department and her willingness to help
6. Dr. Athol Hudson for his continued support and willingness to help
7. Dr. Nkosazana Ngema for her continued guidance and support throughout the programme
8. Ms. Karin Maude and Millners management for availing the intra oral scanner to be used in the research
9. Dr. Yolande Ngqoyi for awarding me the opportunity to study towards Orthodontics
10. To all the consultants in the Department of Orthodontics
11. To the dental assistants of the Department of Orthodontics

DEDICATION

This thesis is dedicated to my children, family, friends and colleagues for the support and encouragements they provided to me during the duration of my studies.

KEYWORDS

Orthodontics

Digital models

Direct intraoral scans

Impression scanner

ABSTRACT

Measurements and a variety of analyses of dental casts are essential for precise diagnosis of an orthodontic case. Study models have long been an essential part of orthodontic diagnosis and treatment planning. Currently virtual computerized models are available to clinicians, supplemented by dedicated software for performing needed measurements (Zilberman *et al*, 2003).

Digital impression methods are now available and intraoral digital scanning techniques make it possible to generate study models directly from the scanning of the dentition.

The aim of this study was to compare measurements taken after scanning the dental impressions to the measurements obtained from using direct intraoral scanning of the dentition.

Alginate impressions of the maxillary and mandibular dentitions were taken on 20 patients and these impressions were scanned using a 3 Shape R 700 TM scanner. Direct intraoral scans of both dentitions were then performed for the same patient. Ortho analyzer TM software was used to measure the mesiodistal widths of individual teeth, and the intercanine and intermolar on digital models of the scanned impressions and digital models obtained from direct intraoral scans of the maxillary and the mandibular dentitions.

The results indicated that there were no statistically significant differences between mesiodistal widths, and intercanine and intermolar distances between the two techniques ($p > 0.05$). Because of the high level of accuracy of the virtual measurements compared to those of the scanned impressions, it can be concluded that direct intraoral scanning of the dentition can be used with confidence in the clinical situation to measure tooth sizes and inter-arch distances for orthodontic purposes.

Orthodontists commonly use models for various areas in the practice, clinical research and medico-legal documentation (Marcel, 2001)

INDEX OF CONTENTS

Page

INDEX OF FIGURES

INDEX OF TABLES

Chapter 1: Introduction

Traditionally study models have been used for many decades in the orthodontic office. Even today most orthodontic practices still make use of study models for records as they form an integral part of patient records that are taken for diagnosis and treatment planning, case presentation and for the evaluation of progress of treatment. Study models are an important communication tool to use when communicating with patients and dental colleagues involved with the case. Study models also provide a useful tool for teaching purposes. They are essential for multidisciplinary management of patients requiring orthodontics, orthognathic surgery and prosthodontics (Bell *et al*, 2003). Orthodontists most commonly use models for various areas in the practice, clinical research and medico-legal documentation (Marcel, 2001)

Study models independently provide an adequate amount of information for treatment planning and account for about 55% of orthodontic treatment planning tool that an orthodontist derives from a consultation. The other 45% of information comes from clinical examination, photographs and radiographs (Rheude *et al*, 2005).

The traditional gypsum-based study models have been found to be heavy and bulky, posing storage and retrieval problems. They are liable to damage and can be difficult and time consuming to measure (Keating *et al*, 2008). Even though the above is true about plaster models, traditional plaster models have and will continue to have a place in the practice of orthodontics, particularly for the fabrication of appliances.

Because the Consumer Protection Act expects medical records to be kept for not less than 11 years, long term storage of study models in a safe environment where they will not be damaged or lost is necessary. Safe storage needs space and can be costly. This has led to a need to look at alternative methods of storing records (Bell *et al*, 2003).

According to the South African Health Professionals Council, in South Africa Health records should be stored for a period of not less than six (6) years as from the date they became dormant. For minors under the age of 18 years health records should be kept until the minor's 21st birthday because legally minors have up to three years after they reach the age of 18 years to bring a claim. (http://www.hpcsa.co.za)

To help solve the storage and other problems associated with traditional plaster models, virtual digital models were introduced in USA in 1999 by OrthoCAD (Stevens *et al*, 2006). Recent advances in technology include the introduction of computer-based dental casts. The introduction of digital models in orthodontic practices has made the storage and retrieval of models an easy task, producing three dimensional models that can be easily manipulated (Torassian *et al*, 2010).

Research on replacing plaster with digital models is now moving at lightning speed in the field of orthodontics. According to recent literature digital models can produce a high quality in accuracy of impressions and at the same time provide the patient with a more comfortable experience (van der Meer *et al*, 2012). The past decade has seen the advent of digital models with acceptable quality, allowing the orthodontic record to become completely digitized.

Currently, most digital models are made from alginate impressions, which are scanned directly, or poured in plaster then scanned. The development of chair-side oral scanners now allows direct digital acquisition of the clinical situation in the mouth (Grünheid *et al*, 2014).

For orthodontics, the most important expectation from a digital model system lies in its diagnostic accuracy and reliability. Although the consensus is that measurements with digital models compare well with those derived from plaster study models, studies that have investigated complex measurements such as space available, irregularity index, and Bolton analysis indicate that mean differences between the plaster and digital models can exceed 1.5 mm (Akyalcin, 2013). These differences may not be clinically acceptable. However, there is also contrary evidence in the literature that supports the validity of digital models for the aforementioned measurements (Akyalcin, 2013).

Aim

The aim of this study was to compare measurements taken from scanning the dental impressions to the measurements obtained from using direct intra- oral scans of the maxillary and mandibular dentitions.

The objectives were:

To quantify the differences between measurements on digital models created from scanned impressions and from intra-oral scans of the same patient, taken on the same day.

To evaluate the accuracy and validity of the use of the virtual models in assessing the intercanine and intermolar distances on impressions obtained from scanned impressions and from direct intraoral scans.

Chapter 2: Literature review

2.1 History of digital models

Taking dental impressions to make study models in orthodontics dates back to the early 1700s. The first impressions were taken using heated sealing wax to obtain a negative representation of the dental arches which was then used to pour a cast in Plaster of Paris. In the mid - 19th century, other materials such as Plaster of Paris, gutta – percha, and thermoplastic modelling compound became popular for taking impressions (Peluso *et al*,2004).

Digital models came into being in the late 1990's. OrthoCAD™ was the first company to introduce digital models, with the aim of giving orthodontists an alternative to the conventional method of plaster models. Orthodontists could have their models digitized and stored as soft copies.

Digital models were later followed by E-Models™ (Geodigm Corp., Chanhassen, MN, USA) in 2001. Both the digital and E-models have been evaluated and found to be useful in the process of treatment planning (Dalstra & Melson, 2009).

Digital models can be produced by several different methods, the most direct system being the use of the intra-oral scanner. Digital models can also be created by a negative surface model technique generated by scanning the inner surface of impressions. The most commonly used system seems to be to pour a plaster model, which is then either non-destructively digitized using stereophotogrammetry, a surface laser scanner or industrial computer tomography, or destructively digitized using the sequential slicing technique (Dalstra & Melson, 2009).

2.2 Advantages and disadvantages of digital models

The replacement of plaster study models with virtual images has several advantages including the ease of access, storage and transfer, and accuracy of the image capture technique has been reported (Keating *et al*, 2008).

Digital storage eliminates inherent problems related to physical storage of models. Up to 17 cubic meters of storage space required for storage of traditional plaster models for one thousand patients, according to Fleming et al, 2011.

With digital model the time needed for the digitization as well as fabrication process is reduced and potential errors, such as expansion, shrinkage, and distortion of impression materials and/or the gypsum master model are eliminated or minimized (Patzelt *et al*, 2013).

The advantages of digital archives most frequently cite include ease of record duplication, low financial and time expense, space saving benefits, portability, speed and ease of access of records, and ease of information sharing (Abelson, 1995).

Disadvantages of digital images include lack of tactile input for the orthodontist and time needed to learn how to use the system. Other disadvantages are associated with the technology itself. There is a scarcity of digital model supplier companies and there are questions surrounding the accuracy of digital models (Alcan *et al*, 2009).

Chair side oral scanners allow direct digital acquisition of the intraoral situation and can eliminate the need for conventional impressions. Currently, most digital models are made from alginate impressions which are either scanned directly or poured in plaster and then scanned. The development of chair side oral scanners now allows direct digital acquisition of the clinical situation in the mouth and this can eliminate the need for conventional impressions (Grünheid *et al*,2014).

With the ultimate aim of ‘paperless’ orthodontic offices and with the already existing possibilities of incorporating digital photographs and radiographs into the electronic patient file, the need for replacement of the plaster casts has become a reality. This has prompted attempts to develop computerized study model databases and analyse (Zilberman *et al*,2003).

A summary of most of the advantages and disadvantages of digital images of study models is presented in Table 1.

Advantages	**Disadvantages**
No more model breakage	Lack of tactile input
No more storage problems	Not easy learn and master fast
Models can be retrieved instantly	Questions surrounding the accuracy of digital models not fully answered
Ease of communication with patients and colleagues	Scarcity of digital model supplier companies
Accurate	
Convenient presentation tool	
Easy to transfer data	
Financial saving	
Ease of portability	

Table 1; Advantages and Disadvantages of Digital images (Fleming *et al*, 2011 Torassian, 2010, Quimby *et al*, 2004)

2.3 Accuracy and Reliability of digital models

Bell *et al* (2003) and Mullen *et al* (2007) showed that measuring the mesiodistal tooth dimensions on digital models could be done faster than those done using digital calipers on stone casts.

Bell *et al* (2003) evaluated the accuracy of a three-dimensional virtual model for archiving purposes. He found that the average difference between measurements on dental casts and 3D images was 0.27mm. This difference was within the range of operator error and was not statistically significant.

Zilberman *et al* (2003) found that measurements with digital calipers on plaster models produced the most accurate and reproducible results and that, although OrthoCAD measurement tool showed high accuracy and reproducibility, the measurements were inferior to measurements done on the plaster models. These results however, were found to be clinically acceptable. They concluded that it is likely that, taking into consideration its present advantages and future possibilities, 3D virtual model procedures will become the day-to-day standard for use in orthodontic orthodontic practice.

Similar studies to those of Zilberman *et al* (2003) by Keating *et al* (2008) and Santoro *et al* (2003) found statistically significant differences between measurements on plaster models and digital models, with the digital measurements being smaller than the manual measurements. However the magnitude of these differences was so small that they were not clinically relevant.

Quimby *et al* (2004) evaluated the accuracy (validity), reproducibility (reliability), efficacy, and effectiveness of measurements made on computer based models. A plastic model i.e. the dentoform, served as a gold standard to evaluate the systemic errors associated with producing either plaster or computer based models. They found that only measurements of maxillary and mandibular space available made on computer- based models differed from the measurements made on the dentoform gold standard. There was significantly greater variance for measurements made from computer-based models. Reproducibility was high for measurements made on both computer-based and plaster models. They concluded that measurements made from computer- based models appear to be generally as accurate and reliable as measurements made from plaster models.

Mullen *et al* (2007) studied the accuracy and speed of measuring the overall arch length and Bolton ratio, and the time to perform a Bolton analysis for each patient. They found some statistically significant differences, but none that were clinically significant. Using the E-model software they found that measuring the patients' dentition and calculating the Bolton ratio was just as accurate as and could be faster than using digital calipers with plaster models. Mandibular arch length measurements between the plaster models and the E-models were significantly different between the two methods of measurements. The plaster models had an average of 1.5 +/ - 1.36mm greater arch length than the E-models. Maxillary arch length measurements between the plaster models and the E-models were significantly different. The plaster models had an average of 1.47 +/- mm greater arch length than E-model.

Mullen *et al* (2007) stated that there are factors that may explain measurement differences between E-models and digital calipers. One is that with the E-models software it is difficult to find the greatest mesio-distal width of the teeth. To precisely calculate the points chosen as the greatest diameter, the model can be rotated on the screen, but there is still difficulty doing this. Although E-models have a high resolution, it is often difficult to select the correct contact point between any two teeth.

Dalstra and Melsen (2009) evaluated the accuracy and reproducibility of alginate and digital models. They found that measurements carried out in relation to the Bolton analysis were not significantly different from those carried out on the models poured immediately after the impression was taken, the 'gold standard', whether this was the original plaster model from which the virtual model was developed or a dentoform model. Furthermore, it was evident that although linear measurements with a digital caliper on a physical model have been reported to be more accurate than their counterparts, the accuracy of the digital measurements was considered to be clinically acceptable.

Mullen et al 2007 reported that there are factors that may be attributed to explain measurement differences between E-models and digital calipers. One was that with the E-models software it is difficult to find the greatest mesio-distal width of the teeth. To precisely calculate the points chosen as the greatest diameter, the model can be rotated on the screen, but there is still difficulty doing this. Although E-models have a high resolution, it is difficult to select the correct contact point between any two teeth.

Dalstra and Melsen (2009) investigated the difference in accuracy of digital models when the pouring of plaster was not done immediately. They found that a delay of 3 to 5 days in pouring a plaster model from an alginate impression did not affect the accuracy of the model, as no statistically significant differences were observed between the measurements performed on the plaster models obtained from the other sets poured immediately. They found out that some of the longer measurements (maxillary arch width and length) appeared to be slightly shorter in the set which had been in the mail, possibly due to some shrinkage of the alginate. These changes were not statistically significant.

Horton *et al* (2010) did a study to determine the best technique for measuring mesio-distal tooth widths on digital models. In this study they measured from molar to molar in both jaws on 32 plaster models and on the corresponding digital models. The digital models were measured using five different techniques: the occlusal aspect, occlusal aspect zooming in on each individual tooth, facial aspect rotating as needed, facial aspect from three standard positions (R buccal, facial, and L buccal), and qualitatively rotating the model in any position deemed necessary. According to their findings, the occlusal measurement technique for digital models provided the best combination of accuracy, repeatability, and speed of measurement.

Lee *et al* (2013) evaluated the difficulty level and operator perception of digital and conventional implant impressions taken by dental students and by experienced clinicians. The difficulty level of digital impressions was similar between the student and clinician group. Conventional impressions were more difficult for the student group to perform compared to the clinician group. The student group favored the digital impression technique, whereas the clinician group did not show preference over either impression technique. The clinician group felt more proficient with using conventional impression, whereas the student group preferred the digital impression technique.

Naidu and Freer, (2013) evaluated the validity, reliability, and reproducibility of the IOC intraoral scanner assessing tooth widths and Bolton ratios. Tooth widths were measured with digital calipers from physical modes and with OrthoCad software from digital models. These authors concluded that the IOC/OrthoCad system has clinically acceptable accuracy in measuring tooth widths and calculating Bolton ratios, and that the reliability and reproducibility of the digital method was excellent. They reported that the IOC/OrthoCad system is a clinically acceptable alternative to calipers and study models for making tooth-width measurements and calculating Bolton ratios.

Sebastein *et al* (2013) evaluated the accuracy of four intra oral scanners against a reference industrial scanner. They found that, except for one intraoral scanner system, all tested systems showed a comparable level of accuracy for full-arch scans of prepared teeth.

Grünheid *et al* (2014) conducted a study to evaluate the clinical use of a direct chair side oral scanner, assessing accuracy, time and patient acceptance. In the study fifteen patients had digital models made from both intra oral scans (Lava COS, 3MESPE, St Paul, Minn) and alginate impressions. Each procedure was timed, and patient preference was assessed in this survey. In addition, digital models were made from 5 plaster model pairs using the intraoral scanner and an orthodontic model scanner. Model pairs were digitally superimposed and differences between the models were quantified. They found that the digital models made using the chair side oral scanner and either impressions or the orthodontic model did not differ significantly. The chair time required to take impressions was significantly shorter than the time required for intraoral scan. It was interesting to note that 73.3% of the patients preferred impressions because they were easier or faster, whereas 26.7% preferred the scan because it was more comfortable.

Yuzbasioglu *et al* (2014) evaluated the patients' perception, treatment comfort, effectiveness and clinical outcomes of digital and conventional techniques. The following findings were obtained: The digital impression technique was more efficient than the conventional impression technique. The overall treatment time for the conventional impression technique was longer than for the digital impression technique. When compared with the conventional impression technique, the digital impression technique was accepted as the preferred and effective technique, according to subjects' perception. The treatment comfort of the digital impression technique was higher than that of the conventional impression technique when it was performed by an experienced operator.

2.4 Provision of 3D imaging to orthodontists

Given the remarkable development of computer science, and increased interest in 3D images among orthodontists, a number of companies currently offer services to transform plaster casts into three-dimensional digital models. This method has several advantages, including reduced physical space used for storage of plaster models, averting the risk of breakage, easy data storage, simultaneous exchange of information with colleagues, and greater efficiency and productivity in dental practice. However, despite all these advantages, the exclusive use of digital models in daily practice is not yet routine as it also has some disadvantages in its application. Some disadvantages are data loss in case of degradation of electronic storage, dependence on third parties, time-consuming software support, needs to learn the operating system, and high cost of equipment (Correia, 2014).

2.5 Description of the intraoral scanning process

A scanner is described as a device which acquires images of the dentition which are converted to three-dimensional frames of data. The data from the several frames are registered to each other to provide a complete three-dimensional virtual model of the dentition. Individual tooth objects are obtained from the virtual model. A computer-interactive software program provides for treatment planning, diagnosis and appliance from the virtual tooth models (Rubbert *et al*, 2003). (Fig 1)

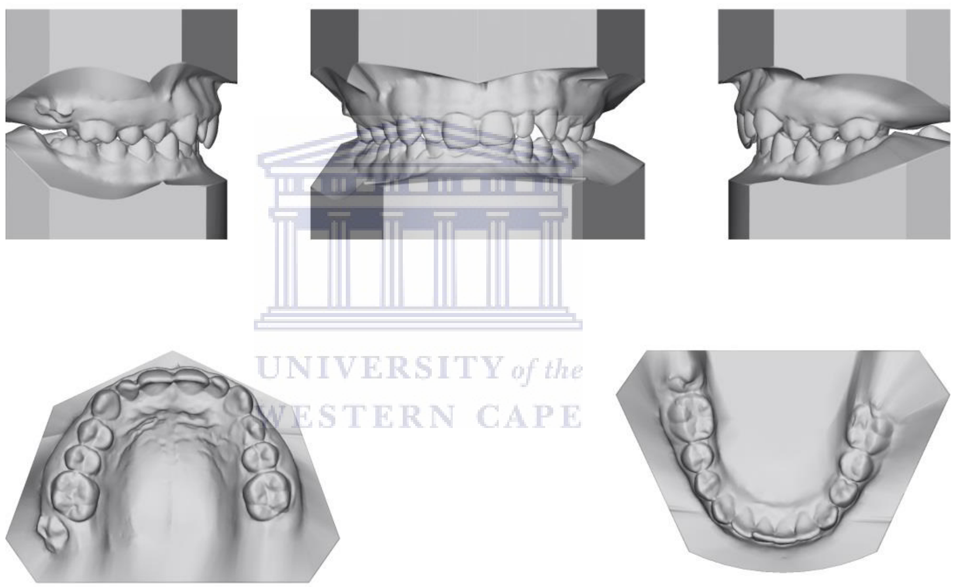


Fig. 1: An example of 3D images produced by an intraoral scanner (3Shape Ortho Analyser ™)

It is generally accepted that the conventional method of impression taking using trays and impression material cannot eliminate the error of expansion, shrinkage, irregular thickness or detachment of impression material and distortion of the impression. Additional problems could be dimensional changes caused by the expansion of the dental stone (Rhee *et al*, 2015). Current literature reports that a mean deviation of about 10 µm occurs when taking impressions and fabricating a cast, considered as negligible to make an accurate observation.

Intraoral scanning can provide a possibility to overcome the errors associated with using study models. But intraoral scanning too has technology related errors, including lack of fixed references, because the first image made by the scanner is used as the reference. All subsequent images are "stitched" to the previous one by a best fit algorithm that represents the best possible overlap of images. Each overlap has an inherent error; as a consequence, the final error should be gradually increased with every stitching process. Hence, it can be anticipated that the longer the scanning field, and the more stitching processes completed, the larger the errors would be presented. Maximum differences, up to 170 µm have been found in the posterior area during complete arch scanning (Rhee,2015).

Nowadays, digitalization of study models is an advancing development in orthodontics. Replacement of plaster models with these new virtual counterparts can benefit orthodontics in a number of ways including improved efficiency, instant retrieval of digital information of patient records, and immediate information exchange for consultation and referral; cost saving with no need for storage of plaster models and no risk of damage or loss of plaster models; time saving with ease of digital measurement; and improved production with the possibility to perform digital setup (Wiranto *et al*,2013).

2.6 Classification of Scanners

Intraoral cameras are optical scanners and they can be separated into two types; the single image cameras and the video cameras

2.6.1 Single image cameras

Single image cameras record individual images of the dentition. The iTero (Align Technology), PlanScan (Plan- meca), CS 3500 (Carestream Dental LLC), and Trios (3 shape) cameras are single image cameras which record about three teeth in a single image. To record larger areas of the dentition, a series of overlapping individual images are recorded such that the software program can assemble these into a larger three-dimensional virtual model. The camera is positioned in different angles to ensure accurate recording of data below the height of contour that would be hidden from the camera if only an occlusal view was obtained. Those areas not visualized by the camera in the overlapping images would then be extrapolated by the software program to fill in the missing data areas in the virtual mode.

2.6.2 Video cameras

Video cameras which are used by the True Definition scanner (newest version of the Lava Chairside Oral Scanner, COS), Apollo DI (Sirona) and OmniCam (Sirona) systems (Alghazzawi, 2016).

Chapter 3: Methods and Materials

3.1 Study design

This was a comparative study which quantified the difference in accuracy of digital models obtained from scans of impressions versus direct intra oral scans. Two study models of same patient were taken in two different ways, firstly by taking an alginate impression and scanning the impression, then secondly, a set of virtual study models was obtained by scanning the mouth directly using an intra-oral scan. A flow diagram in figure 6 shows a step by step outline of the methodology used in this research project.

3.2 Study population

The sample of this study consisted of 20 patients who were randomly selected from patients who presented with a variety of typical malocclusions, who had accepted orthodontic treatment at the offices of an orthodontist in private practice. The sample was considered acceptable because in each patient both upper and lower jaws were measured and individual teeth were measured in each jaw.

3.3 Subject selection

Inclusion criteria : Patients selected for the study

- did not have orthodontic appliances at the time,
- had permanent dentition erupted from first molar to first molar,
- had not more than 2 teeth per arch missing from first molar to first molar
- had stable centric occlusion with at least 3 occlusal contacts

Exclusion criteria : Patients were excluded from the study if they

- Were in the mixed dentition phase
- Had multiple missing teeth

3.4 Orthodontic Impressions

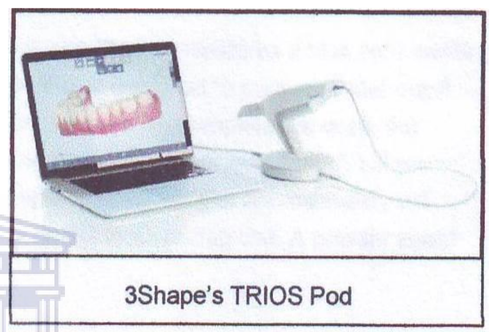
Alginate impressions of both the maxilla and the mandible were taken using Aroma fine Plus fast set (GC)^{R}. The alginate was used according to manufacturer’s instructions. The impressions were scanned immediately using 3 Shape R 700 ™ scanners (Fig.2). The scanning process took place by inserting the impression in the scanner and switching on the scanning process. After the impression scanning was complete, images were captured and produced in 3D. 3Shape Ortho Analyzer ™ premium scanning software from 3Shape was used for an automatic manipulation of fully surfaced 3D digital models from the acquired point cloud data to produce images in Fig. 1.

Figure:2 Impression scanner 3M R700 ™

3.5 Intraoral scanning

Immediately after the impressions were taken, both arches were scanned using the 3Shape's Trios intra-oral scanner. This was done by inserting the camera in the mouth and scanning each quadrant of the jaw, then scanning the bite for occlusion. A 3D picture was then produced on the monitor (Fig. 3).

(a)



(b)

Figure: 3 3D picture of the mandibular dentition using direct intra-oral scan, the 3Shape's TRIOS Pod. Fig 3(a) shows the process of scanning of the dentition, fig 3(b) shows the final product after the scanning process has been completed

3.6 Measurements

A single examiner measured tooth and interdental widths on both the maxillary and mandibular casts (teeth 16-26 and 36-46). Intercanine and intermolar distances were also measured for both maxillary and mandibular dentition of all 20 patients. The results were statistically evaluated. The data capture sheet is shown in addendum A.

3.6.1 Mesiodistal tooth widths

Measurements were done with OrthoAnalyser ™ software[R]. Mesiodistal widths of each tooth were measured at their greatest width according to the methods used by Mullen *et al* (2007), measuring the largest mesiodistal measure of incisors, canines, premolars and molars on both sides in this sequence using digital calipers (Fig. 4) .

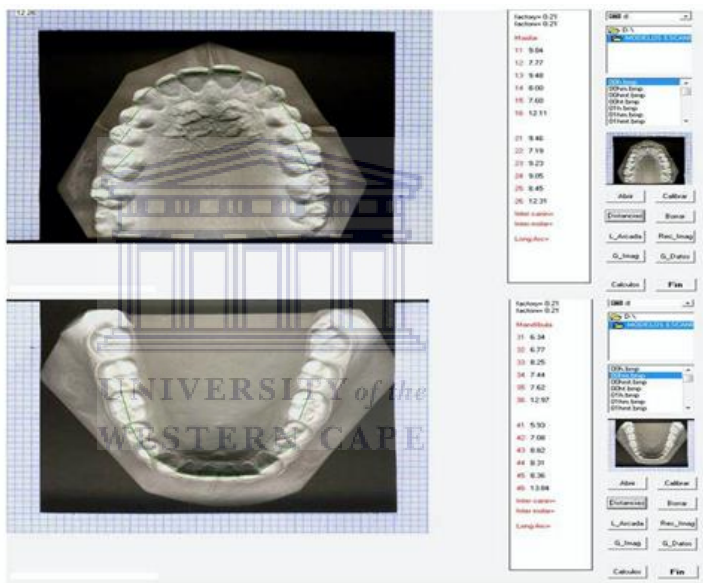


Figure: 4 Digital measurement of mesiodistal widths indicated by the lines on individual teeth

3.6.2. Intercanine and intermolar widths

The intercanine and intermolar widths of both the maxillary and mandibular dentitions were measured for each tooth. Intermolar widths were measured as the distance between the mesiobuccal cusp tips of the permanent first molars. Intercanine widths were measured as the distance between the crown tips of the permanent canines according to methods used by Quimby *et al* (2004) (Fig. 5). Measurements were done with OrthoAnalyser TM^{R} software.

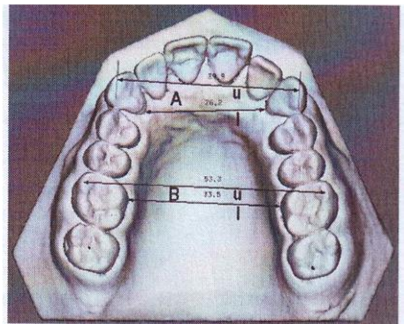


Figure:5 The measurements of (A) indicating the intercanine and (B) indicating the intermolar distances on a mandibular model.

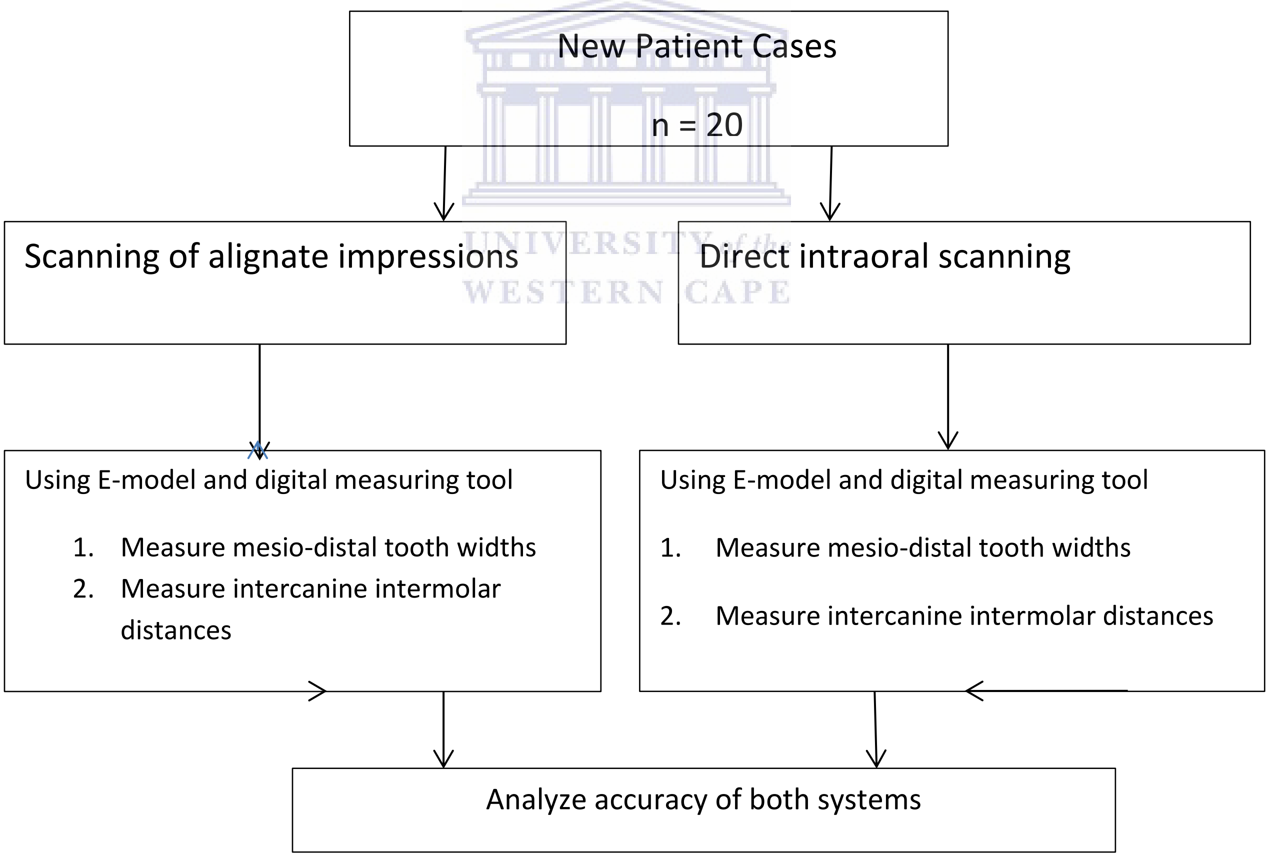


Fig. 6 Flow chart of methodology used in this research project.

3.7 Statistical Analysis

The stated aim of this study was to assess the relative accuracy of two methods of measuring the dentition. There are two important elements in the notion of accuracy; one is bias, the other random error. Bias refers to one method giving consistently greater or smaller readings than the other. Random errors are those uncontrollable deviations from true values that can result from variation in settings of instruments, difficulties in reading scales, etc.

Basic descriptive statistics for the measurements of tooth dimensions of individual teeth (16-26, 36-46) and the intercanine and intermolar distances for maxilla and mandible are presented. t-tests of significance of difference of the means were calculated to test for differences between measurements recorded for each of the two techniques. To test for accuracy of the two techniques, statistical analyses based on bias and random error were used.

The statistical significance of bias in this study was tested using the paired t-test approach. Error variances were estimated by making use of paired differences and as well as overall between patient variances of measurements on particular teeth. Paired values of error variance estimates were obtained and their relative sizes compared by sign and paired t-test methods.

3.8 Ethics Statement

This research proposal was presented to the Research Committee of the Faculty of Dentistry of the University of Western Cape and to the Senate Research Committee for ethics approval and for registration as a research project (Project no SHD 2015/12, approved on 15/12/2015).

All patients who participated were informed about the research project and asked for consent before records were taken. All participants in this study were patients who had accepted to have orthodontic treatment done in the orthodontics practice of Dr. K Johannes (Addendum B).

No additional impressions or other records were done over and above those usually taken before starting orthodontic treatment and no extra fees were charged to the patient.

Participating patients were identifiable from the records that were used as each form had a patient's details on it.

Chapter 4: Results

For the purpose of this study the different scanning methods have been abbreviated as follows: OS= direct intra-oral scan and MS= impression scan

4.1 Mesio-distal measurements

The mean and standard deviation values for the mesio-distal measurements of the teeth using scans of impressions and direct intra-oral scans are presented in Table 2 .

Tooth	Mean(M)	S.D.(M)	Mean(O)	S.D.(O)
11	7.9825	0.9097	8.0400	0.9245
12	6.5385	1.0885	6.5570	1.0996
13	7.4535	0.7348	7.4235	0.7400
14	6.7175	0.5750	6.7125	0.5802
15	6.6847	0.5998	6.7653	0.6110
16	10.1940	1.0716	10.2660	1.1348
21	7.7840	0.9457	7.9015	0.9543
22	6.4950	1.0778	6.5505	1.1017
23	7.0235	0.4904	7.0895	0.5415
24	6.5538	0.6405	6.5600	0.6211
25	6.4695	0.5418	6.5321	0.5658
26	9.9470	0.8359	9.9290	0.8785
31	4.8900	0.7117	4.9455	0.6933
32	5.5385	0.7918	5.5540	0.7814
33	6.2620	0.6543	6.2630	0.6483
34	7.2468	0.6515	7.2574	0.6506
35	7.4580	0.5336	7.4530	0.5366
36	10.7735	0.5292	10.7470	0.5616
41	4.8830	0.5779	4.8975	0.5816
42	5.6405	0.8083	5.6705	0.8002
43	6.3485	0.7897	6.3310	0.7935
44	7.0925	0.9570	7.0485	0.9608
45	6.9780	0.6833	6.9815	0.6841
46	10.5825	0.7895	10.6130	0.7877

Table 2. Means and standard deviations for the mesio-distal measurements of the teeth using scans of impressions (MS) and direct intra-oral scans (OS).

t-tests of significance of difference of means were performed and the results are presented in table 3. As an example consider MS11 vs OS11: the mean of the pairwise differences, MS11-OS11, is -0.0575, and it is not significantly different from zero: t = -1.5351, df = 19, p-value = 0.1413. The mean of MS11-OS11, -0.0575 and p-value, 0.1413, rounded to 3 decimals, are reproduced in the first row of the column headed M1-O1 of Table 3. The rest of this table summarizes the results of similar t-tests.

	M1-O1		M2-O2		M3-O3		M4-O4	
	Mean	P-value	Mean	P-value	Mean	P-value	Mean	P-value
1	-0.058	0.141	-0.118	0.172	-0.056	0.190	-0.015	0.193
2	-0.019	0.536	-0.056	0.261	-0.016	0.330	-0.030	0.410
3	0.030	0.355	-0.066	0.084	-0.001	0.945	0.018	0.330
4	0.005	0.841	-0.006	0.728	-0.011	0.163	0.044	0.213
5	-0.081	0.193	-0.063	0.270	0.005	0.330	-0.004	0.732
6	-0.072	0.193	0.018	0.671	0.027	0.335	-0.031	0.229

Table 3. Results of the means of the pairwise differences of mesiodistal tooth measurements on the impression scanner (MS) and intra-oral scanner (OS)

To detect if any bias was present, plots of OS and MS were done. The plots of MS vs OS per quadrant are presented in figure 7(a-d), representing data for each of the four quadrants of the dentition. The straight line in these plots has an intercept of 0 and slope of 1; this is the "no bias" line. In all four quadrants there is now evidence of any systematic trend away from the relevant no bias line. The points all cluster around these lines.

The visual impressions of the four graphs in figure 7(a-d) below therefore support the results of the paired t-tests of significance of difference of means in table 3. There were no statistically significant differences between any of the OS and matching MS values (p>0.05). It is interesting to note, however, that 17 of the 24 mean differences were negative, indicating that there is a real tendency for OS values to be greater than the matching MS values. The paired t-test using all the MS and OS differences reveal that the overall bias is relatively small, and therefore probably not clinically significant.

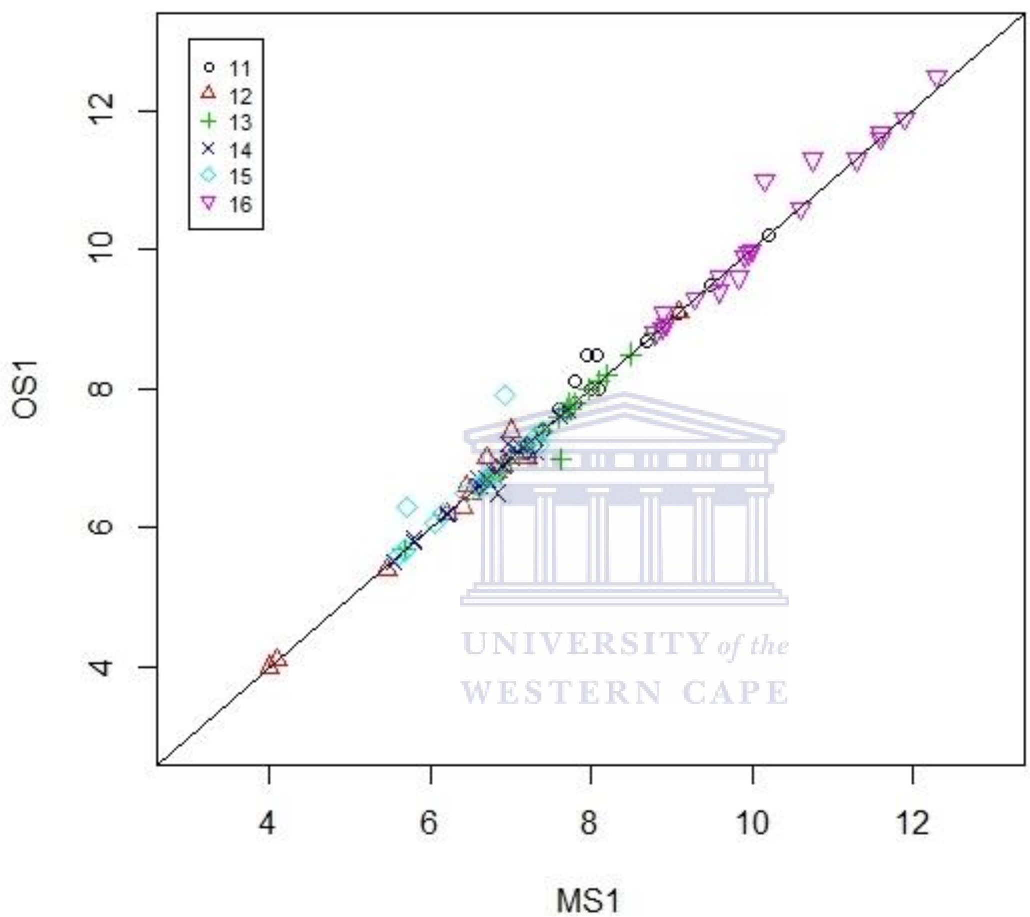


Fig. 7 (a) OS vs MS per 1st quadrant displaying bias

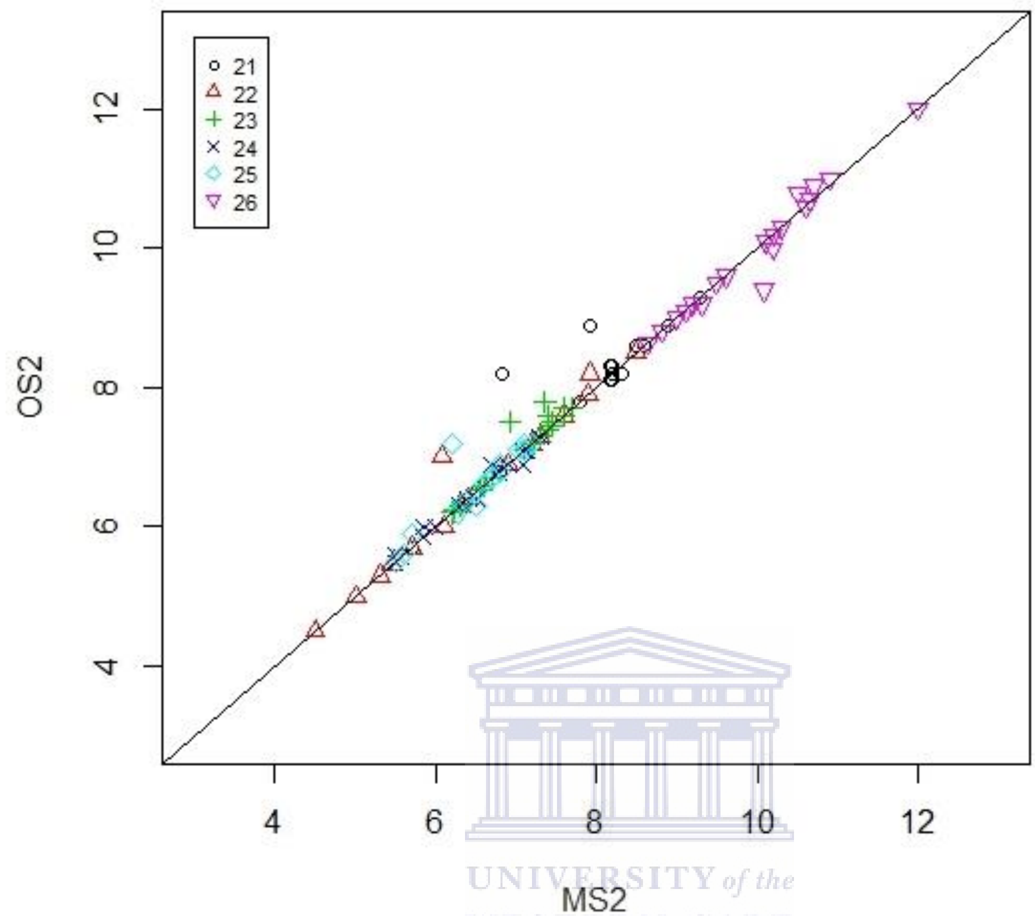


Fig. 7(b) OS vs MS 2nd quadrant displaying bias

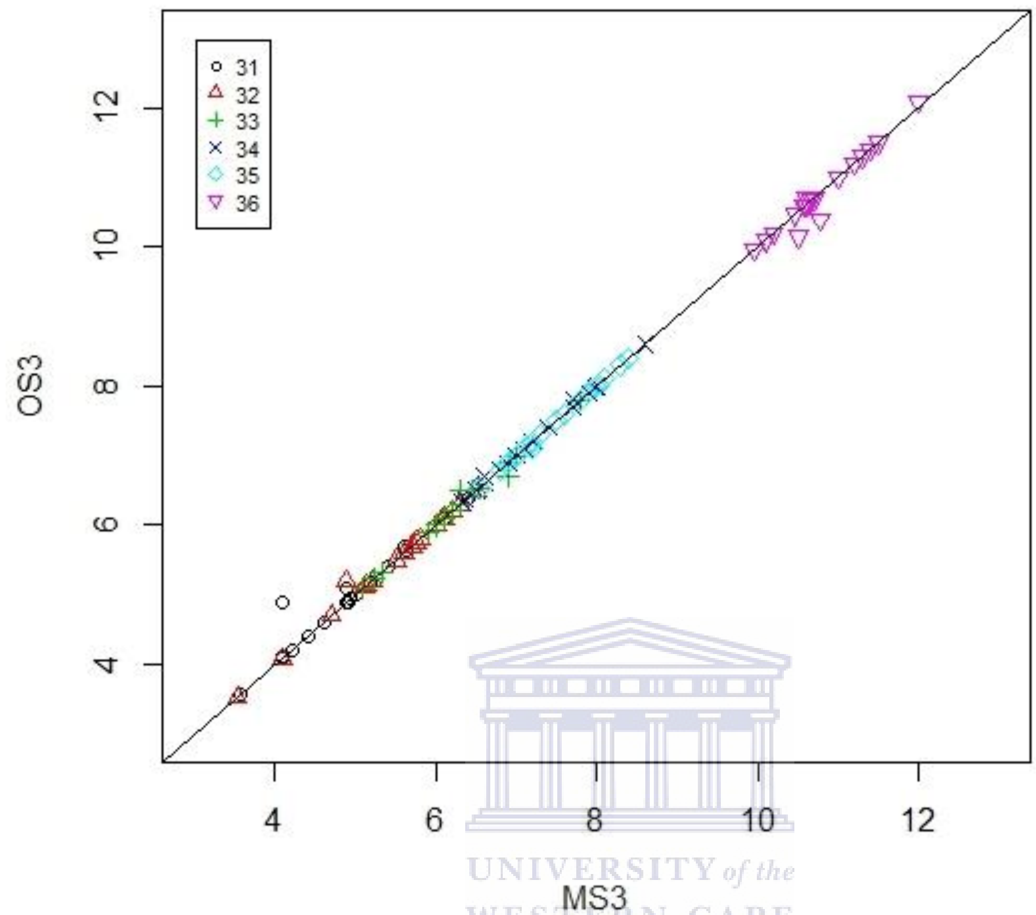


Fig 7(c) OS vs MS 3rd quadrant displaying bias

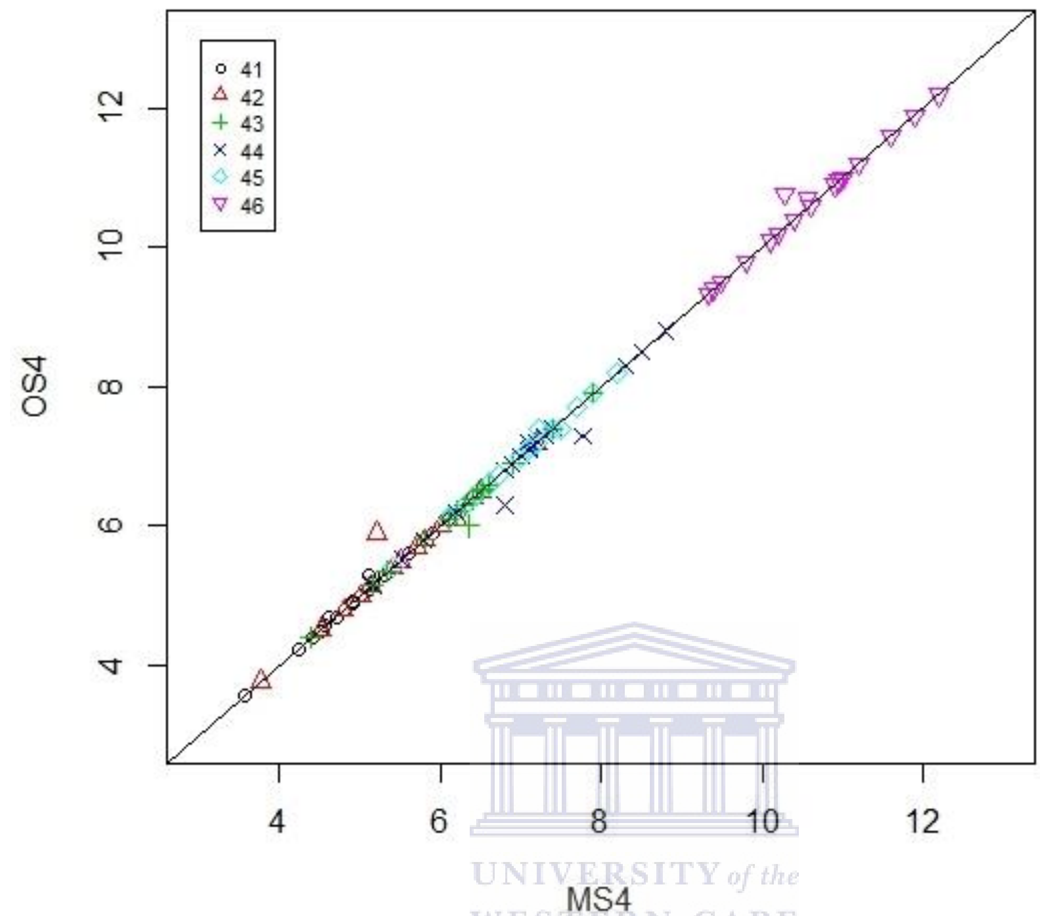


Fig. 7(d) OS vs MS 4th quadrant displaying bias

4.2 Intercanine and intermolar distances

The means and results of pairwise t-tests of the significance of difference of the means for the intercanine and intermolar distance of the two methods MO and OS are indicated in Table 4.

Only one of the mean differences is statistically significant (MSACDmn vs OSICDmn; p=0.04545). There is no obvious pattern in the results and the differences are small. Three of the four mean differences are negative and one is positive.

		Mean	Mean	Mean difference	p-value
Maxilla	MSICD VS OSICD	MSICD=34.5720	OSICD=35.8725	-1.3005	0.3489
	MSIMD VS OSIMD	MSIMD=45.1705	OSIMD=45.1115	0.0590	0.3148
mandible	MSICD VS OSICD	MSICD=27.1910	OSICD=27.4215	-0.2305	0.04545
	MSIMD VS OSIMD	MSIMD=39.7880	OSIMD=39.8220	-0.0340	0.8536

Table 4 Means and pairwise t-tests for the intercanine and intermolar distances

Key:

MSICD- impression scanner, intercanine distance

OSICD- oral scanner, intercanine distance

MSIMD-impression scanner, intermolar distance

OSIMD- oral scanner intermolar distance

Chapter 5: Discussion

Computer technology is expanding to include more areas in various scientific fields, and orthodontics is no exception. Orthodontists use computers for record keeping, practice management, patient education and many other tasks. The introduction of digital models offers the orthodontist an alternative to plaster study models routinely used.

The purpose of this study was to compare accuracy of digital models obtained from scanning the impression with those models obtained from direct intraoral scanning, measuring tooth dimensions and the intercanine and intermolar distances for diagnostic and treatment planning purposes.

Although there are several studies comparing the accuracy of measurements on impressions scanning with plaster, there are few studies comparing measurements on scanned impressions with those on direct intraoral scans.

In orthodontics, study models provide information that is useful for diagnostic purposes in order to make a treatment planning decisions, to assess treatment outcomes and in making removing appliances. These require accurate impressions that will represent the soft and hard tissues. With digital records becoming available to be used in the dental field, they should be able to hold up to the clinical standards for them to be regarded as reliable.

In all studies cited in the literature review of this study where accuracy, validity, reliability and reproducibility of linear dental measurements on digital models obtained from scans of alginate impressions and plaster model scanning were tested, results showed that digital models are valid, reliable, and reproducible methods to obtain dental measurements for diagnostic purposes (Naidu *et al*, 2013, Santoro *et al*,2003, Rheude *et al*,2005). The literature suggests that little statistical and/or clinical differences exist between the two methods with respect to utilizing the models for treatment planning.

This study took the above subject further by comparing digital models obtained from scanning alginate impressions with digital models obtained from direct intra oral scans. This study showed that although there is some bias between the two methods, it is so small it can be considered negligible. Because a strong correlation exists between measurements on the impression scan and the direct intra oral scan, the bias therefore has no statistically significant difference and it should not restrict clinical use of intra oral scan.

In table 3 none of the P-value is smaller than 0.05, 17 out of the 24 mean differences are negative, and under a hypothesis of the no bias line, the probability of at least 17 negatives is small, namely 0.032. This suggests that there is a real tendency of the oral scan values to be greater than the matching impression scan values. Even though the bias is noted with the P-values, compared to overall bias it is very small and can be considered negligible and clinically insignificant.

(Rhee, 2015) explains that some of the possible reasons for the differences in comparing scanned impressions with the conventional method are that intraoral scanning too has technology related errors. The lack of fixed references is a problem, because, the technology uses the first image made by the scanner as its reference. All subsequent images are "stitched" to the previous one by a best fit algorithm that represents the best possible overlap of images. Each overlap has an inherent error; as a consequence, the final error should be gradually increased with every stitching process. Hence, it can be anticipated that the longer the scanning field, and the more stitching processes completed, the larger the errors would be presented.

Quimby et al. (2004) also hypothesized that the larger values for measurements made on the computer-based models may have several possible sources: (1) the increased time that elapsed before the irreversible hydrocolloid impressions were poured in plaster, (2) the process of producing the plaster casts by the manufacturer, (3) the process of scanning and recording data points from the plaster model, (4) the display and measurement algorithms of the manufacturer's proprietary software, and (5) the examiners' lack of familiarity with the computer-based measurement of computer-based models.

The computer-based model software is routinely being updated to provide more features and to improve the accuracy of the measurements. More recent versions of the software have new features that theoretically could improve accuracy. It is the opinion of the authors quoted in this study that the accuracy and reliability of the computer-based models is acceptable, and it will be the relative convenience and total cost of the computer-based model that determines its acceptance. Models can be viewed chair-side in seconds, and thousands can be stored in the space of a moderately sized hard cover novel. The model can be shared over a network within an office or offices of a practice or with another party without it ever leaving the practice or without the danger of the models being damaged by handling. A copy of the model can be secured at a second site for minimal or no cost. All these benefits are based on networked chair-side computers with their associated benefits and costs. However, computer failure, software failure, or manufacturer insolvency can possibly mean that the models may become inaccessible for a time or forever (Quimby *et al*. 2004)

Based on the results of this study, it is reasonable to conclude that 3-dimensional digital models acquired by intra oral scanning of the dentition are accurate and can be considered as a reliable method to be used confidently in the process of diagnosis and treatment planning.

For orthodontics, the most important expectation from a digital model system lies in its diagnostic accuracy and reliability, and this expectation has been met by the results of this research

Chapter 6: Conclusion

The results of this study show that measurements obtained from scanning an impression produced interchangeable results with measurements obtained from direct intraoral scanning, making the intraoral scanning method sufficient for use in orthodontic diagnosis and treatment planning.

With most health departments and orthodontic practices attempting to digitize health records, it stands to reason that dental models must also cross this divide and become digital. Eliminating the taking of impressions altogether in orthodontic practice is ultimately where technology is leading us.

Based on the results of this study, the paired t-test of the different methods revealed that the overall bias was relatively small and probably not clinically significant therefore should not restrict clinical use of intra oral scanning.

References

Abelson, M.N., 1995. Computerized archiving of records. *American journal of orthodontics and dentofacial orthopedics*: Official publication of the American Association of Orthodontists, its constituent societies, and the *American Board of Orthodontics*, 108(5), p.562.

Akyalcin, S., Are Digital Models Replacing Plaster Casts? *Dentistry*, *2011*.

Alcan, T., Ceylanoğlu, C. & Baysal, B., 2009. The relationship between digital model accuracy and time-dependent deformation of alginate impressions. *The Angle Orthodontist*, 79(1), pp.30-36.

Alghazzawi, T.F., 2016. Advancements in CAD/CAM technology: Options for practical implementation. *Journal of Prosthodontic Research*, 60(2), pp.72-84.

Bell, A., Ayoub, A.F. & Siebert, P., 2003. Assessment of the accuracy of a three-dimensional imaging system for archiving dental study models. *Journal of Orthodontics.* 30, pp.219-223.

Correia, G.D.C., Habib, F.A.L. & Vogel, C.J., 2014. Tooth-size discrepancy: A comparison between manual and digital methods. *Dental Press Journal of Orthodontics*, 19(4), pp.107-113.

Dalstra, M. & Melsen, B., 2009. From alginate impressions to digital virtual models: accuracy and reproducibility. *Journal of Orthodontics*, 36(1), pp.36-41.

Fleming, P.S., Marinho, V. & Johal, A., 2011. Orthodontic measurements on digital study models compared with plaster models: a systematic review. *Orthodontics & Craniofacial Research*, 14(1), pp.1-16.

Grünheid, T., McCarthy, S.D. & Larson, B.E., 2014. Clinical use of a direct chairside oral scanner: an assessment of accuracy, time, and patient acceptance. *American Journal of Orthodontics and Dentofacial Orthopedics*, 146(5), pp.673-682.

Horton, H.M., Miller, J.R., Gaillard, P.R. & Larson, B.E., 2010. Technique comparison for efficient orthodontic tooth measurements using digital models. *The Angle Orthodontist*, 80(2), pp.254-261.

Keating, A.P., Knox, J., Bibb, R. & Zhurov, A.I., 2008. A comparison of plaster, digital and reconstructed study model accuracy. *Journal of Orthodontics*, 35(3), pp.191-201.

Lee, S.J., MacArthur, R.X. & Gallucci, G.O., 2013. An evaluation of student and clinician perception of digital and conventional implant impressions. *The Journal of Prosthetic Dentistry*, 110(5), pp.420-423.

Marcel, T.J., 2001. Three-dimensional on-screen virtual models. *American Journal of Orthodontics and Dentofacial Orthopedics*, 119(6), pp.666-668.

Mullen, S.R., Martin, C.A., Ngan, P. & Gladwin, M., 2007. Accuracy of space analysis with emodels and plaster models. *American Journal of Orthodontics and Dentofacial Orthopedics*, 132(3), pp.346-352.

Naidu, D. & Freer, T.J., 2013. Validity, reliability, and reproducibility of the iOC intraoral scanner: a comparison of tooth widths and Bolton ratios. *American Journal of Orthodontics and Dentofacial Orthopedics*, 144(2), pp.304-310.

Patzelt, S.B., Emmanouilidi, A., Stampf, S., Strub, J.R. & Att, W., 2014. Accuracy of full-arch scans using intraoral scanners. *Clinical Oral Investigations*, 18(6), pp.1687-1694.

Peluso, M.J., Josell, S.D., Levine, S.W. & Lorei, B.J., 2004, September. Digital models: an introduction. In *Seminars in Orthodontics* (Vol. 10, No. 3, pp. 226-238). WB Saunders.

Quimby, M.L., Vig, K.W., Rashid, R.G. & Firestone, A.R., 2004. The accuracy and reliability of measurements made on computer-based digital models. *The Angle Orthodontist*, 74(3), pp.298-303.

Rhee, Y.K., Huh, Y.H., Cho, L.R. & Park, C.J., 2015. Comparison of intraoral scanning and conventional impression techniques using 3-dimensional superimposition. *The Journal of Advanced Prosthodontics*, 7(6), pp.460-467.

Rheude, B., Lionel Sadowsky, P., Ferriera, A. & Jacobson, A., 2005. An evaluation of the use of digital study models in orthodontic diagnosis and treatment planning. *The Angle Orthodontist*, 75(3), pp.300-304.

Rubbert, R., Weise, T., Riemeier, F., Sachdeva, R., Butscher, W., Sporbert, P., Imgrund, H., Pfeil, L., Geerdes, H.F., Kouzian, D. and Leichner, M., 2003. *Interactive Orthodontic Care System Based on Intra-oral Scanning of Teeth*. U.S. Patent 6,648,640.

Santoro, M., Galkin, S., Teredesai, M., Nicolay, O.F. & Cangialosi, T.J., 2003. Comparison of measurements made on digital and plaster models. *American Journal of Orthodontics and Dentofacial Orthopedics*, 124(1), pp.101-105.

Stevens, D.R., Flores-Mir, C., Nebbe, B., Raboud, D.W., Heo, G. & Major, P.W., 2006. Validity, reliability, and reproducibility of plaster vs digital study models: comparison of peer assessment rating and Bolton analysis and their constituent measurements. *American journal of Orthodontics and Dentofacial Orthopedics*, 129(6), pp.794-803.

Torassian, G., Kau, C.H., English, J.D., Powers, J., Bussa, H.I., Marie Salas-Lopez, A. & Corbett, J.A., 2010. Digital models vs plaster models using alginate and alginate substitute materials. *The Angle Orthodontist*, 80(4), pp.662-669.

van der Meer, W.J., Andriessen, F.S., Wismeijer, D. & Ren, Y., 2012. Application of intra-oral dental scanners in the digital workflow of implantology. *PLoS One*, 7(8), p.e43312.

Wiranto, M.G., Engelbrecht, W.P., Nolthenius, H.E.T., van der Meer, W.J. & Ren, Y., 2013. Validity, reliability, and reproducibility of linear measurements on digital models obtained from intraoral and cone-beam computed tomography scans of alginate impressions. *American Journal of Orthodontics and Dentofacial Orthopedics*, 143(1), pp.140-147.

Yuzbasioglu, E., Kurt, H., Turunc, R. & Bilir, H., 2014. Comparison of digital and conventional impression techniques: evaluation of patients' perception, treatment comfort, effectiveness and clinical outcomes. *BMC Oral Health*, 14(1), p.1.

Zilberman, O., Huggare, J. & Parikakis, K.A., 2003. Evaluation of the validity of tooth size and arch width measurements using conventional and three-dimensional virtual orthodontic models. *The Angle Orthodontist*, 73(3), pp.301-306.

http://www.hpcsa.co.za [Accessed 01 April 2016]

ADDENDUM A

Patient.______________

Folder no.___________

Form A :alginate impressions

B :direct intraoral scan

A	B

(mark with X)

Max right	11	12	13	14	15	16
Max left	21	22	23	24	25	26
Man right	41	42	43	44	45	46
Man left	31	32	33	34	35	36

MAXILLA	**INTERCANINE**	**INTERMOLAR**

MANDIBLE	**INTERCANINE**	**INTERMOLAR**

ADDENDUM B

Addendum B

Department of Orthodontics
Faculty of Dentistry & WHO Oral Health Collaborating Centre

Private Bag X1, Tygerberg 7705
South Africa
Telephone: +27 21 937 3106/3030//3172
Fax: +27 21 931 2287

Private Bag X08, Mitchell's Plain 7785
South Africa
Telephone: +27 21 370 4400/4470/4411
Fax: +27 21 392 3250

SEPTEMBER 2014

Informed consent

Dear Patient,

Dr. Vuyani Dubula is a postgraduate student at the Faculty of Dentistry, University of the Western Cape. He will be using the impressions that will be taken as part of your normal orthodontic records to scan into a computer; he also will be using an intra-oral scan to scan through your teeth to obtain some measurements of your teeth. This is all part of the normal procedures during record taking in the course of your orthodontic treatment.

The information obtained from the impressions and the intra oral scan will then be used by Dr. Dubula for the purpose of a research project investigating the accuracy of orthodontic digital study models. There will be no cost implications to you the patient other than what is set out by Dr. Johannes for record taking. There will be no extra cost as a result of the research project.

The information that we receive from the impressions will be treated with strict confidentiality. Participation in the project is completely voluntary. No patient will be identifiable from the records and no patient related information will be used if research project is published.

Participation is voluntary and if you decide for your records not to be used, it will not affect whether you receive treatment or not. Please do not hesitate to contact me should you require any further information: Dr. Vuyani Dubula Tel: 082 628 1013 e-mail: vuyand@yahoo.co.uk

Supervisors: Prof. A. Harris-021-9373105/6

: Dr. K. Johannes- (041) 3640884

Thanking you in advance for your participation.

Dr. Vuyani Dubula

Registrar- Orthodontics

ADDENDUM – B part 2

Addendum B

Department of Orthodontics

Faculty of Dentistry & WHO Oral Health Collaborating Centre

Private Bag X1, Tygerberg 7705
South Africa
Telephone: +27 21 937 3106/3030//3172
Fax: +27 21 931 2287

Private Bag X08, Mitchell's Plain 7785
South Africa
Telephone: +27 21 370 4400/4470/4411
Fax: +27 21 392 3250

I understand the information that has been provided to me and I hereby give consent for my records to be used for the research project.

Patient Name & Signature:____

Witness Name & Signature:____

Date:_______________________________