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Using a mathematical model to determine dental arch- perimeter in Class II patients presenting at UWC Orthodontic clinics

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KEYWORDS

Arch Length

Inter-molar width

Arch Depth

Tooth size Arch length discrepancy

Parabola

Arc length

Orthodontics

ABSTRACT

Introduction

Determining arch perimeter is of importance in both a clinical setting, where it is used to determine space requirements, as well as in an epidemiological setting where it is used to describe large populations.

Physical measurement of arch perimeter is time consuming and may be prone to operator errors when done on study casts and even more so in a clinical situation.

The use of a simple mathematical model to predict arch perimeter, using a few measurements that can be done easily and reliably, would be of great use to the practitioner.

Aim

The aim of this study was to assess the accuracy of equations previously used by Mills (1965), and as the formula used by Spiegel (2008) to determine the arch perimeter in Class II individuals with different arch forms, in a population group presenting at UWC Orthodontic clinics.

Materials and Methods

The sample consisted of 74 models from 37 Class II patients, with 25 females and 12 males, of which 27 were Division 1 and 10 were Division 2 malocclusions. Patient records were selected from model archives of the Orthodontic Department at the University of the Western Cape.

The models were digitized using the Sirona Primescan Intra-oral scanner and measurements were done with the Cerec Ortho SW 2.0 and Blender 2.83LTS 3D software.

Measurements were done by four examiners, of which two were qualified orthodontists and two final-year registrars. Using a Two-way random effects model the inter-rater and intra-rater reliability was shown to be very high for all

measurements except intermolar width.

Two mathematical equations for a parabola were evaluated in determining arch perimeter, using Intermolar width and arch depth measurements only.

The mathematically determined arch perimeter was compared to the physically measured gold standard to determine accuracy and precision.

The sample was divided into subgroups to test the mathematical model with different covariates.

Results

Regression models on data of the present study demonstrated that gender and upper or lower arch played a significant role in the determination of arch perimeter. Type of Class II malocclusion and archform was shown to play a less significant role in determining Arch perimeter.

The mathematical model (Modelper) proposed by Mills (1965) was found to predict arch perimeter measurements with a higher concordance correlation coefficient than the equation proposed by Spiegel (Modelper2) (2008).

Modelper had substantial concordance (0,96) for the upper arch but was poor (0,88) for the lower arch. When adding archform as covariate, the concordance in the upper arch was substantial for Ovoid arches (0,97) but moderate for Square and Tapered arches (0,95 and 0,94 respectively). In the lower arch the concordance was found to be poor for Ovoid and Square arches (0,83 and 0,86).

Modelper did not show bias but showed some variability.

Modelper2 showed bias, underestimating the Arch perimeter in most cases. The concordance was worse than that obtained with Modelper, with the upper and lower arch measurement having a poor concordance (0,88 and 0,79 respectively).

When adding archform as co-variate, the concordance using Modelper2 was

moderate for tapered arches (0,94), but poor for Ovoid and Square arches (0,8 and 0,84 respectively). For the lower arch concordance was poor for both Ovoid and Square arches (0,74 and 0,75).
Because the sample contained too few lower tapered this data was not subjected to statistical analysis.

Conclusions

Using digitized models and doing measurements digitally is highly reproducible as shown by the almost perfect inter-rater reliability.
The mathematical model introduced by Mills is more accurate in predicting Arch perimeter than the model proposed by Spiegel.

The concordance and mean differences between the gold standard and results obtained from the mathematical models are statistically significant. This would indicate that the mathematical models for a parabola do not describe the upper or lower arch to a significant degree, and should not be used in determining Arch perimeter in situations where a great degree of accuracy and precision is required.

DECLARATION

I declare that "*Using a mathematical model to determine dental arch- perimeter in Class II patients presenting at UWC Orthodontic clinics*" is my own work, that it has not been submitted for any degree or examination in any university, and that all the sources I have used or quoted have been indicated and acknowledged by complete references.

I hereby declare no known conflict of interest or have any financial incentive for conducting the study.

Full name: Frederick Johannes du Raan Date: 01 October 2020

Signature of Candidate

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My fellow registrars for making these past four years truly memorable. It would not have been the same without you!

DEDICATION

This thesis is dedicated to my family who has supported me on this long road to the fulfillment of my dream of becoming an orthodontist. It has not always been easy, but it has always been worth it.

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LIST OF ABBREVIATIONS

TSALD – Tooth size arch length discrepancy

Goldper – Gold standard for Arch Perimeter

Modelper – Arch Perimeter obtained with Mills' mathematical equation

Modelper2 – Arch Perimeter obtained with Spiegel's mathematical equation

ICC – Intraclass Correlation Coefficient

CCC- Concordance Correlation Coefficient

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CHAPTER 1

1. INTRODUCTION

Irregularity, or crowding of the dentition is perceived as unaesthetic, and as such it is one of the main motivating factors for people to obtain orthodontic treatment (Gosney, 1986).

Crowding is the manifestation of the discrepancy between the available arch length and the sum of the mesio-distal widths within the dental arch (van der Linden, 1974). This discrepancy can be multi-factorial in origin. To account for this discrepancy, the teeth might be excessively large, the skeletal/bony bases might be too small, or there might be a combination of these two factors (Howe *et al.,* 1983).

Tooth Size Arch Length Discrepancy (TSALD) can be defined as the interaction between the space available (arch length) and the space needed (tooth size) (Howe *et al.*, 1983). Arch length, together with arch width, can be seen as a reflection of the underlying skeletal bases. Deficient arch length, as measured from the mesial of the left molar, to the mesial of the right molar, has been shown to be one of the most important indicators for the occurrence of dental crowding (Mills, 1964; Radnzic, 1988; Howe *et al., 1983*).

The need to have a quick and reliable method to determine arch length during model analysis is the driving idea of testing the validity of the mathematical method. The validity of using different mathematical models in determining dental arch length has been investigated by various researchers (Mills and Hamilton, 1965; Currier, 1969; Begole, 1980; Battagel, 1996; Braun *et al.*, 1998; Noroozi *et al.*, 2001; Alharbi *et al.*, 2008). However, it is evident from the literature that using the formula for a parabola to determine dental arch length has not been researched intensively. Furthermore, no studies reporting the use of mathematical models to determine dental arch lengths have been done on the population of the Western Cape, South Africa.

CHAPTER 2

2. LITERATURE REVIEW

2.1. Dental Arch Crowding

The etiology of crowding is not fully understood, and there are contradictory findings in the literature as to the contribution of different parameters to crowding of the dental arches. Crowding can be seen as the discrepancy between the available arch length and the sum of the mesio-distal widths of the teeth in the arch (van der Linden, 1974). Excessively large teeth, small skeletal/bony bases, or a combination of these two factors is seen as the causative factors (Howe *et al.*, 1983).

2.1.1 Tooth Size discrepancies

While certain authors have found that the mesio-distal dimensions of the teeth are larger than normal in crowded dentitions (Doris *et al.*, 1981; Poosti and Jalali, 2007; Puri *et al.*, 2007; Normando *et al.*, 2016), others have found that there are no definite correlations with tooth size and the occurrence of crowding (Radnzic 1988; Howe *et al.,* 1983). These studies indicate that where significant crowding is present, the mesio-distal tooth sizes are larger than in arches with mild or moderate crowding. In spaced arches, the mesiodistal dimensions are smaller than in mildly crowded arches.

2.1.2 Arch Dimension

With regards to the dimensions of the skeletal/bone bases, there is a wealth of information as to the role that arch length, intercanine width and intermolar width plays in the occurrence of crowded and uncrowded dentitions.(Mills, 1964; Howe *et al.*, 1983; D. Radnzic, 1988; Melo *et al.*, 2001; Bernabé *et al.*, 2005). It has been reported that there is a significant difference in the arch width and depth between crowded and uncrowded cases (Howe *et al.,* 1983).

Being one of the parameters involved in determining arch perimeter, arch width has been shown to play an important role in determining if an arch will be crowded or not. The most common width measurements taken are the inter- molar and intercanine widths.

Inter-canine width:

Studies evaluating the influence of the arch-width variables have shown that the role that intercanine width plays is unclear and shows contradictory results. While some authors (Fastlicht, 1970) show differences in intercanine width between crowded and uncrowded cases, others (Sampson and Richards, 1985) have reported no differences.

The different results in these studies could be due to the fact that different techniques for measuring intercanine width have been employed.

These different techniques include measuring between canine cusp tips (Sampson and Richards, 1985) or measuring between maximum buccal prominences (Fastlicht, 1970).

Inter-molar width:

Intermolar width has been shown to be highly correlated to arch length, and thus to crowding in the arch.

The maxillary intermolar arch width difference between crowded and uncrowded cases has been reported to be, on average, +- 6mm in males and females, while total arch length differences was, on average, +- 5mm in males and females (Howe *et al.*, 1983).

2.2 Dental Space Analysis

Dental space analysis is done by measuring the mesio-distal widths of the individual teeth in the arch. To determine the space available to accommodate the teeth, the arch perimeter is measured, and the sum of the mesio-distal widths is subtracted from the space available.

2.2.1 Plaster vs Digital models

Space analysis to determine a TSALD can be done on plaster or digitized models with a high degree of accuracy. Numerous studies have looked at the accuracy of different measuring methods, and have concluded that plaster and digitized models compares favorably (Gracco *et al.*, 2007; Mullen *et al.*, 2007; Naidu *et al.*, 2009). In the absence of digitized models, plaster models can be measured using digital calipers, Vernier's gauges or brass wire.

In this study models were digitized with the Sirona Primescan Intra-oral scanner. Ender et al (2019) reported that the Primescan models showed that the trueness and precision of full arch scans deviated less than 50µm from those of conventional models poured from polyvinylsiloxane impressions. This deviation from conventional models is deemed to be well within the range of clinical acceptability.

2.2.2 Arch length measurement

Arch length can be measured manually or digitally, by measuring arch perimeter from one first molar to the other over the contact points of posterior teeth and following the basal bone in the anterior region (Kirschen *et al.*, 2000).

The two methods most commonly used to measure the arch length are firstly, to divide the dental arch into segments that can be measured as straight line approximation of the arch, and secondly by contouring a piece of wire (or a curved line on the computer screen) to the line of occlusion and then straightening it out for measurement (Proffit *et al.*, 2013)

It is important to note that arch length, as used in certain texts (Mills, 1964; Mills and Hamilton, 1965) refers to arch depth. Arch depth is a midline measurement from the incisal papilla to a line formed from the distal of the left first molar to the distal of the right first molar. In these articles, arch length as it is understood in current terminology, is referred to as arch perimeter.

Measuring the actual arch perimeter is quite time consuming and may be subject to error during measurement. Ideally an easy and reliable method of determining arch perimeter would benefit the clinician during diagnosis and treatment planning of an orthodontic case.

With the increase in digital workflow in many orthodontic practices, more practitioners are relying on the use of software analysis of digitized models. To be of use, these measurements should ideally be accurate, reproduceable and quicker to perform than using the “golden standard” of measuring with a brass wire.

A study done on dental measurements using different technologies (Grünheid et al., 2014) concluded that measurements on digital models can be as accurate as those taken on plaster models and might be more reproducible and significantly faster.

Another quick method of calculating the arch-perimeter, which this study examined, is the use of a mathematical equation describing a specific arch form, which could be done while the patient is in the chair and requiring only limited measurements.

2.3 Dental Arch Form Analysis

Arch width in the inter-canine and inter-molar region increases from age 3 to 13. Thereafter there is a slight decrease in width just after eruption of the permanent dentition, where after it stabilizes (Bishara *et al.*, 1997).

Arch length has been shown to increase till the age of 8 in the mandibular arch and until age of 13 in the maxillary arch. After these ages there is, however, a significant decrease in arch length up to the age of 45 (latest age of the study) (Bishara et al., 1998)

The dental arch has been described by numerous authors to have specific geometric or mathematical forms.

Shapes commonly ascribed to the dental arch includes semi-circular (Hawley, 1905, as cited in Lee *et al.*, 2011), elliptical (Currier, 1969), parabolic (Mills and Hamilton, 1965), hyperbolic or having a catenary curve shape (White, 1977; Battagel, 1996).

Studies done to fit the catenary curve to the mandibular arch have proven to be more effective than for the maxillary arch. Even so it was found that the curve only fitted 27% of the arches in the study sample (White, 1977)

Currier (1969) has shown that the middle curve of the upper and lower arches can be described best as being parabolic. The parabola shows the least variance when compared to other geometric shapes when fitted onto this curve (Currier, 1969). When measuring arch perimeter during space analysis, a line following this middle curve is used, stretching from the middle of the mesial aspect of the left first molar to the middle of the mesial aspect of the right first molar. The landmarks used along which the length will be measured are the central fossae of the molars, the mesial and distal fossae of the premolars, the cusp tip of the canine and the incisal edges of the central and lateral incisors (Kirschen *et al.* , 2000).

2.4 Mathematical models to determine arch length

Various mathematical models with varying complexity have been tested to determine their efficacy in calculating dental arch length. The mathematical models rely on the arch being described as having a specific shape/form.

Mathematical models that have been tested by other researchers includes cubic spline function (Begole, 1980), polynomial functions including fourth- order polynomial (Alharbi *et al.* , 2008), beta function curves (Braun *et al*., 1998; Noroozi *et al.*, 2001) and parabola arc length functions (Mills and Hamilton, 1965).

2.4.1 Cubic Spline function

The use of the cubic spline function has been proven to be accurate in well aligned models but has not adequately been tested in malaligned models (Begole, 1980; Alharbi *et al.*, 2008). By using more numerous knots in positioning the splines, a more accurate length determination will be obtained, but this entails more effort on the part of the clinician, which defies the purpose of using a mathematical equation to simplify the task of arch length determination.

2.4.2 Polynomial Curves

The use of beta function curves as well as fourth order polynomials has proven to be effective in determining arch length in various different types of malocclusions (Braun *et al*., 1998; Noroozi *et al*, 2001) and could have been used in this study as well.

2.4.3 Beta function Curves

The use of Beta curves has been proven to be accurate in describing dental arch forms for various malocclusions (Braun *et al.*, 1998), with a correlation coefficient of .98, but the use of a curve fitting program was found to be necessary to fit a relevant Beta curve to the different models.

2.4.4 Parabolic Curves

The use of a mathematical equation for determining the arc length of a parabola in the determination of arch perimeter was also reported (Mills and Hamilton, 1965) and may be used due to the simplicity of the equation, as well as the evidence by Currier (1969) that the middle curve of dental arches follows a parabolic shape.

Mills & Hamilton (1965) used a mathematical equation to determine the arc length of a parabola to determine dental arch length:

Arch length = $2\sqrt{y^2 + \frac{4x^2}{3}}$

In this equation X= arch depth and Y= Intermolar width (Figure 2.4.1). In the study by Mills, no mention was made as to the origin of the equation used to determine the arch perimeter.

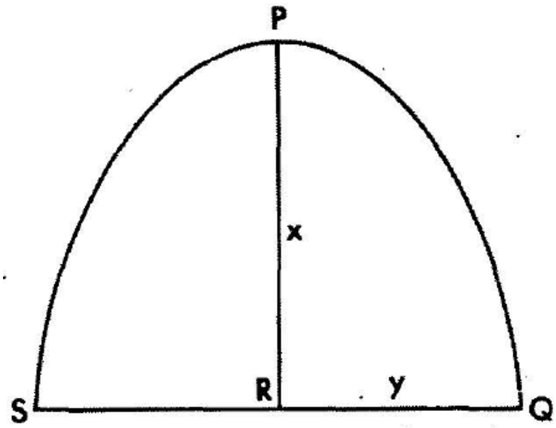

Figure 2.4.1 The length of the arc of a parabola, as arc SPQ, where x = PR, and y =QR (From Mills and Hamilton, 1965).

The perimeter of any section of a parabola can be obtained using this formula by taking the X and Y measurements at the relevant section which needs to be measured. Mills & Hamilton (1965) found that 96,13% of the measurements using the mathematical formula fell within the 95% confidence interval. All of the models that fell outside the desired confidence interval had either highly tapered or square arch shapes.

This mathematical formula has been shown to be accurate and time-saving and has proven to be more time efficient and equally reliant as direct measurement on dental casts (Radnzic, 1988).

The study done by Mills and Hamilton (1965) does have a few shortcomings.
The population studied included only males of mixed European descent between the ages of 17-21, therefore no validity of the equation for different racial or sexual groupings of various ages was determined.

In the initial study done in 1964 the models were not grouped according to Angle type of malocclusion or dental arch-form, which might give have given more insight as to the accuracy of using the formula in these sub-groups (Mills, 1964).

According to Spiegel (2008), the formula to determine the arc length of a parabola is:

$$L = \frac{1}{2}\sqrt{b^2 + 16 \cdot a^2} + \frac{b^2}{8 \cdot a}\ln\left(\frac{4 \cdot a + \sqrt{b^2 + 16 \cdot a^2}}{b}\right)$$

In the equation, L = arc length (Arch perimeter), a = axis length (arch depth) and b = perpendicular cord length (intermolar width).

CHAPTER 3

3. AIM AND OBJECTIVES

3.1 Aim

The aim of this study was to assess the accuracy of equations previously used by Mills (1965), as well as the formula used by Spiegel *et al* (2008) to determine the arch perimeter in Class II individuals with different arch forms, in a population group presenting at UWC Orthodontic clinics.

3.2 Objectives

The objectives of the study were to:

Measure the inter-molar arch width and arch depth on the scanned pre-treatment study models using Blender 2.83LTS 3D software.

Physically measure the arch perimeter using a virtual brass wire (Cerec Ortho SW 2.0).

Calculate the overall length of the arc using two different equations for parabolas.

Compare the physically measured overall length of the arc to the length of the arc calculated using the equation.

3.3 Hypothesis

The null hypothesis of this study is that a mathematical formula for determining the arc length of a parabola can be used to reliably determine dental arch length in the Class II population seen at the Orthodontic clinics of the University of the Western Cape.

CHAPTER 4

4. MATERIALS AND METHODS

4.1 Study design

This study was an Analytical Cross-Sectional study

4.2 Sampling

Pre-treatment study models of patients that have been or are currently under treatment by the orthodontic registrars at the Department of Orthodontics at the University of the Western Cape were included.
The patients were from both the Tygerberg Orthodontic clinic, as well as the Mitchell's Plain Orthodontic clinic.

After noting if the patient was male or female, the study models were allocated a computer-generated number to prevent identification of the patient via the study models (Appendix C). No names of any patient were on any of the information gathering sheets, only the the generated model number.
Models were grouped into male and female groups and Angle Class II division (div) 1 and Class II div 2 groups.
The models were also grouped according to arch form (tapered, ovoid and square).
Grouping into the different archform was done by best fit to an archform template by G&H Orthodontics (Franklin, USA). The Tapered archwire used for classification was the Bioform III wire, for Ovoid arches the Europa I archform and the Trueform I archform for square arches (Figure 4.2.1)
This resulted in a total of four co-variate groups to compare the accuracy of the mathematical methods compared to the virtual brass-wire method.

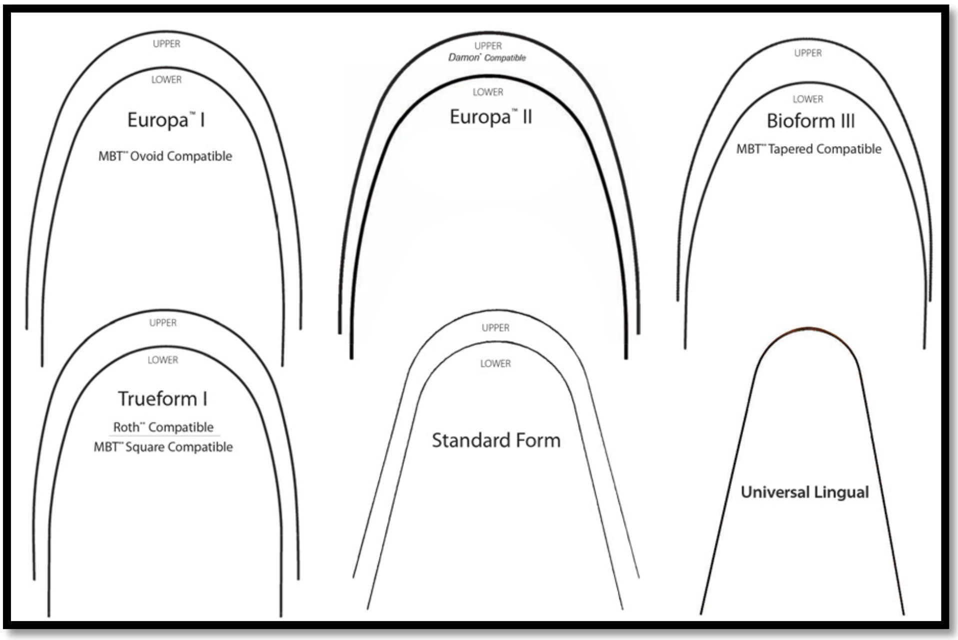

Figure 4.2.1: Archwires used to sub-classify sample into archforms. Archforms used were he Bioform III (Tapered), Europa I (Ovoid) and Trueform I (Square)

(From G&H Orthodontics catalogue,Franklin,USA)

4.3 Inclusion Criteria

Models of male and female patients between the ages of 11 and 25.

Models of patients must show that they are in the permanent dentition phase.

A full complement of teeth up to (and including) the first molars.

No obvious loss of tooth material mesiodistally as a result of caries, fractures, interproximal wear.

4.4 Exclusion Criteria

Subjects who have undergone orthognathic surgery.

Models of patients with known syndromes that affect the dentition, head and neck, or any metabolic/systemic conditions known to affect growth.

Blatant asymmetry of the arches.

Patients who have undergone previous orthodontic treatment.

Flaws in the models such that they cannot be measured.

4.5 Acquisition of scanned models

Only Pre-treatment study models was measured. As previous orthodontic treatment is part of the exclusion criteria, no post-treatment records were used for this study.

Measurements were done on models digitized with a Sirona Primescan intra-oral scanner (Dentsply Sirona, York, USA), using the manufacturers indicated digital orthodontic analysis program, Cerec Ortho SW 2.0 Dentsply Sirona, York, USA). The precision and trueness of full-arch models scanned with the Primescan has been shown to have clinically adequate accuracy to be used in this study (Ender *et al.*, 2019).

4.6 Data Collection

Two mathematical models for determining the arc length of a parabola were tested to a physically measured Arch Perimeter that functioned as the Gold standard (Virtual Brass-wire measurement).

Neither the gold standard nor mathematical model is based on knowledge of the absolute value of the parameters being measured (Arch Perimeter, Arch depth and Intermolar width).

4.6.1 Measurement with a Virtual Brass-wire

All measurements were done by four observers. Two of the observers are qualified orthodontists and two, including the main researcher, are final year registrars.
Inter-observer and Intra-observer variability were measured and analyzed as described in section 5.2 and 5.3, below.

Physical measurement of the arch perimeter was done using the Model Analysis module of the Cerec Ortho SW 2.0. The use of this technique, and not the “golden standard” of a brass wire is due to the findings that measurements on digital models can be as accurate as, and might be more reproducible and significantly faster than, those taken on plaster models (Grünheid *et al*., 2014)

The Arch length was measured according to the technique described by Kirschen *et al* (2000), where the arch-form should reflect the majority of teeth, not necessarily the arch passing through the incisal edge of the most prominent incisor in each quadrant (Figure 4.6.1).

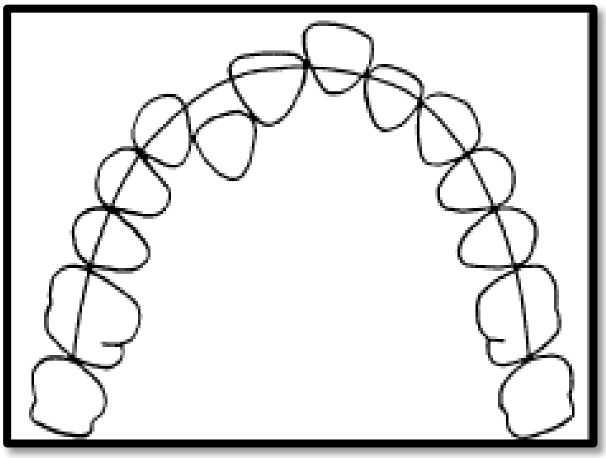

Figure 4.6.1: **Arch form selected for assessment of crowding reflects majority of teeth.**

The landmarks used along which the length was measured were the central fossae of the molars, the mesial and distal fossae of the premolars, the cusp tip of the canine and the incisal edges of the central and lateral incisors.

Measurements for the total arch length were taken from the mesial aspect of the left first molar to the mesial aspect of the right first molar.

4.6.2 Measurement for mathematical formulae

Measurement of the variables needed for the mathematical equations were done with Blender 2.83LTS 3D software, an industry-grade 3D analysis program.

Arch width measurement was taken from the midpoint of the mesial aspect of the two opposing first molars, Figure 4.6.2 -II.

Arch depth for the total arch length was measured from the interdental papilla between the 11 and 21 towards a line connecting the mesial aspects of the opposing first molars, Figure 4.6.2 - IV.

In the event that the arches are asymmetrical the arch depth will be an average of the distance a line from the interdental papilla perpendicular to a line from the left first molar and the distance a line from the interdental papilla perpendicular to a line from the right first molar.

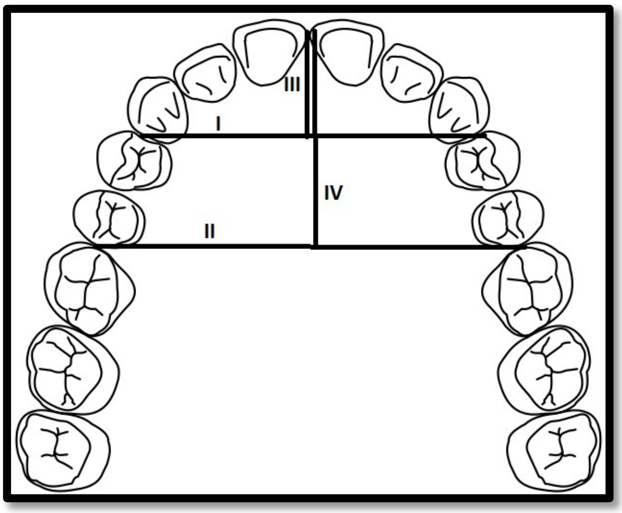

Figure 4.6.2: **Measurements taken to determine arch width and arch depth.**

I- Anterior segment width; **II-** Total Arch length width; **III-** Anterior segment Arch depth; **IV-** Total Arch length depth.

To ensure that the physical arch-length measurement and points used for the mathematical equation are exactly the same, a pencil mark was placed on the start and end point of the anterior and overall arc.

4.7 Statistical Analysis

All recorded data was entered into an Excel® spread sheet (Appendix D and Appendix E). Categorical variables were summarized by frequency and percentage tabulation. Continuous variables were summarized by the mean, standard deviation, median and interquartile range.

Interrater and reclassification reliability were quantified by Lin's Concordance Correlation Coefficient (Lawrence and Lin, 1989)

Lin's concordance correlation coefficient (ρc) is a measure of how well a set of bivariate data (Y) compares to a "gold standard" measurement or test (X). You can also compare two sets of measurements without a gold standard comparison. In that case, the second set of measurements would be substituted for the gold standard.

(ρc) ranges from 0 to ±1 and should be interpreted according to the guidelines given by McBride (2005). (Table 4.7.1)

Table 4.7.1: Interpretation of Lin's CCC

Lin's CCC	Interpretation of correlation
< 0.90	poor
0.90 to 0.95	moderate
0.95 to 0.99	substantial
> 0.99	almost perfect

The association between the different mathematical models and the gold standard was analyzed with Lin's CCC and Spearmans's correlation and Pearson's correlation coefficients.

Interpretation of Spearman and Pearson's correlation coefficient (r) can be seen in Table 4.7.2 (Akoglu, 2018)

Table 4.7.2: Interpretation of Spearman and Pearson's correlation coefficient

Correlation coefficient		Interpretation of correlation
+1	−1	Perfect
+0.9	−0.9	Very Strong
+0.8	−0.8	Very Strong
+0.6	−0.6	Moderate
+0.3	−0.3	Fair
+0.1	−0.1	Poor
0	0	None

The relationship between gender, archform and type of arch to Arch Perimeter was determined by ordinal logistic regression with Arch Perimeter as the dependent variable and gender, archform and arch type as the independent variables.

Data analysis was carried out in STATA 16.1 Statistics/Data analysis (Statacorp LLC, Texas).

The 5% significance level was used for all statistical tests.

4.8 Ethical considerations

Permission to conduct the study was obtained from the Biomedical Research Ethics Committee (BMREC) of the School of Dentistry at the University of the Western Cape (Appendix A).

Approval was also obtained from the Dean of the School of Dentistry (UWC) to access archived orthodontic records, and in particular initial study models (Appendix B).

The study conducted was a retrospective study. Therefore, no new records were taken, or expenses incurred by the patients for the purpose of conducting this research as all the study models examined had already been taken as part of prior clinical examinations.

Patient anonymity was respected, and the identity of the patients was not revealed. Every study model collected was assigned a random number for identification (Appendix C). This was to de-identify the patients and to ensure that patient confidentiality was maintained during the completion of this research.

The information was only retained by the main researcher (RC) and stored on a password safe computer.

The author declares to have no affiliation with, and therefore no conflict of interest regarding the use of the Sirona Primescan or their digital orthodontic analysis program, Cerec Ortho SW 2.0

CHAPTER 5

5. RESULTS

5.1 Descriptive statistics

The final sample size was 74 arches obtained from 37 patients. Descriptive data for the sample is given in Table 5.1.1.
Between the genders, females were overrepresented, accounting for 67,57% of the sample.
An equal number of upper and lower arches were used.

With regards to type of Class II malocclusion, the Class II division 2 cases were underrepresented, making up only 27,03% of the sample, which was expected due to the natural lower distribution of these cases.

Tapered archforms were represented the least at 16,22%, while ovoid archforms made up half of the sample.

Table 5.1.2 depicts data describing a regression model using the covariates of arch type (upper or lower arch), gender and archform on the subject of the measured arch perimeter (Goldperimeter) as random effect in linear mixed effects model.
Significant differences in arch perimeter were found between the upper and lower arches, with upper arches having an average of 10,26 mm larger perimeter than lower arches.

Males were found to have, on average, 6,3mm greater arch perimeter, making gender a significant determinant in the arch perimeter.
Arch form however was not found to be a significant determinant of arch perimeter (p=0,0577).

The variance component of the subjects are substantial, with the intra-class correlation coefficient at 0.45 (12.56/(12.56+15.68)).

Thus, the between subject variation is substantial and this means that the correlation between the upper and lower arch length is high.

Table 5.1.1: Descriptive statistics of the sample used.

Tabulation of gender

Gender	Freq.	Percent	Cum.
Female	25	67.57	67.57
Male	12	32.43	100.00
Total	37	100.00	

Tabulation of arch

Arch	Freq.	Percent	Cum.
Lower	37	50.00	50.00
Upper	37	50.00	100.00
Total	74	100.00	

Tabulation of class

Class	Freq.	Percent	Cum.
Div 1	27	72.97	72.97
Div 2	10	27.03	100.00
Total	37	100.00	

Tabulation of archform

Archform	Freq.	Percent	Cum.
Ovoid	37	50.00	50.00
Square	25	33.78	83.78
Tapered	12	16.22	100.00
Total	74	100.00	

Table 5.1.1: Regression model using covariates of arch, gender and archform on the subject of perimeter as random effect in linear mixed effects model.

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Computing standard errors:
                                                Wald chi2(4)      =     165.68
Log likelihood = -224.53522                     Prob > chi2       =     0.0000

------------------------------------------------------------------------------
     Goldperimeter |      Coef.   Std. Err.      z    P>|z|     [95% Conf. Interval]
-------------+----------------------------------------------------------------
          _Iarch_2 |   10.26739   .9844415    10.43   0.000     8.337916    12.19686
        _Igender_2 |   6.297107   1.593618     3.95   0.000     3.173672    9.420541
      _Iarchform_2 |   .9708868   1.267248     0.77   0.444    -1.512874    3.454647
      _Iarchform_3 |   3.881168   1.638309     2.37   0.018     .6701418    7.092195
             _cons |   65.35405   1.111791    58.78   0.000     63.17498    67.53312
------------------------------------------------------------------------------
------------------------------------------------------------------------------
  Random-effects Parameters  |   Estimate   Std. Err.     [95% Conf. Interval]
-----------------------------+------------------------------------------------
id: Identity                 |
                  var(_cons) |   12.56959   5.270842      5.525665    28.59288
-----------------------------+------------------------------------------------
               var(Residual) |   15.67713   3.726238      9.838923     24.9796
------------------------------------------------------------------------------
LR test vs. linear model: chibar2(01) = 7.38          Prob >= chibar2 = 0.0033

Overall test for arch form
. test _Iarchform_2 _Iarchform_3

 ( 1)  [goldper]_Iarchform_2 = 0
 ( 2)  [goldper]_Iarchform_3 = 0
           chi2(  2) =    5.71
         Prob > chi2 =    0.0577
```

5.2 Inter-rater reliability for model measurement

Measurements were performed by four different individuals. Table 5.2.1 and Figures 5.2.1 – 5.2.3 gives an overview of the descriptive data for the measurements obtained from the observers, as well as determining the gold standard of each measurement from their pooled data. The gold standard obtained was used as the physically measured Arch Perimeter against which the mathematical models were tested.

Table 5.2.1: Descriptive statistics of measured parameter per observer.

ARCH	VARIABLE	N	mean	sd	min	max
Lower	archdepth_1	37	24.44243	2.348376	20.32	33.24
	archdepth_2	37	24.44	2.339409	20.21	33.19
	archdepth_3	37	24.51676	2.33279	20.28	33.39
	archdepth_4	37	24.53432	2.341561	20.34	33.34
	archdepth~g	37	24.48395	2.338564	20.28	33.29
	archperim_1	37	68.12973	4.963078	58.9	80.8
	archperim_2	37	67.94595	4.897595	58.5	80.6
	archperim_3	37	67.91622	5.033969	58.6	80.7
	archperim_4	37	67.93514	5.004565	58	80.6
	archperim~g	37	67.97176	4.965758	58.5	80.675
	intermolar_1	37	39.29216	2.279965	34.25	44.26
	intermolar_2	37	39.03892	2.265963	34.67	44.15
	intermolar_3	37	39.10216	2.310344	34.81	44.3
	intermolar_4	37	39.19541	2.312014	34.87	44.28
	intermolar~g	37	39.15747	2.282806	34.65	44.2475
	goldperim	37	67.97351	4.965966	58.5	80.68
	modelperim	37	68.83757	5.093428	59.17	86.37
Upper	archdepth_1	37	29.14703	3.960415	23.41	41.82
	archdepth_2	37	29.16351	3.990405	23.58	41.75
	archdepth_3	37	29.21054	3.966396	23.71	41.86
	archdepth_4	37	29.24081	3.962364	23.64	41.86
	archdepth_g	37	29.19178	3.96692	23.578	41.8225
	archperim_1	37	79.18108	7.716606	67.4	105.6
	archperim_2	37	78.95676	7.511234	67.6	104.6
	archperim_3	37	78.88378	7.626725	67.5	104.7
	archperim_4	37	78.98378	7.721453	67.7	105
	archperim_g	37	78.99946	7.646427	67.64	104.975
	intermolar_1	37	42.39541	2.915067	34.1	47.72
	intermolar_2	37	42.10216	2.912489	33.94	47.56
	intermolar_3	37	42.10378	2.984585	33.81	48.03
	intermolar_4	37	42.2127	2.95952	33.52	47.84
	intermolar~g	37	42.20288	2.934856	33.77	47.7875
	goldperimeter	37	79.00135	7.6463	67.64	104.98
	modelperimeter	37	79.63405	8.749717	65.74	106.74

For the lower arch the mean Arch Depth of the gold standard was 24.48 mm, with a SD of 2.34 mm, while the mean upper arch depth was found to be 29.19 mm with a SD of 3.97 mm.

The mean Intermolar width for the lower arch was 39.16 mm (SD = 2.28 mm) and 42.20 mm (SD = 2.93 mm) for the upper arch.

The mean Arch Perimeter calculated as gold standard for the lower arch was 67.97 mm (SD = 4.96) and 78.99 mm (SD= 7.65) for the upper arch.

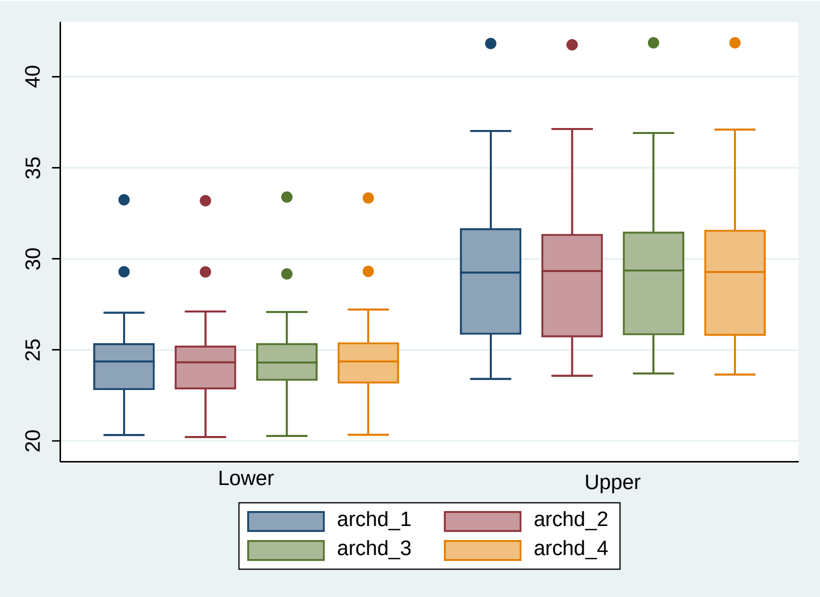


Figure 5.2.1: **Boxplot of Arch Depth per observer**

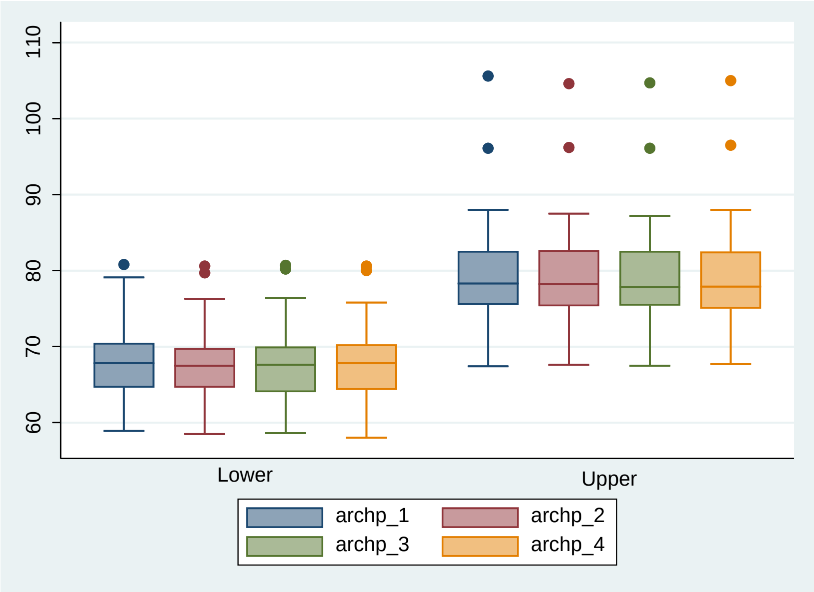


Figure 5.2.2: **Boxplot of Arch Perimeter per observer**

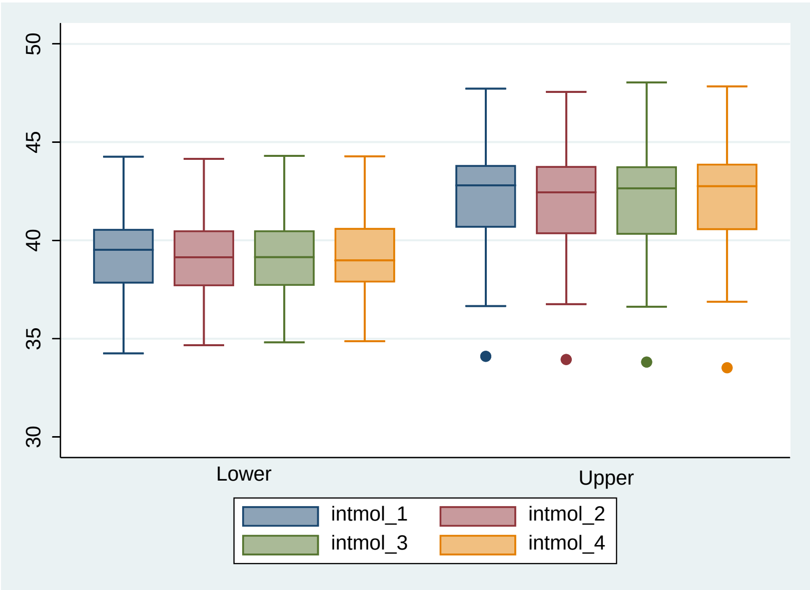


Figure 5.2.3: **Boxplot of Intermolar Width per observer**

Using a Two-way random effects model the inter-rater reliability for Arch Depth was determined to be very good, with a intraclass correlation coefficient (ICC) of 0.9976 (95% CI: 0.996 - 0.9986) for the upper arch and an ICC of 0.9930 (95% CI: 0.993 – 0.9977) (Table 5.2.2). For both arches the rater variance (sigma r) is a small proportion of the subject variance (sigma s), hence the very good intraclass correlation coefficient.

Table 5.2.2: Two-way random effects model to estimate the interrater reliability for Arch Depth

UPPER ARCH

Interrater reliability — Number of subjects = 37

Two-way random-effects model — Ratings per subject = 4

	Coef.	F	df1	df2	P>F	[95% Conf.	Interval]
ICC(2,1)	0.9976	1685.39	36.00	108.00	0.000	0.9960	0.9986
sigma_s	3.9652 (subject variance)						
sigma_r	0.0290 (rater variance)						
sigma_e	0.1932 (error variance)						

LOWER ARCH

Interrater reliability — Number of subjects = 37

Two-way random-effects model — Ratings per subject = 4

	Coef.	F	df1	df2	P>F	[95% Conf.	Interval]
ICC(2,1)	0.9959	1047.87	36.00	108.00	0.000	0.9930	0.9977
sigma_s	2.3361						
sigma_r	0.0431						
sigma_e	0.1444						

Table 5.2.3: Two-way random effects model to estimate the interrater reliability for Arch Perimeter

UPPER ARCH

Interrater reliability — Number of subjects = 37

Two-way random-effects model — Ratings per subject = 4

	Coef.	F	df1	df2	P>F	[95% Conf.	Interval]
ICC(2,1)	0.9970	1443.85	36.00	108.00	0.000	0.9950	0.9983
sigma_s	7.6339						
sigma_r	0.1085						
sigma_e	0.4019						

LOWER ARCH

Interrater reliability — Number of subjects = 37

Two-way random-effects model — Ratings per subject = 4

	Coef.	F	df1	df2	P>F	[95% Conf.	Interval]
ICC(2,1)	0.9961	1123.65	36.00	108.00	0.000	0.9935	0.9979
sigma_s	4.9662						
sigma_r	0.0866						
sigma_e	0.2964						

Table 5.2.3 shows that the Inter-rater reliability for Arch Perimeter measurement were very good with ICC of 0.997 (95% CI: 0995 – 0.998) for the upper arch and ICC 0.996 (95% CI: 0.993-0.997) for the lower arch.

A very good intraclass correlation coefficient is present for both arches due to the rater variance being a small proportion of the subject variance.

The inter-rater reliability for Intermolar Width measurements, as described in Table 5.2.4, were still very good for both the upper jaw (ICC = 0.99 - 95% CI: 0.982 – 0.994) and lower jaw (ICC = 0.985 – 95% CI: 0.974 – 0.992), but given the between subject variance this measurement has more interrater variability (sigma r = 0,13 and 0,1 for the upper and lower arches respectively) than the measurements for Arch Depth and Arch Perimeter.

Table 5.2.4: Two-way random effects model to estimate the interrater reliability for Intermolar Width.

UPPER ARCH

Interrater reliability — Number of subjects = 37

Two-way random-effects model — Ratings per subject = 4

	Coef.	F	df1	df2	P>F	[95% Conf.	Interval]
ICC(2,1)	0.9903	511.45	36.00	108.00	0.000	0.9820	0.9948
sigma_s	2.9316						
sigma_r	0.1312						
sigma_e	0.2595						

LOWER ARCH

Interrater reliability — Number of subjects = 37

Two-way random-effects model — Ratings per subject = 4

	Coef.	F	df1	df2	P>F	[95% Conf.	Interval]
ICC(2,1)	0.9849	302.07	36.00	108.00	0.000	0.9741	0.9917
sigma_s	2.2771						
sigma_r	0.1018						
sigma_e	0.2625						

The pairwise scatterplots depicted in Figures 5.2.4 – 5.2.6 clearly depicts the very good correlation between measurements of the different observers, with the increased inter-rater variability for Intermolar Width measurements visible in Figure 5.2.6

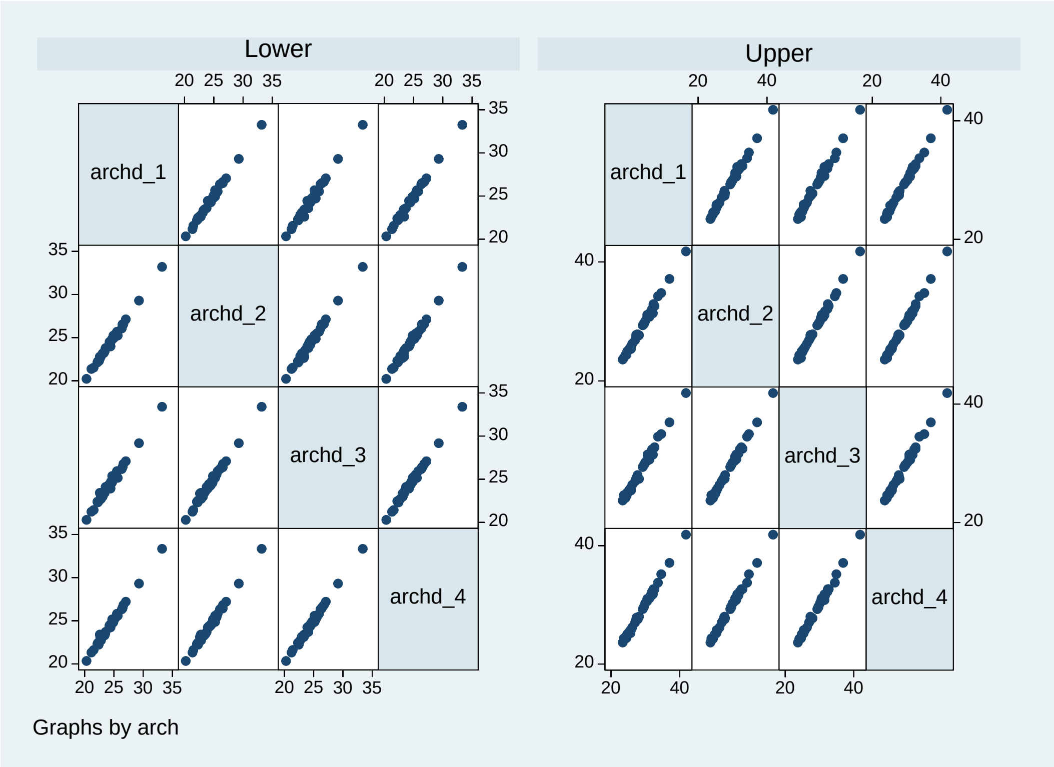


Figure 5.2.4: **Arch Depth pairwise scatterplot matrices for Inter-rater reliability**

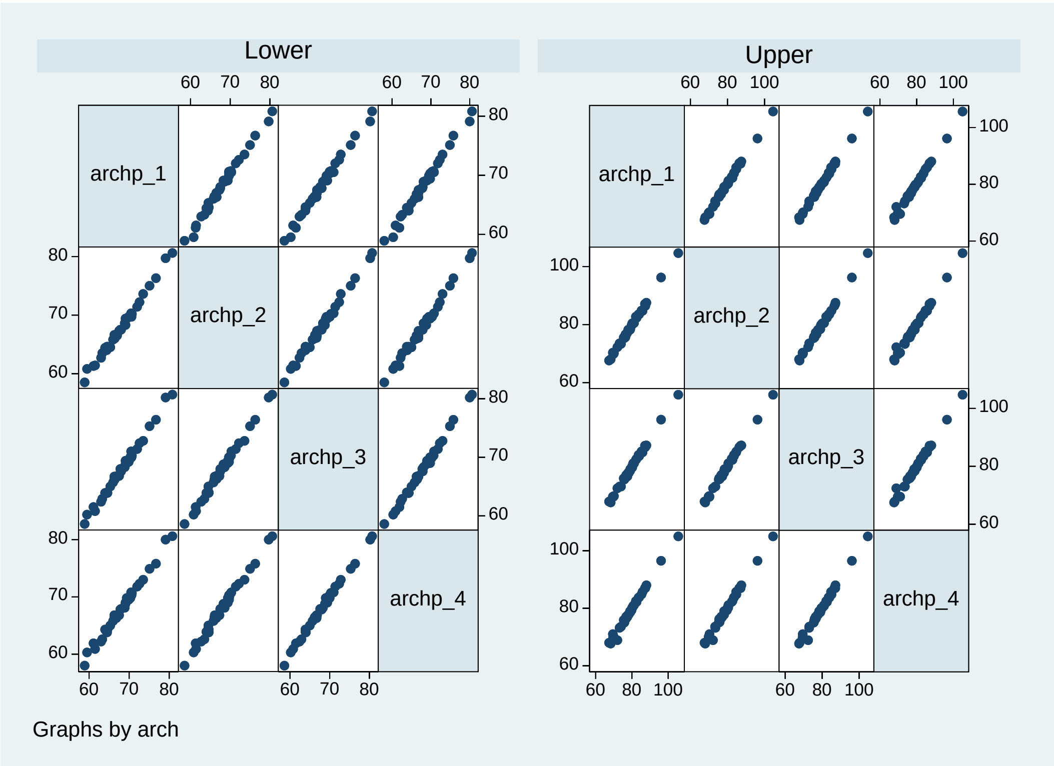


Figure 5.2.5: **Arch Perimeter pairwise scatterplot matrices for Inter-rater reliability**

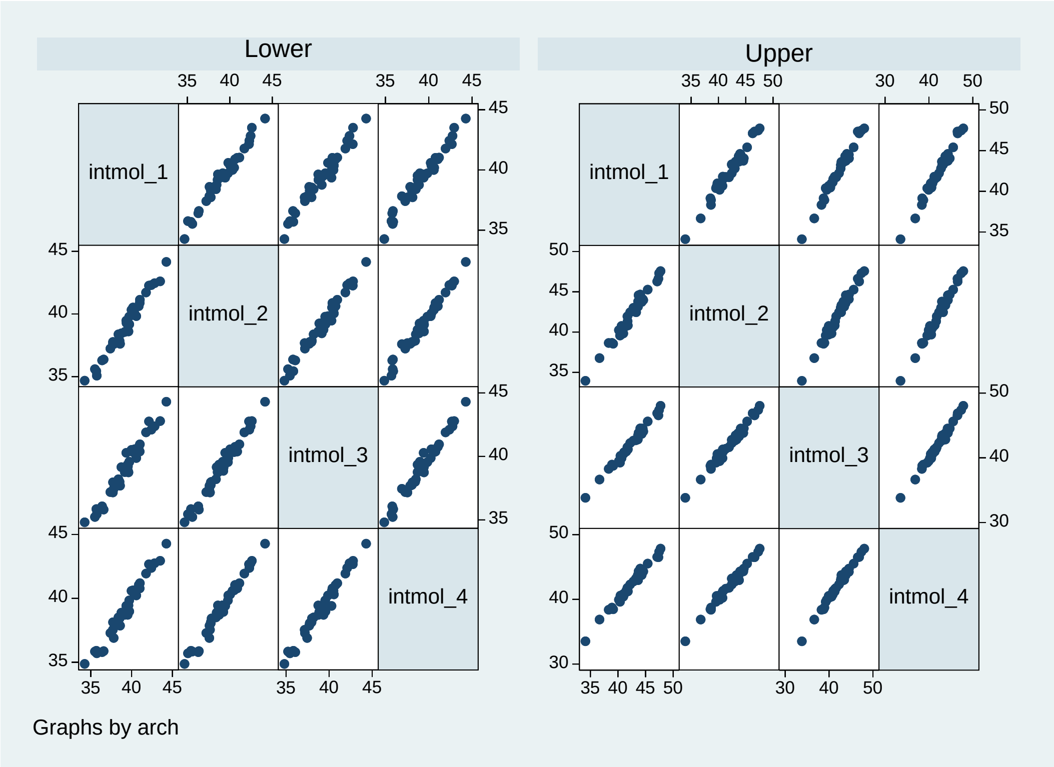


Figure 5.2.6: **Intermolar Width pairwise scatterplot matrices for Inter-rater reliability.**

5.3 Intra-rater reliability for model measurement

15 Models (20%) were reclassified after 2 weeks by the main researcher. The sample consisted of 8 Upper- and 7 lower models.

For Arch Depth the reclassification reliability was very good, with the correlation concordance coefficient (CCC) for the upper arch at 0,998 (95 % CI: 0.996 – 1.00) with average difference between repeat measurements of 0,194 mm (SD 0,093 mm).
For the lower arch the CCC was 0.998 (95% CI: 0.996 -1.00). Measurements differed on average 0,03mm (SD 0,092mm) (Table 5.3.1 and Figure 5.3.1)

Very good reclassification reliability was also found for Arch Perimeter measurements (Table 5.3.2 and Figure 5.3.2). For the upper arch the CCC was 0,999 (95% CI: 0,998 – 1,00), with a mean difference in measurements of 0,275mm (SD 0,225 mm).
An CCC of 0,990 (95% CI: 0,979 – 1,00) and difference in measurement of 0,414 mm (SD 0,302 mm) was found for the lower arch.

For all parameters measured in both arches, the Pearson's r value was more than 0.95, indicating very good correlation. (Akoglu, 2018)

Table5.3.1: Correlation coefficients to estimate the intra-rater reliability for Arch Depth.

```
UPPER ARCH
Concordance correlation coefficient (Lin, 1989, 2000):
 rho_c   SE(rho_c)   Obs    [   95% CI   ]     P        CI type
---------------------------------------------------------------
 0.998     0.001       8     0.996  1.000    0.000   asymptotic
                             0.995  1.000    0.000  z-transform

Pearson's r =  1.000  Pr(r = 0) = 0.000  C_b = rho_c/r =  0.999
Reduced major axis:   Slope =     0.984   Intercept =     0.259

Difference = archd_1 - archd_12
        Difference                 95% Limits Of Agreement
   Average     Std Dev.             (Bland & Altman, 1986)
---------------------------------------------------------------
    -0.194       0.093                -0.375     -0.012

LOWER ARCH
Concordance correlation coefficient (Lin, 1989, 2000):
 rho_c   SE(rho_c)   Obs    [   95% CI   ]     P        CI type
---------------------------------------------------------------
 0.998     0.001       7     0.996  1.001    0.000   asymptotic
                             0.993  0.999    0.000  z-transform

Pearson's r =  0.999  Pr(r = 0) = 0.000  C_b = rho_c/r =  0.999
Reduced major axis:   Slope =     0.960   Intercept =     0.973

Difference = archd_1 - archd_12
        Difference                 95% Limits Of Agreement
   Average     Std Dev.             (Bland & Altman, 1986)
---------------------------------------------------------------
    -0.030       0.092                -0.210      0.150
```

Table5.3.2: Correlation coefficients to estimate the intra-rater reliability for Arch Perimeter.

```
UPPER ARCH
Concordance correlation coefficient (Lin, 1989, 2000):
 rho_c    SE(rho_c)   Obs    [   95% CI   ]     P        CI type
---------------------------------------------------------------
 0.999     0.001       8     0.998  1.000    0.000   asymptotic
                             0.996  1.000    0.000  z-transform

Pearson's r =  1.000  Pr(r = 0) = 0.000  C_b = rho_c/r =  0.999
Reduced major axis:   Slope =     0.990   Intercept =     1.043

Difference = archp_1 - archp_12

        Difference                 95% Limits Of Agreement
   Average     Std Dev.             (Bland & Altman, 1986)
---------------------------------------------------------------
     0.275       0.225                -0.166      0.716

LOWER ARCH
Concordance correlation coefficient (Lin, 1989, 2000):
 rho_c    SE(rho_c)   Obs    [   95% CI   ]     P        CI type
---------------------------------------------------------------
 0.990     0.006       7     0.979  1.002    0.000   asymptotic
                             0.968  0.997    0.000  z-transform

Pearson's r =  1.000  Pr(r = 0) = 0.000  C_b = rho_c/r =  0.990
Reduced major axis:   Slope =     1.080   Intercept =    -5.049

Difference = archp_1 - archp_12
        Difference                 95% Limits Of Agreement
   Average     Std Dev.             (Bland & Altman, 1986)
---------------------------------------------------------------
     0.414       0.302                -0.178      1.007
```

Table5.3.3: Correlation coefficients to estimate the intra-rater reliability for Intermolar Width.

```
UPPER ARCH
Concordance correlation coefficient (Lin, 1989, 2000):
 rho_c    SE(rho_c)   Obs    [   95% CI   ]     P        CI type
---------------------------------------------------------------
 0.996     0.003       8      0.990  1.002    0.000   asymptotic
                              0.982  0.999    0.000  z-transform

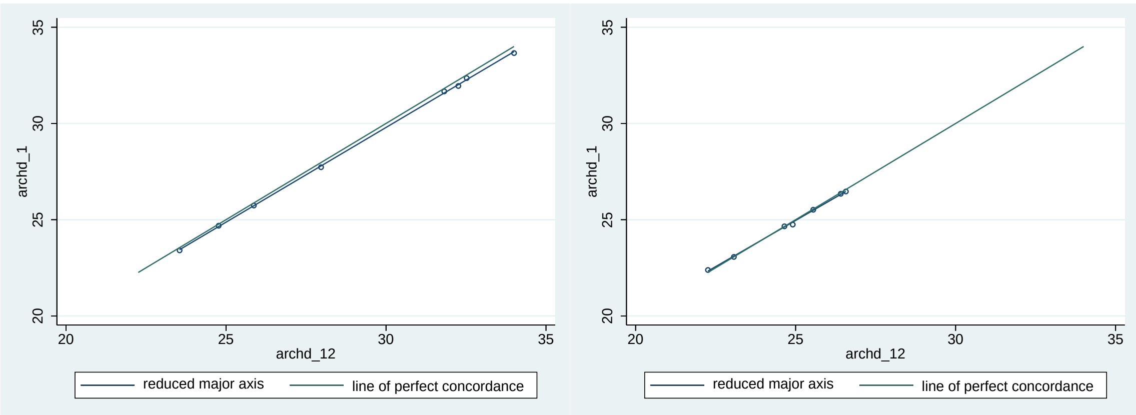
Pearson's r =  0.997  Pr(r = 0) = 0.000  C_b = rho_c/r =  0.999
Reduced major axis:   Slope =     1.016   Intercept =    -0.425

Difference = intmol_1 - intmol_12
        Difference                    95% Limits Of Agreement
   Average     Std Dev.                (Bland & Altman, 1986)
---------------------------------------------------------------
     0.240       0.366                  -0.478      0.958

LOWER ARCH
Concordance correlation coefficient (Lin, 1989, 2000):
 rho_c    SE(rho_c)   Obs    [   95% CI   ]     P        CI type
---------------------------------------------------------------
 0.945     0.044       7      0.858  1.032    0.000   asymptotic
                              0.749  0.989    0.000  z-transform

Pearson's r =  0.952  Pr(r = 0) = 0.001  C_b = rho_c/r =  0.992
Reduced major axis:   Slope =     0.885   Intercept =     4.615

Difference = intmol_1 - intmol_12
        Difference                    95% Limits Of Agreement
   Average     Std Dev.                (Bland & Altman, 1986)
---------------------------------------------------------------
     0.021       0.467                  -0.893      0.936
```



Upper Arch **Lower Arch**

Figure 5.3.1: Arch Depth concordance correlation coefficient graph depicting Intra-rater reliability.

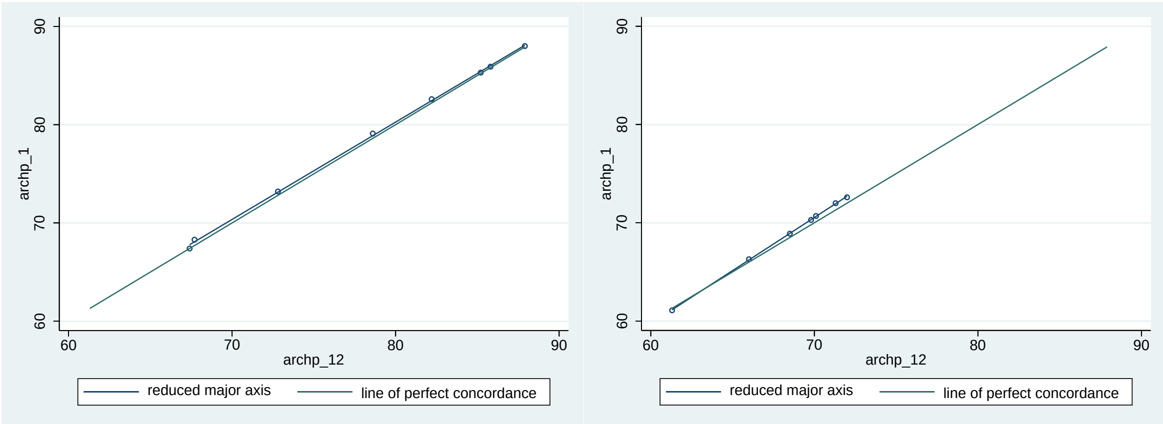


Figure 5.3.2: **Arch Perimeter concordance correlation coefficient graph depicting Intra-rater reliability.**

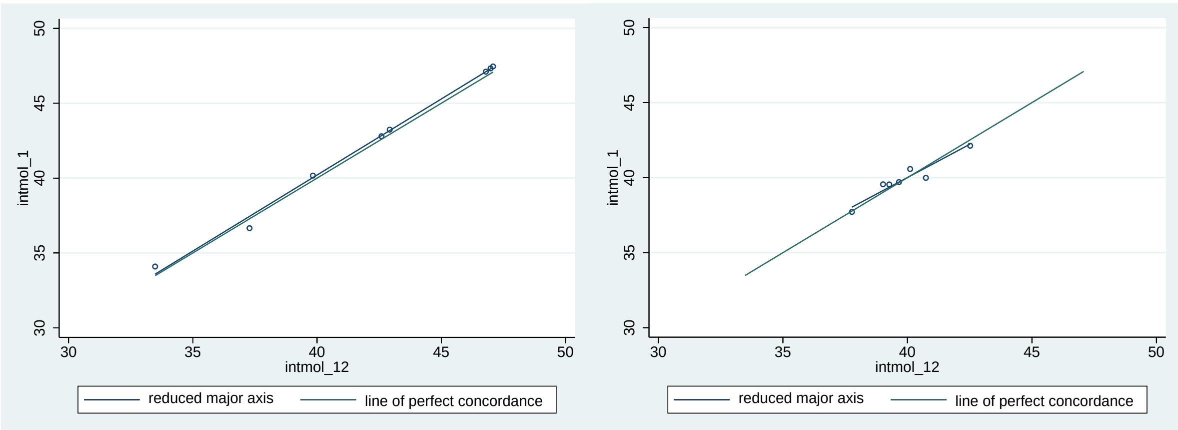


Figure 5.3.3: **Intermolar width concordance correlation coefficient graph depicting Intra-rater reliability.**

5.4 Comparison of measured Arch perimeter and Calculated Arch perimeters

5.4.1 Using Upper or Lower Arch as Co-variate

Descriptive statistics comparing the mean, standard deviation and range of measurements are given in Table 5.4.1 and Figure 5.4.1.

Mean values for the first mathematical model are slightly higher the gold standard, while the second mathematical model underestimates the Arch Perimeter.

Table 5.4.1: Descriptive statistics of the measured (goldper) and mathematically determined (modelper and modelper2) arch perimeters.

ARCH	VARIABLE	N	mean	sd	min	max
Lower	goldper	37	67.97351	4.965966	58.5	80.68
	modelper	37	68.83757	5.093428	59.17	86.37
	modelper2	37	65.67892	4.584823	56.87	80.67
Upper	goldper	37	79.00135	7.6463	67.64	104.98
	modelper	37	79.63405	8.749717	65.74	106.74
	modelper2	37	75.44	7.821204	62.64	99.11

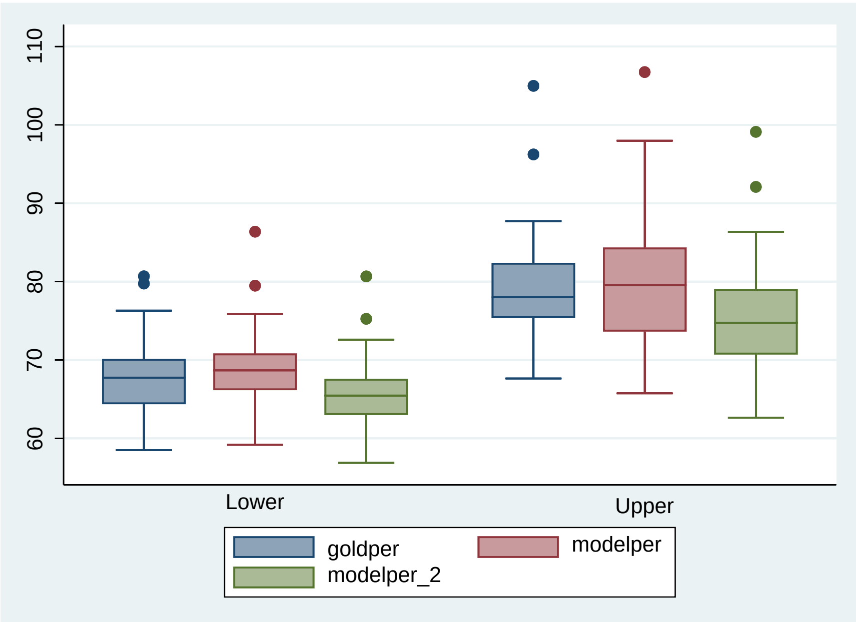


Figure 5.4.1: Boxplot of the measured and calculated arch perimeter values

The concordance coefficient is the product of precision (as measured by Pearson's r) and accuracy (as expressed by the bias correction factor C_b).

Comparison of the goldper with modelper in the Upper arch shows substantial concordance correlation (0,96), whereas Pearson's shows a very strong concordance (0,97). Table 5.4.2 and Figure 5.4.2

Modelper has a higher mean measurement of 0,63mm, with a significant standard deviation.

Table 5.4.2: **Concordance between goldper and modelper of the Upper Arch**

```
Concordance correlation coefficient (Lin, 1989, 2000):
rho_c   SE(rho_c)   Obs    [   95% CI   ]     P        CI type
---------------------------------------------------------------
0.959     0.012      37     0.935  0.982    0.000   asymptotic
                            0.927  0.977    0.000  z-transform

Pearson's r =  0.970  Pr(r = 0) = 0.000  C_b = rho_c/r =  0.988
Reduced major axis:   Slope =     0.874   Intercept =     9.410

Difference = goldper - modelper

Difference                 95% Limits Of Agreement
Average     Std Dev.             (Bland & Altman, 1986)
---------------------------------------------------------------
-0.633       2.279                 -5.099      3.833

Correlation between difference and mean = -0.488

Bradley-Blackwood F = 7.286 (P = 0.00226)
```

Comparison of the goldper with modelper2 in the Upper arch (Table 5.4.3 and Figure 5.4.2) shows poor concordance correlation (0,876), whereas Pearson's concordance is very strong (0,97).

Modelper2 has a smaller mean measurement of 3,56 mm.

Table 5.4.3: Concordance between goldper and modelper2 of the Upper Arch

```
Concordance correlation coefficient (Lin, 1989, 2000):
 rho_c   SE(rho_c)   Obs    [   95% CI   ]     P        CI type
---------------------------------------------------------------
 0.876     0.031      37     0.816  0.936    0.000   asymptotic
                             0.801  0.924    0.000  z-transform

Pearson's r =  0.972  Pr(r = 0) = 0.000  C_b = rho_c/r =  0.902
Reduced major axis:   Slope =     0.978   Intercept =     5.248

Difference = goldper - modelper_2

        Difference                 95% Limits Of Agreement
   Average     Std Dev.             (Bland & Altman, 1986)
---------------------------------------------------------------
     3.561       1.832                 -0.029      7.152

Correlation between difference and mean = -0.096

Bradley-Blackwood F = 68.760 (P = 0.00000)
```

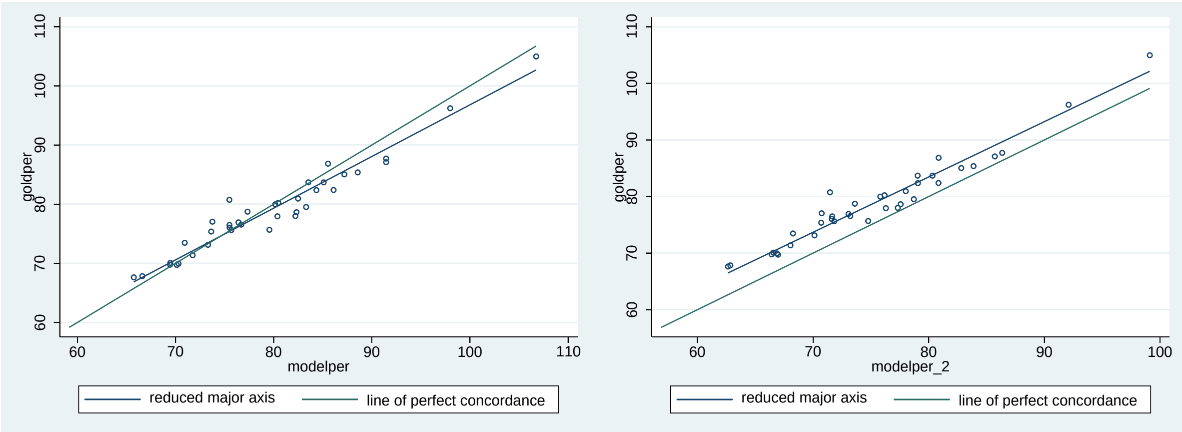


Figure 5.4.2: **Graphic representation of concordance between the measured arch perimeter to the mathematical models for the Upper Arch**

For the upper arch, modelper has the more accurate prediction (C_b = 0,98) but lacks precision (r = 0,970) when compared to modelper2 (r = 0,972). This is reflected in the small mean difference, but the substantial standard deviation of 2,28 mm.

Comparison of the goldper with modelper in the Lower arch (Table 5.4.4 and Figure 5.4.3) shows poor concordance correlation (0,876). This is due to the low accuracy (r = 0,89), as seen in figure 5.4.3.

Modelper has a larger mean measurement of 0,864 mm.

Table 5.4.4: Concordance between goldper and modelper of the Lower Arch

```
Concordance correlation coefficient (Lin, 1989, 2000):
 rho_c   SE(rho_c)   Obs    [   95% CI   ]     P        CI type
---------------------------------------------------------------
 0.876     0.039      37     0.801  0.952    0.000   asymptotic
                             0.775  0.934    0.000  z-transform

Pearson's r =  0.890  Pr(r = 0) = 0.000  C_b = rho_c/r =  0.985
Reduced major axis:   Slope =     0.975   Intercept =     0.859

Difference = goldper - modelper

        Difference                 95% Limits Of Agreement
   Average     Std Dev.             (Bland & Altman, 1986)
---------------------------------------------------------------
    -0.864       2.365                 -5.498      3.770

Correlation between difference and mean = -0.055

Bradley-Blackwood F = 2.463 (P = 0.09981)
```

Comparison of the goldper with modelper2 in the Lower arch (Table 5.4.5 and Figure 5.4.3) shows poor concordance correlation (0,799), due to accuracy and precision less than 0,9.

Modelper2 has a smaller mean measurement of 2,29 mm with a wide standard deviation of 2,2 mm.

Table 5.4.5: Concordance between goldper and modelper2 of the Lower Arch

```
Concordance correlation coefficient (Lin, 1989, 2000):
 rho_c   SE(rho_c)   Obs    [   95% CI   ]     P        CI type
---------------------------------------------------------------
 0.799     0.053      37     0.696  0.902    0.000   asymptotic
                             0.670  0.881    0.000  z-transform

Pearson's r =  0.896  Pr(r = 0) = 0.000  C_b = rho_c/r =  0.891
Reduced major axis:   Slope =     1.083   Intercept =    -3.165

Difference = goldper - modelper_2

        Difference                 95% Limits Of Agreement
   Average     Std Dev.             (Bland & Altman, 1986)
---------------------------------------------------------------
     2.295       2.206                  -2.028      6.617

Correlation between difference and mean = 0.177

Bradley-Blackwood F = 20.669 (P = 0.00000)
```

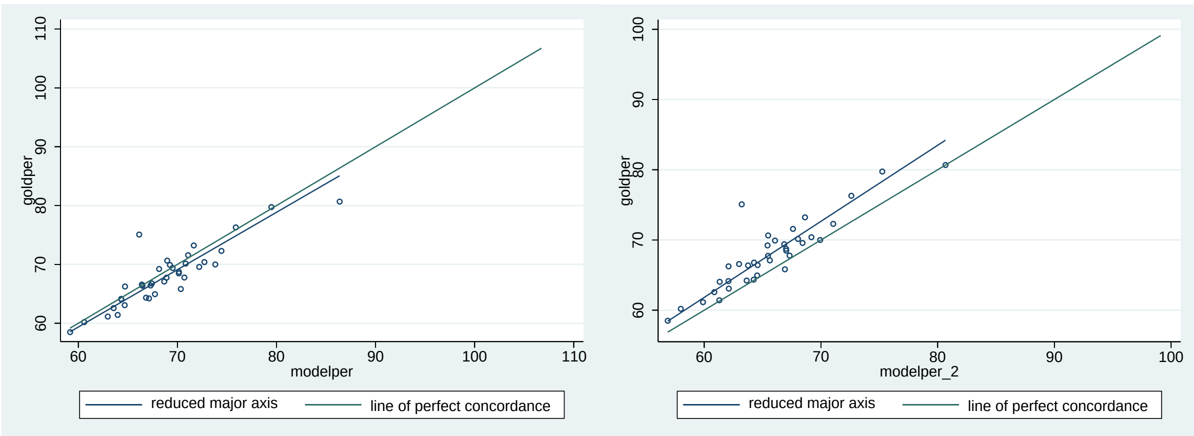


Figure 5.4.3: **Graphic representation of concordance between the measured arch perimeter to the mathematical models for the Lower Arch.**

Table 5.4.6 shows the Spearman correlation between the different methods for obtaining Arch Perimeter for the different arches.

Correlation in the upper arch is better between the mathematical models (0,998) than between the mathematical model and goldstandard (0,952 for modelper and modelper2)

Correlation in the lower arch is better between the mathematical models (0,996) than between the mathematical model and goldstandard (0,859 for modelper and 0,866 for modelper2).

Table 5.4.6: Spearman Correlation of Arch perimeters.

	goldup~r	goldlo~r	~1dupper	~1dlower	~2dupper	~2dlower
goldupper	1.0000					
goldlower	0.4786	1.0000				
	0.0000					
model1dupper	0.9526	0.4469	1.0000			
	0.0000	0.0001				
model1dlower	0.5720	0.8592	0.5486	1.0000		
	0.0000	0.0000	0.0000			
model2dupper	0.9526	0.4507	0.9988	0.5495	1.0000	
	0.0000	0.0001	0.0000	0.0000		
model2dlower	0.5600	0.8663	0.5312	0.9957	0.5313	1.0000
	0.0000	0.0000	0.0000	0.0000	0.0000	

Figure 5.4.4 and 5.4.5 show Arrow plots of a combined upper and lower arch per patient with the start point the golden standard measurement and the end of the arrowhead the mathematically determined measurement. The direction and magnitude of the arrow indicates the difference in measurements, where ideally the two points should coincide to show similar measurements. Changes in the X-axis indicates differences in the lower arch measurements and changes in the Y-axis indicates changes in the upper model measurements.

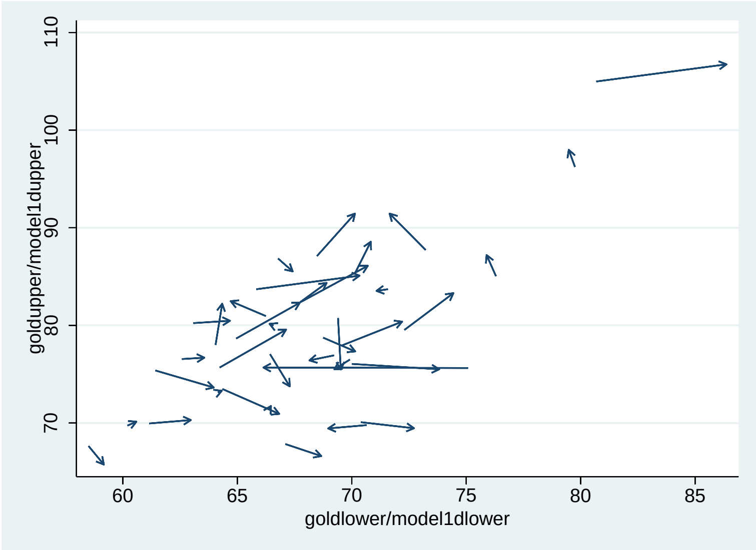


Figure 5.4.4: **Arrow Plot of gold standard measurement to mathematical model 1 measurements per patient.**

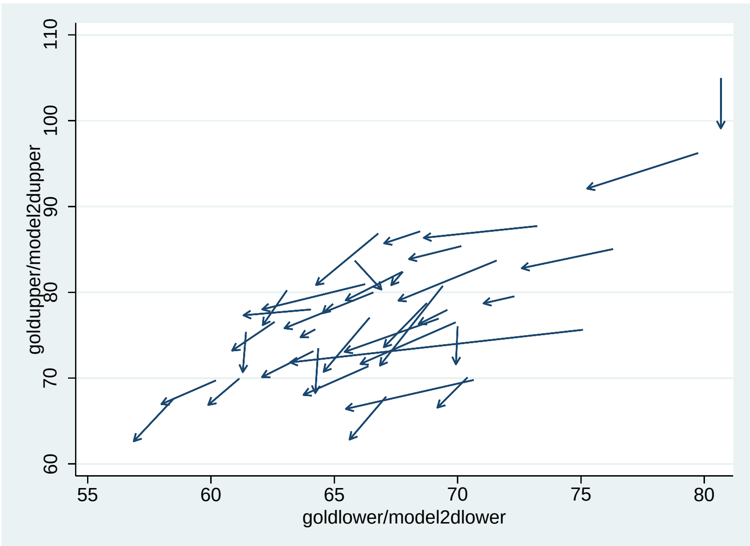


Figure 5.4.5: **Arrow Plot of gold standard measurement to mathematical model 1 measurements per patient.**

The Arrow plot for modelper (Figure 5.4.4) shows very little bias but some variability around the underlying true value, while modelper2's Arrow plot (Figure 5.4.5) clearly show systematic bias with lower estimates for most values of the mathematical measurements.

5.4.2 Using Archform as Co-variate

Table 5.4.7 shows the breakdown of the sample sub-classified by archform.

Due to the limited sample size, not all sub-classes had enough representation to perform concordance analysis. The power of results is low due to small sample sizes.

Table 5.4.7: Description of population according to Archform

Archform	Arch: Lower	Arch: Upper	Total
Ovoid	21	16	37
Square	14	11	25
Tapered	2	10	12
Total	37	37	74

Lin's correlation coefficient is only moderate for Tapered and Square archforms in the upper arch when goldper and modelper are compared (Table 5.4.8), whereas it is substantial for Ovoid arches.

The mean difference in measurements is clinically insignificant for the Square and Ovoid arches, but significant for tapered archforms.

For Square arches modelper underestimates the length and for Tapered and Ovoid arches the length is overestimated.

Table 5.4.8: Comparison of goldper and modelper for the different archforms in the Upper arch

Archform	Concordance Correlation coeff	C_b	Pearson's correlation	Difference	
				Average	**Std. Deviation**
Tapered	0.943	0,958	0.985	-2,57	1.60
Ovoid	0.967	0,989	0.978	-0.381	1.422
Square	0.955	0,981	0.973	0,763	2.712

When comparing goldper and modelper in the lower arch (Table 5.4.9), Lin's CCC for Ovoid and Square arches were found to be poor with 0,83 and 0,86 respectively.

The mean difference for Square arches was insignificant, overestimating the length by 0,08 mm but showed a large standard deviation. The mean difference and standard deviation for Ovoid arches was more than 1mm.

For the Tapered lower arch, with a sample size of two (2), no concordance analysis could be done.

Table 5.4.9: Comparison of goldper and modelper for the different archforms in the Lower arch.

Archform	Concordance Correlation coeff	C_b	Pearson's correlation	Difference	
				Average	Std. Deviation
Tapered		0,849	1	-3.545	3.033
Ovoid	0.832	0,938	0.888	-1.131	1.529
Square	0.866	0,997	0.869	-0.081	3.049

Lin's correlation coefficient is poor for Ovoid and Square archforms in the upper arch when goldper and modelper2 are compared (Table 5.4.10), and moderate for Tapered arches.

The mean difference and standard deviation in measurements is clinically insignificant for all the archforms, with the lengths being underestimated.

Table 5.4.10: Comparison of goldper and modelper2 for the different archforms in the Upper arch.

Archform	Concordance Correlation coeff	C_b	Pearson's correlation	Difference	
				Average	Std. Deviation
Tapered	0.936	0,950	0.985	2.501	1.715
Ovoid	0.808	0,825	0.979	3.429	1.139
Square	0.840	0,864	0.973	4.717	2.207

When comparing goldper and modelper2 in the lower arch (Table 5.4.11), Lin's CCC for Ovoid and Square arches were found to be poor at 0,74.

The mean difference and standard deviation were significant for both arches, with modelper2 underestimating the Arch perimeter.

For the Tapered lower arch, with a sample size of two (2), no concordance analysis could be done.

Table 5.4.11: Comparison of goldper and modelper2 for the different archforms in the Lower arch.

Archform	Concordance Correlation coeff	C_b	Pearson's correlation	Difference	
				Average	Std. Deviation
Tapered		0,982	1	0.875	1.223
Ovoid	0.740	0,821	0.901	1.963	1.426
Square	0.745	0,858	0.868	2.995	3.035

6. DISCUSSION

Consensus is found in the literature that Arch Perimeter is an important determinant whether there will be crowding within the dental arches. To this end, crowding is an expression of a Tooth size and Arch length (perimeter) discrepancy (TSALD) (van der Linden, 1974)

It is therefore important for the clinician to be able to determine Arch Perimeter accurately during diagnosis and treatment planning.

In the context of clinical practice, but even more so during epidemiological studies, obtaining the arch perimeter efficiently is of great value. Finding a mathematical model that can accurately calculate Arch perimeter with a few easily obtained measurements would contribute greatly to the efficiency of determining TSALD.

A host of mathematical models has also been tested in the past, with some using simpler equations e.g. Mill's equation for a parabola (Mills, 1964) and others using complex polynomial (Braun et al., 1998; Noroozi *et al.*, 2001) or Beta function curves (Braun *et al.*, 1998)

In this study, a comparison between the Arch Perimeter obtained from two different mathematical models for a parabola was compared to that of a physically measured Arch Perimeter acting as the gold standard.

6.1 Reliability of measurements

For the study to be reliable and reproducible the measurement error should be as small as possible. The gold standard in determining arch perimeter, is by physical measurement using a brass wire (Carey, 1958) or callipers/vernier gauge (Stuart Hunter and Priest, 1960)

In this study the physical measurement of the Arch Perimeter was done with the aid of digital imaging software (Cerec Ortho 2.0) and measurements of Intermolar width and Arch depth were done with 3D software (Blender 2.83LTS) due to the accuracy, reproducibility and efficiency (Grünheid *et al.*, 2014).

As the Arch perimeter measurement acting as the gold standard is not an absolute measurement, which may be prone to measurement errors, multiple measurements by different examiners were performed to minimize the measurement error. The mean measurement obtained from the four examiners were used as the gold standard measurement.

Using a Two-way random effects model the inter-rater reliability was determined to be almost perfect (ICC ≥ 0,99) for all measurements except for the Intermolar width in the lower arch, which had a very good inter-rater reliability (ICC = 0,985).

The difference in the mean measurements for all the parameters were all less than 0,3 mm.

The high level of inter-rater accuracy supports the previous claims of reproducibility of digital imaging (Grünheid *et al.*, 2014)

The main researcher reclassified 20% of the measurements after 2 weeks and the reclassification reliability was found to be very good (Akoglu, 2018). The Pearson's r for all measurements were above 0,95.

The reproducibility of the measurements acted as basis for accepting the digitally measured Arch perimeter as the gold standard against which the mathematical models would be tested.

6.2 Sampling and co-variates

Gender, archform, type of Class II malocclusion and upper or lower arch were used as co-variates in an effort to ascertain a relationship with arch perimeter.

In this study only gender and the upper/lower jaw were shown to have a significant effect on arch perimeter. This correlates with well with other longitudinal studies (Bishara *et al.*, 1998; Carter and McNamara, 1998)

The type of Class II malocclusion (div 1 or div 2) as well as the archform (Tapered, Ovoid or Square) was not found to correlate to a significant degree with Arch perimeter. Our findings with regards to Arch perimeter and type of Class II malocclusion or archform concurs to those of various other authors (Frölich, 1962; Bishara, 2006).

For this study only upper or lower arch, as well as archform were used as co-variates.

Based on the rule of thumb given by Peduzzi *et al*. (1996) and the research design, twenty-five models per group is needed for adequate power.

Using Upper and Lower jaws as co-variate, 50 models were needed, and the study included 37 models per co-variate. The power of the study with these co-variates alone can be classified as adequate.

Using Archform as co-variate along with upper and lower jaw would require 150 models in total, with 25 models in each of the 6 sub-groups. This sample size would have ensured an equal representation of all arch forms and both arches in the sample.

In the study, only 74 models could be obtained. None of the subgroups for archform had adequate numbers, with Tapered lower arches totaling only 2 models. Thus, the analysis for these co-variates may not be adequately powered.

Upper and lower models of the same patients were used in the study, therefor the spread between upper and lower arches were equal.

In this study Ovoid archform was found to be the most prevalent, making up 50% of the sample. Tapered archforms were the least prevalent at 16,22 % overall and accounting for only 5,4% of the lower archforms. Other research on the prevalence of archforms in specific population groups showed some racial distinction. In a Pakistani population, Tapered archforms were the most prevalent (49%), followed by Ovoid archforms (29%) and lastly Square archforms (21%) (Tajik *et al.*, 2011). Nojima *et al* (2001) evaluated archforms of Caucasian and Japanese samples and found similar result as Tajik for the Caucasian sample, but for the Japanese sample, the most prevalent archform was Square (46%) followed by Ovoid (42%) and lastly Tapered archforms, clearly showing a racial difference in archform prevalence (Nojima *et al.*, 2001). The racial diversity of the population used in our study might contribute to the different distribution of archforms.

6.3 Mathematical model predictions

The first mathematical model used for predicting the Arch Perimeter (modelper) was similar to that used by Mills (1965). Mills found that 96% percent of the predicted measurements fell within 0,52 mm ($p < 0.05$).

The second mathematical model has not been tested before in relation to Arch perimeter prediction, making the results from this study novel.

6.3.1 Upper and Lower arch as only co-variates

When looking at the upper and lower arches in isolation, the average difference for both mathematical models fell outside the 0,52 mm range.

The upper arch average difference of modelper overestimating the Arch perimeter by 0,63 mm was the closest to the gold standard, while the lower arch had a mean overestimated difference of 0,86 mm.

Modelper2 underestimated the Arch perimeter in the upper arch by 3,56 mm on average, while the lower arch underestimated the length by 2,29 mm on average.

The results for our study therefore do not concur with those of Mills (1965). This might be due to the difference in the population examined, prevalence of crowding and malalignments, type of malocclusion or as a result in the difference in prevalence of specific archforms.

In the Mills study, all the subjects were males between 17-21 years of age and of mixed European descent (Mills, 1964). No other descriptive data of the sample was given, except that the subjects did not have previous orthodontic treatment.

In our study the subjects ranged between 12-23 years and consisted of mixed races, all having a Class II malocclusion.

No indication of archform was reported in the Mills study. Archform and size has been reported to be influenced by race, and might be a contributing factor in the difference of prediction by the mathematical model (Burris and Harris, 2000).

Braun (1998) has also reported that there is a statistically significant difference between the archforms of the three different Angle malocclusion groups. Class II malocclusions showed a tendency to have narrower arches than both Class I and III subjects, which might explain why the Mills mathematical formula comparatively overestimated the Arch perimeter in our sample.

In the Mills study, a large proportion of the subjects had almost perfectly aligned arches which was shown to be associated with wider arches, but not increased arch perimeter when compared to subjects with more malalignment (Mills, 1964). In the present study, most subjects had malalignment, being the main cause for seeking orthodontic treatment.

Greater intermolar width would require decreased arch depth to ensure similar arch perimeter. This altered ratio between arch depth and intermolar width seen in well aligned subjects might be one of the causes for obtaining different results between the studies. Once again, the expected narrower arches of the malaligned arches in this study, might contribute to the different outcomes if the two studies

With a Lin's CCC = 0.96 in modelper compared to 0.88 in modelper2 for the upper arch and a CCC = 0.88 in modelper compared to 0.8- in modelper2 for the lower arch, it can be seen that the concordance is poorer in the second mathematical model than the model based on Mills' formula for a parabola.

The use of the mathematical model is more accurate in the upper arch than the lower arch for both equations.

6.3.2 Archform as co-variate

The power of the study with regards to archform as co-variate can not be deemed strong. None of the sub-classes of archform per arch had the required 25 models to ensure adequate power.

For tapered lower arches, the sample consisted of only 2 models, and as such, no concordance analyses could be done.

Regression models on the different co-variates indicated that archform is not a significant determinant of arch perimeter(Carter and McNamara, 1998).

Due to the nature of the mathematical equations describing a specific geometric shape, the decision was made to use archform as a co-variate even though it was found to not be a determinant in Arch perimeter.

Using modelper in the upper arch for Ovoid and Square archforms does show substantial correlation with the measured Arch perimeter. Ovoid arches show the least mean difference between the values (0,38 mm), as well as the smallest standard deviation (1,42 mm), making the use of the mathematical formula a viable option.

Tapered upper arches have moderate concordance and the mean overestimation of 2,57 mm is statistically and clinically significant.

The concordance for the lower arch when using modelper is significantly lower. Despite Square arches having a very good accuracy score (C_b = 0,997), it showed a low precision score (r = 0,869), making the concordance of the measurements poor.

The concordance of modelper2 measurements with goldper is poor for all archforms in both arches, except for Tapered upper arches showing moderate concordance. The precision for measurements are comparable to those of modelper measurements, the accuracy of the measurements are low.

The mean difference between goldper and modelper2 is statistically and clinically significant for all archforms in both arches.

In our study, the mathematical formula as tested by Mills was found to predict Arch perimeter with a higher concordance to the measured goldstandard than the mathematical formula for a parabola as calculated by Spiegel.

The upper arch was shown to be closer in shape to a parabola than the lower arch. This was deduced from the stronger concordance levels for the upper arch when compared to the lower arch, using modelper as well as modelper2.

Even though the concordance of measurements for goldper and modelper can be classified as substantial for Ovoid and square upper arches, it still does not reach almost perfect concordance. This would indicate that none of the archforms can be fully classified as having a parabolic shape. This correlates to previous studies on determining arch form, where no specific geometric shape could be used to describe all arches (Braun *et al.*, 1998)

7. CONCLUSIONS

This study researched the viability of using a mathematical formula, using two measurements, to determine Arch perimeter.
The measurements were done on digitized models and as shown by the almost perfect Inter-rater and Intra-rater reliability, this method of measurement is extremely reproducible and accurate.

The mathematical formula by Mills is more accurate than the formula by Spiegel in predicting Arch perimeter for all archforms in both the upper and lower arches.
The Spiegel equation shows bias, underestimating the value for the Arch perimeter.

None of the archforms in either arch could fully be described as a parabola, but the arch with the best concordance was the Ovoid upper arch.

Though statistically significant, the mean difference between goldper and modelper might be deemed clinically less significant and may still be of use in clinical practice where preliminary arch perimeter is to be obtained with few measurements.
In large epidemiological studies where large amounts of measurements and data has to be analyzed the statistically significant difference might however be of importance.

The mean difference between godper and modelper2 is statistically as well as clinically significant and as such, predictions with this mathematical model should be avoided when calculating Arch perimeter.

8. LIMITATIONS AND DIRECTIONS FOR FUTURE RESEARCH

The limited number of models in the archform sub-groups had an influence on the statistical analysis of the data.
The importance of an adequate sample size can be explained as follows. When two variables are independent, the standard error of the measured correlation coefficient is = $1/\sqrt{(n-1)}$, where n = sample size. The measured correlation coefficient is considered statistically significant when bigger than $2/\sqrt{(n-1)}$.
From the above it follows that, depending on the sample size, the same correlation coefficient can be either statistically significant or not (Joubert *et al,* 2019)
The size of the sample influences the precision of the estimates as well as the power of the study to draw conclusions. In general, larger sample sizes allow more accurate generalization of findings to the population at large.

The regression models showed that gender is a significant determinant in Arch perimeter. This study did not analyse how gender as co-variate influences the accuracy of the mathematical models.
The sample used consists of a diverse population; however, this study did not evaluate ethnic variations nor did the study evaluate and compare the viability of the mathematical models for each ethnic group. Studies has shown that archform and size does differ between different ethnic groups (Burris and Harris, 2000).
Future studies might include using gender and ethnicity as co-variates

The concordance of measurements between the gold standard and mathematical models describing parabolas were not perfect for any of the archforms. Different mathematical formulae has been used, with multiple polynomials and Beta function curves (Braun *et al.*, 1998; Noroozi *et al.*, 2001) showing promise. These more complex formulae might be used to determine the accuracy in the population seen in our study.

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10. APPENDIX

10.1 Appendix A: Ethics Clearance

UNIVERSITY *of the* WESTERN CAPE

60 YEARS *of hope, action & knowledge*

25 August 2020

Dr F Du Raan

Faculty of Dentistry

Ethics Reference Number: BM20/3/9

Project Title: Using a mathematical model to determine dental arch-perimeter in Class II patients presenting at UWC Orthodontic clinics.

Approval Period: 25 August 2020 – 25 August 2023

I hereby certify that the Biomedical Science Research Ethics Committee of the University of the Western Cape approved the scientific methodology and ethics of the above mentioned research project.

Any amendments, extension or other modifications to the protocol must be submitted to the Ethics Committee for approval.

Please remember to submit a progress report annually by 30 November for the duration of the project.

Permission to conduct the study must be submitted to BMREC for record-keeping.

The Committee must be informed of any serious adverse event and/or termination of the study.

Ms Patricia Josias
Research Ethics Committee Officer
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NHREC Registration Number: BMREC-130416-050

FROM HOPE TO ACTION THROUGH KNOWLEDGE.

10.2 Appendix B: Letter to Dean requesting permission to use stored records

UNIVERSITY of the WESTERN CAPE

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10 October 2019

Dear Prof Y. Osman

Re: Request to use orthodontic study models for research purposes

I, Dr Frederick Johannes du Raan, student nr: 2921936, would hereby like to obtain permission to have access to stored patient records to conduct my research study titled:

Using a mathematical model to determine dental arch-perimeter in Class II patients presenting at UWC Orthodontic clinics.

The research project is part of the M.ChD. Orthodontics course.

Records needed are the study initial study models of patients treated in the Department of Orthodontics at Tygerberg and Mitchell's Plain dental clinics.
The Orthodontic study models selected will be analysed and stored securely on-site at the Department of Orthodontics of UWC, Tygerberg campus for the duration of the study. The records will de-identified after selection.

No new study models will be taken, or patients examined during the study. Upon completion of the study the study models will be returned to the archives at the Department of Orthodontics.

Thank you in advance,

Approval granted. Please clear time with P.A Baker or Dr Shaikh. Regards.

Dr. F.J. du Raan

10.3 Appendix C: Raw Metadata

Designated Number	Arch	Malocclusion	Archform	Gender
DUR10001	Upper	Div 1	Tapered	Female
DUR10002	Lower	Div 1	Ovoid	Female
DUR10003	Upper	Div 1	Ovoid	Female
DUR10004	Lower	Div 1	Ovoid	Female
DUR10005	Upper	Div 1	Ovoid	Female
DUR10006	Lower	Div 1	Square	Female
DUR10007	Upper	Div 1	Tapered	Female
DUR10008	Lower	Div 1	Ovoid	Female
DUR10009	Upper	Div 2	Square	Female
DUR10010	Lower	Div 2	Square	Female
DUR10011	Upper	Div 1	Square	Male
DUR10012	Lower	Div 1	Ovoid	Male
DUR10013	Upper	Div 1	Tapered	Female
DUR10014	Lower	Div 1	Ovoid	Female
DUR10015	Upper	Div 2	Square	Female
DUR10016	Lower	Div 2	Ovoid	Female
DUR10017	Upper	Div 2	Ovoid	Female
DUR10018	Lower	Div 2	Ovoid	Female
DUR10019	Upper	Div 1	Square	Male
DUR10020	Lower	Div 1	Square	Male
DUR10021	Upper	Div 2	Square	Female
DUR10022	Lower	Div 2	Ovoid	Female
DUR10023	Upper	Div 1	Tapered	Female
DUR10024	Lower	Div 1	Square	Female
DUR10025	Upper	Div 1	Ovoid	Female
DUR10026	Lower	Div 1	Tapered	Female
DUR10027	Upper	Div 2	Square	Female
DUR10028	Lower	Div 2	Ovoid	Female
DUR10029	Upper	Div 1	Ovoid	Female
DUR10030	Lower	Div 1	Square	Female
DUR10031	Upper	Div 1	Ovoid	Female
DUR10032	Lower	Div 1	Ovoid	Female
DUR10033	Upper	Div 1	Square	Male
DUR10034	Lower	Div 1	Square	Male
DUR10035	Upper	Div 1	Square	Female
DUR10036	Lower	Div 1	Square	Female
DUR10037	Upper	Div 2	Ovoid	Female
DUR10038	Lower	Div 2	Square	Female
DUR10039	Upper	Div 2	Square	Male
DUR10040	Lower	Div 2	Ovoid	Male
DUR10041	Upper	Div 2	Square	Female
DUR10042	Lower	Div 2	Square	Female
DUR10043	Upper	Div 1	Tapered	Male

DUR10044	Lower	Div 1	Tapered	Male
DUR10045	Upper	Div 1	Ovoid	Male
DUR10046	Lower	Div 1	Ovoid	Male
DUR10047	Upper	Div 1	Ovoid	Male
DUR10048	Lower	Div 1	Square	Male
DUR10049	Upper	Div 1	Ovoid	Female
DUR10050	Lower	Div 1	Ovoid	Female
DUR10051	Upper	Div 1	Tapered	Male
DUR10052	Lower	Div 1	Ovoid	Male
DUR10053	Upper	Div 1	Tapered	Female
DUR 10054	Lower	Div 1	Ovoid	Female
DUR 10055	Upper	Div 1	Ovoid	Female
DUR10056	Lower	Div 1	Square	Female
DUR10057	Upper	Div 1	Ovoid	Female
DUR10058	Lower	Div 1	Ovoid	Female
DUR10059	Upper	Div 1	Ovoid	Female
DUR10060	Lower	Div 1	Square	Female
DUR10061	Upper	Div 1	Tapered	Female
DUR10062	Lower	Div 1	Ovoid	Female
DUR10063	Upper	Div 1	Square	Male
DUR10064	Lower	Div 1	Square	Male
DUR10065	Upper	Div 2	Tapered	Female
DUR10066	Lower	Div 2	Ovoid	Female
DUR10067	Upper	Div 1	Ovoid	Male
DUR10068	Lower	Div 1	Ovoid	Male
DUR10069	Upper	Div 1	Ovoid	Female
DUR10070	Lower	Div 1	Ovoid	Female
DUR10071	Upper	Div 2	Ovoid	Male
DUR10072	Lower	Div 2	Square	Male
DUR10073	Upper	Div 1	Tapered	Male
DUR10074	Lower	Div 1	Ovoid	Male

10.4 Appendix D: Raw Data of the measured Arch perimeter, used for inter-rater reliability, intra-rater reliability and calculated Arch perimeters

Model	Du Raan	Du Raan 2nd Measure	Carim	Joubert	Walton	Average
DUR10001	79,8		79,7	79,3	79,3	79,525
DUR10002	72,6	72	72,2	72,4	72,3	72,3
DUR10003	84		83,5	83,5	83,8	83,7
DUR10004	66		65,8	65,7	65,8	65,825
DUR10005	78		78,2	77,8	77,8	77,95
DUR10006	69,9		69,7	69,2	69,5	69,575
DUR10007	82,6	82,2	82,3	82,6	82,2	82,38
DUR10008	68		67,5	67,6	67,9	67,75
DUR10009	74		73,3	73	73,6	73,475
DUR10010	64,6		64,6	63,9	64,3	64,35
DUR10011	88	87,9	87,5	87,2	88	87,72
DUR10012	73,5		73,6	72,8	73	73,225
DUR10013	78,3		78,1	77,7	77,9	78
DUR10014	64,4		64	63,9	63,9	64,05
DUR10015	68,3	67,7	68	67,5	67,7	67,84
DUR10016	67,5		67,3	66,8	66,8	67,1
DUR10017	83,7		83,5	83,9	83,7	83,7
DUR10018	72	71,3	71,4	71,4	71,8	71,58
DUR10019	80,7		80,5	81	80,8	80,75
DUR10020	69,4		69,4	69	69,8	69,4
DUR10021	77,5		77,2	76,5	77	77,05
DUR10022	66,3		66,6	66,3	66,5	66,425
DUR10023	81,2		80,5	81	81,1	80,95
DUR10024	66,4		66	66,2	66,4	66,25
DUR10025	79,1	78,6	78,4	79	78,6	78,74
DUR10026	69,1		68,3	68,8	68,8	68,75
DUR10027	69,5		70,3	69,5	71	70,075
DUR10028	70,7	70,1	70,2	70,3	70,7	70,4
DUR10029	76,4		75,6	75,9	76,3	76,05
DUR10030	70,3		69,8	69,8	70,1	70
DUR10031	79		78,2	78,4	79	78,65
DUR10032	65,3		64,5	65	65	64,95
DUR10033	85,9	85,8	84,7	84,8	85,7	85,38
DUR10034	70,6		69,7	70	70,3	70,15
DUR10035	87,4		86,4	86,6	87	86,85
DUR10036	67		66,5	66,8	66,8	66,775
DUR10037	69,6		70,2	69,4	69,7	69,725
DUR10038	59,5		60,8	60,2	60,3	60,2
DUR10039	76,5		76,6	76,4	76,5	76,5

DUR10040	70,3	69,8	69,7	70	69,8	69,92
DUR10041	75,8		75,3	75,4	75	75,375
DUR10042	61,1	61,3	61,3	61,5	61,9	61,42
DUR10043	105,6		104,6	104,7	105	104,975
DUR10044	80,8		80,6	80,7	80,6	80,675
DUR10045	80,2		80,4	80,1	80,2	80,225
DUR10046	63,3		63,5	62,9	62,6	63,075
DUR10047	85,3	85,2	84,8	85,1	84,8	85,04
DUR10048	76,7		76,3	76,4	75,8	76,3
DUR10049	76,8		76,4	76,6	76,4	76,55
DUR10050	63		62,7	62,4	62,2	62,575
DUR10051	87,2		87,1	87,1	87	87,1
DUR10052	68,9	68,5	68,6	68,3	68,1	68,48
DUR10053	75,5		75,5	75,8	75,9	75,675
DUR 10054	64,5		64,6	64	63,8	64,225
DUR 10055	75,9		75,8	75,6	75,2	75,625
DUR10056	75,1		75	75,3	74,9	75,075
DUR10057	70,1		70,1	69,7	69,9	69,95
DUR10058	61,5		61,4	60,8	60,9	61,15
DUR10059	67,4	67,4	67,6	67,8	68	67,64
DUR10060	58,9		58,5	58,6	58	58,5
DUR10061	82,2		82,7	82,2	82,5	82,4
DUR10062	67,8		67,5	68	67,8	67,775
DUR10063	96,1		96,2	96,1	96,5	96,225
DUR10064	79,1		79,7	80,2	80	79,75
DUR10065	72		72,2	72,4	68,9	71,375
DUR10066	66,3	66	66,1	66,7	66,8	66,38
DUR10067	76,9		76,7	77	77,1	76,925
DUR10068	69,1		69,4	69,4	69	69,225
DUR10069	73,2	72,8	73,5	73	73,2	73,14
DUR10070	64		64,4	63,9	64,3	64,15
DUR10071	69,8		69,8	69,5	70	69,775
DUR10072	70,5		70,3	71	70,8	70,65
DUR10073	80,2		80	79,6	80,1	79,975
DUR10074	66,8		66,5	66,7	66,3	66,575

10.5 Appendix E: Raw Data of Measured and Calculated Arch Perimeters

Model	Cerec Perimeter	Math Perimeter	Math Perimeter2
DUR10001	79,53	83,30	78,71
DUR10002	72,30	74,44	71,05
DUR10003	83,70	85,09	80,32
DUR10004	65,83	70,34	66,91
DUR10005	77,95	80,38	76,29
DUR10006	69,58	72,20	68,42
DUR10007	82,38	84,35	79,06
DUR10008	67,75	68,90	65,46
DUR10009	73,48	70,93	68,26
DUR10010	64,35	66,83	64,23
DUR10011	87,72	91,45	86,35
DUR10012	73,23	71,65	68,63
DUR10013	78,00	82,21	77,32
DUR10014	64,05	64,34	61,32
DUR10015	67,84	66,61	62,84
DUR10016	67,10	68,67	65,62
DUR10017	83,70	83,53	79,04
DUR10018	71,58	71,08	67,60
DUR10019	80,75	75,48	71,46
DUR10020	69,40	69,52	66,85
DUR10021	77,05	73,75	70,74
DUR10022	66,43	67,29	64,57
DUR10023	80,95	82,48	78,01
DUR10024	66,25	64,71	62,08
DUR10025	78,74	77,33	73,61
DUR10026	68,75	70,15	67,01
DUR10027	70,08	69,46	66,56
DUR10028	70,40	72,72	69,18
DUR10029	76,05	75,50	71,61
DUR10030	70,00	73,82	69,93
DUR10031	78,65	82,32	77,57
DUR10032	64,95	67,73	64,53
DUR10033	85,38	88,56	83,87
DUR10034	70,15	70,83	68,03
DUR10035	86,85	85,53	80,85
DUR10036	66,78	67,42	64,26
DUR10037	69,73	70,13	66,97
DUR10038	60,20	60,59	57,99
DUR10039	76,50	75,49	71,65
DUR10040	69,92	69,24	66,06
DUR10041	75,38	73,63	70,70
DUR10042	61,42	63,97	61,29

DUR10043	104,98	106,74	99,11
DUR10044	80,68	86,37	80,67
DUR10045	80,23	80,47	76,18
DUR10046	63,08	64,68	62,10
DUR10047	85,04	87,20	82,81
DUR10048	76,30	75,89	72,60
DUR10049	76,55	76,69	73,21
DUR10050	62,58	63,56	60,86
DUR10051	87,10	91,45	85,71
DUR10052	68,48	70,14	67,02
DUR10053	75,68	79,56	74,76
DUR 10054	64,23	67,13	63,63
DUR 10055	75,63	75,68	71,83
DUR10056	75,08	66,14	63,21
DUR10057	69,95	70,30	66,87
DUR10058	61,15	62,97	59,89
DUR10059	67,64	65,74	62,64
DUR10060	58,50	59,17	56,87
DUR10061	82,40	86,10	80,84
DUR10062	67,78	70,70	67,31
DUR10063	96,23	97,98	92,09
DUR10064	79,75	79,48	75,25
DUR10065	71,38	71,74	68,04
DUR10066	66,38	66,47	63,75
DUR10067	76,93	76,41	73,06
DUR10068	69,23	68,15	65,42
DUR10069	73,14	73,30	70,12
DUR10070	64,15	64,32	62,07
DUR10071	69,78	69,44	66,41
DUR10072	70,65	68,97	65,47
DUR10073	79,98	80,15	75,81
DUR10074	66,58	66,41	62,98

10.6 Appendix F: Consent Form

Using a mathematical model to determine dental arch-perimeter in Class II patients presenting at UWC Orthodontic clinics

Consent to take part in research

- I……………………………………… voluntarily agree to participate in this research study.

- I understand that even if I agree to participate now, I can withdraw at any time or refuse to answer any question without any consequences of any kind.

- I understand that I can withdraw permission to use data from my records, in which case the material will not be available for further use in the study.

- I have had the purpose and nature of the study explained to me in writing and I have had the opportunity to ask questions about the study.

- I understand that participation involves no further input or resources from me other than the records taken to do my orthodontic diagnosis and treatment planning.

- I understand that I will not benefit directly from participating in this research.

- I understand that all information I provide for this study will be treated confidentially.

- I understand that in any report on the results of this research my identity will remain anonymous. This will be done by not using my name and disguising any details of my records used which may reveal my identity.

- I understand that anonymized information from my records may be used in academic publications, such as fulfillment of a research thesis or journal article.

- I understand that signed consent forms will be kept in a locked cabinet of the researcher to which only he will have access for 3 years and original records will be retained in the storage room of the department of Orthodontics as per institutional regulations

- I understand that under freedom of information legalization I am entitled to access the information I have provided at any time while it is in storage as specified above.

- I understand that I am free to contact any of the people involved in the research to seek further clarification and information.

Dr. Frederick Johannes du Raan, B.Ch.D (Stell); PDD Orthodontics (UWC); M.Sc. Orthodontics (UWC). Current registrar in M.Ch.Orthodontics program.
Contact nr: 0725117415.
Supervisor: Prof. AMP Harris

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Signature of participant Date

I believe the participant is giving informed consent to participate in this study.

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Signature of researcher Date