TOOTH SIZE MEASUREMENTS AND BOLTON ANALYSIS FOR FAST-SET PLASTER MODELS VERSUS COMPUTER-BASED MODELS RENDERED FROM DUAL POUR ALGINATE IMPRESSIONS

by

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Objective: The objective of this in vitro study is to compare measured values of pre-treatment tooth sizes and the Bolton overall and anterior analyses for fast-set plaster dental casts versus computer-based dental models made from a dual pour alginate impression.

Materials and Methods: Maxillary and mandibular alginate impressions were made for a sample of thirty-six patients with permanent dentitions from first molar to first molar. Impressions were poured in fast-set orthodontic plaster within one hour and allowed to set for 8-10 minutes. Casts were removed from the impressions, cleaned of any observable plaster and re-examined for quality. Impressions were packaged and sent to OrthoCAD for generation of digital models.

Measurements of mesiodistal tooth width were made using digital calipers or OrthoCAD proprietary software. Overall and anterior Bolton analyses were performed for all models. Measurements were repeated no less than two weeks later. Results were statistically analyzed for correlation coefficients and 2 x 2 MANOVA.

Results: Correlations showed very high intrarater reliability for measurements made on both plaster and digital casts. Statistical significance was found for differences between plaster and digital casts in mesiodistal measurements of maxillary and mandibular anterior segments and total arch circumference, Bolton overall ratio and Bolton anterior ratio. Values of mean difference between plaster and digital casts for the anterior segment were 0.33 mm in the

maxillary arch and 0.70 mm in the mandibular arch. Mean differences over the total arch were 0.68 mm in the maxillary arch and 1.35 mm in the mandibular arch. Value of mean difference between plaster and digital casts was 0.89% for the anterior Bolton ratio and 0.80% for the overall Bolton ratio.

Conclusions: The results of this study show statistical differences for tooth size measurements between plaster casts made from the initial pour of alginate impressions and digital casts generated from the second pour. Statistical differences were also demonstrated for both the anterior Bolton ratio and total arch Bolton ratio, indicating differences between measurements were not the result of a uniform distortion occurring between the first and second pour. The small absolute value of mean differences may or may not have clinical significance. Individual practitioners should decide whether the absolute value for these small differences have clinical significance to their practice.

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1.0 INTRODUCTION

Orthodontic treatment planning poses significant challenges for clinicians with respect to their ability to provide the most predictable results for patients in a safe, effective, and efficient manner. Similarly, orthodontists must address the challenge of assessing treatment results in an objective manner. A number of quantitative tools have been developed to aid in these endeavors, including the Bolton analysis of interarch tooth-size relationships.

In a 1958 publication, Dr. Wayne Bolton first described the steps for an analysis designed to reveal interarch discrepancies in tooth sizes. Significant discrepancies can prevent the attainment of ideal occlusion. Based on a sample of fifty-five dental casts demonstrating ideal dental occlusions, his study provided a baseline ratio for clinical use when assessing the relative proportion of the summed tooth sizes from first molar to first molar between the maxillary and mandibular arches. Using his analysis on measured dental casts during orthodontic evaluations can provide information pertinent to clinically relevant treatment planning decisions.

Traditional plaster dental casts have, and will continue to have, a place in the practice of orthodontics, particularly for the fabrication of oral appliances such as those used in space maintenance, anchorage control, palatal expansion and/or retention. However, recent advances in technology include the introduction of computer-based dental models. Computer software allows for the manipulation and measurement of digital models in all three dimensions. A number of studies have shown that the dimensional representations found in digital models and their use in the analysis of patient malocclusions have statistically and/or clinically insignificant differences when compared to those using conventional plaster models (Costalos *et al.*, 2005; Garino, F. and Garino, JB, 2002; Leifert *et al.*, 2009; Mayers *et al.*, 2005; Mullen *et al.*, 2007; Okunami *et al.*, 2007; Quimby *et al.*, 2004; Rheude *et al.*, 2005; Santoro *et al.*, 2003; Stevens *et al.*, 2006; Tomassetti, *et al.,* 2001; Whetten *et al.*, 2006; Zilberman *et al.*, 2003).

The advantages of digital media as an aid to efficiency in the orthodontic office have also been described (Abelson, 1995). Studies have not addressed, however, whether multiple pours of the alginate impressions have impacted the dimensional accuracy of digital models in a statistically or clinically significant manner. The objective of this in vitro study is to compare measured values of pre-treatment tooth-sizes and Bolton overall and anterior analyses for plaster casts against computer-based renderings of dental models made from a dual pour alginate impression to determine if significant differences exist.

2.0 REVIEW OF THE LITERATURE

2.1 INTERARCH TOOTH SIZE DISCREPENCIES: BOLTON ANALYSIS

In 1958, Dr. Wayne Bolton published his investigation on interarch tooth size discrepancies and their influence on diagnosis and treatment planning. In his study, he measured a sample of fifty-five adult dentitions with no missing teeth, forty-four of which had received previous orthodontic treatment. Using three-inch needle-pointed dividers and a finely calibrated millimeter ruler, he measured the mesiodistal dimensions of the teeth in each arch from first molar to first molar.

To establish an overall ratio, he summed the total value for measurements made in the respective arches and calculated the ratio of these totals for the maxillary arch to those of the mandibular arch. He also took the ratio of the summed values for the maxillary teeth from canine to canine to the summed value of their mandibular counterparts for calculation of the anterior ratio. His calculations resulted in mean values of 91.3 ± 1.91% for the overall ratio and 77.2 ± 1.65% for the anterior ratio.

Bolton compared his mean values to the respective values measured from an untreated 14 year-old female's permanent dentition with no history of caries or restorations considered to have ideal occlusion. His ratios had no statistically significant difference when compared to those of the untreated, ideal occlusion. Incidentally, mean values for his sample of ideal occlusions did not differ significantly for other measurements he made, including percentage overbite, overjet, incisor angle or posterior cusp heights. The mean ratios Bolton derived also correlated very closely to ratios calculated from tooth dimensions considered ideal for establishing the ideal restorative setup for the adult dentition (Wheeler, 1940).

Bolton's study demonstrated the clinical impact of mathematically calculating these ratios. He recommended that interarch tooth-size discrepancies observed in patient dentitions beyond one standard deviation from his values indicated consideration in treatment planning regarding extractions or the need for diagnostic set-ups. With respect to more contemporary orthodontic mechanics, his ratios also aid in clinical decisions regarding amount and site of interproximal reduction or restorations necessary to finish orthodontic treatments with ideal buccal occlusion, overbite and overjet. Currently, clinicians regard ratios with values in excess of two standard deviations beyond Bolton's values merit consideration as having clinical significance, although a number of studies challenge the notion that the values he derived apply universally to gender and ethnicity (Bernabe´ *et al.*, 2004; Crosby *et al*., 1989; Freeman *et al.*, 1996; Heusdens *et al.*, 2000; Kayalioglu *et al.*, 2005; Paredes *et al.*, 2006; Santoro *et al.*, 2000; Smith *et al.*, 2000; Ta *et al.*, 2001; Uysala *et al.*, 2005).

2.2 ORTHODONTIC RECORDS IN THE DIGITAL AGE

Orthodontic treatment planning poses significant challenges for clinicians with respect to their ability to provide the most predictable results for patients in a safe, effective and efficient manner. While clinicians regard the clinical exam as the gold standard for viewing real time dental occlusion, maxillomandibular relationships and soft tissue conditions, orthodontic records provide invaluable information. Along with examination of oral conditions, the necessary components for orthodontic diagnosis and treatment planning include dental and skeletal radiographs, analysis of the lateral cephalogram, accurate dental study models and photographs (Faubion, 1966). Some pioneering orthodontists also consider the use of gnathologic devices necessary to achieve an appropriate analysis of the orthodontic records (Lischer, 1930; Salzmann, 1942; Strang and Thompson, 1958). The many methods for performing examinations and the analysis of records have been investigated and evaluated, and various philosophies on the matter have been discussed in educational forums and synthesized in the literature (Graber et al., 2005; Jacobson and Jacobson, 2006; Proffit, Fields and Sarver, 2007; Proffit, White and Sarver, 2003).

Regardless of how a clinician evaluates the findings in a patient's established record, the components have no comprehensive value unless accuracy and consistency exists among them. Medicolegally, risk managers stress that the patient record plays the most vital role in providing evidence to eliminate doubt of any breach of standards of care, and should reflect the history of the patient-doctor relationship honestly (Jerrold, 2000, 2003). Inconsistencies and/or inaccuracies in the observations gleaned from the full complement of data prevent the development of any logical conclusions about the hard and soft tissue relationships used in orthodontic diagnosis.

Orthodontists most commonly employ diagnostic dental casts for various areas of clinical practice, clinical research and medico-legal documentation (Marcel, 2006). From a treatment planning perspective, one must consider the idea that any single element of the complete patient record alone does not yield a high level of consistency in final clinical decisions among practitioners. Han *et al.* (1991) presented orthodontists with elements of the patient's record sequentially, starting with plaster models, followed by extraoral photographs, panoramic radiograph, lateral cephalogram and a cephalometric tracing. They demonstrated that while study models independently provided an adequate amount of information for consistent treatment planning among multiple practitioners 55% of the time, consecutive addition of the other elements of the orthodontic record improved their agreement as the full compliment of orthodontic records became available (including casts, photos, panoramic radiographs, lateral cephalograms and their tracings). Casts, therefore, seem to have more benefit when employed with intraoral and extraoral photographs, panoramic radiographs, cephalograms and their tracings, all of which most effectively and usefully demonstrate their various characteristics of a patient's malocclusion.

Recently, technological advances have created a new source of practical issues in data collection for diagnosis and treatment planning. Many orthodontists still use traditional records, such as conventional film photographs, plain film radiographs traced on acetate sheets for cephalometric analysis and poured plaster casts. In contrast, others have begun to integrate less proven and/or mainstream media such as digital photographs, computer-based models and digital radiography as a means to collect, share, store and evaluate the data collected in their offices. They also use computer software when generating treatment plans and for communication with other professionals.

The advantages of digital archives most frequently cited 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). Software to integrate photographs, digital radiographs and digital casts, sometimes in a three dimensional manner, have become a new available technology for application in a computer-based treatment record (Marcel, 2001).

Dentists and dental specialists continue to integrate paperless charts and various types of digital technology into their practices.

2.3 COMPUTER-BASED DENTAL STUDY MODELS

As computer software technology continues to progress, advances may provide for a single piece of imaging equipment, such as a cone beam computed tomographer, to provide the full compliment of information on hard and soft tissue data and analysis (Nakasima *et al.*, 2005). However, the utility of this technology in an orthodontic practice is questionable. Clinically relevant benefits to diagnosis and treatment planning may not justify the high costs associated with the purchase of the hardware, software and/or possible need to outsource for generating and reading the images.

In the meantime, study models maintain their vital tradition as an essential part of the orthodontic process of diagnosis, treatment planning and outcome appraisal. For many years, the only medium to provide the positive representation of impressions made in any material has been either a plaster or stone cast. They provide a measurable three-dimensional record of the original malocclusion that observers can manipulate and view from multiple angles. Progress models allow for evaluation and further treatment planning at any stage during active treatment, and post-treatment models act as a major contributor to treatment outcome assessment.

Despite the indispensable role casts play in diagnosis, treatment planning and progress and treatment outcome evaluation, they have several practical disadvantages. Space considerations in an office make storage of stone or plaster casts problematic, and difficulty in their recovery from the storage sites can occur as well, particularly if a clinician uses an off-site storage facility. Plaster has a fragile quality that requires great care in handling to ensure no loss of diagnostic information or accuracy in the depiction of the oral structures and relationships that the models capture. Non-destructive manipulation for the purpose of observing aspects of a malocclusion, such as tooth angulations, overbite and overjet, limits their usefulness as well. Furthermore, the bulk of traditional casts also makes them difficult to transport and/or transfer for review by insurance companies or to other members of the patients' health care team.

Digital photographs and digital radiographs have already found a regular place in orthodontic offices. The introduction of computer-based study models has made another stride toward a fully electronic orthodontic patient record. Previous attempts at digitizing casts had poor success. Some involved digitally photographing the models from five vantage points (frontal, right and left buccal, upper occlusal and lower occlusal). These photographs could then be stored, viewed, and measured from the occlusal view for space assessments, intermolar and intercanine measurements. The relatively basic system helped primarily with storage problems, as the amount of assessment possible from the stored image was limited only to that represented in the photographs and ~~it~~ provided no means of manipulation of the models. In addition, the models had to first be cast and then set up for a time consuming photographic session. Researchers have also attempted to develop three-dimensional models through laser scanning technology or generation of holographic images (Martensson and Ryden, 2004; Rossouw *et al.*, 1991). These technologies, however, require complex equipment and have significant cost. Furthermore, the laser technology has limitations in capturing overlapping interproximal areas.

In contrast, since its introduction in the mid- 1990s, scanning technology has improved over the past several years from advances in software development. Several companies, including GeoDigm (GeoDigm Corp., Chanhassen, Minn) and OrthoCAD (CADENT, Ind., Fairview, NJ), have dramatically refined this approach. These advances have made the capture of scanned images a commercially viable enterprise and OrthoCAD utilizes the computer-aided design technology (CAD) for generation of its digital study models.

2.4 ORTHOCAD DIGITAL STUDY MODELS

OrthoCAD software provides the orthodontist with a three-dimensional set of digital models that may be manipulated in all planes of space, sectioned in any plane and measured along any plane with considerable accuracy. In 2004, Joffe thoroughly outlined the process by which OrthoCAD generates its version of computer-based study models. OrthoCAD uses computer-aided design (CAD) to generate a digital cast. The orthodontist may then access and use these models via a software user interface that allows manipulation of the models in all planes of space as well as data analysis through a range of diagnostic tools.

Generating a digital OrthoCAD model first requires the fabrication of a high quality impression and accurate bite registration. Typically, irreversible hydrocolloid materials are used, although the impressions can be made from any of the regular dental impression materials, such as polyvinyl silicone or polyether materials. OrthoCAD also prefers use of plastic impression trays of various sizes that they provide, although any disposable stock tray works. The clinical objective is a set of impressions with the greatest possible accuracy and dimensional stability for their clinical use, bearing in mind that the impressions must weather a potentially lengthy journey to OrthoCAD for pouring and processing.

Once made, the clinician should sanitize the alginate impressions, individually wrap them in damp paper towels and package them in sealable plastic bags to ensure moisture retention. The moist environment helps to provide dimensional stability for as long as possible. Generally, at least a twenty-four hour period typically will elapse prior to the initial pour. If longer periods of time will go by prior to the initial pouring, more stable impression materials should be considered.

Upon receipt by OrthoCAD, the company optically scans a plaster equivalent of the impression, which they store in their computer database. This process results in the destruction of the original cast. OrthoCAD then securely sends the three-dimensional digital renderings of the patient's model to the orthodontist via the Internet, where a designated office computer automatically downloads it. Each model has multiple identifiers, including patient name, an office serial number and the number of models allocated for that patient.

Once downloaded, users can easily store, retrieve, diagnose, treatment plan and electronically communicate with the digital casts. Offices may access the models from any office computer equipped with the user interface and networked to the designated storage folder (but not necessarily to the downloading station). Manipulation in the user browser is made possible by OrthoCAD propriety software. Features include a 'grab and drag' tool for free manipulation of the digital cast in all planes of space and a jaw alignment tool for anterior, posterior, transverse and rotation adjustments to the bite registration. A view control tool with a zoom feature allows for static views of the model from any perspective, including pre-determined direct anterior, posterior, right and left buccal and occlusal views, as well as a printable gallery of these five typical views in a one-to-one ratio with the model's actual size.

An occlusogram feature depicts a color-coded scheme of the bite registration that highlights points of occlusal contact. A diagnostics tool allows for automatic storage of detailed measurements of overbite and overjet, tooth width measurements, intermolar and intercanine arch width measurements and a virtual archwire used for arch circumference estimation. The software automatically provides Moyers and Tanaka-Johnston predictions, Bolton analysis and calculation of tooth size-arch size discrepancy based on the entered data for mesiodistal tooth size. Software includes the American Board of Orthodontists' Discrepancy Index and allows for transverse and vertical sectioning in any desired plane. In addition, software features include storage of diagnostic and treatment notes, case presentations, printouts of measurements and analyses and capabilities for direct email transmission of any printable information to the patient or other health care professionals. Users may even electronically send an entire file for view on any computer equipped with the OrthoCAD user interface.

Perhaps the most important benefits of using digital models are storage of the models and their measurements, ease of data retrieval (particularly from multiple sites), and information exchange. Other advantages include storage and integration into the patient's complete digital file (i.e. digital photographs, digital x-rays and computerized clinical notes) and chair-side retrieval and viewing along with the other clinical data. Because electronic storage of the models requires a relatively small amount of memory for each model, storage costs have negligible impact. OrthoCAD is also compatible with both Windows and Macintosh operating systems, and can be fully integrated with many orthodontic management and imaging software packages.
For some clinicians, particularly those who diagnose, treatment plan and evaluate treatment outcomes from gnathological paradigms, the lack of ability to evaluate an articulator-mounted set of casts in reference to the patient's temporomandibular joint function proves a great disadvantage of digital models. Software also does not fully allow for effective evaluation of feasibility models or for model surgery needed for orthognathic cases. Users must also consider the economic costs associated with shipping their impressions, generating the models and having

the technological hardware in the office to utilize them. Some clinicians may avoid this new medium due to the associated learning curve; however, a rapid prototyping method makes production of traditional models from the digital casts available if the computer format does not suffice clinical needs.

2.5 ACCURACY, RELIABILITY AND VALIDITY OF DIGITAL MODELS

A number of studies have demonstrated the accuracy of the dimensions of digital models and their measurements, and others have demonstrated comparable and consistent treatment planning decisions when using digital casts against plaster casts. In 2001, Tomassetti *et al.* evaluated the accuracy and efficiency of performing Bolton's tooth size analysis using manual measurements of plaster casts with a Vernier caliper compared with three computerized methods. They studied a sample of twenty-two sets of pretreatment and post-treatment casts selected with inclusion criteria of a maximum of 3 mm of crowding in the arches and models that were in good condition. Using a Vernier caliper, Tomassetti measured tooth sizes and completed a timed Bolton tooth-size analysis three times on each set of casts. He completed the initial analyses of all casts in random order within a 1-month period and waited at least 2 weeks between measurements. The data from these measurements was averaged and considered the gold standard.

The models were then digitized into the QuickCeph Image Pro program (version 6.2), casts were measured, and the Bolton analysis was calculated using the software. This procedure was also timed. A third analysis employed the Hamilton Arch Tooth System (HATS) software. Using digital calipers connected to a computer, the models were measured, and the procedure timed. The HATS software calculated the Bolton analysis. A final timed Bolton analysis was performed on digital images using OrthoCAD software (version 1.14). For all types of models, Tomassetti calculated the overall Bolton ratio between the arches from first molar to first molar and the anterior Bolton ratio between the six anterior maxillary and mandibular teeth. For statistical purposes, all Bolton tooth-size discrepancies were expressed as maxillary excesses or deficiencies.

Comparing the overall discrepancies for OrthoCAD models specifically, the latter differed from measurements using calipers on average by 1.20 mm. For the discrepancy of the anterior 6 teeth, a mean difference of 1.02 mm occurred. ANOVA and paired t-test statistics did not reveal statistically significant differences for the overall or anterior analysis. The only significant difference present was for the time involved in performing the analysis. On average, the Vernier caliper method took about eight minutes whereas OrthoCAD took approximately five and a half minutes.

The results of the study revealed that no statistically significant differences existed between the methods used to measure tooth-size discrepancies with the Bolton analysis. When compared with measurements using the calipers on plaster models, the HATS program had very similar results, whereas OrthoCAD and QuickCeph were less correlated. The investigators found no significant differences in intraexaminer statistics between media type. They considered the differences clinically significant for all methods relative to the plaster gold standard, but did not specify where the clinical significance occurred. Additionally, they found statistically significant differences for the time needed to complete the analysis. QuickCeph took the least time, followed, in order, by HATS, OrthoCAD, and measuring with Vernier calipers. Tomassetti concluded that more time-efficient methods to measure a Bolton tooth-size analysis exist than those for traditional models. He did not conclude, however, that digital models produced results any more or less accurate than traditional methods.

In a 2002 study, Garino and Garino investigated whether differences in dental arch measurement occur between stone and digital casts of the same patient. They selected forty patients in various stages of dentition from the authors' practice, including twenty-four boys and sixteen girls ages eight to sixteen years old. They obtained stone casts from a silicon-based impression that they poured in type 4 stone and trimmed according to the bite registration. OrthoCAD prepared digital casts from the silicon impressions and bite registrations taken by the same operator on the same day with the same procedures used for the stone casts.

The researchers used digital calipers for measurements on stone casts and OrthoCAD proprietary software (version 1.7) for the digital models. They measured the intercanine and intermolar widths in both arches. They also measured the mesiodistal dimension of each maxillary and mandibular incisor as the distance between the anatomic contact points. Each investigator measured on two occasions at least two weeks apart.

Their results showed statistical differences in the measurements between the stone and digital casts. Caliper measurements made on the stone casts had higher values than the digital counterparts. Interestingly, the investigators did not use the data to draw conclusions comparing the measurements of the two types of casts, as stated in the objective of the study. While the values obtained on digital models showed greater precision and interexaminer consistency, the authors also seemed to imply that the values represented by the digital models were a better representation of reality due to the more precise measuring capability of the OrthoCAD software over the digital calipers. They did not consider distortion of the impressions material or a processing problem associated with the generation of the virtual cast as a possible cause of the differences in the actual measured values of the stone versus digital casts. This study did, however, demonstrate the superiority of precise measurements made possible by the digital software capabilities.

In contrast, Santoro *et al.* conducted a study in 2003 that also compared the accuracy of measurements made by the OrthoCAD system on digital models with measurements made by hand on traditional plaster models. To determine any major bias, they first selected 20 random subjects, each having the permanent teeth erupted from first molar to first molar, no missing teeth from first molar to first molar, and no existing orthodontic appliances in place. They made two consecutive alginate impressions from each subject and poured them both immediately in plaster. The bite was recorded using a wax wafer. A single examiner measured mesiodistal tooth width, overbite, and overjet on both casts using an orthodontic-style Boley gauge to the nearest 0.1 mm. The results were then statistically evaluated.

The examiners next gathered an additional sample of 76 patients, each having the permanent teeth erupted from first molar to first molar, no missing teeth from first molar to first molar, no pretreatment orthodontic appliances, and at least three occlusal contacts in centric occlusion. They made two consecutive alginate impressions that were examined for quality. One impression was poured the same day to fabricate the plaster model. The second was sent to generate a digital OrthoCAD model. They selected only the highest quality models free of voids, blebs or fractured teeth.

Two independent examiners recorded mesiodistal width for the maxillary and mandibular teeth from first molar to first molar on the plaster and digital models. They also recorded overbite as the amount of vertical overlap of the mandibular incisor in millimeters, and overjet in millimeters from the labial surface of the mandibular incisor to the labial surface of the maxillary incisor. On the plaster casts, overjet and overbite were measured with a graduated, calibrated periodontal probe to the nearest 0.5 mm. They measured tooth size with an orthodontic-style Boley gauge to the nearest 0.1 mm. Digital casts were measured using the OrthoCAD software tools available through the user interface. The results were then statistically evaluated.

The results demonstrated no statistical differences between measurements made on plaster casts poured from the consecutively made alginate impressions. Excellent interexaminer correlation allowed for consideration of both examiners' measurements as a single database. ANOVA revealed a statistically significant difference between tooth width measurements made by the 2 methods, with all the digital measurements smaller than the corresponding plaster model measurements. Results also demonstrated a statistically significant difference in overbite measurement between the plaster and digital models, but showed no statistically significant difference between the overjet measurements by the 2 methods. All digital measurements had smaller values than those of the manual measurements, with the mean difference being 0.49 mm.

Based on these results, they postulated that alginate shrinkage during transportation to OrthoCAD and different pouring times provided the most likely explanations for the differences between plaster and digital casts. They concluded that the magnitude of the differences do not have clinical significance, discussing that factors such as variable probe angulation could have introduced some inconsistency in overbite measurements for the traditional models. They also suggested that the generalized and uniform variation in digital measurements does not threaten diagnostic capability because it does not affect proportional measurements used in cast analyses. They believed that digital models seem to offer a clinically acceptable alternative to stone casts for the routine measurements used in orthodontic practice.

In 2003, Zilberman *et al*. tested the accuracy of the conventional method using calipers to measure plaster casts as compared to measurements made with the OrthoCAD software tool. They made twenty artificial set-ups of teeth for which they immediately poured corresponding alginate impressions into plaster models. They made an additional twenty addition-type silicone impressions (first with putty, then a wash) and sent them to OrthoCAD for digitization.

They measured mesiodistal tooth size, intermolar arch width and intercanine arch width using digital calipers for the plaster models and the artificial set ups. They measured the tooth sizes having removed them from set up to theoretically make the measures the most accurate. They used OrthoCAD version software 1.14 to measure the digital casts. They took measurements to the nearest 0.1 mm.

Zilberman mentioned that a newer software version 1.17 had better tools that allowed for more accurate measurements. The version used in the study measured tooth width as the distance between two non-adjustable points. In contrast, the newer version calculated tooth width as the distance measured between a pair of adjustable planes.

The results showed high correlation between all measurements made on the plaster and digital casts. They also revealed good interexaminer and intraexaminer agreement for all measurements. The study revealed no statistically significant differences between the artificial set-up, plaster cast and computer-based model, although correlation between plaster models and the artificial set-up had a higher value than that of OrthoCAD models to the set-up. Correlation of plaster casts to the OrthoCAD model had the worst correlation for the raw data. Nevertheless, these raw data revealed nothing to regard as significant.

The authors attributed the poorer performance of the digital format to the general characteristics of computer-based models. Even though the OrthoCAD model represents all three dimensions, the viewer sees only a two-dimensional rendering of these three dimensions. Thus, identification of points, axes and planes becomes more difficult. This may have hampered the results of OrthoCAD regarding validity, reproducibility, and consumed time needed for the selection of points. Therefore, the authors consider OrthoCAD a clinically useful modality, but possibly inferior to plaster for research purposes due to the high level of accuracy needed in research. They suggest users must become familiar with the digital medium, especially when using digital casts for purposes where accuracy has high priority.

Zilberman concluded that diagnosis with OrthoCAD models constitutes a valid method for evaluating tooth width and arch width. While measurement with digital calipers on plaster models produced the most accurate and reproducible results, the OrthoCAD measurement tool also showed high accuracy and reproducibility. He considered use of plaster models and digital calipers more suitable for scientific work; however, he suggested that computer-based models produce clinically acceptable accuracy and that they have other advantages and future possibilities outside the providence of traditional plaster casts.

In a similar 2004 study, Quimby *et al.* examined the accuracy and reproducibility of measurements made on plaster models and on computer-based models as compared with those of an artificial typodont occlusion. They also evaluated the efficacy and effectiveness of measurements made on a computer-based model of a natural dentition with measurements made on a plaster model of the same natural dentition. Their sample consisted of fifty consecutive patients having a full adult dentition with no obvious anatomic abnormalities/restorations, each having two sets of maxillary and mandibular alginate impressions made, one set poured in plaster within one hour and the other sent to OrthoCAD for generation of a digital model. They also made ten sets of alginate impressions of a typodont that they poured in traditional plaster and ten additional sets that they sent to OrthoCAD for generation of a digital cast.

The investigators measured mesiodistal tooth widths, arch length, intercanine and intermolar widths, overjet and overbite, and calculated the space available and space required for each type of model. They also made these measurements directly on the typodont. For efficacy and reproducibility, two examiners measured all fifty casts on separate occasions two weeks apart. For effectiveness, ten different examiners measured ten randomly selected plaster and digital cast sets twice, each of these set of measurements recorded in sessions separated by a two week interval.

The results showed no significant differences between measurements made on the plaster models and those made on the typodonts, indicating that plaster models provide an accurate depiction of the actual morphology they represent. Measurements made on the computer-based models differed with statistical significance from those made directly on the typodont only for mandibular and maxillary space available. They found that the variance of measurements made on the computer-based models was also significantly greater than those made on the plaster models, except for mandibular intercanine width.

Intrarater analysis showed that examiners made reproducible measurements with good reliability for both plaster and digital casts. While they rounded plaster cast measurements to the nearest 0.5mm and recorded exactly for digital casts, repeated measures ANOVA showed statistically significant differences in all measurements, except for lower canine arch width and the mandibular arch length required. They found higher raw values in all categories for the digital casts except for overbite and overjet, which were greater in plaster.

For effectiveness, the results showed significant differences between measurements of the two systems for all categories except for mandibular intercanine width. Differences were also significant for all categories amongst the various examiners. The authors commented, however, that the actual differences in value between the two systems did not indicate the computer-based system any less practically effective than plaster if applied in a realistic setting.

The direct measurements of the plastic teeth in the dentoform served as the control to evaluate the accuracy of measurements made on plaster and computer-based models. Measurements made on plaster casts poured within one hour of the impression did not differ significantly from those made directly on the typodont. Likewise, measurements made on the computer-based models the day after the impressions were taken did not differ significantly, except for mandibular and maxillary space available.

The authors hypothesized that the larger values they observed for measurements made on the computer-based models may have come from several possible sources. Firstly, differences may have resulted from the increased elapsed time prior to the creation of the digital models. Also, errors may have resulted from the processing steps inherent to the creation of digital casts. Lastly, differences may result from the display and measurement algorithms of the manufacturer's proprietary software, and the lack of examiner familiarity with the measurement procedures for computer-based models.

The results of Quimby's study showed statistically significant, though generally small, differences in measurements between the plaster and computer models. They concluded that computer models have reasonable reliability and accuracy. Digital models can provide the clinician with adequate information to develop a treatment plan and help eliminate storage and retrieval problems associated with plaster casts. They left open the question of the clinical significance of the differences they found, and suggested that the true test of clinical significance would be to determine whether treatment plans produced with computer-based models differed significantly from treatment plans produced with plaster models.

In 2005, Rheude *et al.* conducted such a study to determine the diagnostic and treatment planning value of digital models when compared with plaster study casts. In addition, they assessed whether the level of orthodontic experience of the examiner influenced the decision-making process. They made two impressions for each of thirty randomly selected orthodontic patients, one used to produce a plaster study cast and the other for a computerized model generated by GeoDigm. They narrowed the sample to seven cases that closely mirrored the American Board of Orthodontics certification case presentation requirements and selected seven members of the University of Alabama orthodontic faculty to generate diagnostic descriptions, treatment plans, and treatment mechanics. They also divided the evaluators into two groups based on their level of experience. Group 1 comprised orthodontists who had less than 15 years of clinical experience, whereas group 2 comprised orthodontists who had 15 years or more clinical experience.

The investigators gave each participating evaluator a standardized questionnaire that recorded the evaluator's diagnosis based on use of the digital study models. The evaluators also wrote a brief description of their treatment plans and the treatment mechanics that they would employ. The final question asked if the evaluator would like a plaster model for additional observation and the reasons why they made the request. In a separate session occurring within thirty minutes, the evaluators filled out an identical questionnaire based on their assessments with use of the plaster casts. Rheude made comparisons between the answers to the questionnaires as completed by each evaluator at the two treatment planning sessions.

The results evaluated three sets of data. Firstly, they identified the total percentage of all evaluators' changes in diagnoses, treatment mechanical procedures, and proposed treatment plans resulting from a subsequent review of the plaster study models. Next, they recorded the number of times and reasons why evaluators requested plaster study models after evaluation of the digital models. Lastly, they compared group 1 to group 2 with respect to the number of times of diagnoses, treatment mechanics or proposed treatment plans changed after evaluating the plaster study models.

The results showed statistically significant differences in the amount of changes made for 14 of 21 categories between the plaster and digital media, with the most changes in diagnosis occurring for molar and cuspid classifications, then overjet, overbite, and mandibular crowding, and next for tooth angulations and posterior crossbite. Changes also occurred in the categories of arch asymmetry, maxillary crowding, anterior crossbite, tooth size, tooth morphology, maxillary curve of Spee, and midline coincidence. Arch form and mandibular curve of Wilson comprised the only two diagnostic descriptions that demonstrated no changes between digital and plaster model diagnoses.

The authors also found a statistically significant difference for treatment plan changes. Three of the evaluators each changed one treatment plan; however, all three changes occurred for the same patient. The authors hypothesized that the material submitted to GeoDigm for this patient likely included a faulty bite registration that resulted in differences significant enough to cause the three evaluators to change their plans. They calculated a statistically significant difference for changes in treatment mechanics, but one evaluator accounted for four of the six changes reported. In addition, the authors commented that the observations resulting in the changes would have been identified easily in a clinical setting and were thus of no practical significance to overall treatment. The four reasons evaluators requested plaster study models after viewing the digital models included to see how much decompensation was needed for a surgical treatment, to see how much transverse expansion was needed for a surgical treatment, to assess for an unusual asymmetric extraction possibility and to see better detail of tooth morphology for interproximal recontouring.

A statistically significant difference occurred between the two evaluator groups for diagnostic changes in the categories of molar classification, overjet, maxillary crowding, posterior crossbite, inclination, tooth size, and midline coincidence. Orthodontists with less than 15 years experience recorded more changes. The authors postulated that their limited experience in collecting data from limited records resulted in the difference. Although they found statistically significant differences between the groups for changes made in diagnostic characteristics between the two sessions, the authors considered them minor and clinically insignificant. They found no statistically significant differences between the groups in the number of treatment planning procedure changes or proposed treatment mechanical changes.

The researchers concluded that despite the statistically significant differences for many diagnostic characteristics observed between plaster and digital casts, the degree of recorded changes was minor and considered clinically insignificant. They commented that diagnostic acumen improved with experience using the new digital medium and that the changes in diagnostic characterizations between the two model types decreased as more experience with digital models occurred. This seemed to indicate a distinct learning curve associated with the use of digital casts. They recommended the use of both types of models when transitioning from plaster to digital casts, and that practitioners record the dental classification, overjet, and overbite as observed in the clinical exam. The authors also concluded that plaster casts may provide more accurate data for surgical patients or proposed plans involving unusual extraction patterns. Nevertheless, they believed that the results of this study indicated suitability of digital models as orthodontic records for the majority of patients.

In 2005, Mayers *et al.* conducted a study to determine the validity and reliability of PAR occlusal index scores derived from digital study models compared with scores from plaster models of the same patients. They specifically focused on comparison of PAR scores generated from digital models with the PAR scores from orthodontic plaster casts, intraexaminer reliability of PAR scores from plaster models and digital models, and the reliability of the component scores of the PAR index as generated from plaster and digital models.

A single examiner made two sets of maxillary and mandibular alginate impressions on each of forty-eight patients. From the impressions, forty-eight sets of models were made, one plaster and the other its digital analog. They selected models in random order and calculated PAR scores in two sessions separated by two weeks. They also timed how long each PAR evaluation took to complete.

Results of the study supported the validity and reliability of PAR index scores derived from digital models. The investigators found no statistically significant differences in PAR scores from digital models compared with PAR scores from plaster models of the same patient. High correlation occurred for PAR scores calculated on digital models with the plaster models representing the gold standard, and all the scores were reliably reproducible. They found that PAR scoring for digital models took almost twice as long to complete than for traditional plaster casts.

While the sample excluded dentitions with deciduous teeth, impactions or lateral open bites, all other measurable occlusal traits of the PAR index were present. They concluded that digital models provide a valid, reliable medium for measuring malocclusion with the PAR index. Because of the longer time required to perform a PAR index for digital models, they recommended software package development that might make it easier to perform a PAR analysis.

Similarly, Costalos *et al.* studied whether digital models had reasonable accuracy and reliability for assessing patients' final occlusion at the end of orthodontic treatment, but used as their standards those according to the American Board of Orthodontics. They evaluated a sample of twenty-four finished cases of full permanent dentition with visually acceptable molar and canine relationships, overjet and overbite. The investigators made alginate impressions that they sent to OrthoCAD to fabricate both the plaster and digital models. Once calibrated, a postgraduate student and a 4th year dental student conducted an American Board of Orthodontics Objective Grading System (ABO OGS) evaluation of the plaster casts. A second ABO OGS evaluation occurred at least 4 weeks later using OrthoCAD software. Investigators also timed each evaluation.

They employed statistical analyses to investigate the accuracy and repeatability of the score for each component of the ABO OGS evaluation and for total Discrepancy Index score. The results indicated very high intraexaminer reliability for both examiners for both types of models. They also found a significant interexaminer difference, with a better correlation between the examiners occurred for the digital format. Tests of significance showed that the means of the total score and scores for marginal ridges, occlusal contacts, occlusal relationship, overjet, and interproximal contacts had no significant differences between plaster and digital models. However, they found that the means for the alignment and buccolingual inclination categories showed significant differences between plaster and computer-based models.

Therefore, plaster casts and digital models had good correlation except for alignment and buccolingual inclination.

The authors postulated that landmark identification may act as a possible source of error between the two formats for alignment and buccolingual inclination. In the case of alignment, the digital format allows for landmark identification from microscopic perspectives, whereas the plaster format uses macroscopic evaluation. For buccolingual inclination, the ABO gauge allows for proper bisection of the teeth in plaster, whereas deficiencies in the OrthoCAD software do not allow this.

They concluded that plaster and digital models showed generally similar values for total score and for 5 of the 7 criteria measured. Interexaminer reliability was somewhat better with digital models. Software improvements may help to attain greater reliability in measuring alignment and buccolingual inclination, but the use of digital models produced by the OrthoCAD system seems to be a viable alternative to plaster models.

In a 2006 investigation, Stevens *et al.* compared plaster models, again taken as the gold-standard, to digital models with respect to measurements of tooth sizes and occlusal relationships. They duplicated a sample of twenty-four existing casts with a complete permanent dentition from first molar to first molar that represented the ABO categories of certification malocclusions. To avoid any inconsistencies occurring from multiple impressions and distortion from delaying an initial pour, they poured the alginate impressions in plaster and sent the trimmed models to GeoDigm for digitization into a computer-based format. GeoDigm returned the plaster models for measurement comparisons with the digital models. Thus, the investigators presumed any observed variance resulted from operator error or errors occurring during conversion into the digital medium.

Three examiners independently recorded measurements needed for a Bolton analysis and a Peer Assessment Review (PAR) indexing for both the plaster and digital casts. This included mesiodistal tooth dimensions, contact displacements (as raw millimeter measurements for ≤ 1 mm and approximations for displacements greater than 1 mm), overjet, overbite, deviation from the ideal posterior interdigitation and midline deviation. The examiners used digital calipers for plaster cast measurements and proprietary software for the computer-based models. Statistical analysis appraised reliability and validity of the measurements made on the digital casts as compared to those made for plaster.

The results revealed high interexaminer and intraexaminer measurements for both plaster and digital models. Though statistical differences resulted, the investigators did not detect clinically significant differences in reliability between plaster casts and computer-based models with respect to the actual tooth-size measurements or PAR index scores. They also did not find a clinically significant difference of mean measurement for either the anterior or the full arch Bolton analyses, or for arch length, PAR score, overjet or overbite.

The authors commented that midlines, occlusal anatomy, and wear facets were not as clear on the digital models, and that the most difficult characteristic to distinguish was posterior cross-bites. For a deep overbite, however, they found it easier and more reliable to check midline coincidence and measure overbite and overjet by using computer-based models and the corresponding digital software tools. They also found difficulty in evaluating the precision of buccal interdigitation on a digital model relative to its plaster counterpart.

They concluded that, because no measurement associated with Bolton analysis or PAR index made on plaster as compared to digital models showed a clinically significant difference, digital models provide a clinically valid replacement for plaster casts for routine measurements like those made in most orthodontic practices. Also, because the PAR index and its constituent measurements are not clinically significantly different between the plaster and digital media, and because preliminary results gave no indication that digital models would cause an orthodontist to make a different diagnosis of malocclusion than with plaster models, digital models would not compromise treatment planning and diagnosis.

Whetten *et al.* (2006) investigated whether differences exist for intra-rater agreement in measurements for surgery, extractions and need for auxiliary appliances based on the study model medium. Inclusion criteria for their sample included an ANB angle between 4° and 9°, positive overjet of at least 4 mm, a minimal age of 13 years at the time of records, and having at least a half step Class II molar relation on one side. Of twenty-four patients with these criteria, they randomly selected a sample of fifteen patients that a focus group of three faculty members at the University of Alberta narrowed to a final sample of ten that the faculty ranked according to difficulty.

They duplicated ten sets of plaster models and sent the duplicates to GeoDigm for scanning and digitization. An experimental group of private practice orthodontists that had never used digital models for treatment planning received the full pretreatment record of each patient, including digital study models of the duplicated casts, extraoral photographs, panoramic radiographs, lateral cephalograms and their corresponding tracings. The group conducted two diagnosis and treatment planning sessions with the full compliment of pretreatment records. In the first, they used either a plaster or digital cast and repeated the exercise at least one month later in a second session with models derived from the opposite, unused format. A control group did two treatment planning sessions at least one month apart using plaster casts at both sessions. The investigators provided a treatment planning decision tree that targeted choices for surgery versus no surgery, extraction or non-extraction, and whether or not to use auxiliary appliances (such as rapid palatal expanders, headgear/facebow, functional appliances, etc).

The results revealed that neither the digital model nor the plaster model skewed the orthodontists to make treatment decisions regarding surgery. If changes in the decision for surgery occurred, they did so in almost identical numbers between the experimental and control groups. No statistically significant discrepancy occurred between the groups on extraction decisions, although a slightly higher actual value in favor of extractions occurred for decisions made with plaster casts. Results comparing the groups also showed that the model format did not influence orthodontists with respect to their recommendations for auxiliary appliances. Statistical analysis indicated that actual choices of treatment most likely represent a function of which orthodontist the patient happens to contact rather than the format of the models.

Whetten concluded that digital orthodontic study models offer a valid alternative to traditional plaster study models in treatment planning for Class II malocclusions. The study attempted to simulate a real-life clinical situation in which the use of study models occurred within the context of a full compliment of diagnostic records. The analysis indicated that treatment planning decisions did not change to any significant extent when using digital models in place of plaster models. Whetten considered that in some instances the orthodontist may have even relied almost entirely on records other than study models in formulating a treatment plan. Furthermore, this study indicated that treatment planning decisions for this patient group and this group of orthodontists resulted from the orthodontists' subjective judgments and personal biases rather than the format of study models.

In 2007, a study conducted by Okunami *et al.* emphasized comparing the results of the American Board of Orthodontics Objective Grading System when manually measuring traditional casts and ~~with~~ measuring digital casts with the OrthoCAD software. They examined thirty casts of finished orthodontic cases that included the permanent dentition from second molar to second molar. They included cases that involved bilateral bicuspid extractions. They sent the casts to OrthoCAD for direct scanning. Once calibrated, the principal investigator and one senior ABO examiner evaluated the plaster casts using the ABO gauge and the digital models using the OrthoCAD software. The investigators measured two plaster and two OrthoCAD models each day until all were done, and repeated the measurements two weeks later.

They found no statistical differences for intra-examiner reliability between the plaster and digital models. They found statistical differences for evaluation of occlusal contacts, determining occlusal relationships, and consequently for the total ABO OGS score. Problems with determination of occlusal contacts occurred due to software deficiencies, and the software did not allow for acceptable determination of buccolingual inclinations as well. They believe that the differences found for occlusal relationship (represented by Angle classification) occurred because they are derived from a fixed buccal view provided by software for digital models, whereas a parallax effect may occur if viewing occlusal relationships in plaster from a different angle. They also speculated, however, that the difference for occlusal relationship may not have a practical contribution to the difference seen in the total ABO OGS score.

Despite the desirable potential clinical benefits of digital models, they concluded that the OrthoCAD software program was not proven equal or superior to the gold standard of plaster casts for conducting the ABO OGS evaluation. The authors recommended that OrthoCAD develop software applications that correct for the deficiencies. According to this study, however, OrthoCAD models are not valid or reliable for evaluation when compared to a plaster cast gold standard.

Mullen *et al.* (2007) compared the accuracy of the Bolton analysis performed on digital models to their plaster counterparts and recorded the time needed to perform the analysis. The sample included thirty complete adult dentitions with a first molar to first molar dentition in both arches. They made alginate impressions of both arches in each patient and sent them to GeoDigm for fabrication of a plaster model that was subsequently scanned for generation of the digital model. GeoDigm then returned the plaster model and sent the computer-based model via the internet for measurements. Therefore, the plaster model and the digital model were fabricated from the same impressions and should presumably possess identical dimensions.

The investigators performed measurements on the plaster and digital casts for overall length of both arches (the sum of mesiodistal widths of all teeth from first molar to first molar), calculated the Bolton ratio, and recorded the time required to perform the Bolton analysis. They used digital calipers for measurements on plaster casts, and used the available proprietary software for measurements of the digital models. They also evaluated whether any dimensional changes from a plaster cast occurred in the process of creating its computer-based counterpart.

They found no statistically significant difference between the Bolton ratios calculated using plaster models and digital models. They concluded, therefore, that calculation of the Bolton ratio with the digital model provided results as accurate as those found using the traditional method with caliper measurements of plaster models. They did find a statistically significant difference in the calculation of arch length and tooth structure in both arches with the different methods of measurement. This would indicate some magnification error, but it occurred within a range that the authors considered clinically insignificant. They also found both statistically and clinically significant differences in the time necessary to make the measurements and perform the calculations. The digital model software allowed for an average time of 65 seconds faster. They concluded that the software for measuring a patient's dentition and calculating the Bolton ratio on digital models allows for equal accuracy in less time versus using digital calipers to measure plaster models.

In 2009, Leifert *et al.* compared space analysis measurements made on digital models with those from plaster dental casts. Their sample consisted of 25 sets of two alginate impressions from which they fabricated one traditional plaster cast and one digital OrthoCAD models. They measured the mesiodistal tooth width from first molar to first molar, calculated arch length, and performed a space analysis.

Results revealed slight (0.4 mm), but statistically significant, differences in the space analysis measurements made for the maxillary models. Measurements on the mandibular models were not significantly different. They found no significant difference between the measurements of the two examiners. They concluded, therefore, that the accuracy of the software for space analysis evaluation on digital models is clinically acceptable and reproducible when compared with those analyses performed on traditional plaster study models.

3.0 STATEMENT OF THE PROBLEM

Evaluation of pre-treatment dental occlusion and assessment of treatment outcomes requires use of the full patient record, including study models of the patient's dentition. Plaster casts poured from alginate impressions currently comprise the gold-standard for orthodontic models. Computer technology now allows the clinician to fabricate, manipulate, observe and measure dental models poured from alginate impressions in a digital format. The time lag prior to the pouring of the alginate impressions constitutes a major disadvantage of the digital format. Many researchers attribute the measurable differences between plaster and digital casts to the distortion that occurs in the set alginate over this prolonged time.

In general, dental professionals advocate a single pour of alginate impressions when fabricating plaster casts due to the potential distortion that the curing process and removal of the set cast can cause in the impression material. As a result, orthodontists must often make multiple impressions of a patient's dentition if they require casts for multiple purposes. This requires additional time, materials and fortitude on the part of the patient who must repeatedly endure the impression-making process. Because a clinically negligible distortion of alginate impressions occurs when rendering digital models, regardless of the number of pours, a dual pour of an alginate impression may allow clinicians to fabricate an accurate plaster cast for clinical use and a digital cast for the permanent patient record that has statistically and/or clinically insignificant differences from a single pour, plaster gold-standard. No studies have examined if any statistically or clinically significant differences occur between plaster and computer-based dental models both poured from a single alginate impression.

4.0 OBJECTIVES

The objective of this in vitro study is to compare measured values of pre-treatment tooth sizes and the Bolton overall and anterior analyses for fast-set plaster dental casts versus computer-based dental models made from a dual pour alginate impression.

4.1 SPECIFIC AIMS

1. Determine if a preliminary pour of alginate impressions in fast-set orthodontic stone produces significant changes in the actual tooth measurements between the plaster cast and its subsequently poured digital counterpart.
2. Determine if a preliminary pour of alginate impressions in fast-set orthodontic stone produces significant proportional changes in hard tissue representations between the plaster cast and its subsequently poured digital counterpart via use of the Bolton overall and anterior ratios.

5.0 RESEARCH QUESTION

What effect does initially pouring an alginate impression in fast-set plaster have on the measureable characteristics of orthodontic study models subsequently rendered in the computer-based format from the same alginate impression?

6.0 MATERIALS AND METHODS

To evaluate for significant changes between plaster and digital casts, maxillary and mandibular alginate impressions (Jeltrate® Plus Antimicrobial Dustless Alginate Impression Material-Fast Set, Dentsply, Milford DE) using OrthoCAD disposable plastic trays treated with Bosworth brush-on liquid TAC® (Bosworth Co., Skokie, IL) were made for a sample of thirty-six patients possessing permanent dentitions from first molar to first molar.

Impressions were spray sterilized, examined for quality and wrapped in moist paper towels for no more than one hour until they were poured in fast-set orthodontic stone (Fast Cast® White Die Stone, Dentsply-Raintree Essix, Bradenton, FL). The casts were allowed to set for 8-10 minutes. They were carefully removed from the impressions; care was taken to avoid any damage to plaster casts and tears or pulling of alginate away from the sides of the tray. Casts were examined for quality.

Impressions were rinsed under cool running water and gently brushed with a soft toothbrush to remove any observable stone material and were re-examined for quality. Impressions were re-wrapped in damp paper towels, sealed in a zip-lock type bag and sent to OrthoCAD for generation of digital casts.

Measurements of mesiodistal tooth width were made using digital calipers for plaster casts and proprietary software for OrthoCAD models (version 2.9). Overall and anterior Bolton analyses were performed for all models. Measurements were repeated for all models in the same manner no less than two weeks later. Results were analyzed using 2 x 2 multivariate analysis of variance (MANOVA) and correlation statistics for intraexaminer reliability.

7.0 RESULTS

7.1 INTRARATER RELIABLILITY

Statistical analysis for intrarater reliability shows very high correlation between first and second measurements, indicating excellent reliability. The mean differences between the first and second set of measurements for each segment have very small absolute values. This indicates a high degree of consistency between the first and second measurement. Because the standard deviation and standard error from the mean also have very small values for most pairs, the differences between measurement sets have statistical significance. Results are summarized below:

Table 1. Coefficient Correlations between First and Second Measurements

Measured Segment	Correlation
Plaster- Maxillary Anterior	0.979
Plaster- Maxillary Arch	0.946
Plaster- Mandibular Anterior	0.954
Plaster- Mandibular Arch	0.978
Digital- Maxillary Anterior	0.986
Digital- Maxillary Arch	0.990
Digital- Mandibular Anterior	0.989
Digital- Mandibular Arch	0.988

Table 2. Mean Difference, Standard Deviation, Standard Error and T-test Significance between First and Second Measurements

Measured Segment	Mean (mm)	Standard Deviation (mm)	Standard Error (mm)	Significance (2- tailed)
Plaster- Maxillary Anterior	0.25	0.54	0.09	$p = 0.009$
Plaster- Maxillary Arch	-0.34	1.55	0.26	$p = 0.194$
Plaster- Mandibular Anterior	0.27	0.57	0.10	$p = 0.008$
Plaster- Mandibular Arch	0.33	0.89	0.15	$p = 0.033$
Digital- Maxillary Anterior	-0.11	0.44	0.07	$p = 0.146$
Digital- Maxillary Arch	-0.31	0.62	0.10	$p = 0.005$
Digital- Mandibular Anterior	-0.18	0.27	0.04	$p < 0.0005$
Digital- Mandibular Arch	-0.52	0.62	0.10	$p < 0.0005$

7.2 MANOVA FOR CAST MEASUREMENTS

Statistical analysis for differences between the eight measured segments comparing plaster casts to their digital analogs utilizes 2 x 2 MANOVA, including Wilks' Lambda and Sphericity Assumed tests. Values are based on the average of measurements for each investigated segment. Multivariate and univariate analyses reveal statistically significant effects for maxillary and mandibular arches as well as for plaster and digital media ($p < 0.0005$). The interaction effect for the measured arch segment and the medium (plaster vs computer-based) also has statistical significance ($p < 0.0005$). The significance again owes to the fact that the absolute difference between mean values is very small. Tests are of very high power due to the low variance and relatively large sample. Higher values occurred for computer-based models. Data is summarized below:

Table 3. Average Means and Standard Deviations of Measured Segments

Measured Segment	Average Mean (mm)	Average Standard Deviation (mm)
Plaster- Maxillary Anterior	48.32	2.57
Digital- Maxillary Anterior	48.65	2.58
Plaster- Mandibular Anterior	37.61	1.82
Digital- Mandibular Anterior	38.31	1.76
Plaster- Maxillary Arch	98.96	4.56
Digital - Maxillary Arch	99.64	4.36
Plaster- Mandibular Arch	91.10	4.16
Digital- Mandibular Arch	92.45	3.93

Table 4. Difference in Average Mean and Standard Deviation, Plaster vs Digital Casts

Measured Segment	Difference in Average Mean (mm)	Difference in Average Standard Deviation (mm)
Maxillary Anterior	0.33	0.01
Mandibular Anterior	0.70	0.06
Maxillary Arch	0.86	0.20
Mandibular Arch	1.35	0.23

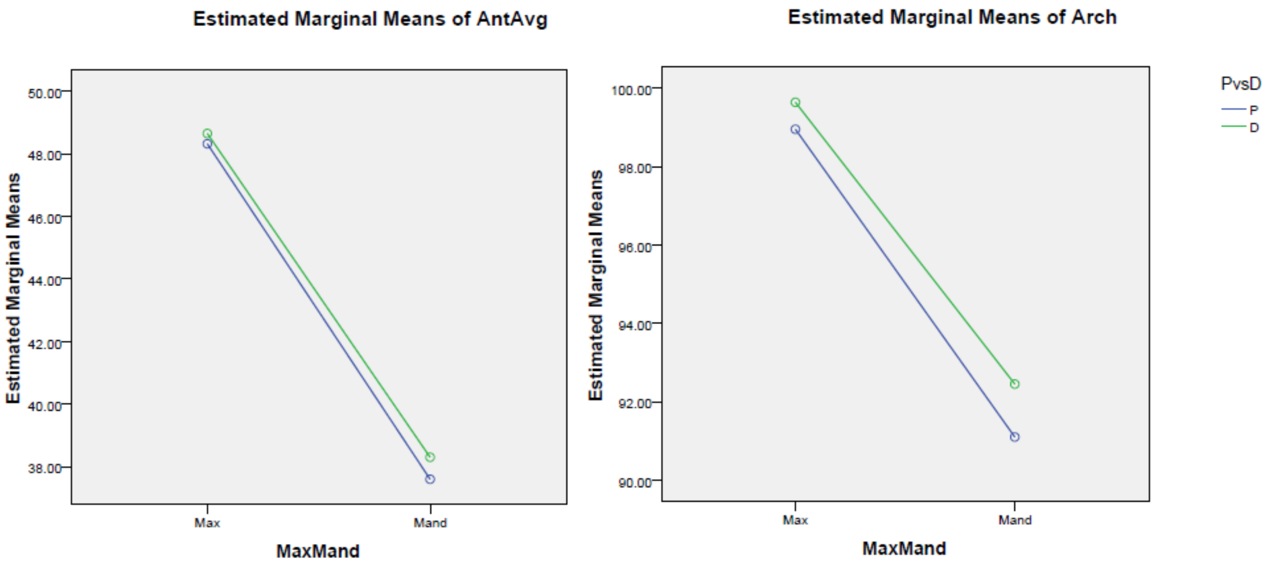

Figure 1. Graphical depiction of differences (mm) between average mesiodistal measurements for teeth in the anterior arch segment (left) and total arch circumference (right) for plaster casts (blue) and computer-based models (green). Digital models have larger measurements than plaster casts with more discrepancy in the mandibular casts than the maxillary casts.

7.3 MANOVA FOR ANTERIOR AND TOTAL ARCH BOLTON RATIOS

2 x 2 MANOVA utilizing the Wilks' Lambda test was also performed to compare Anterior and Arch Bolton ratios. Analysis shows that statistical differences exist between the calculated values for plaster casts versus those for digital casts ($p < 0.0005$). Once again, the statistical significance results from the low variance, high power and relatively large sample size comprising the measurements. Absolute differences between mean values of plaster and digital casts for anterior and total arch ratios were 0.89% and 0.80%, respectively. Higher values occurred for computer-based models. Results are summarized below:

Table 5. Means of Anterior and Total Arch Bolton Ratios for Plaster and Digital Casts

Measured Segment	Mean (%)	Standard Deviation (%)
Plaster- Anterior Ratio	77.88%	2.23%
Digital- Anterior Ratio	78.77%	2.37%
Plaster- Arch Ratio	91.99%	1.80%
Digital- Arch Ratio	92.79%	1.76%

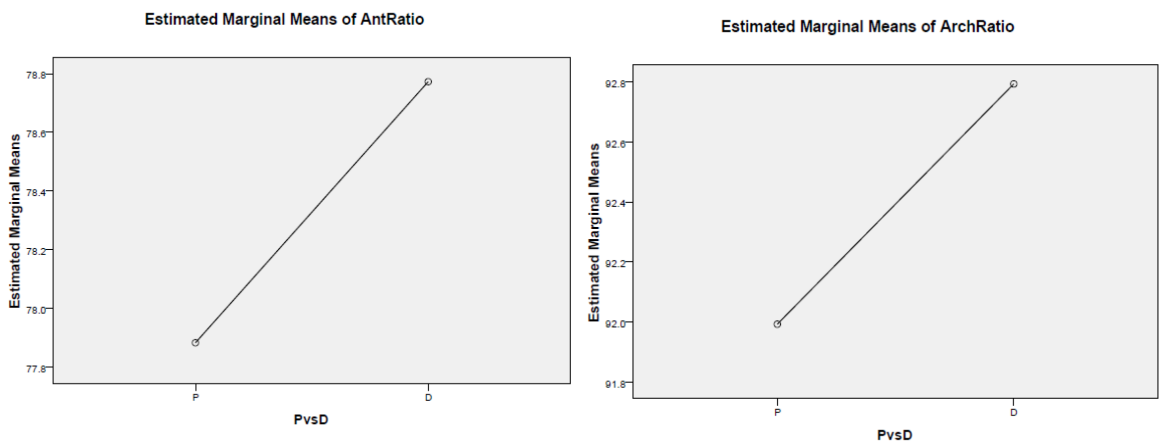

Figure 2. Graphical depiction of mean differences in anterior (left) and total arch Bolton ratios (right) for plaster (P) and digital (D) models. In both cases, digital models show larger ratios for the sample than for their plaster analogs.

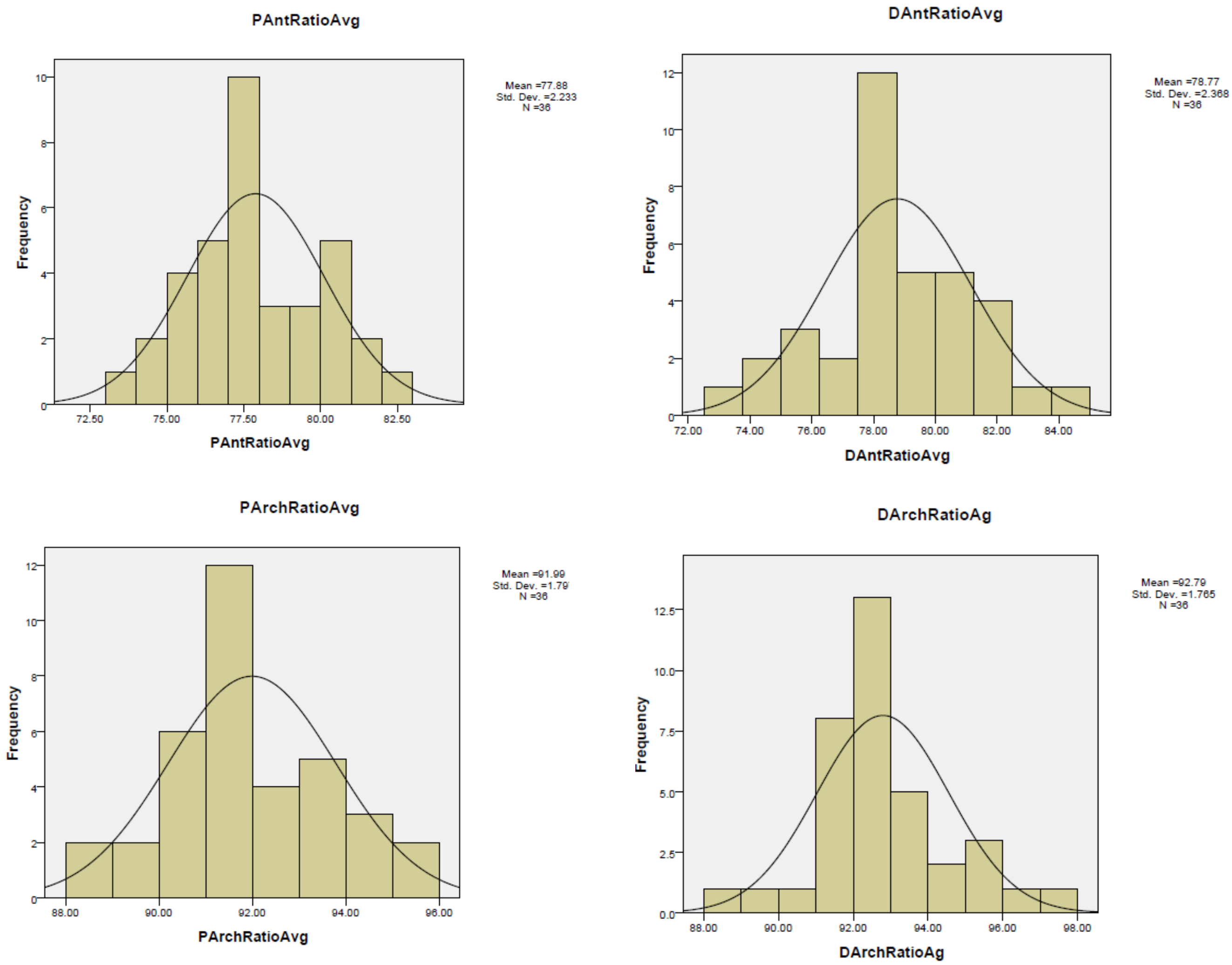

Figure 3. Histograms depicting distributions of anterior (top row) and total arch (bottom row) Bolton ratios for plaster casts (P) and digital (D) analogs. As expected, distributions are similar, and both sets mean values fall within 1 standard deviation of the Bolton norms.

8.0 DISCUSSION

Dental professionals have a variety of materials to choose from when making oral impressions. These materials vary in dimensional stability and accuracy in capturing and reproducing dental anatomy. When deciding which material to use, individual practitioners must consider relevant factors largely dependent on the impression's clinical purpose and a cost-benefit evaluation. In the arena of impression-making, clinicians tend to prefer more expensive, accurate and dimensionally stable materials for fabrication of indirect restorations and/or appliances that must fit precisely in actual oral environments. Less expensive materials have use in record making, for guiding general assessments of hard and soft tissue anatomy and for use in fabrication of appliances requiring a less precise fit and/or reproduction of dental anatomy (such as custom trays or temporary restorations).

In orthodontics, casts provide diagnostic information for making treatment planning decisions, assessing treatment outcomes, fabrication of temporary appliances used in treatment mechanics and retainers. The latter two require fairly accurate representations of the hard and soft tissue relationships. The former two require that the information derived be useful within the greater context of the full diagnostic record, including the clinical exam. As digital records continue to integrate into general and specialty dental practices, the new format must hold up to the clinical standards of traditional media. Prior investigations indicate that computer-based models digitized from single pour alginate impressions as compared to gold-standard plaster casts have accuracy and validity of for most aspects of diagnosis and treatment planning in clinical orthodontics. The literature suggests that little statistical and/or clinical differences exist between the two media with respect to utilizing the models for cast measurements or treatment decisions when used with the entirety of the patient record. Differences do exist when measuring clinical outcomes, specifically for the evaluation of treatment results based on ABO standards.

Different clinicians place varying levels of importance on 'plaster on the table' relative to their treatment decisions and outcome assessments. Evidence suggests computer-based media has validity as an alternative to plaster casts in this regard. However, some clinicians prefer to avoid the digital technology, likely due to practice preference rather than objections over the shortcomings of the medium.

The present study sought to elucidate the impact of pouring alginate materials twice with respect to its effect on tooth size measurements and a single analysis utilized in orthodontic treatment planning. A statistical significance occurred for mesiodistal dimensions in the anterior and whole arch segments when comparing a first-pour plaster cast to its second-pour digital analog. A statistical difference also occurred when comparing their anterior and total Bolton ratios. The differences revealed slightly larger values for the digital casts rendered from the second pour, as one might expect. The larger values likely resulted from distortion produced in the alginate material that occurred during setting and removal of the initial plaster pour. While these statistical differences occurred, one must consider the source of the differences and the clinical relevance. Quimby *et al*. (2004) hypothesized that the larger values they observed on computer-based models may have come from the increased elapsed time prior to the creation of the digital models, the processing steps for creation of the digital casts and to the display and measurement algorithms of the manufacturer's proprietary software. Measurements on traditional casts require manipulation of the calipers around the anatomical position of actual plaster teeth. Adjacent structures sometimes interfere with the ability to precisely engage the calipers in the best position to measure individual teeth. Conversely, OrthoCAD software enables the user to manipulate and angle the measuring planes through any adjacent structures in order to find appropriate positions on the tooth for making the measurements. OrthoCAD's software zoom feature also allows the user to very precisely choose the position of the measuring plane on the tooth under scrutiny. The difference in the tools for measuring may have contributed to the differences observed in this investigation.

Furthermore, the statistical significance of the measurement differences observed in this study resulted from the consistency and highly correlated values between the first and second sets of measurements for both plaster and computer-based models. The size of the sample, low variance and highly powered analysis led to statistical significance, even though comparison of the absolute differences in the measurements for plaster taken against those of digital casts had such a small range (0.33-0.70 mm in the anterior arch and 0.68-1.35 mm over the entire arch). The clinical effect of these very small differences may have negligible impact in the context of orthodontic diagnosis, treatment planning and outcome assessment.

Statistically significant differences were also observed with respect to the calculated Bolton ratios. These differences indicate that the process of a dual pouring did not lead to a uniform alteration of the impression material; rather, the measurement variance between the two media resulted in variance in the ratios. A lack of uniform distortion also suggests that the long period of time between pours had little effect on the impression anatomy, as was suggested by Quimby *et al*. (2004). Furthermore, a recent study by Imbery *et al*. (2010) investigated the differences between casts fabricated from traditional alginate impressions (Jeltrate Plus antimicrobial) and those taken with an extended-pour alginate (Cavex ColorChange). Their study revealed that the dimensions of casts fabricated from traditional alginate that sat in proper storage for up to five days did not violate clinical conditions for fabrication of diagnostic casts, occlusal splints, acrylic appliances and possibly removable partial denture frameworks. Their results shattered a long-established notion that alginate impressions require pouring as quickly as possible to ensure clinical acceptability. This suggests that measured differences observed in digital casts do not likely originate from the elapsed time between impression-making and pouring.

A uniform distortion of the impressions used in this study would theoretically result in insignificant differences for the ratio of maxillary to mandibular tooth-sizes. Therefore, it seems likely that the differences in Bolton ratios resulted from the measured values for mesiodistal dimensions of the teeth that were entered into the Bolton equation. Once again, the statistical differences occurred due to the high correlation between first and second sets of measurements, low variance and high power for a relatively large sample size. Absolute differences in the anterior and total Bolton ratios were 0.89% and 0.80% respectively, with similar standard deviations for both. Clinical significance for the differences may occur in some cases, particularly for values that linger near the edges of the standard deviations to the Bolton norms.

One limitation of this investigation occurs due to the fact that no observations were made whether differences in measurements exist between two sets of plaster casts, or between two sets of digital casts, that were both fabricated from dual-pour alginate impressions. If differences between first and second pours of casts in a single medium have similar differences to those seen in this study, one may conclude with greater certainty that the secondary pour of the impression led to the differences observed. However, if differences between first and second pours do not exist in similar medium, or have a more uniform difference in measurements that does not effect Bolton ratios, then the observed differences in this study likely result from making the measurements in different media. Furthermore, the differences observed impact diagnostic criteria limited to measurements of mesiodistal tooth dimensions. Further investigations that focus on other aspects of the cast anatomy and the relative positions of their constituent parts are necessary to help reveal the full clinical impact of dual pour alginates, particularly for treatment planning and treatment outcome assessment. This would aid clinicians in establishing an evidence-based comfort level with pouring alginate impressions twice.

If the clinical impact of evaluating computer-based models made from a second pour proves negligible, the possibility exists to use a stone model made from the initial pour for certain purposes without compromising aspects of diagnosis and treatment planning. This might impact the efficiency of overall treatment by eliminating steps necessary for both creation of an accurate patient record and for fabrication of diagnostic wax-ups, some orthodontic appliances used in early treatment stages and/or some retainers. Clinicians could benefit from the advantages of computer-based models described in the literature and also from savings in chair time necessary to make multiple impressions, lab time to pour and trim multiple plaster models, costs associated with impression materials and decrease the amount of distress that the impression making process has on patients. Of course, the necessity for a dual pour need only occur for clinical situations that call for it, not as a routine practice. If further studies reveal negligible clinical impact of pouring alginates twice, practitioners may make an informed decision as to whether or not doing so would benefit their practice of orthodontics.

9.0 SUMMARY

Accuracy of the data in the record is vital to establishing appropriate treatment plans and for assessing treatment outcome. Dental casts play an important role in these pursuits for orthodontics. The validity and reliability of computer-based models has been shown in the literature, indicating that the media has a sound place in clinical orthodontics. Traditionally, alginate impressions are used one time for fabrication of a single cast that one may use for various purposes in orthodontics, including diagnosis, treatment planning, diagnostic wax-ups and fabrication of appliances. Orthodontists' patterns of practice with respect to how they choose and manipulate impression materials must ensure that the casts they render possess anatomical accuracy appropriate for their clinical application. The objective of this in vitro study is to compare measured values of pre-treatment tooth-sizes and Bolton overall and anterior ratios for plaster casts to their computer-based analogs made from a single, dual pour alginate impression in order to determine if significant differences exist.

Maxillary and mandibular alginate impressions were made for a sample of thirty-six patients with permanent dentitions from first molar to first molar. Impressions were poured in fast-set orthodontic plaster, removed and cleaned. Impressions were then packaged and sent to OrthoCAD for generation of digital casts from a second pour.

Two sets of measurements of mesiodistal tooth width were made on the plaster casts using digital calipers and on the computer-based models using proprietary software. Overall and anterior Bolton analyses were performed. Intrarater reliability for measurement sets was determined with coefficients of correlation. Values for the measurements and Bolton ratios were compared between the plaster and digital media using multivariate analysis of variance (MANOVA).

Results show statistically significant differences between plaster casts and their digital analogs for measurements of the maxillary anterior segment, mandibular anterior segment, the maxillary arch from first molar to first molar and mandibular arch from first molar to first molar. Statistical significance was also seen for values of the anterior and total Bolton ratios. The very small absolute millimetric differences in the measurements, however, may have minimal or no clinical impact. Future studies utilizing this dual pour technique to compare the two media in studies similar to those previously done with single pour impressions will help validate this assertion. More evidence will allow clinicians to decide whether a dual pour technique is appropriate for their clinical practice of orthodontics.

10.0 CONCLUSIONS

Based on the results of this investigation, the following conclusions may be made:

1) Statistically significant differences exist between plaster casts and their digital analogs with respect to tooth size measurements made for the maxillary anterior segment, mandibular anterior segment, maxillary total arch from first molar to first molar and the mandibular total arch from first molar to first molar.
2) Statistically significant differences exist between plaster casts and their digital analogs with respect to values of the anterior and total Bolton ratios, indicating that differences in tooth size measurements do not result from a uniform distortion of the alginate impression occurring between the first and second pour.
3) The very small absolute values for the differences observed in measurements of the teeth and the resulting Bolton ratios they produce may lack significant clinical impact; however, future studies are necessary to confirm or rebuke such an assertion.

APPENDIX A

RAW DATA

Mesiodistal tooth size, Anterior segment and total arch segment measurements with calculations of anterior and total arch Bolton ratios

A.1 FIRST PLASTER MEASUREMENTS

ID #		R6	R5	R4	R3	R2	R1	L1	L2	L3	L4	L5	L6	Anterior Total	Anterior Ratio	Arch Total	Complete Ratio
		mm												mm	%	mm	%
1	**MAX**	10.7	7	6.8	7.8	7.2	8.9	9.6	7.6	7.9	6.8	7	10.5	49	80.98	97.8	95.49
	MAND	11.2	8.1	7.4	7.3	6.5	6	6	6.5	7.3	7.4	8.2	11.3	39.7		93.4	
2	**MAX**	10.3	7.2	7.8	8.2	7.6	8.9	9	7.4	8.2	7.9	7.3	10.2	49.3	78.52	100	93.21
	MAND	11.6	7.1	8	6.9	6.6	6.1	5.6	6.8	6.8	8	7.5	11.7	38.7		93.2	
3	**MAX**	11.3	7.2	7.7	9	7	9.4	9.4	7.2	9.3	7.7	7.4	11.2	51.4	77.83	103.9	92.01
	MAND	11.8	8.1	7.7	7.5	6.6	6	5.9	6.4	7.6	8.1	8	11.9	40		95.6	
4	**MAX**	10.5	7	8	8.8	7.8	9	9.1	7.7	9.2	7.6	7.3	10.7	51.6	77.75	102.7	92.65
	MAND	11.9	7.4	7.9	7.6	6.6	5.9	5.9	6.4	7.7	8.1	7.6	12	40.1		95.1	
5	**MAX**	11.3	7.5	7.9	8.7	6.9	9.2	9	7.1	8.7	7.4	7.3	11.3	49.5	82.26	102.2	96.33
	MAND	12.5	8.1	8.3	8	6.7	5.9	6	6.6	7.7	8.1	8.3	12.4	40.8		98.4	
6	**MAX**	10.7	6.9	7.8	8.4	7.5	8.9	8.9	6.5	8.5	8.3	6.9	10.7	48.6	80.52	100.1	95.3
	MAND	12.4	7.7	7.9	7.3	6.4	5.9	5.8	6.5	7.3	7.7	8.3	12.3	39.1		95.4	
7	**MAX**	10.8	6.9	7.9	7	6.4	9.4	9.3	5.9	7	7.8	6.9	10.8	45	80.71	96.1	95.89
	MAND	12.5	7.5	7.9	6.7	6.2	5.5	5.4	6	6.5	7.9	7.5	12.5	36.3		92.2	
8	**MAX**	11.2	7.5	8.1	8.8	8.2	10.1	10.4	8	8.7	8.4	7.7	11.6	54.2	74.35	108.8	89.93
	MAND	11.8	8.6	8.3	7.9	6.4	6	5.9	6.5	7.5	8.4	8.5	11.8	40.3		97.8	
9	**MAX**	10.8	7.8	8.1	8.2	7.6	9.2	9.5	7.4	8.3	7.9	7.8	10.7	50.2	80.94	103.3	94.7
	MAND	12.3	8.1	8.3	7.3	6.7	6.1	6.1	6.9	7.4	8.2	8.1	12.2	40.6		97.8	
10	**MAX**	10.4	6.6	6.7	8.1	6.5	8.4	8.2	6.5	8.1	6.4	6.7	10.1	45.7	76.94	92.6	91.95
	MAND	10.4	7.2	7.1	6.8	5.5	5.2	5.1	5.5	7.1	6.8	7.3	11.1	35.2		85.2	
11	**MAX**	10.9	7.3	7.8	8.4	7.2	8.8	8.8	6.8	8.3	7.5	7.3	10.8	48.4	83.37	99.8	94.34
	MAND	11.9	7.5	7.7	7.6	6.8	5.9	6	6.9	7.2	7.5	7.3	11.9	40.4		94.2	
12	**MAX**	10.3	7.3	7.9	8.5	6.9	8.5	8.5	7.3	8.3	8	7.5	10.2	47.9	76.96	99.2	92.34
	MAND	11.6	8	7.8	7.5	6.2	5	4.9	5.7	7.5	7.7	8	11.6	36.9		91.6	
13	**MAX**	10.6	7.3	7.2	7.2	6.8	9	9.1	6.5	7.4	7.1	7.1	10.6	46	78.81	96.1	91.16
	MAND	11.5	7.3	7.3	6.6	6	5.7	5.7	6	6.2	7.2	7.2	10.9	36.3		87.6	
14	**MAX**	10.9	7.2	7.9	8.3	7.8	8.9	9.1	7.5	7.9	7.4	6.9	10.8	49.5	79.55	100.5	93.23
	MAND	11.3	7.8	7.9	7.1	6.4	6.4	6	6.6	6.9	8	7.6	11.7	39.4		93.7	
15	**MAX**	10.1	7.1	7	7.7	6.2	8.6	8.7	6.3	7.1	6.8	7.1	9.9	44.5	79.28	92.6	91.62
	MAND	10.4	7.6	7.1	6.2	5.7	5.4	5.3	6	6.8	7.1	6.9	10.4	35.3		84.8	
16	**MAX**	10.4	7.3	7.3	8.3	7.2	9.4	9.4	7.3	8.3	7.3	6.9	10.6	49.9	74.57	99.8	90.43
	MAND	11.4	8	7.5	6.7	6.2	5.8	5.9	5.9	6.7	7.3	7.6	11.1	37.2		90.2	
17	**MAX**	11.3	7.4	8.1	8.4	7	8.8	8.6	7	8.6	8	8.1	11.6	48.5	77.94	102.9	91.42
	MAND	12.7	7.4	8	7.5	6.3	5.4	5.4	6.3	6.8	7.7	8.1	12.5	37.8		94.1	
18	**MAX**	11	7.7	8.3	8.3	8.2	9.4	9.5	8.3	8.4	8.3	7.6	11.1	52.1	74.98	106.2	92.2
	MAND	12.2	8.4	8.7	7.3	6.5	5.8	5.7	6.4	7.4	8.5	8.6	12.5	39.1		98	
19	**MAX**	11.3	6.9	7.2	8.6	7.5	9.8	9.7	7.5	8.6	7.2	7	11.2	51.7	78.91	102.3	92.82
	MAND	11.6	7.9	7.6	7.4	6.4	6.3	6.1	6.6	7.8	7.5	7.6	12.1	40.8		95	
20	**MAX**	10.9	7.5	8.2	8.4	7.4	9.8	9.8	6.9	8.6	7.8	7	10.9	50.9	78.46	103.3	93.26
	MAND	11.9	8.2	8.5	8	6.2	5.7	5.7	6.3	8	8.1	7.8	11.8	40		96.3	
21	**MAX**	9.8	6.8	7.2	7.8	6.7	7.7	7.8	6.8	8	7.3	6.8	9.3	44.9	80.47	92.1	93.51

	MAND	10.2	7	7.7	6.8	5.9	5.3	5.2	6.1	6.9	7.7	7.3	10.2	36.1		86.1	
22	**MAX**	10.9	7.1	7.3	7.7	6.1	8.4	8.3	6.3	7.6	7.3	6.9	10.9	44.3	79.45	94.8	92.79
	MAND	11.7	7.7	7.2	6.4	5.9	5.3	5.4	5.9	6.4	7	7.4	11.7	35.2		87.9	
23	**MAX**	10.9	7.3	7.9	8.8	8.5	9.7	9.4	8.4	8.5	7.9	6.8	10.6	53.3	75.9	104.7	89.19
	MAND	11.4	7.3	7.6	7.7	6.5	6	6.1	6.6	7.5	7.8	7.5	11.5	40.4		93.4	
24	**MAX**	11.8	7.7	7.7	8.3	7.3	9.2	9.2	7.4	8.5	7.7	7.8	11.7	50	78.67	104.4	91.92
	MAND	12.4	7.9	7.9	7.6	6.2	6	5.9	6.1	7.5	7.9	8.3	12.2	39.3		96	
25	**MAX**	10.8	6.8	7.4	8.2	7.3	8.9	8.8	7.3	8.2	7.3	6.8	11.2	48.8	79.1	98.9	91.95
	MAND	11.1	7.7	7.7	7.4	6.4	5.7	5.6	6.1	7.4	7.5	7.5	11.1	38.6		91	
26	**MAX**	10.7	7.3	7.3	7.5	6.6	8.9	8.9	5.9	7.9	7.3	7	10.6	45.6	82.22	95.9	93.72
	MAND	11.8	7.3	7.2	6.9	6.3	5.7	5.8	6.3	6.5	7.1	7.2	11.8	37.5		89.8	
27	**MAX**	10.2	6.8	7.2	7.9	7.3	9	9	7.2	7.6	7.4	6.9	10	48	78.07	96.5	94.01
	MAND	11.6	7.5	7.4	6.9	6	5.7	5.8	6.1	7	7.4	7.6	11.8	37.5		90.7	
28	**MAX**	10.4	7.5	7.3	7.8	6.2	8.8	8.9	7.1	7.7	7.6	7.3	10.3	46.5	77.77	96.9	91.83
	MAND	11	7.6	7.7	6.8	6	5.3	5.4	5.9	6.8	7.7	7.8	11	36.2		89	
29	**MAX**	9.9	6.9	7.4	8.3	6.9	8.8	8.8	7	8.4	7.5	6.7	9.7	48.3	81.42	96.4	93.7
	MAND	10.9	7.1	7.6	7.6	6.3	5.8	5.7	6.4	7.5	7.6	7.1	10.7	39.9		90.3	
30	**MAX**	10.7	6.6	7.1	7.4	6.8	8.2	8.4	7	7.8	7.3	7	10.8	45.6	77.44	95	91.78
	MAND	10.6	7.8	7.4	6.7	5.8	5.2	5.1	5.8	6.6	7.4	7.9	10.8	35.3		87.2	
31	**MAX**	11	8.2	8.3	8.6	7.4	9.5	9.5	7.4	8.3	8.6	8	10.5	50.6	76.17	105.1	92.62
	MAND	12.4	8.4	8.4	7.3	6.3	5.6	5.9	6.4	7.2	8.4	8.7	12.4	38.6		97.3	
32	**MAX**	10.8	7.2	7.8	7.4	6.7	9.1	9	6.9	7.2	7.4	7.2	10.8	46.4	81.96	97.5	92.96
	MAND	11.3	7.9	7.6	6.8	6	6	6	6.1	7.2	7.5	7.4	10.8	38		90.6	
33	**MAX**	10.9	8.2	8.9	8.4	8.1	8.7	8.7	8.1	8.5	8.5	7.9	10.7	50.6	75.51	105.8	92.03
	MAND	11.7	8.5	9.2	7.5	6.2	5.4	5.5	6.2	7.4	9	9.3	11.6	38.2		97.4	
34	**MAX**	10.3	6.7	7.4	7.8	6.6	9	9.2	6.4	8	7.4	6.8	10.3	47	84.14	95.9	97.07
	MAND	11.9	7.3	7.5	7.4	6.6	5.8	5.8	6.6	7.4	7.7	7.5	11.8	39.5		93.1	
35	**MAX**	9.9	7.2	7.5	7.7	7.7	8.8	8.7	7.8	7.5	7.4	6.7	10.2	48.2	78.32	97.1	92.7
	MAND	10.9	7.3	7.9	7.3	5.9	5.8	5.8	6	6.9	7.6	7.5	11.1	37.7		90	
36	**MAX**	11.7	7.6	7.9	8.3	7.6	9.9	9.9	7.3	8.2	7.9	7.7	11.6	51.2	78.62	105.5	93.05
	MAND	12.8	8.5	8.1	7.4	6.5	5.9	6	6.9	7.5	8	8.2	12.4	40.3		98.2	

A.2 SECOND PLASTER MEASUREMENTS

ID #		R6	R5	R4	R3	R2	R1	L1	L2	L3	L4	L5	L6	Anterior Total	Anterior Ratio	Arch Total	Complete Ratio
		mm												mm	%	mm	%
1	**MAX**	10.6	6.67	6.68	7.69	7.17	9.04	9.12	7.17	7.64	6.79	6.69	10.65	47.83	0.8016	95.91	0.95725
	MAND	11.09	8.19	7.43	7.02	6.35	5.8	5.8	6.33	7.04	7.39	8.29	11.08	38.34		91.81	
2	**MAX**	10.42	7.12	7.62	8.04	7.55	8.93	8.97	7.36	8.08	7.69	6.99	10.45	48.93	0.7719	99.22	0.91433
	MAND	11.5	7.33	7.66	6.72	6.52	5.71	5.61	6.51	6.7	7.69	7.3	11.47	37.77		90.72	
3	**MAX**	11.26	7.29	7.5	8.58	7.33	9.09	9.15	7.3	8.67	7.5	7.23	11.16	50.12	0.7749	102.06	0.92142
	MAND	12.01	8.02	7.57	7.33	6.29	5.81	5.77	6.34	7.3	7.71	7.98	11.91	38.84		94.04	
4	**MAX**	10.56	7.01	7.86	8.89	7.68	9.02	8.9	7.7	8.97	7.82	7.08	10.68	51.16	0.7758	102.17	0.92189
	MAND	11.93	7.52	7.79	7.51	6.52	5.83	5.8	6.52	7.51	7.82	7.51	11.93	39.69		94.19	
5	**MAX**	10.9	7.29	7.73	8.76	6.83	9.04	9.06	6.92	8.77	7.71	7.33	11.1	49.38	0.8078	101.44	0.94312
	MAND	12.16	7.81	7.94	7.56	6.36	6.06	6.03	6.36	7.52	7.94	7.78	12.15	39.89		95.67	

6	**MAX**	10.79	6.75	7.77	8.13	6.79	8.72	8.69	6.73	8.09	7.74	6.92	10.78	47.15	0.8216	97.9	0.97344
	MAND	12.3	8.23	7.75	7.45	6.36	5.53	5.57	6.4	7.43	7.73	8.19	12.36	38.74		95.3	
7	**MAX**	11.68	6.7	7.96	7.23	6.72	9.56	9.28	5.91	7.13	7.85	6.92	11.65	45.83	0.7879	98.59	0.93316
	MAND	12.61	7.59	7.9	6.6	6.01	5.49	5.42	5.99	6.6	7.78	7.48	12.53	36.11		92	
8	**MAX**	11.54	7.51	8.27	8.58	8.19	10.11	10.25	8.14	8.58	8.3	7.54	11.49	53.85	0.7393	108.5	0.89244
	MAND	11.71	8.88	8.03	7.57	6.37	5.98	5.89	6.47	7.53	8.17	8.52	11.71	39.81		96.83	
9	**MAX**	10.34	7.52	7.91	8.06	7.74	9.38	9.46	7.26	8.1	7.88	7.63	10.41	50	0.8002	101.69	0.94621
	MAND	12.05	7.96	8.13	7.37	6.45	5.95	6.16	6.76	7.32	8.06	7.94	12.07	40.01		96.22	
10	**MAX**	10.42	6.72	6.84	7.72	6.72	8.35	8.01	6.56	7.65	7.05	6.7	10.46	45.01	0.7709	93.2	0.903
	MAND	11.01	7.15	6.78	6.84	5.46	5.01	5.16	5.5	6.73	6.85	7.2	10.47	34.7		84.16	
11	**MAX**	10.7	7	7.55	8.39	7.12	8.71	8.67	7.24	8.42	7.56	7.17	10.68	48.55	0.8051	99.21	0.93186
	MAND	11.73	7.49	7.55	7.15	6.64	5.53	5.98	6.65	7.14	7.42	7.46	11.71	39.09		92.45	
12	**MAX**	10.95	7.22	7.68	8.15	6.86	8.2	8.2	6.85	8.14	7.68	7.57	10.84	46.4	0.7737	98.34	0.90879
	MAND	11.33	7.89	7.49	7.23	5.91	4.81	4.84	5.91	7.2	7.47	7.86	11.43	35.9		89.37	
13	**MAX**	10.55	7.12	7.14	6.88	6.54	8.95	8.95	6.44	6.9	7.11	6.74	10.52	44.66	0.7936	93.84	0.91347
	MAND	10.92	7.2	7	6.18	5.87	5.66	5.68	5.78	6.27	7.02	7.22	10.92	35.44		85.72	
14	**MAX**	10.77	7.17	7.6	7.98	7.36	9.21	9.17	7.32	8.03	7.48	7.16	10.75	49.07	0.7703	100	0.9106
	MAND	11.54	7.52	7.62	6.64	6.13	6.11	6.08	6.1	6.74	7.59	7.51	11.48	37.8		91.06	
15	**MAX**	9.82	7.07	7.07	7.28	6.42	8.52	8.58	6.28	7.3	7.03	6.92	9.84	44.38	0.7609	92.13	0.89743
	MAND	10.86	6.89	6.68	6.47	5.35	5.11	5.09	5.32	6.43	6.73	6.82	10.93	33.77		82.68	
16	**MAX**	10.59	6.85	7.13	8	7.19	9.08	9.05	7.2	7.97	7.24	6.81	10.61	48.49	0.7488	97.72	0.90299
	MAND	11.13	7.67	7.14	6.47	6.03	5.72	5.72	5.91	6.46	7.14	7.7	11.15	36.31		88.24	
17	**MAX**	11.76	7.79	7.71	8.38	7.03	8.54	8.52	7.06	8.49	7.96	7.9	11.66	48.02	0.7622	102.8	0.89251
	MAND	12.23	7.66	7.68	6.91	6.06	5.34	5.29	6.14	6.86	7.76	7.79	12.03	36.6		91.75	
18	**MAX**	11	7.72	8.39	8.21	8.01	9.38	9.42	8.01	8.15	8.29	7.54	11.08	51.18	0.7601	105.2	0.91654
	MAND	11.96	8.31	8.22	7.27	6.36	5.82	5.8	6.38	7.27	8.18	8.4	12.45	38.9		96.42	
19	**MAX**	11.11	7.01	7.2	8.59	7.59	9.61	9.63	7.64	8.5	7.22	7.06	11.05	51.56	0.7644	102.21	0.92007
	MAND	11.89	7.78	7.59	6.95	6.48	6.2	5.97	6.51	7.3	7.57	7.8	12	39.41		94.04	
20	**MAX**	10.77	7.11	7.86	8.55	6.99	9.37	9.27	7	8.53	7.78	6.98	10.82	49.71	0.7636	101.03	0.89162
	MAND	10.94	7.31	7.87	7.63	5.98	5.35	5.35	6.01	7.64	7.49	7.21	11.3	37.96		90.08	
21	**MAX**	9.55	6.8	6.99	7.43	6.6	7.64	7.68	6.62	7.41	7.03	6.82	9.54	43.38	0.8011	90.11	0.92365
	MAND	10.09	6.89	7.21	6.56	5.88	4.96	4.94	5.87	6.54	7.18	7	10.11	34.75		83.23	
22	**MAX**	10.83	6.77	7.23	7.39	6.04	8.08	8.05	6.13	7.32	7.03	6.79	10.77	43.01	0.7801	92.43	0.91269
	MAND	11.39	7.29	6.79	6.08	5.52	5.06	5.03	5.6	6.26	6.75	7.24	11.35	33.55		84.36	
23	**MAX**	11.22	6.83	7.8	8.69	8.39	9.45	9.39	8.29	8.54	7.81	6.94	11.21	52.75	0.7471	104.56	0.87404
	MAND	11.44	7.08	7.34	7.42	6.41	5.9	5.88	6.42	7.38	7.38	7.04	11.7	39.41		91.39	
24	**MAX**	11.89	7.24	7.65	8.31	7.39	9.18	9.23	7.35	8.42	7.63	7.46	11.75	49.88	0.7943	103.5	0.93227
	MAND	12.63	7.83	8.12	7.46	6.38	5.98	5.99	6.33	7.48	7.87	7.91	12.51	39.62		96.49	
25	**MAX**	11.02	6.68	7.23	8.15	7.04	8.86	8.89	7.01	8.16	7.26	6.62	11.06	48.11	0.7766	97.98	0.90774
	MAND	11.02	7.38	7.42	7.09	5.93	5.59	5.64	6.05	7.06	7.44	7.26	11.06	37.36		88.94	
26	**MAX**	10.6	6.9	7.38	7.75	6.28	8.78	8.84	6.22	7.82	7.17	6.83	10.46	45.69	0.8019	95.03	0.92287
	MAND	11.64	6.95	6.94	6.6	6.12	5.55	5.58	6.12	6.67	6.97	6.89	11.67	36.64		87.7	
27	**MAX**	10.58	6.83	6.91	7.76	7.18	8.91	8.88	7.17	7.73	6.93	6.83	10.63	47.63	0.7722	96.34	0.92911
	MAND	11.55	7.49	7.3	6.79	5.94	5.67	5.77	5.89	6.72	7.29	7.52	11.58	36.78		89.51	
28	**MAX**	11.18	6.94	7.68	7.84	6.18	8.87	8.83	6.84	7.9	7.65	6.93	11.17	46.46	0.7817	98.01	0.91072
	MAND	11.11	7.39	7.83	7	5.9	5.3	5.23	5.91	6.98	7.79	7.69	11.13	36.32		89.26	
29	**MAX**	9.96	6.46	7.55	8.29	7.06	8.67	8.67	7.05	8.29	7.54	6.42	9.97	48.03	0.8245	95.93	0.93725
	MAND	10.82	6.9	7.41	7.66	6.39	5.76	5.69	6.46	7.64	7.41	6.93	10.84	39.6		89.91	
30	**MAX**	10.56	6.84	6.99	7.41	6.72	8.03	8.11	6.78	7.47	7.02	6.82	10.52	44.52	0.7615	93.27	0.90586
	MAND	10.63	7.52	7.11	6.26	5.75	4.94	4.95	5.77	6.23	7.11	7.57	10.65	33.9		84.49	
31	**MAX**	10.89	7.74	8.18	8.74	7.33	9.38	9.35	7.29	8.64	8.25	7.7	10.94	50.73	0.7333	104.43	0.91066
	MAND	12.17	8.33	8.43	6.84	6.07	5.59	5.73	6.1	6.87	8.44	8.32	12.21	37.2		95.1	

32	**MAX**	10.89	6.91	7.45	7.28	6.86	9.05	9.06	6.85	7.24	7.36	7.11	10.84	46.34	0.7913	96.9	0.90351
	MAND	10.81	7.34	7.26	6.59	5.95	5.72	5.85	5.95	6.61	7.28	7.34	10.85	36.67		87.55	
33	**MAX**	10.8	8.35	8.64	8.52	8.08	8.84	8.87	8.12	8.58	8.65	8.28	10.84	51.01	0.7463	106.57	0.90588
	MAND	11.73	8.53	9.03	7.35	6.28	5.38	5.41	6.33	7.32	8.96	8.86	11.36	38.07		96.54	
34	**MAX**	11.18	6.6	7.37	7.87	6.61	9.07	9.07	6.62	8.01	7.42	6.59	11.28	47.25	0.7989	97.69	0.92343
	MAND	11.57	7.32	7.29	6.76	6.31	5.81	5.82	6.32	6.73	7.36	7.34	11.58	37.75		90.21	
35	**MAX**	9.98	6.91	7.52	7.56	7.77	8.68	8.49	7.76	7.59	7.54	6.85	9.99	47.85	0.7657	96.64	0.91215
	MAND	10.87	7.21	7.67	6.99	5.67	5.63	5.67	5.65	7.03	7.64	7.24	10.88	36.64		88.15	
36	**MAX**	11.73	7.53	8.2	8.42	7.42	9.68	9.88	7.53	8.07	8.15	7.67	11.72	51	0.7778	106	0.92509
	MAND	12.43	8.44	8.5	7.57	6.41	5.78	5.85	6.47	7.59	8.26	8.32	12.44	39.67		98.06	

A.3 FIRST DIGITAL MEASUREMENTS

ID #		**R6**	**R5**	**R4**	**R3**	**R2**	**R1**	**L1**	**L2**	**L3**	**L4**	**L5**	**L6**	**Anterior Total**	**Anterior Ratio**	**Arch Total**	**Complete Ratio**
							mm							**mm**	**%**	**mm**	**%**
1	**MAX**	10.6	7.1	7	7.8	7.3	9.1	9.5	7.4	7.8	7	7.1	10.6	49	80.25	98.4	94.59
	MAND	11.2	8.1	7.5	7.3	6.3	5.9	6.2	6.4	7.3	7.6	8.2	11.2	39.3		93.1	
2	**MAX**	10.2	7.4	7.7	8.2	7.6	8.7	9	7.4	8.1	8.2	7.1	10.3	49	77.93	99.9	92.47
	MAND	11.7	7.5	8	6.7	6.7	5.7	6	6.2	7	7.9	7.7	11.5	38.2		92.4	
3	**MAX**	11.3	7.2	7.7	9	7	9.3	9.3	7.1	9.2	7.5	7.3	11.2	51	77.8	103.1	91.84
	MAND	11.8	8	7.8	7.6	6.5	5.9	5.9	6.4	7.5	7.9	7.9	11.7	39.7		94.7	
4	**MAX**	10.3	7	8	9	7.7	9	9.1	7.7	9.1	7.6	7.5	10.6	51.7	78	102.6	92.83
	MAND	11.9	7.7	7.9	7.9	6.5	5.9	5.9	6.4	7.7	8.1	7.6	11.9	40.4		95.3	
5	**MAX**	11.2	7.7	7.7	8.3	6.7	9	9.1	6.8	8.6	7.1	7	11.1	48.4	83.1	100.2	96.85
	MAND	12.2	7.9	8.2	7.8	6.6	5.7	6	6.6	7.6	8.4	8	12	40.2		97	
6	**MAX**	10.8	6.8	8	8.3	7.6	8.9	8.8	6.8	8.4	8.1	6.9	10.3	48.8	79.19	99.8	94.87
	MAND	12.4	8.2	7.6	7.2	6.5	5.6	5.7	6.4	7.3	7.9	7.7	12.3	38.7		94.7	
7	**MAX**	10.4	6.9	7.9	7.2	6.5	9.5	9.5	5.9	7	8	7	10.4	45.6	79.91	96.1	96.1
	MAND	12.4	7.6	7.9	6.7	6.2	5.6	5.5	5.9	6.6	8	7.7	12.4	36.4		92.4	
8	**MAX**	11.3	7.6	8.1	9	8.6	10.2	10.4	8.1	8.7	8.4	7.8	11.3	55	72.93	109.5	88.43
	MAND	11.4	8.6	8.3	7.8	6.4	6	5.9	6.5	7.5	8.3	8.4	11.8	40.1		96.8	
9	**MAX**	10.8	7.7	8	7.9	7.6	9.2	9.6	7.4	8.1	8	7.7	10.6	49.8	80.95	102.4	95.19
	MAND	12.1	8.1	8.4	7.2	6.7	5.9	6.1	6.9	7.5	8.1	8.4	12.1	40.3		97.5	
10	**MAX**	10.3	6.9	6.4	8	6.4	8.3	8.3	6.8	7.8	6.4	6.9	10.4	45.6	76.98	92.8	91.19
	MAND	10.8	7.4	6.7	7.1	5.5	5.1	5.1	5.5	6.8	7.1	7.1	10.5	35.1		84.7	
11	**MAX**	10.7	7.4	7.7	8.2	7.2	9	9.2	7.5	8.4	7.6	7.3	10.6	49.4	81.59	100.7	93.22
	MAND	11.8	7.5	7.6	7.7	6.8	5.8	6	6.8	7.2	7.6	7.2	11.9	40.3		93.9	
12	**MAX**	10.5	7.3	8	8.3	6.8	8.3	8.4	7.3	8.3	8	7.4	10.5	47.4	78.01	99.1	92.35
	MAND	11.5	7.9	7.8	7.5	5.7	4.9	5.1	6.2	7.5	7.8	8	11.5	37		91.5	
13	**MAX**	10.4	7.2	7.6	7.3	6.6	9.3	9.2	6.4	7.7	7.1	7	10.3	46.3	78.09	95.9	90.94
	MAND	11.2	7.4	7	6.5	6.1	5.7	5.6	5.9	6.4	7.1	7.2	11.1	36.2		87.2	
14	**MAX**	10.5	7.1	7.6	8.2	7.5	9.2	9.2	7.4	8.1	7.6	7.1	10.5	49.5	78.57	100	92.12
	MAND	11.5	7.6	7.6	7	6.2	6.3	6.2	6.2	7	7.6	7.4	11.5	38.9		92.1	
15	**MAX**	10.1	7.1	7.1	7.7	6.2	8.6	8.6	6.2	7.2	6.9	7.1	10.1	44.4	78.7	92.9	90.85

	MAND	10.4	7.3	7.2	6.4	5.7	5.4	5.2	5.9	6.4	7.2	7	10.4	35		84.4	
16	**MAX**	10.4	7	7.3	8.1	7	9.4	9.2	7.3	8.2	7.4	7	10.6	49.1	74.68	98.8	90.92
	MAND	11.1	8.1	7.5	6.6	6.2	5.8	5.8	5.8	6.5	7.3	7.7	11.4	36.7		89.8	
17	**MAX**	11.4	7.3	7.8	8.4	6.9	8.9	8.7	7	8.6	8.2	8	11.5	48.4	78.42	102.7	91.58
	MAND	12.4	7.4	7.8	7.2	6.4	5.5	5.5	6.2	7.1	8	8	12.3	38		94.1	
18	**MAX**	10.7	7.6	8.4	8.3	8.3	9.4	9.6	8.1	8.1	8.3	7.8	10.9	51.8	74.92	105.5	92.09
	MAND	12.2	8.3	8.6	7.4	6.3	5.9	5.7	6.2	7.4	8.4	8.6	12.2	38.8		97.2	
19	**MAX**	11.2	7	7.1	8.6	7.5	9.7	9.7	7.5	8.6	7.1	7.1	11.1	51.5	78.95	102.2	92.9
	MAND	11.7	7.8	7.5	7.3	6.5	6.4	6.1	6.6	7.9	7.5	8	11.9	40.7		95	
20	**MAX**	10.9	7.7	8	8.6	7.2	9.6	9.7	6.8	8.7	7.7	7	10.8	50.7	77.48	102.9	90.98
	MAND	11.5	7.7	8.3	7.8	6.1	5.5	5.6	6.7	7.7	8	7.4	11.4	39.3		93.6	
21	**MAX**	9.5	6.9	7	7.6	6.6	7.9	7.9	6.7	7.8	7.3	6.8	9.7	44.5	80.54	91.7	92.58
	MAND	10.2	7	7	6.7	5.9	5.2	5.2	6.1	6.8	7.4	7.4	10	35.9		84.9	
22	**MAX**	10.7	7.4	7.2	7.5	6.2	8.1	8.2	6.4	7.5	7.4	6.9	10.6	43.9	80.86	94.1	92.78
	MAND	11.4	7.5	7.1	6.3	5.9	5.3	5.4	5.9	6.8	7.1	7.5	11.3	35.5		87.3	
23	**MAX**	11	7.6	8	8.7	8.3	9.6	9.6	8.2	8.5	7.8	7	10.7	52.8	75.87	104.8	88.7
	MAND	11.5	7.5	7.5	7.6	6.4	6	6	6.4	7.6	7.5	7.4	11.5	40.1		93	
24	**MAX**	11.9	7.7	7.8	8.3	7.6	9.2	9.3	7.7	8.1	7.6	7.6	11.7	50.1	78.18	104.4	91.97
	MAND	12.2	8.3	7.9	7.5	6.2	5.8	6	6.2	7.5	7.9	8	12.5	39.2		96	
25	**MAX**	10.4	6.7	7.5	8.4	7.3	8.9	8.7	7.3	8.2	7.3	6.8	10.8	48.8	79.1	98.1	92.29
	MAND	10.9	7.6	7.5	7.4	6.3	5.9	5.5	6.1	7.4	7.5	7.4	11	38.6		90.5	
26	**MAX**	10.2	6.9	7.3	7.5	6.4	8.8	8.7	5.9	7.7	7.3	6.9	10.1	45	81.53	93.7	93.79
	MAND	11.4	7.2	7	6.6	6.2	5.6	5.6	6.3	6.4	7	7.2	11.4	36.7		87.9	
27	**MAX**	10.1	6.8	7.1	7.9	7.3	8.9	9	7.3	7.9	7.4	6.8	9.7	48.3	77.67	96.2	94.23
	MAND	11.5	7.7	7.5	6.8	6.3	5.7	5.8	6.1	6.9	7.3	7.5	11.6	37.5		90.7	
28	**MAX**	10.3	7.6	7.2	7.6	6.3	8.8	8.8	6.9	7.6	7.8	7.3	10.1	46	78.18	96.4	92.08
	MAND	11	7.6	7.7	6.8	6	5.3	5.2	5.9	6.8	7.8	7.6	11	36		88.7	
29	**MAX**	10.2	6.8	7.2	8.5	7	8.7	8.7	7.1	8.4	7.5	6.7	10	48.3	82.23	96.7	93
	MAND	10.6	7	7.5	7.7	6.4	5.7	5.7	6.5	7.7	7.5	7	10.5	39.7		90	
30	**MAX**	10.7	6.8	7.1	7.4	6.9	8	8.3	6.9	7.6	7.2	6.8	10.7	45.1	77.96	94.3	91.75
	MAND	10.6	7.6	7.3	6.7	5.7	5.1	5.2	5.8	6.6	7.2	7.8	10.9	35.2		86.6	
31	**MAX**	10.9	8.1	8.1	8.6	7.5	9.5	9.5	7.5	8.5	8.4	8	10.4	51.2	75.68	105.1	92.27
	MAND	12	8.2	8.4	7.2	6.3	5.7	5.9	6.4	7.3	8.5	8.7	12.4	38.7		97	
32	**MAX**	10.8	7	7.7	7.6	6.7	8.9	8.9	7	7.6	7.5	7	10.8	46.7	81.32	97.5	92.39
	MAND	11.2	7.7	7.4	6.7	6.1	6	6	6.1	7	7.4	7.5	11	38		90.1	
33	**MAX**	11.1	8.2	8.7	8.3	8.1	8.8	8.8	8.1	8.3	8.6	7.8	10.7	50.3	75.88	105.6	92.32
	MAND	11.5	8.8	9.1	7.3	6.2	5.5	5.5	6.2	7.4	9.1	9.3	11.5	38.2		97.5	
34	**MAX**	10.3	6.7	7.4	7.4	6.8	9	8.9	6.8	7.8	7.2	6.8	10.2	46.7	84.05	5.5	97.23
	MAND	11.8	7.4	7.5	7.1	6.6	5.8	5.9	6.5	7.3	7.6	7.5	11.8	39.3		92.8	
35	**MAX**	9.8	6.8	7.5	7.6	7.6	8.7	8.7	7.7	7.7	7.6	6.8	10.2	47.9	79.06	96.6	93.15
	MAND	10.8	7.3	7.9	7.4	5.9	5.9	5.7	6	6.9	7.8	7.4	11	37.9		90	
36	**MAX**	11.7	7.5	8.2	8.6	7.4	9.9	9.9	7.2	8.3	7.5	7.7	11.6	51.3	78.22	105.6	93.15
	MAND	12.4	8.3	8.2	7.5	6.7	6	5.9	6.7	7.5	8.5	8.4	12.5	40.1		98.4	

A.4 SECOND DIGITAL MEASUREMENTS

ID #		R6	R5	R4	R3	R2	R1	L1	L2	L3	L4	L5	L6	Anterior Total	Anterior Ratio	Arch Total	Complete Ratio
		mm												mm	%	mm	%
1	MAX	10.7	7	6.8	7.8	7.2	8.9	9.6	7.6	7.9	6.8	7	10.5	49	80.98	97.8	95.49
	MAND	11.2	8.1	7.4	7.3	6.5	6	6	6.5	7.3	7.4	8.2	11.3	39.7		93.4	
2	MAX	10.3	7.2	7.8	8.2	7.6	8.9	9	7.4	8.2	7.9	7.3	10.2	49.3	78.52	100	93.21
	MAND	11.6	7.1	8	6.9	6.6	6.1	5.6	6.8	6.8	8	7.5	11.7	38.7		93.2	
3	MAX	11.3	7.2	7.7	9	7	9.4	9.4	7.2	9.3	7.7	7.4	11.2	51.4	77.83	103.9	92.01
	MAND	11.8	8.1	7.7	7.5	6.6	6	5.9	6.4	7.6	8.1	8	11.9	40		95.6	
4	MAX	10.5	7	8	8.8	7.8	9	9.1	7.7	9.2	7.6	7.3	10.7	51.6	77.75	102.7	92.65
	MAND	11.9	7.4	7.9	7.6	6.6	5.9	5.9	6.4	7.7	8.1	7.6	12	40.1		95.1	
5	MAX	11.3	7.5	7.9	8.7	6.9	9.2	9	7.1	8.7	7.4	7.3	11.3	49.5	82.26	102.2	96.33
	MAND	12.5	8.1	8.3	8	6.7	5.9	6	6.6	7.7	8.1	8.3	12.4	40.8		98.4	
6	MAX	10.7	6.9	7.8	8.4	7.5	8.9	8.9	6.5	8.5	8.3	6.9	10.7	48.6	80.52	100.1	95.3
	MAND	12.4	7.7	7.9	7.3	6.4	5.9	5.8	6.5	7.3	7.7	8.3	12.3	39.1		95.4	
7	MAX	10.8	6.9	7.9	7	6.4	9.4	9.3	5.9	7	7.8	6.9	10.8	45	80.71	96.1	95.89
	MAND	12.5	7.5	7.9	6.7	6.2	5.5	5.4	6	6.5	7.9	7.5	12.5	36.3		92.2	
8	MAX	11.2	7.5	8.1	8.8	8.2	10.1	10.4	8	8.7	8.4	7.7	11.6	54.2	74.35	108.8	89.93
	MAND	11.8	8.6	8.3	7.9	6.4	6	5.9	6.5	7.5	8.4	8.5	11.8	40.3		97.8	
9	MAX	10.8	7.8	8.1	8.2	7.6	9.2	9.5	7.4	8.3	7.9	7.8	10.7	50.2	80.94	103.3	94.7
	MAND	12.3	8.1	8.3	7.3	6.7	6.1	6.1	6.9	7.4	8.2	8.1	12.2	40.6		97.8	
10	MAX	10.4	6.6	6.7	8.1	6.5	8.4	8.2	6.5	8.1	6.4	6.7	10.1	45.7	76.94	92.6	91.95
	MAND	10.4	7.2	7.1	6.8	5.5	5.2	5.1	5.5	7.1	6.8	7.3	11.1	35.2		85.2	
11	MAX	10.9	7.3	7.8	8.4	7.2	8.8	8.8	6.8	8.3	7.5	7.3	10.8	48.4	83.37	99.8	94.34
	MAND	11.9	7.5	7.7	7.6	6.8	5.9	6	6.9	7.2	7.5	7.3	11.9	40.4		94.2	
12	MAX	10.3	7.3	7.9	8.5	6.9	8.5	8.5	7.3	8.3	8	7.5	10.2	47.9	76.96	99.2	92.34
	MAND	11.6	8	7.8	7.5	6.2	5	4.9	5.7	7.5	7.7	8	11.6	36.9		91.6	
13	MAX	10.6	7.3	7.2	7.2	6.8	9	9.1	6.5	7.4	7.1	7.1	10.6	46	78.81	96.1	91.16
	MAND	11.5	7.3	7.3	6.6	6	5.7	5.7	6	6.2	7.2	7.2	10.9	36.3		87.6	
14	MAX	10.9	7.2	7.9	8.3	7.8	8.9	9.1	7.5	7.9	7.4	6.9	10.8	49.5	79.55	100.5	93.23
	MAND	11.3	7.8	7.9	7.1	6.4	6.4	6	6.6	6.9	8	7.6	11.7	39.4		93.7	
15	MAX	10.1	7.1	7	7.7	6.2	8.6	8.7	6.3	7.1	6.8	7.1	9.9	44.5	79.28	92.6	91.62
	MAND	10.4	7.6	7.1	6.2	5.7	5.4	5.3	6	6.8	7.1	6.9	10.4	35.3		84.8	
16	MAX	10.4	7.3	7.3	8.3	7.2	9.4	9.4	7.3	8.3	7.3	6.9	10.6	49.9	74.57	99.8	90.43
	MAND	11.4	8	7.5	6.7	6.2	5.8	5.9	5.9	6.7	7.3	7.6	11.1	37.2		90.2	
17	MAX	11.3	7.4	8.1	8.4	7	8.8	8.6	7	8.6	8	8.1	11.6	48.5	77.94	102.9	91.42
	MAND	12.7	7.4	8	7.5	6.3	5.4	5.4	6.3	6.8	7.7	8.1	12.5	37.8		94.1	
18	MAX	11	7.7	8.3	8.3	8.2	9.4	9.5	8.3	8.4	8.3	7.6	11.1	52.1	74.98	106.2	92.2
	MAND	12.2	8.4	8.7	7.3	6.5	5.8	5.7	6.4	7.4	8.5	8.6	12.5	39.1		98	
19	MAX	11.3	6.9	7.2	8.6	7.5	9.8	9.7	7.5	8.6	7.2	7	11.2	51.7	78.91	102.3	92.82
	MAND	11.6	7.9	7.6	7.4	6.4	6.3	6.1	6.6	7.8	7.5	7.6	12.1	40.8		95	
20	MAX	10.9	7.5	8.2	8.4	7.4	9.8	9.8	6.9	8.6	7.8	7	10.9	50.9	78.46	103.3	93.26
	MAND	11.9	8.2	8.5	8	6.2	5.7	5.7	6.3	8	8.1	7.8	11.8	40		96.3	
21	MAX	9.8	6.8	7.2	7.8	6.7	7.7	7.8	6.8	8	7.3	6.8	9.3	44.9	80.47	92.1	93.51
	MAND	10.2	7	7.7	6.8	5.9	5.3	5.2	6.1	6.9	7.7	7.3	10.2	36.1		86.1	
22	MAX	10.9	7.1	7.3	7.7	6.1	8.4	8.3	6.3	7.6	7.3	6.9	10.9	44.3	79.45	94.8	92.79
	MAND	11.7	7.7	7.2	6.4	5.9	5.3	5.4	5.9	6.4	7	7.4	11.7	35.2		87.9	
23	MAX	10.9	7.3	7.9	8.8	8.5	9.7	9.4	8.4	8.5	7.9	6.8	10.6	53.3	75.9	104.7	89.19
	MAND	11.4	7.3	7.6	7.7	6.5	6	6.1	6.6	7.5	7.8	7.5	11.5	40.4		93.4	
24	MAX	11.8	7.7	7.7	8.3	7.3	9.2	9.2	7.4	8.5	7.7	7.8	11.7	50	78.67	104.4	91.92

	MAND	12.4	7.9	7.9	7.6	6.2	6	5.9	6.1	7.5	7.9	8.3	12.2	39.3		96	
25	**MAX**	10.8	6.8	7.4	8.2	7.3	8.9	8.8	7.3	8.2	7.3	6.8	11.2	48.8	79.1	98.9	91.95
	MAND	11.1	7.7	7.7	7.4	6.4	5.7	5.6	6.1	7.4	7.5	7.5	11.1	38.6		91	
26	**MAX**	10.7	7.3	7.3	7.5	6.6	8.9	8.9	5.9	7.9	7.3	7	10.6	45.6	82.22	95.9	93.72
	MAND	11.8	7.3	7.2	6.9	6.3	5.7	5.8	6.3	6.5	7.1	7.2	11.8	37.5		89.8	
27	**MAX**	10.2	6.8	7.2	7.9	7.3	9	9	7.2	7.6	7.4	6.9	10	48	78.07	96.5	94.01
	MAND	11.6	7.5	7.4	6.9	6	5.7	5.8	6.1	7	7.4	7.6	11.8	37.5		90.7	
28	**MAX**	10.4	7.5	7.3	7.8	6.2	8.8	8.9	7.1	7.7	7.6	7.3	10.3	46.5	77.77	96.9	91.83
	MAND	11	7.6	7.7	6.8	6	5.3	5.4	5.9	6.8	7.7	7.8	11	36.2		89	
29	**MAX**	9.9	6.9	7.4	8.3	6.9	8.8	8.8	7	8.4	7.5	6.7	9.7	48.3	81.42	96.4	93.7
	MAND	10.9	7.1	7.6	7.6	6.3	5.8	5.7	6.4	7.5	7.6	7.1	10.7	39.9		90.3	
30	**MAX**	10.7	6.6	7.1	7.4	6.8	8.2	8.4	7	7.8	7.3	7	10.8	45.6	77.44	95	91.78
	MAND	10.6	7.8	7.4	6.7	5.8	5.2	5.1	5.8	6.6	7.4	7.9	10.8	35.3		87.2	
31	**MAX**	11	8.2	8.3	8.6	7.4	9.5	9.5	7.4	8.3	8.6	8	10.5	50.6	76.17	105.1	92.62
	MAND	12.4	8.4	8.4	7.3	6.3	5.6	5.9	6.4	7.2	8.4	8.7	12.4	38.6		97.3	
32	**MAX**	10.8	7.2	7.8	7.4	6.7	9.1	9	6.9	7.2	7.4	7.2	10.8	46.4	81.96	97.5	92.96
	MAND	11.3	7.9	7.6	6.8	6	6	6	6.1	7.2	7.5	7.4	10.8	38		90.6	
33	**MAX**	10.9	8.2	8.9	8.4	8.1	8.7	8.7	8.1	8.5	8.5	7.9	10.7	50.6	75.51	105.8	92.03
	MAND	11.7	8.5	9.2	7.5	6.2	5.4	5.5	6.2	7.4	9	9.3	11.6	38.2		97.4	
34	**MAX**	10.3	6.7	7.4	7.8	6.6	9	9.2	6.4	8	7.4	6.8	10.3	47	84.14	95.9	97.07
	MAND	11.9	7.3	7.5	7.4	6.6	5.8	5.8	6.6	7.4	7.7	7.5	11.8	39.5		93.1	
35	**MAX**	9.9	7.2	7.5	7.7	7.7	8.8	8.7	7.8	7.5	7.4	6.7	10.2	48.2	78.32	97.1	92.7
	MAND	10.9	7.3	7.9	7.3	5.9	5.8	5.8	6	6.9	7.6	7.5	11.1	37.7		90	
36	**MAX**	11.7	7.6	7.9	8.3	7.6	9.9	9.9	7.3	8.2	7.9	7.7	11.6	51.2	78.62	105.5	93.05
	MAND	12.8	8.5	8.1	7.4	6.5	5.9	6	6.9	7.5	8	8.2	12.4	40.3		98.2	

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