Comparison of the accuracy of direct versus indirect bracket placement in orthodontics: An in vitro study

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Research thesis presented in fulfilment
of the requirements for the degree Master in Science Orthodontics
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May 2019

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DECLARATION

I, Dr Günther Arthur Streit, hereby declare that this is my own and original work, that I am the sole author thereof (save to the extent explicitly otherwise stated), and that I have never submitted it as a whole or any part of it to any other institution for purposes of earning a qualification.

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ACKNOWLEDGEMENTS

I would like to thank my loving wife Dr Saskia, a devoted vet, for always believing in me, and my parents Klaus and Melinda Streit for challenging me to be better. I would also like to thank Dr Joggie Briedenhann for opening the door and giving me this fine opportunity.

A special thank you to OrthoShop for sponsoring the brackets used in this study. Your support enabled me to undertake this study.

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ABSTRACT

The purpose of this study was to compare the accuracy of direct versus indirect bracket placement in orthodontics in a controlled setting. The more accurate the initial bracket placement is the less time will be required in terms of treatment. Accurate bracket placement can reduce the envelope of error in the three dimensions of vertical (incisal height, height of tooth), horizontal (mesial-distal) and angular (degrees incisal to root apex causing rotational irregularities) based on Andrews' six keys to normal occlusion (Andrews, 1979).

In this comparative experimental study, 10 Class I molar relation study models were selected from the researcher's practice archives. Only the MBT pre-adjusted or angulated orthodontic brackets were used on manikins, followed by the use of 3D CAD CAM technology to evaluate the results against a pre-determined golden standard.

Based on this study, it can be noted that the indirect method of bracket placement in orthodontics is statistically better at accurate placement outcome than the direct method. Overall, indirect bonding showed better bracket placement in bracket height, vertical and angular dimensions ($P < .05$).

Exact target was only found with the indirect method with the result being 0.0. This was found on Teeth 14 and 32. Otherwise, no technique yielded the ideal bracket placement.

Therefore, from this study it appears that the indirect method is a better form of bracket placement for the dental professional.

The findings of the study can be useful to clinicians deciding which methods to utilise to help ensure improved patient care and comfort.

Key words

bracket placement, direct and indirect method, orthodontics, patient care, treatment time

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ACRONYMS AND ABBREVIATIONS

A	angle
ARI	adhesive remnant index
D	direct
H	horizontal
ICC	Intraclass Correlation Coefficient
ID	indirect
MBT	McLaughlin, Bennett and Trevisi
SBS	shear bond strength
SD	standard deviation
STL	STereoLithography
SWA	straight wire appliance
V	vertical

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CHAPTER 1

INTRODUCTION

1.1 INTRODUCTION

This chapter provides an overview of the development of orthodontic procedures, highlighting three ways in which orthodontic brackets can be placed. It also sets out the rationale for the study.

According to academics and historians, orthodontic procedures date back to 400 to 300 BC. Hippocrates and Aristotle considered ways to straighten dentition and mend assorted dental problems (Norman, 2005).

The earliest published recording of orthodontics was in the 19th century by French dentist Pierre Fauchard who is accredited with inventing contemporary orthodontics through his book *The Surgeon Dentist* (Norman, 2005).

The beginning of direct orthodontics began as brackets welded to bands covering the entire tooth. Dr George Newman and Prof Fujio Miura developed bonding to enamel of orthodontic brackets in 1960s. Retief from South Africa helped to develop a strong enough adhesive for brackets, with 3M becoming commercially available in late 1970s (Gange, 2015).

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1.2 THREE WAYS OF PLACING ORTHODONTIC BRACKETS

The placement of orthodontic brackets onto human enamel may be accomplished in three ways:

- **Direct method**: This is where the clinician – the dentist, orthodontist and/or oral hygienist – places the brackets in the ideal position directly onto the tooth surface (Newmann, 1974).
- **Indirect method**: The second method of orthodontic placement is the indirect method, also known as the Thomas indirect method adopted by Sondhi, James and Horn (1999), or the Thomas modified indirect method. This was first introduced by Silverman and Cohen in 1972 (Thomas, 1979.)
- **Combination of both systems**: The third method is to combine the two techniques using the best of each system for the ideal bracket placement. The indirect method is more accurate at the second maxillary premolar and lower left central incisors while the direct method is more

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accurate at the mandibular premolars and upper right lateral. The theory would be to combine both systems' strong points in order to increase accuracy and decrease treatment time (Hocevar, 1988; Hodge *et al*., 2004; Prasad & Varatharajan, 2011).

The three dimensions each had a stronger or more accurate finding in a study by Aguirre and co-researchers, which showed improved vertical placement at the maxillary canines as well as improved angulation at the maxillary and mandibular canines. Indirect bonding, however, proved to be more accurate overall (Aguirre, King & Waldron, 1982).

Since 1972, improvements have resulted in an indirect bonding technique that compares favourably with various direct bonding techniques (Gayake, 2013; Muguruma *et al*., 2010; Omur, 2004; Scholtz, 1983).

The different generations of pre-adjusted brackets include the straight wire appliance (SWA) available since 1972. Roth, and McLaughlin, Bennett and Trevisi (MBT) developed this between 1975 and 1993 after the traditional edge-wise which required more first-order bends and corrections before finishing (McLaughlin, Bennett & Trevisi, 2002).

1.3 RATIONALE OF THE STUDY

The purpose of this study was to compare the accuracy of direct versus indirect orthodontics in a controlled setting: The more accurate the initial bracket placement is the less time is needed on the finishing of the cases to try to correct mistakes on the initial placement. This reduces the envelope of error in the three dimensions of vertical (incisal height, height of tooth), horizontal (mesial-distal) and angular (degrees incisal to root apex causing rotational irregularities) based on Andrews' six keys to normal occlusion (Andrews, 1979).

This will help clarify which of the two methods is indeed more efficient for the purpose of the study in improved patient care and comfort. The findings of the study can be useful to clinicians weighing which methods to utilise.

1.4 RESEARCH QUESTION

The aim of the study was to compare the accuracy of the placement of orthodontic brackets onto the dentition using direct and indirect modes of transfer, using only the MBT pre-adjusted or angulated orthodontic brackets on manikins followed by the use of 3D CAD CAM technology to evaluate the results against the golden standard.

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The objectives of the study were therefore to:

- Compare vertical accuracy of the two methods
- Compare the horizontal accuracy of the two methods
- Compare the angular accuracy of the two methods
- Combining all the values against direct and indirect in order to draw comparisons.

1.5 CHAPTER OUTLAY

This research paper is divided into the chapters outlined below:

- **Chapter 1**: This chapter provides an overview of the development of orthodontic procedures, highlighting three ways in which orthodontic brackets can be placed. It also explains the rationale for the study.
- **Chapter 2**: The literature review provides context for this study by looking at previous research on the topic. The chapter will cover definitions of direct and indirect orthodontic techniques, and explain various aspects of orthodontic treatment.
- **Chapter 3**: The research methodology explains how the research was undertaken.
- **Chapter 4**: The results are displayed graphically with a short description of each pair of measurements.
- **Chapter 5**: The results are discussed and compared to the literature review.
- **Chapter 6:** Conclusions are drawn and recommendations are given for future research. Overall, indirect bonding showed better bracket placement.

1.6 CONCLUSION

Over the past 50 years, various studies have been done on the advantages of each of the three bonding methods for orthodontic brackets: direct, indirect and the combination method.

The purpose of this study was to compare the accuracy of direct versus indirect orthodontics because the more accurate the initial bracket placement is the less time is needed in terms of overall treatment.

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This will help to determine which of the two methods is indeed more efficient in terms of better patient care and comfort. The findings of the study can be useful to clinicians deciding which methods to use in orthodontic treatment.

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CHAPTER 2

LITERATURE REVIEW

2.1 INTRODUCTION

In this chapter, literature relevant to the research question – a comparison of the accuracy of direct versus indirect bracket placement in orthodontics in terms of treatment time and patient care – will be explored.

2.2 DEFINITIONS OF INDIRECT AND DIRECT ORTHODONTICS

Orthodontics comes from the Greek word *orthos*, which means straight, and *odont*, which means tooth (Vocabulary.com, n.d.). The section below will provide definitions of key terminology in the field of orthodontics:

Orthodontics

The branch of dentistry dealing with the prevention and correction of irregular teeth by means of braces (Dictionary.com, 2017; Wikipedia, 2010).

The treatment of problems concerning the position of the teeth and jaws (Oxford Dictionary, 2019).

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Indirect orthodontic technique

A two-step process by which orthodontic attachments are affixed temporarily to teeth of a study cast from which they are transferred to the mouth at one time by means of a template or tray that preserves the predetermined orientation and permits them to be bonded simultaneously (TheFreeDictionary.com. 2017).

Direct orthodontic technique

For comprehensive orthodontic treatment, orthodontic brackets are placed directly onto the tooth surface with gauge and angulated directly in the mouth. Metal wires are inserted into orthodontic brackets (braces), which can be made from stainless steel or a more aesthetic ceramic material, which are placed directly and measured onto patients' teeth (Brandt, Servoss & Wolfson, 1975).

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2.3 DISCUSSION OF ASPECTS OF INDIRECT AND DIRECT ORTHODONTICS

2.3.1 Bond strength

Direct orthodontic treatment has the highest mean tensile strength which translates to a high tensile bond strength with regard to the incisors at 0.15kg mm^2 whereas the Thomas method showed higher tensile bond strength at 0.44kg/mm^2 with regard to the premolar areas. The bracket bonding strength rates indicated that brackets placed using the indirect method had slightly weaker bond strengths after three months at 4.5%, favouring the direct bonding method at 5.3%. Interestingly, after the shear tests, 72% of the forced or deliberate removals of the brackets showed that the bonding resin remained on the bracket which is favourable as this leads to easier cleaning of the tooth as the bulk of the cement stays on the bracket. The shear strength translates to bond strength: 72% indirect amidst 56% to direct, again another contradiction to the studies with no clear outcome (Yi, 2003).

Based on the literature, there seems to be a fierce debate on the robustness of the systems. Yet, they both appear to be equally matched (Omur, 2004; Yi, 2003).

Studies showed that light-cured bonding resin may be stronger and more predictable than the chemically bonded cements. Bond strength is amicable to the adhesive remnant index (ARI) between the two systems. This translates to easier cleaning as less material remains on the tooth surface (Brandon *et al*., 2006; Sondhi, James & Horn, 1999).

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Weibull's analysis showed that the indirect light-cured technique had a lower bond survival rate. However, in many of the articles there is no significant difference in shear bond strength (SBS) between the two systems. Indeed, studies have shown that the bonding strength between direct and indirect orthodontic treatment techniques compare favourably (Daub *et al*., 2006; Linn *et al*., 2006; Omur, 2004). These studies do not reveal the chemical bonding agent's strength as the light-cured resins are the main focus. Some studies do show that the filler resin materials in the resin may prevent stress fractures increasing bond strength (Daub *et al*., 2006; Linn *et al.*, 2006.) The study by Yagci *et al*. showed no significant difference in micro leakage between the two systems (Yagci *et al*., 2010).

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Metal brackets showed better bonding and higher bond strength than the ceramic brackets. Ceramic brackets tend to be more fragile and break easier, and are therefore not recommended for routine orthodontic treatment (Zachrisson, 1978).

2.3.2 Accuracy

The direct method is more accurate in the mandibular premolar area as well as the upper right areas. The indirect method has been shown to be more accurate in the second canines, the second premolar and lower left central incisors (Hocevar, 1988).

A study undertaken by Koo (1999) revealed that both the direct and indirect methods did not manage to show ideal placement although both techniques produced close to acceptable values which accentuates and proves the fact that both are acceptable in terms of accuracy. This, in turn, should make the finishing more predictable in terms of outcome and time, specifically when using the pre-adjusted MBT brackets, adding to the efficiency of the modernised technique (Hodge *et al*., 2004; Koo, 1999).

Accuracy is relevant because the more accurate the bracket placement, the shorter the treatment time required to correct the discrepancies in the final stages of orthodontic treatment. Correct bracket placement is necessary to achieve maximum advantage from fixed orthodontic appliances. This will facilitate the final phases of the treatment, leading to an optimal efficient occlusion (Mohammadi & Moslemzadeh, 2011).

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2.3.3 Periodontal implications

A study by Dalessandri *et al*. (2012) has shown that plaque accumulation has similar outcomes in both techniques (Dalessandri *et al*., 2012). However, a study by Zachrisson showed that direct meshed brackets is favoured over indirect in plaque accumulation if the brackets are positioned closer to the tooth surface, making it easier to clean (Zachrisson, 1978).

A study by Zanini *et al.* showed that the indirect technique has a lower level of compromise in terms of oral health. His study compared the plaque index, gingival indices and quality of gingival crevicular fluid in a randomised study using the split-mouth model, concluding that indirect may be more superior than the direct means of orthodontic placement (Zanini *et al.*, 2016).

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2.3.4 Clinical time

The major advantage of the indirect orthodontic bracket placement technique is revealed through its clinical advantage as less patient time is needed. The clinician calls the patient in and takes the necessary impressions. The records are sent to the dental laboratory and in a few days the clinician can begin with the procedure which, in theory and according to literature, should take only one-third of the time to place as opposed to the direct method (Prasad & Varatharajan, 2011). This in itself leads to a less stressed environment in the dental practice: the clinician receives the transfer tray and places the cementation agent – such as Transbond XT or normal resin as both have proven to be effective in the bracket bonding to the tooth and holding capability (Kasrovi, 1997). Next, this is placed onto the prepared site and light cured. The sheath is removed and the flash is cleaned off. According to the *Handbook of Orthodontics,* direct is the more favoured technique as indirect takes a lot more time to manufacture and costs significantly more in comparison to justify its use (Cobourne, 2015).

2.3.5 Chair time

The indirect method of bracket placement reduces time in the chair as there is no need to concentrate on the placement of brackets on each individual tooth. This also means less chair time for the patient. Faster placement results in less temporal mandibular joint pain for the patient. In addition, overall stress levels in the practice are minimised, leading to increased patient satisfaction. This translates to a higher turnover rate (Aquirre, 1982; Kasrovi, 1997; Prasad & Varatharajan, 2011).

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2.3.6 Clinical experience

Another advantage of the indirect method is that this method can be applied by an inexperienced clinician with little formal training and even by an oral hygienist in a busy orthodontic practice whereas the direct method requires application by an experienced clinician. In case of the oral hygienist performing the bracket placement, the clinician only needs to be present for the initial diagnosis and treatment planning, the checking of the placement of the brackets on the models before the transfer plate and sheath are formed over it and after the bonding to ensure the brackets have not shifted and the resin flash is cleaned off correctly (Kalange, 1999).

The major drawback of the Thomas indirect orthodontic technique is that it is very technique sensitive whereas the direct method is less technique sensitive. This means the clinician and the team need to

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be trained. Another major disadvantage is the costs involved to fabricate the transfer trays (Koo, 1999; Nichols, Gardner & Carballeyra, 2013).

A study showed that the overall time of each of the two techniques is very similar, but this same study showed the clinical time of the indirect method to be one-third faster than the direct method (Bozelli *et al.*, 2013). In 2007, Deahl and his co-researchers did a study and concluded that both systems were adequate as neither differed in treatment times, follow-up or failure rates (Deahl *et al*., 2007).

Based on the literature, there has yet to be a study focusing solely on the benefits of direct versus the indirect orthodontic techniques in terms of time and accuracy of placement. The research shows that both techniques are capable of producing similar results and outcomes with no significant difference between the two techniques (Brandon *et al.*, 2006; Sondhi *et al*., 1999).

2.3.7 The modern age of dentistry and the modern patient

In the age of modern dentistry, various developments have focused on more efficient, fast and accurate orthodontic placement methods. The smartphone era has intensified the need for instant gratification (Miller, 2012).

Orthodontic placement techniques have not truly evolved over the last 100 years. Hence, there is a need to delve deeper into indirect orthodontic research in order for it to be considered a viable technique in the modern practice.

The modern patient expects the freedom of choice. If the private practice can perform both techniques in a fast and efficient manner, it will afford the patient the opportunity to decide between the different techniques, making the practice more appealing to patients.

This modern practice “ideal” of orthodontic work speaks to Sirona’s 3 Shape trios and Planmec’s ideal of the Cerec, giving patients the ease and comfort of fast, accurate and efficient work (3 Shape, 2017; Dentsply Sirona, 2017; Planmeca, 2017; Prasad & Varatharajan, 2011).

The 3D virtual models' procedure have proven to be invaluable to the modern age of dentistry due to its high accuracy and reproductive potential (Zilberman, Huggare & Parikakis, 2003).

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2.4 CONCLUSION

This chapter covered definitions of direct and indirect orthodontic techniques, and looked at various aspects of orthodontic treatment. The next chapter will explain the research methodology used in this study.

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CHAPTER 3

RESEARCH METHODOLOGY

3.1 INTRODUCTION

This chapter will explain how the research was undertaken to compare the accuracy of direct versus indirect orthodontics in a controlled setting. This follows on the discussion of aspects of orthodontic treatment as discussed in the literature review in Chapter 2.

The aim of the study was to compare the accuracy of the placement of orthodontic brackets onto the dentition using direct and indirect modes of transfer, using only the MBT pre-adjusted or angulated orthodontic brackets on manikins followed by the use of 3D CAD CAM technology to evaluate the results against the golden standard.

A comparative experimental study ensures that all the biases are avoided, allowing a clear picture of the results (Codina, 2015; Sibbald & Roland, 1998).

3.2 STUDY DESIGN

In this comparative experimental study, 10 Class I molar relation study models were selected from the researcher's practice archives. The models, based on records taken from previous patients, were fabricated in the dentistry lab using white orthodontic smooth model material. The head of the Orthodontic Department of the practice was asked to set the brackets in the ideal locations, serving as the gold standard and the standard for comparison. The models were treated with a resin compound to prevent the brackets from coming off the models before conducting the measurements.

These models were placed precisely onto the manikins with an exact copy made on the nearby manikin. The operator received the same assistant, who was unaware of the study, to do the light cure and assist with the bracket resin cement placement onto the brackets.

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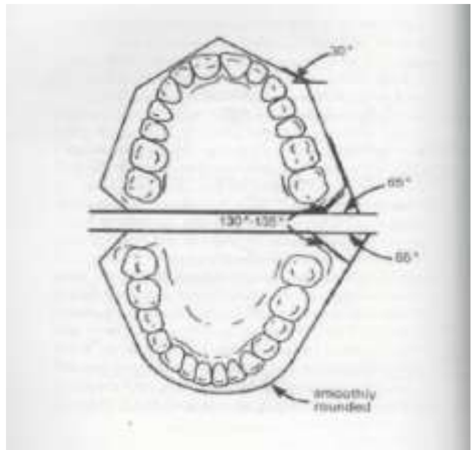

Figure 3.1: Model of orthodontic trimming
Source: Kumar, 2008.

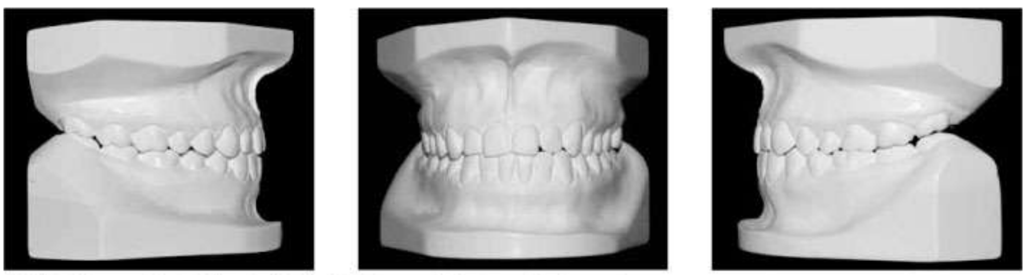

FIGURE 1 - Plaster models of a Class I individual with incipient malocclusion, used in the sample.

Figure 3.2: Plaster models of a Class 1 individual with incipient malocclusion
Source: Azevedo, Torres & Normando, 2010.

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3.2.1 The operator

One operator was identified to participate in the study. The operator is a qualified dentist with orthodontic experience. The operator is therefore familiar with the orthodontic set-up and correct bracket placement.

The operator was asked to perform four bondings: two direct and two indirect, in random order, on four separate days. None of the four study models was the same for the operator on the day. (The operator-study model-bonding type combinations were determined before the start of the study.) Thus, a total of 16 experiments were carried out.

3.2.2 Calibration

To calibrate the operator to a uniform practice application, all practices were performed only after an instructions and training session (Dahlberg, 1940). The operator would place the brackets on the

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white orthodontic models. Next, an orthodontist would examine and confirm that the placements were acceptable on these four models examined in random sequence in order to ensure the validity of these measurements.

3.2.3 Intra-examiner variability

Measurements were re-done on four models two weeks after the last experiment was conducted. This was selected in random order to test the operator's reliability and to run parallel forms of reliability.

3.3 BRACKET PLACEMENT PROCEDURE

The brackets were placed according to the 3M Unitek™ Versatile Appliance Bracket Placement Guide.

The bracket placement guide was used in addition to the visual technique. The bracket placement guide is most helpful in cases where the centre of the dental crown is not easy to establish due to partial eruption, gingival inflammation, or unusual tooth size and/or shape.

In the "average" row, the distance from the incisal or occlusal edge of the tooth to the centre of the dental crown is represented. In the table, the rows above and below the average row provide a 0.5 mm and 1.0 mm positive and negative difference from the average. This is for cases with bigger or smaller dentition.

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The bracket placement consisted of the following:

- Measure the height of the dental crown of all fully erupted teeth on the orthodontic study model.
- Divide figures in half and select the column that most closely represents the average of patient's dentition.
- Decide on a row on the chart which has the most number of recorded information.
- Some modifications may be required for teeth presenting occlusal, incisal wear, fracture and or long tapered cusps.
- In the direct method, place the orthodontic brackets by visualising the vertical long axis of dental crowns and anticipate the centre of the dental crown as a horizontal reference.
- Use a 3M Unitek bracket positioning gauge (REF 900-841) to substantiate that the bracket height lines up with the figures in the bracket placement chart.

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- Use Transbond™ XT light cure adhesive.

The MBT™ Versatile+ Appliance Bracket Placement Guide was used in this study (see Figure 3.3):

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	U7	U6	U5	U4	U3	U2	U1	Upper Arch
A	2.0	4.0	5.0	5.5	6.0	5.5	6.0	+1.0 mm
B	2.0	3.5	4.5	5.0	5.5	5.0	5.5	+0.5 mm
C	2.0	3.0	4.0	4.5	5.0	4.5	5.0	Average
D	2.0	2.5	3.5	4.0	4.5	4.0	4.5	-0.5 mm
E	2.0	2.0	3.0	3.5	4.0	3.5	4.0	-1.0 mm

	L7	L6	L5	L4	L3	L2	L1	Lower Arch
A	3.5	3.5	4.5	5.0	5.5	5.0	5.0	+1.0 mm
B	3.0	3.0	4.0	4.5	5.0	4.5	4.5	+0.5 mm
C	2.5	2.5	3.5	4.0	4.5	4.0	4.0	Average
D	2.0	2.0	3.0	3.5	4.0	3.5	3.5	-0.5 mm
E	2.0	2.0	2.5	3.0	3.5	3.0	3.0	-1.0 mm

Upper Arch - U7 U6 U5 U3 U2 U4 U1

Lower Arch - L7 L6 L5 L4 L3 L2 L1

Figure 3.3: MBT™ Versatile+ Appliance Bracket Placement Guide
Source: 3M Unitek Orthodontics, 2017.

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The accuracy of each of the methods was determined by 3D scans of the models at an independent CAD CAM capable dental lab by superimposition over the ideal lab model. The models were scanned to compare accuracy with the Ortho CAD from Sirona. The models were therefore placed into the Omicam SIRONA Scanner: first the upper and then the lower onto a fixed table with support to hold the model in place, allowing the scanner to take accurate scans of the models at <12 microns. The data was stored in an STL file format onto the computer for the comparison of the different models. STL means STereoLithography – a file format native to the stereolithography CAD software created by 3D Systems (Michael, 2017).

In order for the whole data set to be analysed together, angulation errors were converted into linear measurements by converting degrees into the radius of a circle and line with the length of the arch being the linear expression of the angular difference. Positive values were recorded in horizontal mesially and negative distally. Positive values were recorded in vertical incisally and negative gingivally or apically. Positive angular errors indicated a mesial tilting of the bracket while negative errors indicated distal tilting.

These steps were followed for the simulation:

- The operator began with whichever method was selected by the auto-selection system and asked the assistant to light cure on his or her command as a standard orthodontic technique.
- An independent company scanned the outcome in 3D to determine the accuracy of the brackets' placement.
- This was recorded and plotted onto a graph.
- This was done on the dental simulator (Nissim type 2, see Figure 3.4) as dental phantom head.

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Figure 3.4: Nissim type 2 dental simulator used in the study

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3.4 MATERIALS AND METHODS: INDIRECT METHOD

3.4.1 Model preparation

The impressions were made with Orthoprint alginate (Zhermack). Two parts (level scoops) of Orthoprint alginate were mixed with two parts of water in a measuring cylinder (Zhermack). This was poured into the model base former (OrthoTec) using class III gypsum material (Dentstone KD). All mixtures were vacuumed and mixed with a Vac-U-Mixer (Whip Mix Vacuum Mixer Plus) to ensure bubble-free plaster models.

In the event of bubbles occurring on the model, only bubbles close to the brackets were picked to avoid creating an unwanted negative in the model which can cause the indirect bonding tray to fit inaccurately (Nojima, Araujo & Junior, 2015).

The models were then left to fully crystallise, and either dried in a toaster oven at 150 degrees Celsius for 20 minutes, or air-dried overnight (Rudman, 2008; Sellke, 2008).

Once dried, the models were coated with a thin layer of separator (Vertex Divosep), mixed with water in a 1:1 ratio, and were allowed to dry completely before proceeding with bracket reference points and placement (Nojima *et al*., 2015).

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3.4.2 Placing the brackets

The exact reference points for bracket placement were determined by the intersection of the long axis of each tooth and the mesio-distal marker position relative to the incisal edges and cusp tips. The mesial-distal marker will vary depending on the prescribed bracket set-up. Both were clearly marked with a pencil line to indicate bracket position (Nojima *et al.*, 2015; Sellke, 2008).

Next, a high-quality polyvinyl acetate, commonly referred to as wood glue, was fully be worked into the bracket mesh of each bracket and allowed to set for 20 seconds before securing it to the working model at the reference point, respecting the slot height and long axis of each tooth.

A block-out wax material, Erkogum or an equivalent product, was used to block out bracket slots and hooks to prevent the excess bonding agent from flowing into unwanted areas (Aileni *et al*., 2012).

3.4.3 Custom transfer tray

The custom tray construction started with dispensing a clear inner polyvinylsiloxane bead (elite glass from Zhermack) with a dispensing gun in a continuous motion across all the secured brackets. The material was then intimately adapted around the bracket with a wet paper towel in a mesial-distal direction to create a uniform surface parallel to the brackets and occlusal surface (Rudman, 2008).

A scalpel was then used to cut the inner tray into a uniform shape and section it into three easy-to-use parts: two posterior sections and one anterior section (Rudman, 2008).

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Next, a hard outer polyethylene trephthalate glycol (PETG plastic) thermoforming sheet was vacuum-formed over the inner tray to form the stable outer tray. The complete custom tray was removed from the model with the brackets secured inside and neatly trimmed (Nojima *et al.*, 2015).

3.4.4. Final preparation

The exposed bracket mesh on the custom transfer tray was then cleaned to remove any polyvinyl acetate residue and lightly etched using 50 micron aluminium oxide. Finally, the trays were cleaned with oil-free compressed air.

The trays were placed onto the models that were attached to the manikins, and the resin bracket cement was light cured by an assistant on the operator's command.

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3.5 MATERIALS AND METHODS: DIRECT METHOD

3.5.1 Preparation

Standard MBT brackets with hooks from canine to premolar were used with orthodontic bracket height gauge mirror, bracket holder, flat plastic and probe to place on the brackets to the standard height and position. A regular orthodontic cement (Transbond XT) used was.

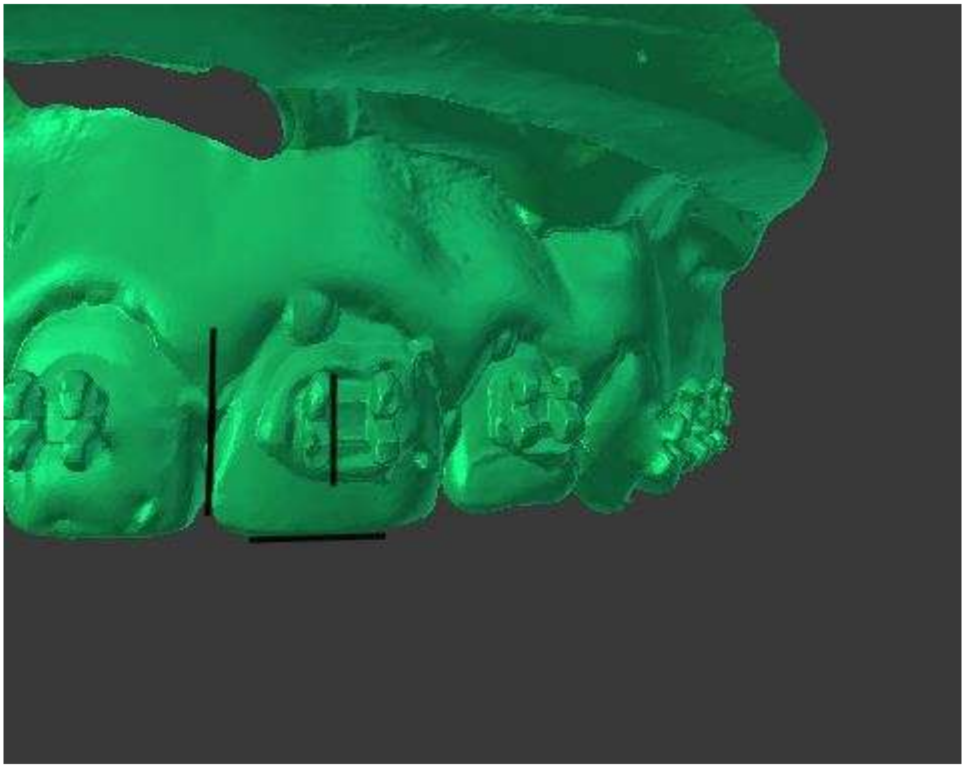

Figure 3.5: Original lines on the golden model demarcating starting points to be measured against

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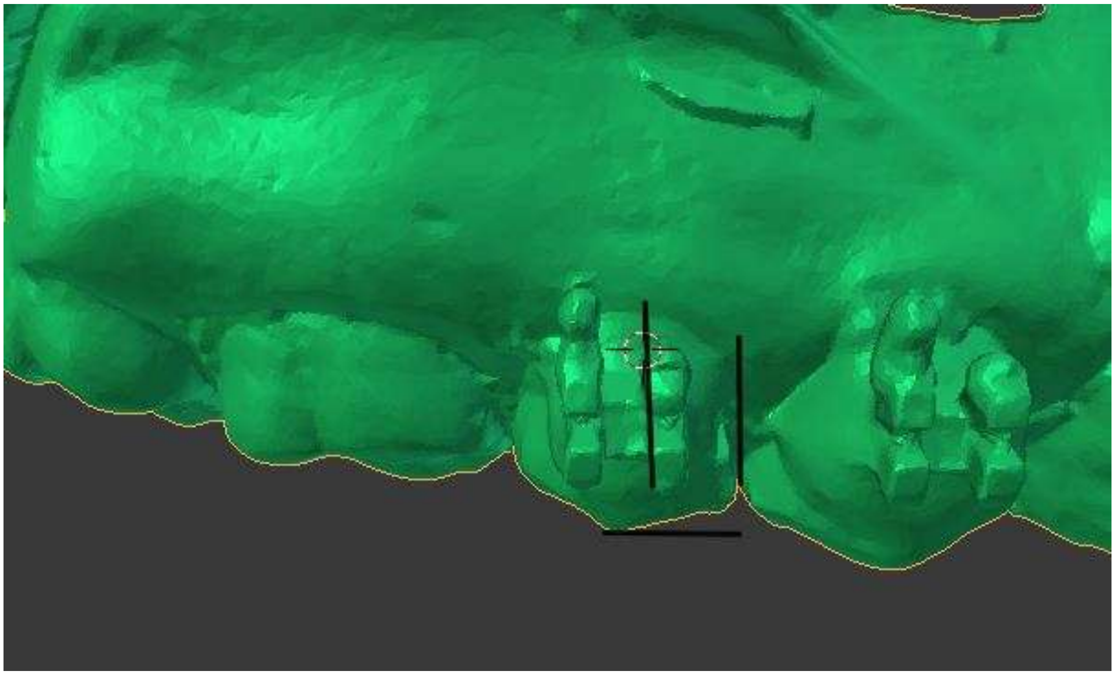

Figure 3.6: Another example of original lines on the golden model demarcating starting points to be measured against

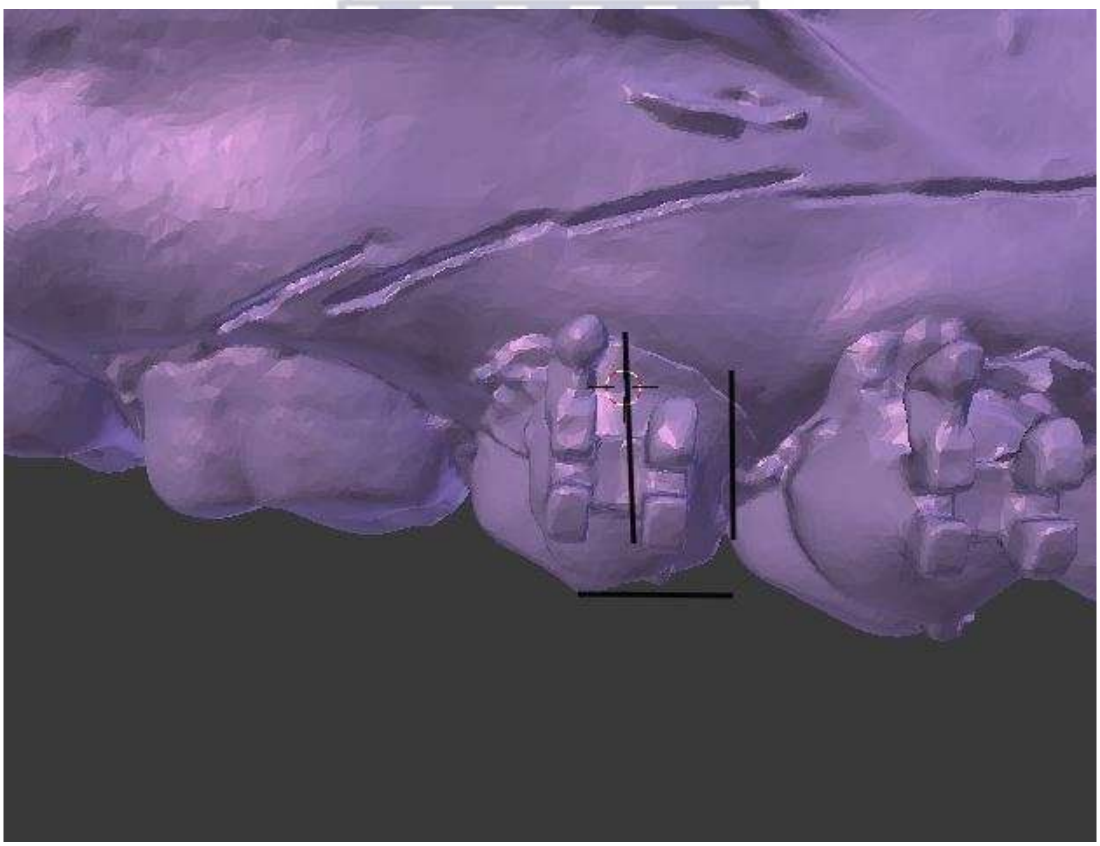

Figure 3.7: Static markers on one of the models to compare the deviations

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Figure 3.8: An example of how horizontal is measured on the test

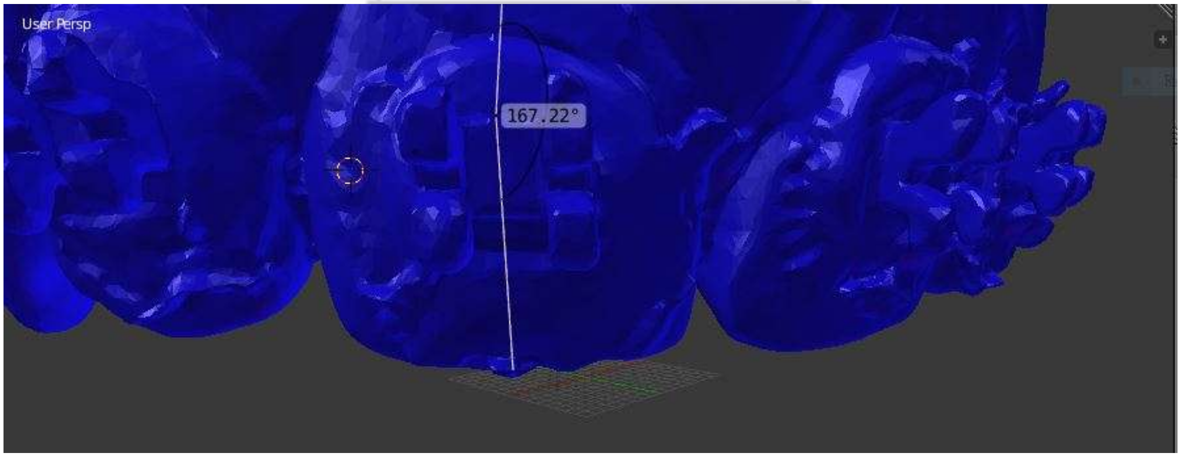

Figure 3.9: An example how angle is measured against the golden model

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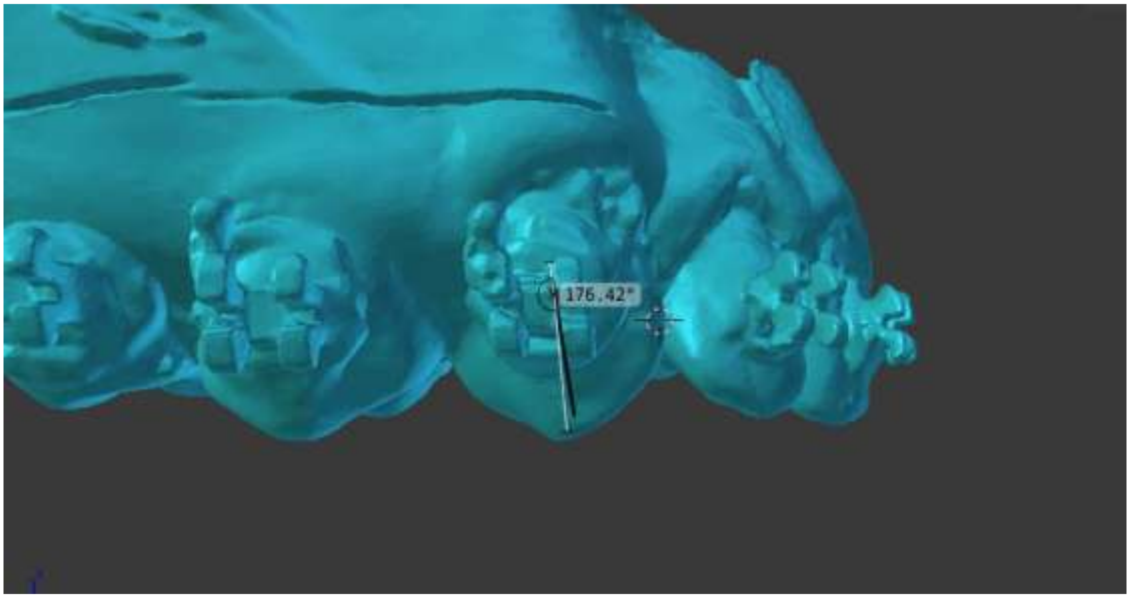

Figure 3.10: Angle mesial and distal – another example of the angle measurement

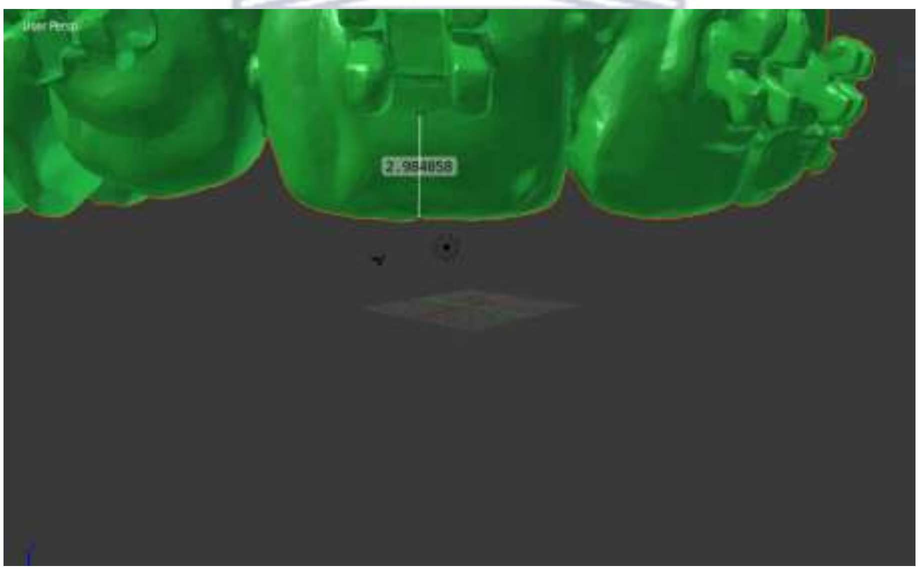

Figure 3.11: An example of horizontal measurement

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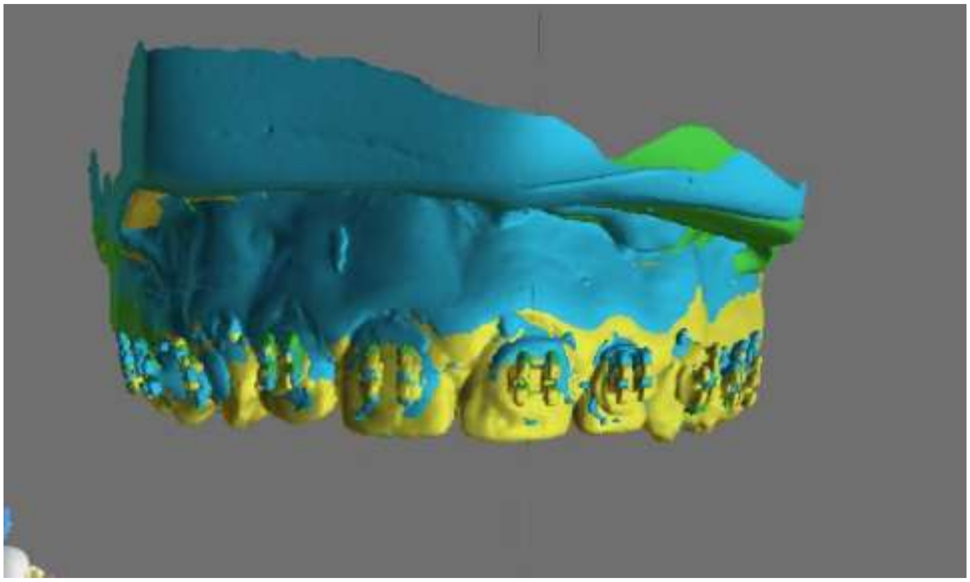

Figure 3.12: How the models look when all three are merged together

3.6 SAMPLE SIZE

Sample size estimation was based on the key research question to be answered, in this case a comparison of the accuracy of direct versus indirect bracket placement (for each tooth) in orthodontics. Sample size estimation was based on the detection of an accuracy difference between methods of 5 degrees with a standard deviation per method of 2.5 degrees (effect size: Cohen's d=2.0). At 80% power and the 5% significance level, a sample size of 10 experiments was required.

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The proposed sample size of 10 experiments was thus adequate for the purposes of the study.

3.7 DATA ANALYSIS

3.7.1 Using descriptive analysis

Descriptive analysis of the data was carried out as follows: Accuracy outcomes (angular, horizontal and height deviation per tooth) were summarised by the mean, standard deviation, median and interquartile range, and their distribution illustrated by means of histograms.

Each outcome for each tooth was compared for the two methods using a mixed model with *outcome* as the dependent variable, *method* as independent variable, and *model and operator* as repeated measures random factors. Data analysis was carried out using the statistical analysis software package SAS. The 5% significance level was used.

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To testing reliability, one model was used for the direct method and another model for the indirect method (or two models altogether if the D/ID distinction did not come into it). The bracket placement exercise was repeated two weeks apart (giving the team two sessions), and recorded all the height, angular and horizontal deviations per tooth as per protocol. (This equals 2 x 2 sets of measurements.) The Fleiss Intraclass Correlation Coefficient (ICC) was run on each of the height, angular and horizontal deviations (across all the teeth), comparing the two sessions to determine intra-researcher reliability.

3.7.2 Data capturing

On the vertical columns:

Table 3.1: Data capturing of experiments, operators, models and methods

Experiment	**Operator**	**Model**	**D_ID**
The sequence in which the experiments were carried out	Operator name, or label the operators A-J	Name or number of model used	Direct (D) or indirect (ID) method used
1	A	1	D
2	A	2	D
3	A	3	ID
4	A	4	ID
5	B	2	D
6	B	3	D
7	B	4	ID
8	B	5	ID
9	C	3	D
10	C	4	D
11	C	5	ID
12	C	6	ID
13	D	4	D
14	D	5	D
15	D	6	ID
16	D	7	ID
17	E	5	D
18	E	6	D
19	E	7	ID
20	E	8	ID
21	F	6	D
22	F	7	D

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23	F	8	ID
24	F	9	ID
25	G	7	D
26	G	8	D
27	G	9	ID
28	G	10	ID
29	H	1	D
30	H	8	D
31	H	9	ID
32	H	10	ID
33	I	1	D
34	I	2	D
35	I	9	ID
36	I	10	ID
37	I	1	D
38	I	2	D
39	I	3	ID
40	I	10	ID

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On the horizontal rows:

H_11	V_11	A_11	H_12	V_12	A_12	H_13	V_13	A_13	H_14	V_14	A_14
H measure ment for tooth 11	V measure ment for tooth 11	A measure ment for tooth 11	H measure ment for tooth 12	V measure ment for tooth 12	A measure ment for tooth 12	H measure ment for tooth 13	V measure ment for tooth 13	A measure ment for tooth 13	H measure ment for tooth 14	V measure ment for tooth 14	A measure ment for tooth 14

H_15	V_15	A_15	H_21	V_21	A_21	H_22	V_22	A_22	H_23	V_23	A_23
H measure ment for tooth 15	V measure ment for tooth 15	A measure ment for tooth 15	H measure ment for tooth 21	V measure ment for tooth 21	A measure ment for tooth 21	H measure ment for tooth 22	V measure ment for tooth 22	A measure ment for tooth 22	H measure ment for tooth 23	V measure ment for tooth 23	A measure ment for tooth 23

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H_24	V_24	A_24	H_25	V_25	A_25	H_31	V_31	A_31	H_32	V_32	A_32
H measure ment for tooth 24	V measure ment for tooth 24	A measure ment for tooth 24	H measure ment for tooth 25	V measure ment for tooth 25	A measure ment for tooth 25	H measure ment for tooth 31	V measure ment for tooth 31	A measure ment for tooth 31	H measure ment for tooth 32	V measure ment for tooth 32	A measure ment for tooth 32

H_33	V_33	A_33	H_34	V_34	A_34	H_35	V_35	A_35	H_41	V_41	A_41
H measure ment for tooth 33	V measure ment for tooth 33	A measure ment for tooth 33	H measure ment for tooth 34	V measure ment for tooth 34	A measure ment for tooth 34	H measure ment for tooth 35	V measure ment for tooth 35	A measure ment for tooth 35	H measure ment for tooth 41	V measure ment for tooth 41	A measure ment for tooth 41

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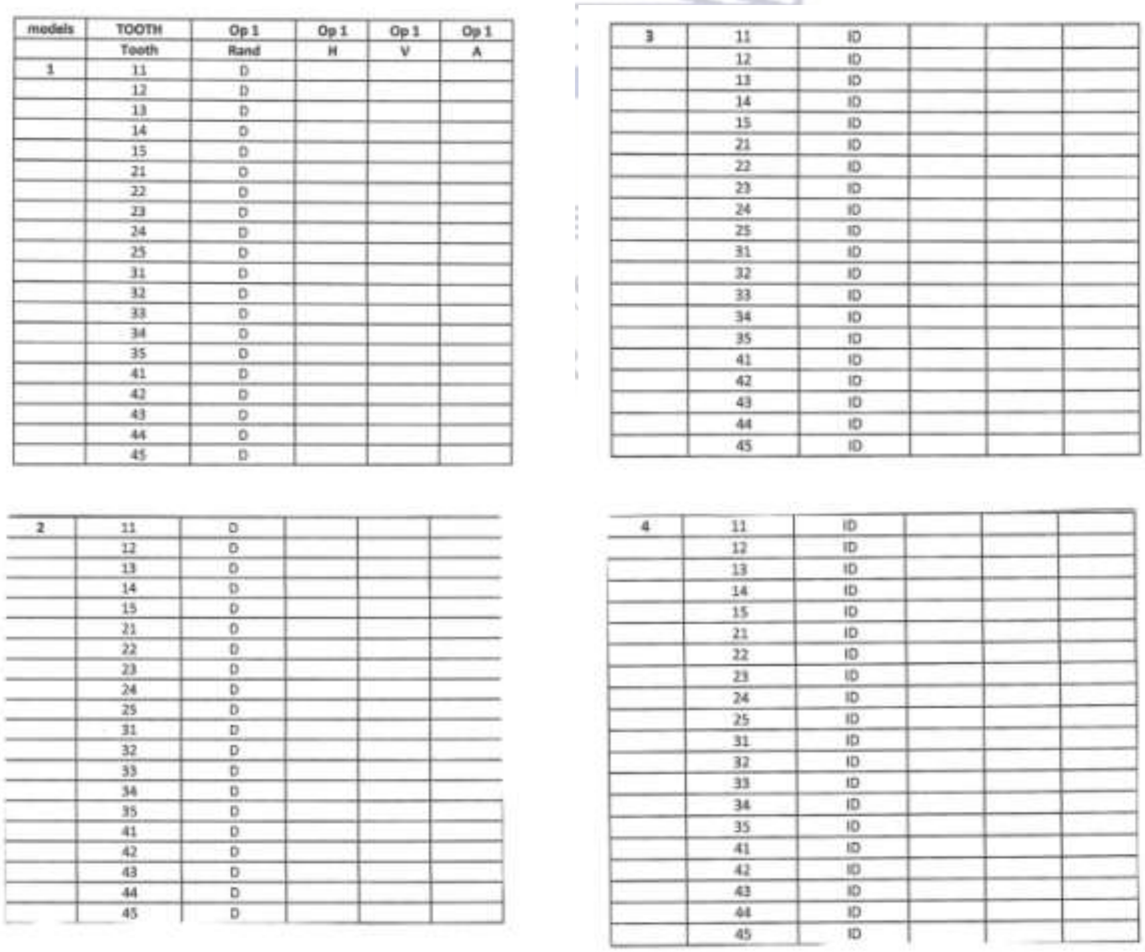
H_42	V_42	A_42	H_43	V_43	A_43	H_44	V_44	A_44	H_45	V_45	A_45
H measurement for tooth 42	V measurement for tooth 42	A measurement for tooth 42	H measurement for tooth 43	V measurement for tooth 43	A measurement for tooth 43	H measurement for tooth 44	V measurement for tooth 44	A measurement for tooth 44	H measurement for tooth 45	V measurement for tooth 45	A measurement for tooth 45

This is an example of Models 1 to 4 with Operator 1 receiving slips for data capture:



models	TOOTH Tooth	Op 1 Rand	Op 1 H	Op 1 V	Op 1 A
1	11	D			
	12	D			
	13	D			
	14	D			
	15	D			
	21	D			
	22	D			
	23	D			
	24	D			
	25	D			
	31	D			
	32	D			
	33	D			
	34	D			
	35	D			
	41	D			
	42	D			
	43	D			
	44	D			
	45	D			

3	11	ID			
	12	ID			
	13	ID			
	14	ID			
	15	ID			
	21	ID			
	22	ID			
	23	ID			
	24	ID			
	25	ID			
	31	ID			
	32	ID			
	33	ID			
	34	ID			
	35	ID			
	41	ID			
	42	ID			
	43	ID			
	44	ID			
	45	ID			

2	11	D			
	12	D			
	13	D			
	14	D			
	15	D			
	21	D			
	22	D			
	23	D			
	24	D			
	25	D			
	31	D			
	32	D			
	33	D			
	34	D			
	35	D			
	41	D			
	42	D			
	43	D			
	44	D			
	45	D			

4	11	ID			
	12	ID			
	13	ID			
	14	ID			
	15	ID			
	21	ID			
	22	ID			
	23	ID			
	24	ID			
	25	ID			
	31	ID			
	32	ID			
	33	ID			
	34	ID			
	35	ID			
	41	ID			
	42	ID			
	43	ID			
	44	ID			
	45	ID			

Figure 3.13: Example of Models 1 to 4 with Operator 1 receiving slips for data capture

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Experiment	Operator	Model	D_ID	H_11	V_11	A_11	H_12	V_12	A_12	H_13	V_13	A_13	H_14	V_14	A_14	H_15	V_15	A_15	H_21	V_21	A_21	H_22	V_22	A_22	H_23	V_23	A_23	H_24	V_24	A_24	H_25	V_25	A_25	H_31	V_31	A_31	H_32	V_32	A_32	H_33	V_33	A_33	H_34	V_34	A_34	H_35	V_35	A_35	H_41	V_41	A_41	H_42	V_42	A_42	H_43	V_43	A_43	H_44	V_44	A_44	H_45	V_45	A_45
this is the sequence in which the experiments are carried out. Will run from 1-40	Operator Name, or label the operators A-J	Name or number of model used	D or ID method used	H measurement for tooth 11	V measurement for tooth 11	A measurement for tooth 11	H measurement for tooth 12	V measurement for tooth 12	A measurement for tooth 12	H measurement for tooth 13	V measurement for tooth 13	A measurement for tooth 13	H measurement for tooth 14	V measurement for tooth 14	A measurement for tooth 14	H measurement for tooth 15	V measurement for tooth 15	A measurement for tooth 15	H measurement for tooth 21	V measurement for tooth 21	A measurement for tooth 21	H measurement for tooth 22	V measurement for tooth 22	A measurement for tooth 22	H measurement for tooth 23	V measurement for tooth 23	A measurement for tooth 23	H measurement for tooth 24	V measurement for tooth 24	A measurement for tooth 24	H measurement for tooth 25	V measurement for tooth 25	A measurement for tooth 25	H measurement for tooth 31	V measurement for tooth 31	A measurement for tooth 31	H measurement for tooth 32	V measurement for tooth 32	A measurement for tooth 32	H measurement for tooth 33	V measurement for tooth 33	A measurement for tooth 33	H measurement for tooth 34	V measurement for tooth 34	A measurement for tooth 34	H measurement for tooth 35	V measurement for tooth 35	A measurement for tooth 35	H measurement for tooth 41	V measurement for tooth 41	A measurement for tooth 41	H measurement for tooth 42	V measurement for tooth 42	A measurement for tooth 42	H measurement for tooth 43	V measurement for tooth 43	A measurement for tooth 43	H measurement for tooth 44	V measurement for tooth 44	A measurement for tooth 44	H measurement for tooth 45	V measurement for tooth 45	A measurement for tooth 45
1	A	1	D																																																								
2	A	2	D																																																								
3	A	3	ID																																																								
4	A	4	ID																																																								
5	B	2	D																																																								
6	B	3	D																																																								
7	B	4	ID																																																								
8	B	5	ID																																																								
9	C	3	D																																																								
10	C	4	D																																																								
11	C	5	ID																																																								
12	C	6	ID																																																								
13	D	4	D																																																								
14	D	5	D																																																								
15	D	6	ID																																																								
16	D	7	ID																																																								
17	E	5	D																																																								
18	E	6	D																																																								
19	E	7	ID																																																								
20	E	8	ID																																																								
21	F	6	D																																																								
22	F	7	D																																																								
23	F	8	ID																																																								
24	F	9	ID																																																								
25	G	7	D																																																								
26	G	8	D																																																								
27	G	9	ID																																																								
28	G	10	ID																																																								
29	H	1	D																																																								
30	H	8	D																																																								
31	H	9	ID																																																								
32	H	10	ID																																																								
33	I	1	D																																																								
34	I	2	D																																																								
35	I	9	ID																																																								
36	I	10	ID																																																								
37	J	1	D																																																								
38	J	2	D																																																								
39	J	3	ID																																																								
40	J	10	ID																																																								

Figure 3.14: Example of the entire data capture sheet

The code book used is shown in Figure 3.15 below:

Code book				
Variable Name	**Meaning**	**Type**	**Units**	**Coding**
D	Direct	Categorical		
ID	Indirect	Categorical		
Rand	Random numbering	Random selection		
Models	Orthodontic models	Categorical		
H	Horizontal	Continuous	Numerical value closest to zero	numerical value higher recorded positive lower negative away from zero away from ideal
V	Vertical	Continuous	Numerical value closest to zero	numerical value mesial recorded positive distal negative away from zero away from ideal
A	Angle	Continuous	Numerical value closest to zero	numerical value angle recorded positively or negatively away from ideal
Tooth	tooth number	quadrant number	11-15,21-25,31-35,41-45	
OP	Operator	Operator	one - ten	numerical value positive value

Figure 3.15: Code book

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3.8 ETHICAL CONSIDERATIONS

3.8.1 Ethical clearance

The protocol of this study was approved by the Research Ethics Committee of the University of Western Cape (BM18/3/10). Permission has therefore been obtained to carry out the study.

3.8.1 Human subjects

No human subjects were directly involved in the study. Patients were de-identified and no patient interests were at risk.

3.8.2 Conflict of interest declare

The study team used proprietary orthodontics (3M Unitek) only for the purpose of keeping a standard for the study. We have no financial interest in the product or company.

An orthodontics materials supplier (OrthoShop) donated the brackets for the study. We have no financial interest in the product or company.

3.8.3 Funding

All the other materials for the study were supplied by the researcher. No external funding was obtained for the materials.

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CHAPTER 4

RESULTS

4.1 INTRODUCTION

The results will be displayed with charts, graphs, tables and a short description of each pair of measurements. The pair consists of the mean average of the results comparing direct and indirect resultant as the actual outcome measurement.

4.2 HYPOTHESES TESTED

The study tested the following hypotheses:

H_1: There is a significant difference between the direct and indirect method of bonding

H_0: There is no significant difference between direct and indirect method of bonding.

4.3 DESCRIPTIVE STATISTICS RECORDED

Table 4.1 and Table 4.2 present the descriptive statistics (mean and standard deviations – SD) of deviation, and with the interquartile range recorded between the first direct and second indirect measurements.

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Table 4.1: Descriptive statistics (mean and standard deviation) of horizontal, vertical and angular using the direct method

Direct method (n=10)								
Variable	N	Mean	Std Dev	Median	Interquartile range		Minimum	Maximum
H_11	10	0.15	0.40	0.20	-0.20	0.50	-0.40	0.64
V_11	10	-0.59	0.74	-0.59	-0.81	-0.05	-1.85	0.42
A_11	10	-2.51	3.57	-2.54	-6.34	1.18	-7.04	2.67
H_12	10	0.20	0.40	0.15	-0.13	0.40	-0.30	0.93
V_12	10	-0.16	0.79	-0.25	-0.68	0.33	-1.23	1.41
A_12	10	-0.94	7.44	0.10	-6.99	3.47	-12.32	9.57
H_13	10	0.10	0.29	0.13	0.01	0.24	-0.53	0.57
V_13	10	-0.09	0.87	0.05	-0.58	0.49	-1.40	1.03
A_13	10	1.64	6.21	1.16	-3.56	4.57	-7.21	14.32
H_14	10	-0.21	0.42	-0.30	-0.39	-0.13	-0.74	0.84
V_14	10	0.07	0.51	0.22	-0.09	0.48	-1.06	0.53
A_14	10	0.28	4.80	2.20	-2.31	2.77	-7.89	5.75
H_15	10	-0.23	0.58	-0.29	-0.63	0.35	-1.22	0.51
V_15	10	0.21	0.47	0.19	0.00	0.70	-0.47	0.84
A_15	10	-1.80	3.44	-0.20	-3.22	0.00	-8.00	3.34
H_21	10	0.48	0.46	0.48	0.20	0.74	-0.16	1.32
V_21	10	-0.52	0.59	-0.41	-0.98	-0.20	-1.50	0.32
A_21	10	0.36	5.62	-0.58	-4.47	2.35	-6.13	12.42
H_22	10	-0.03	0.45	0.12	-0.53	0.35	-0.76	0.49
V_22	10	-0.45	0.83	-0.47	-0.90	0.21	-1.72	0.77
A_22	10	-1.00	7.44	-4.21	-6.21	0.92	-7.87	13.72
H_23	10	0.11	0.58	-0.01	-0.27	0.35	-0.48	1.52
V_23	10	-0.17	0.54	-0.22	-0.58	0.05	-0.78	0.68
A_23	10	1.50	9.84	0.72	-0.99	5.88	-20.10	17.07
H_24	10	0.19	0.60	0.39	-0.50	0.56	-0.75	1.10
V_24	10	-0.05	0.57	-0.06	-0.46	0.27	-1.07	0.88
A_24	10	1.65	11.43	-2.86	-4.12	11.63	-16.48	20.29
H_25	10	0.32	0.34	0.40	-0.01	0.52	-0.17	0.78
V_25	10	-0.16	0.29	-0.17	-0.28	0.04	-0.70	0.28
A_25	10	1.56	6.04	2.41	-2.20	4.82	-8.94	9.54
H_31	10	0.32	0.59	0.27	0.01	0.35	-0.39	1.72
V_31	10	0.03	1.20	0.01	-0.35	0.48	-2.58	2.24
A_31	10	2.10	3.83	3.19	-1.46	5.64	-3.94	6.55
H_32	10	0.50	0.73	0.39	0.13	0.58	-0.25	2.43
V_32	10	-0.20	0.51	-0.26	-0.70	-0.03	-0.79	0.74
A_32	10	2.83	6.29	-0.06	-0.95	10.45	-3.21	13.31
H_33	10	0.62	1.50	0.35	-0.12	0.94	-0.73	4.54
V_33	10	-0.24	0.50	-0.42	-0.52	0.04	-0.69	0.99
A_33	10	1.82	4.48	2.52	0.00	3.70	-7.97	9.50

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H_34	10	0.13	0.76	0.23	-0.43	0.54	-1.25	1.34
V_34	10	-0.09	0.63	-0.26	-0.41	-0.05	-0.71	1.42
A_34	10	-0.80	4.52	-1.17	-6.00	4.22	-6.52	5.39
H_35	10	-0.10	0.31	-0.08	-0.34	0.07	-0.49	0.57
V_35	10	0.08	0.55	0.11	-0.41	0.62	-0.80	0.82
A_35	10	2.99	5.59	2.68	0.00	7.72	-8.79	10.67
H_41	10	0.01	0.22	-0.02	-0.07	0.12	-0.29	0.46
V_41	10	0.02	0.59	-0.09	-0.37	0.57	-0.78	0.86
A_41	10	1.60	4.43	1.20	-2.88	6.30	-3.95	6.92
H_42	10	-0.05	0.29	-0.15	-0.23	0.07	-0.37	0.48
V_42	10	-0.13	0.60	-0.15	-0.59	-0.03	-1.11	0.86
A_42	10	0.01	3.97	0.00	-1.67	1.09	-8.60	7.09
H_43	10	0.16	0.57	0.28	-0.36	0.71	-0.74	0.87
V_43	10	-0.48	0.63	-0.46	-1.00	-0.05	-1.35	0.55
A_43	10	2.99	7.95	0.64	-2.62	9.18	-6.99	17.15
H_44	10	0.26	0.35	0.31	-0.04	0.53	-0.36	0.75
V_44	10	0.16	0.65	0.07	-0.19	0.35	-0.97	1.41
A_44	10	1.01	6.74	-0.31	-2.45	5.90	-11.08	13.34
H_45	10	-0.26	0.33	-0.25	-0.44	-0.05	-0.82	0.22
V_45	10	0.28	0.44	0.33	0.05	0.60	-0.48	0.98
A_45	10	-4.12	18.13	-0.70	-7.90	6.54	-50.74	16.30

Table 4.2: Descriptive statistics (mean and standard deviation) of horizontal, vertical and angular using the indirect method

Indirect Method (n=10)								
Variable	**N**	**Mean**	**Std Dev**	**Median**	**Interquartile range**		**Minimum**	**Maximum**
H_11	10	0.07	0.20	0.07	-0.06	0.20	-0.29	0.33
V_11	10	-0.56	1.11	-0.13	-0.70	0.15	-2.61	0.43
A_11	10	-1.68	4.17	0.00	-2.95	0.12	-12.78	1.50
H_12	10	0.07	0.14	0.08	-0.07	0.18	-0.15	0.23
V_12	10	-0.08	0.37	0.07	-0.06	0.14	-0.89	0.24
A_12	10	-1.35	3.61	0.00	-1.41	0.06	-10.00	1.84
H_13	10	0.06	0.29	0.07	-0.05	0.22	-0.54	0.45
V_13	10	0.05	0.18	0.05	-0.13	0.21	-0.21	0.29
A_13	10	0.26	2.51	0.00	-0.93	0.36	-2.98	6.47
H_14	10	0.00	0.37	0.06	-0.17	0.20	-0.73	0.58
V_14	10	0.16	0.24	0.26	0.19	0.27	-0.40	0.37
A_14	10	-1.55	3.50	-0.75	-4.26	0.00	-7.99	2.70
H_15	10	0.06	0.26	0.13	-0.15	0.18	-0.36	0.41
V_15	10	0.18	0.28	0.17	0.02	0.38	-0.24	0.65
A_15	10	0.35	4.58	0.77	-3.99	4.81	-7.32	5.38
H_21	10	0.04	0.15	0.10	-0.04	0.15	-0.32	0.16
V_21	10	0.08	0.25	0.09	-0.10	0.26	-0.38	0.49

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A_21	10	-0.32	2.09	-0.11	-1.60	0.00	-3.01	4.33
H_22	10	0.02	0.15	-0.02	-0.07	0.15	-0.15	0.33
V_22	10	-0.01	0.24	-0.04	-0.14	0.16	-0.38	0.34
A_22	10	0.45	2.15	0.04	-1.08	2.11	-3.20	3.88
H_23	10	0.10	0.21	0.11	-0.08	0.22	-0.26	0.45
V_23	10	0.14	0.24	0.09	-0.02	0.28	-0.14	0.55
A_23	10	1.38	1.94	0.00	0.00	2.82	0.00	4.95
H_24	10	0.11	0.20	0.12	-0.01	0.24	-0.18	0.46
V_24	10	0.20	0.26	0.24	-0.02	0.30	-0.23	0.67
A_24	10	-0.41	2.09	0.00	-0.36	0.24	-5.53	1.87
H_25	10	0.01	0.22	-0.04	-0.16	0.17	-0.31	0.35
V_25	10	0.29	0.51	0.23	-0.05	0.45	-0.32	1.52
A_25	10	-0.35	3.89	-0.52	-2.64	1.70	-7.40	7.12
H_31	10	-0.01	0.29	0.03	-0.26	0.25	-0.52	0.35
V_31	10	0.07	0.18	0.03	-0.02	0.17	-0.21	0.45
A_31	10	0.49	3.14	0.00	-0.92	0.69	-2.87	8.75
H_32	10	0.00	0.25	0.07	-0.17	0.25	-0.48	0.30
V_32	10	0.07	0.30	-0.02	-0.11	0.32	-0.40	0.59
A_32	10	1.48	3.33	1.12	0.00	2.76	-3.03	8.79
H_33	10	0.53	1.49	0.03	-0.06	0.29	-0.19	4.74
V_33	10	0.14	0.14	0.12	0.03	0.22	-0.06	0.38
A_33	10	0.19	3.20	0.15	0.00	2.30	-5.65	4.38
H_34	10	0.12	0.21	0.15	-0.08	0.28	-0.16	0.42
V_34	10	0.04	0.25	-0.10	-0.12	0.31	-0.26	0.43
A_34	10	0.82	2.20	0.00	0.00	2.86	-2.56	4.66
H_35	10	0.10	0.25	0.13	-0.06	0.30	-0.32	0.41
V_35	10	0.17	0.29	0.27	-0.03	0.42	-0.33	0.48
A_35	10	1.23	3.33	1.00	-1.25	3.29	-2.88	7.34
H_41	10	0.06	0.32	-0.03	-0.12	0.26	-0.27	0.80
V_41	10	0.12	0.54	0.04	-0.13	0.52	-0.92	1.06
A_41	10	-1.39	3.84	-0.46	-2.46	0.65	-10.80	2.60
H_42	10	-0.01	0.22	-0.05	-0.19	0.11	-0.25	0.47
V_42	10	0.20	0.29	0.13	0.02	0.24	-0.10	0.83
A_42	10	0.99	4.68	0.00	0.00	1.95	-6.66	11.70
H_43	10	0.01	0.23	-0.02	-0.16	0.11	-0.29	0.40
V_43	10	0.12	0.27	0.03	-0.04	0.29	-0.27	0.62
A_43	10	-0.87	3.30	0.00	-3.28	0.77	-6.03	3.60
H_44	10	0.11	0.25	-0.01	-0.11	0.36	-0.14	0.52
V_44	10	0.21	0.20	0.19	0.04	0.36	-0.02	0.50
A_44	10	-1.29	4.98	0.00	-0.22	0.00	-15.11	3.22
H_45	10	0.02	0.51	-0.05	-0.15	0.30	-0.93	1.03
V_45	10	0.21	0.33	0.12	-0.05	0.30	-0.14	0.81
A_45	10	-0.49	11.64	0.79	-3.15	2.24	-29.23	13.08

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4.4 TOOTH RESULTS

4.4.1 Tooth #11

For Tooth #11, the mean values for the horizontal measurement were both positive for direct and indirect showing more mesial placement. The standard deviation was 0.028 and the *p* value = 0.5744 H value 0, therefore indicating no statistical significance ($p < 0.05$).

The mean values for the vertical measurement were both negative for direct and indirect, showing more apical placement. The standard deviation was 0.004 and the *p* value = 0.95 H value 0, therefore indicating no statistical significance ($p < 0.05$).

The mean values for the angular measurement were negative for both direct and indirect, showing more distal angle. The standard deviation was 3.428 and the *p* value = 3.428 H value 0, therefore indicating no statistical significance ($p < 0.05$).

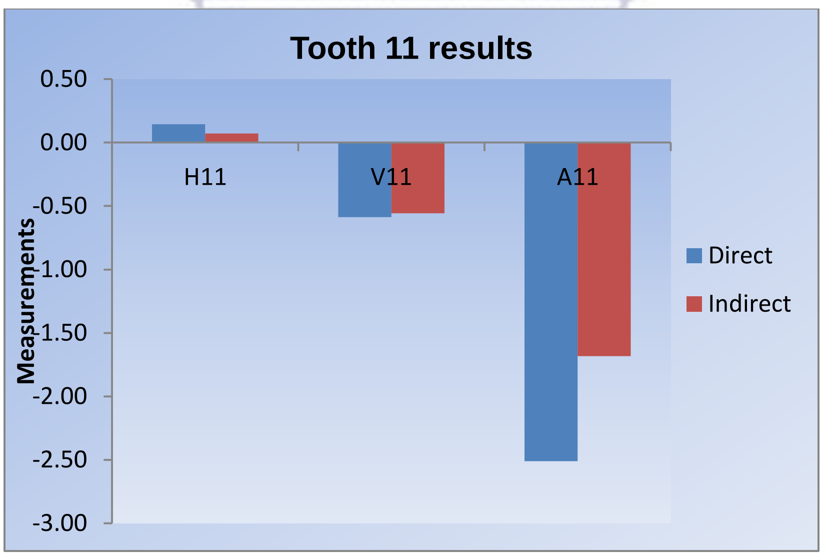

Figure 4.1: Mean height, vertical and angle results of Tooth #11

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Table 4.3: Resultant measurements for Tooth #11

	Direct	Indirect		
H11	0.15	0.07	P=0.5744	H_0
V11	-0.59	-0.56	P=0.95	H_0
A11	-2.51	-1.68	P=0.6127	H_0

Mean Square/deviation 11

H11 = 0.028

V11 = 0.004

A11 = 3.428

4.4.2 Tooth #12

For Tooth #12, the mean values for the horizontal measurement were positive for both direct and indirect, showing more mesial placement. The standard deviation was 0.091 and the p value = 0.3602 H value 0, therefore indicating no statistical significance ($p < 0.05$).

The mean values for the vertical measurement were negative for both direct and indirect, showing more apical placement. The standard deviation was 0.562 and the p value = 0.1404 H value 0, therefore indicating no statistical significance ($p < 0.05$).

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The mean values for the angular measurement were negative for both direct and indirect, showing more distal angle. The standard deviation was 0.832 and the p value = 0.8306 H value 0, therefore indicating no statistical significance ($p < 0.05$).

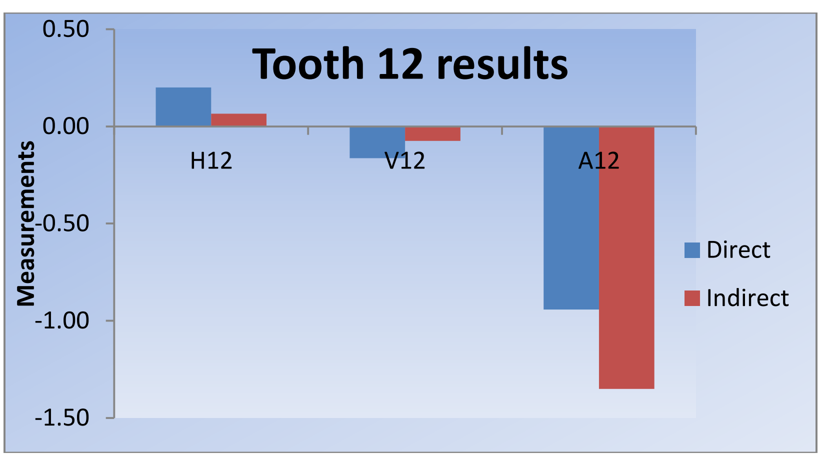

Figure 4.2: Mean height, vertical and angle results of Tooth #12

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Table 4.4: Resultant measurements for Tooth #12

	Direct	Indirect	P	
H12	0.20	0.07	P=0.3602	H_0
V12	-0.16	-0.08	P=0.1404	H_0
A12	-0.94	-1.35	P=0.8306	H_0

Mean Square/deviation 12

H12 = 0.091

V12 = 0.562

A12 = 0.832

4.4.3 Tooth #13

For Tooth #13, the mean values for the horizontal measurement were positive for both direct and indirect, showing more mesial placement. The standard deviation was 0.090 and the *p* value = 0.778H value 0, therefore indicating no statistical significance ($p < 0.05$).

The mean values for the vertical measurement were negative for direct and positive for indirect showing more apical placement for direct and coronal displacement indirect. The standard deviation was 0.090 and the *p* value = 0.6602H value 0, therefore indicating no statistical significance ($p < 0.05$).

The mean values for the angular measurement were positive for both direct and indirect, showing more mesial angle. The standard deviation was 0.296 and the *p* value = 0.8272H value 0, therefore indicating no statistical significance ($p < 0.05$).

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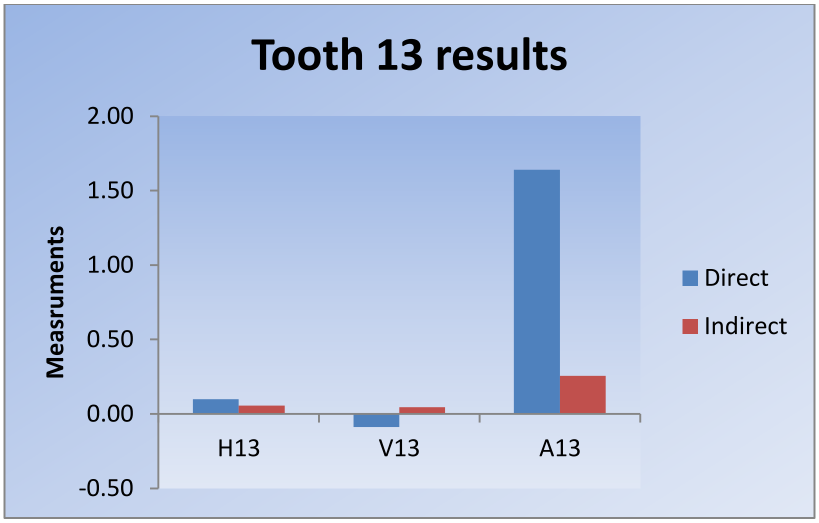

Figure 4.3: Mean height, vertical and angle results of Tooth #13

Table 4.5: Resultant measurements for Tooth #13

	Direct	Indirect		
H13	0.10	0.06	P=0.778	H_0
V13	-0.09	0.05	P=0.6602	H_0
A13	1.64	0.26	P=0.8272	H_0

Mean Square/deviation13

H13 = 0.009

V13 = 0.090

A13 = 0.296

4.4.4 Tooth #14

For Tooth #14, the mean values for the horizontal measurement were negative for direct and positive for indirect, showing more distal displacement for direct and mesial displacement for indirect. The standard deviation was 0.218 and the *p* value = 0.1518H value 0, therefore indicating no statistical significance ($p < 0.05$).

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The mean values for the vertical measurement were positive for direct and positive for indirect, showing more coronal displacement for direct and indirect. The standard deviation was 0.039 and the *p* value = 0.671 H value 0, therefore indicating no statistical significance ($p < 0.05$).

The mean values for the angular measurement were positive for direct and negative for indirect, showing more mesial angle displacement for direct and distal angle displacement for indirect. The standard deviation was 16.818 and the *p* value = 0.27H value 0, therefore indicating no statistical significance ($p < 0.05$).

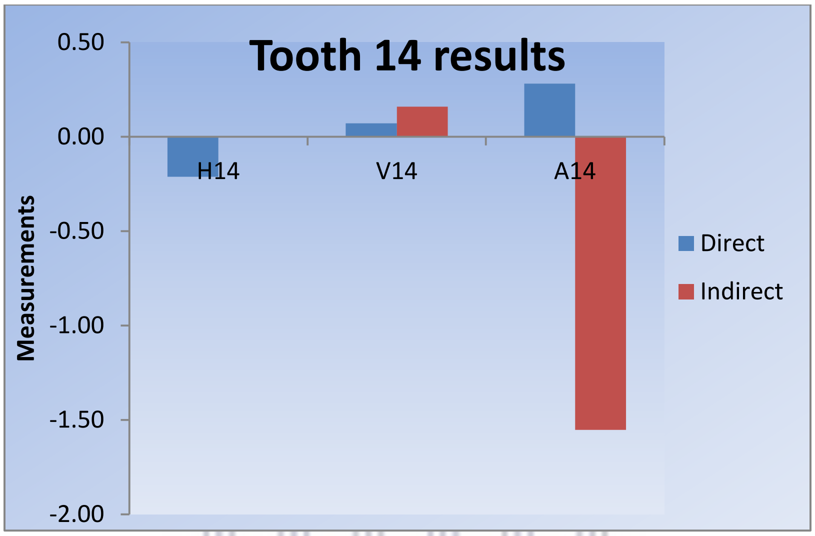

Figure 4.4: Mean height, vertical and angle results of Tooth #14

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Table 4.6: Resultant measurements for Tooth #14

	Direct	Indirect		
H14	-0.21	0.00	P=0.1518	H_0
V14	0.07	0.16	P=0.671	H_0
A14	0.28	-1.55	P=0.27	H_0

Mean Square/deviation14

H14 = 0.218

V14 = 0.039

A14 = 16.818

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4.4.5 Tooth #15

For Tooth #15, the mean values for the horizontal measurement were negative for direct and positive for indirect, showing more distal displacement for direct and mesial displacement for indirect. The standard deviation was 0.415 and the *p* value = 0.1579H value 0, therefore indicating no statistical significance ($p < 0.05$).

The mean values for the vertical measurement were positive for direct and indirect, showing more coronal displacement. The standard deviation was 0.008 and the *p* value = 0.8097 H value 0, therefore indicating no statistical significance ($p < 0.05$).

The mean values for the angular measurement were positive for direct and negative for indirect, showing more mesial angle displacement for direct and distal angle displacement for indirect. The standard deviation was 16.818 and the *p* value = 0.8272H value 0, therefore indicating no statistical significance ($p < 0.05$).

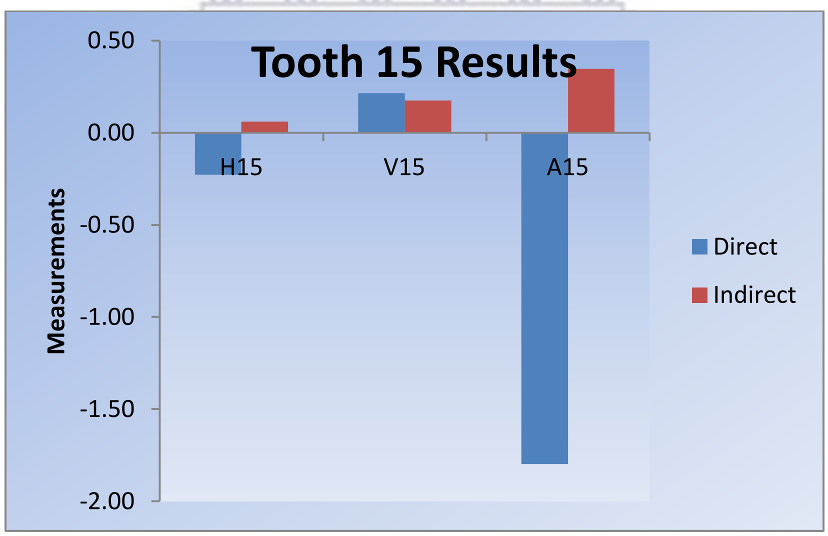

Figure 4.5: Mean height, vertical and angle results of Tooth #15

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Table 4.7: Resultant measurements for Tooth #15

	Direct	Indirect		
H15	-0.23	0.06	P=0.1579	H_0
V15	0.21	0.18	P=0.8097	H_0
A15	-1.80	0.35	P=0.3466	H_0

Mean Square/deviation 15

H15 = 0.415

V15 = 0.008

A15 = 22.962

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4.4.6 Tooth #21

For Tooth #21, the mean values for the horizontal measurement were positive for direct and indirect, showing more mesial displacement. The standard deviation was 0.972 and the *p* value = 0.018H value 1, therefore indicating statistical significance ($p < 0.05$).

The mean values for the vertical measurement were negative for direct and positive for indirect, showing more apical displacement for direct and coronal displacement for indirect. The standard deviation was 1.776 and the *p* value = 0.018H value 1, therefore indicating statistical significance ($p < 0.05$).

The mean values for the angular measurement were positive for direct and negative for indirect, showing more mesial angle displacement for direct and distal angle displacement for indirect. The standard deviation was 2.339 and the *p* value = 0.75H value 0, therefore indicating no statistical significance ($p < 0.05$).

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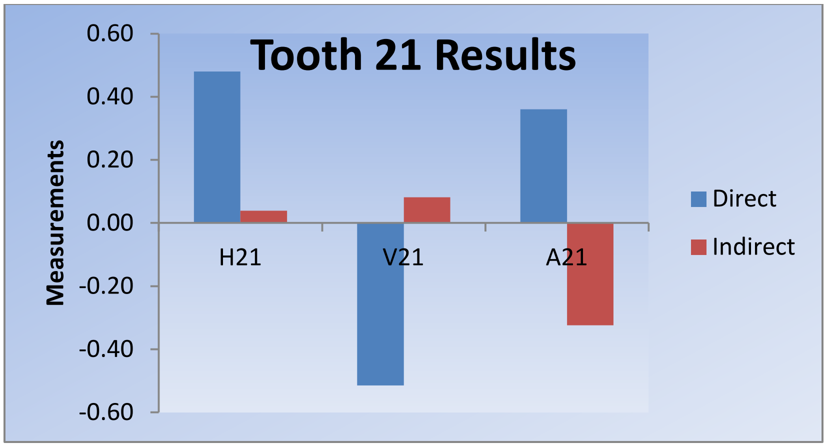

Figure 4.6: Mean height, vertical and angle results of Tooth #21

Table 4.8: Resultant measurements for Tooth #21

	Direct	Indirect		
H21	0.48	0.04	0.018	H_1
V21	-0.52	0.08	0.018	H_1
A21	0.36	-0.32	0.75	H_0

Mean Square/deviation21

H21 = 0.972

V21 = 1.776

A21 = 2.339

4.4.7 Tooth #22

For Tooth #22, the mean values for the horizontal measurement were negative for direct and positive for indirect, showing more mesial displacement for direct and distal displacement for indirect. The standard deviation was 0.016 and the *p* value = 0.6817H value 0, therefore indicating no statistical significance ($p < 0.05$).

The mean values for the vertical measurement were negative for direct and indirect, showing more apical displacement. The standard deviation was 0.977 and the *p* value = 0.1749H value 0, therefore indicating no statistical significance ($p < 0.05$).

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The mean values for the angular measurement were negative for direct and positive for indirect, showing more distal angle displacement for direct and mesial angle displacement for indirect. The standard deviation was 10.455 and the p value = 0.6033H value 0, therefore indicating no statistical significance ($p < 0.05$).

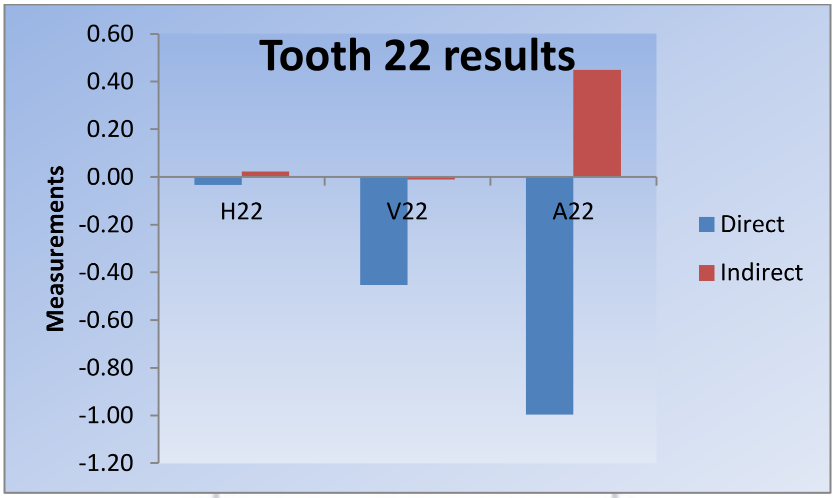

Figure 4.7: Mean height, vertical and angle results of Tooth #22

Table 4.9: Resultant measurements for Tooth #22

	Direct	Indirect		
H22	-0.03	0.02	P=0.6817	H_0
V22	-0.45	-0.01	P=0.1749	H_0
A22	-1.00	0.45	P=0.6033	H_0

Mean Square/deviation 22

H22 = 0.016

V22 = 0.977

A22 = 10.455

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4.4.8 Tooth #23

For Tooth #23, the mean values for the horizontal measurement were negative for direct and positive for indirect, showing more mesial displacement for direct and distal displacement for indirect. The standard deviation was 0.001 and the *p* value = 0.9513H value 0, therefore indicating no statistical significance ($p < 0.05$).

The mean values for the vertical measurement were negative for direct and indirect, showing more apical displacement. The standard deviation was 0.481 and the *p* value = 0.1824H value 0, therefore indicating no statistical significance ($p < 0.05$).

The mean values for the angular measurement were negative for direct and positive for indirect, showing more distal angle displacement for direct and mesial angle displacement for indirect. The standard deviation was 25.063 and the *p* value = 0.2802H value 0, therefore indicating no statistical significance ($p < 0.05$).

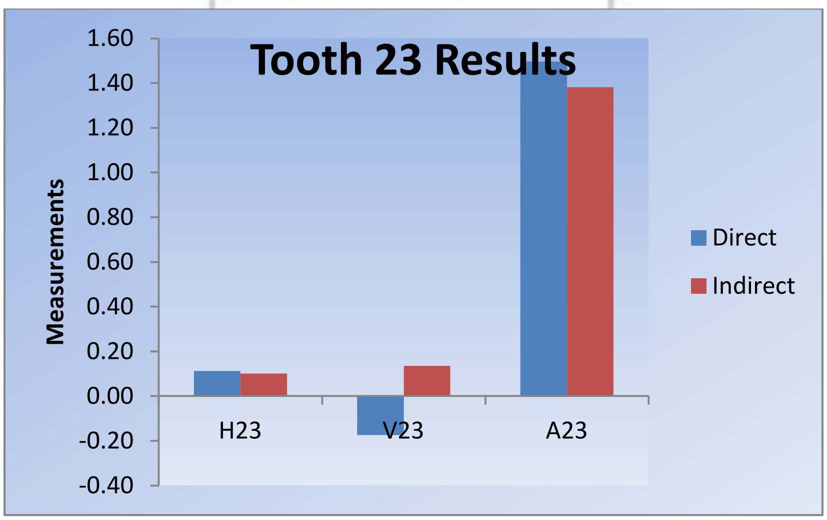

Figure 4.8: Mean height, vertical and angle results of Tooth #23

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Table 4.10: Resultant measurements for Tooth #23

	Direct	Indirect		P	
H23	0.11	0.10		P=0.9513	H_0
V23	-0.17	0.14		P=0.1824	H_0
A23	1.50	1.38		P=0.2802	H_0

Mean Square/deviation 23

H23 = 0.001

V23 = 0.481

A23 = 25.063

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4.4.9 Tooth #24

For Tooth #24, the mean values for the horizontal measurement were positive for direct and for indirect, showing more mesial displacement. The standard deviation was 0.032 and the *p* value = 0.9513H value 0, therefore indicating no statistical significance ($p < 0.05$).

The mean values for the vertical measurement were negative for direct and positive for indirect, showing more coronal displacement direct and apical displacement for indirect. The standard deviation was 0.313 and the *p* value = 0.1824H value 0, therefore indicating no statistical significance ($p < 0.05$).

The mean values for the angular measurement were positive for direct and negative for indirect, showing more mesial angle displacement for direct and distal angle displacement for indirect. The standard deviation was 21.115 and the *p* value = 0.2802H value 0, therefore indicating no statistical significance ($p < 0.05$).

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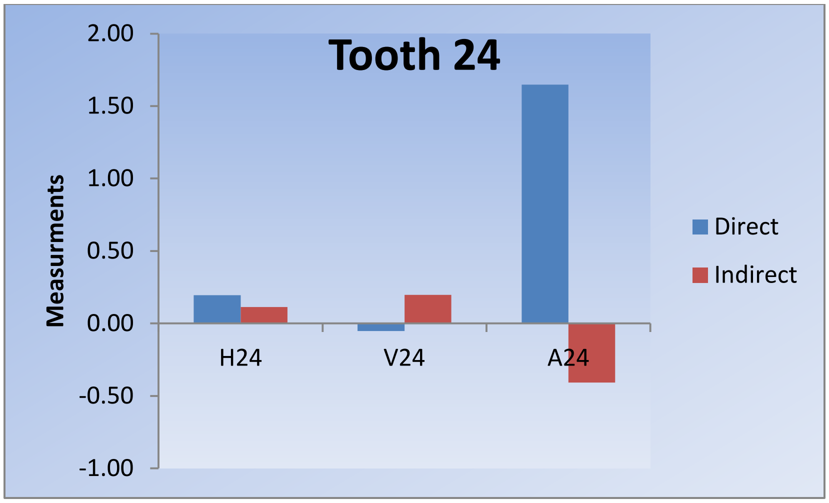

Figure 4.9: Mean height, vertical and angle results of Tooth #24

Table 4.11: Resultant measurements for Tooth #24

	Direct	Indirect		
H24	0.19	0.11	P=0.6639	H_0
V24	-0.05	0.20	P=0.2983	H_0
A24	1.65	-0.41	P=0.6111	H_0

Mean Square/deviation 24

H24 = 0.032

V24 = 0.313

A24 = 21.115

4.4.10 Tooth #25

For Tooth #25, the mean values for the horizontal measurement were positive for direct and for indirect, showing more mesial displacement. The standard deviation was 0.481 and the p value = 0.0159 H value 1, therefore indicating statistical significance ($p < 0.05$).

The mean values for the vertical measurement were negative for direct and positive for indirect, showing more coronal displacement direct and apical displacement for indirect. The standard deviation was 0.490 and the p value = 0.0063 H value 1, therefore indicating no statistical significance ($p < 0.05$).

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The mean values for the angular measurement were positive for direct and negative for indirect, showing more mesial angle displacement for direct and distal angle displacement for indirect. The standard deviation was 18.202 and the *p* value = 0.4049H value 0, therefore indicating no statistical significance ($p < 0.05$).

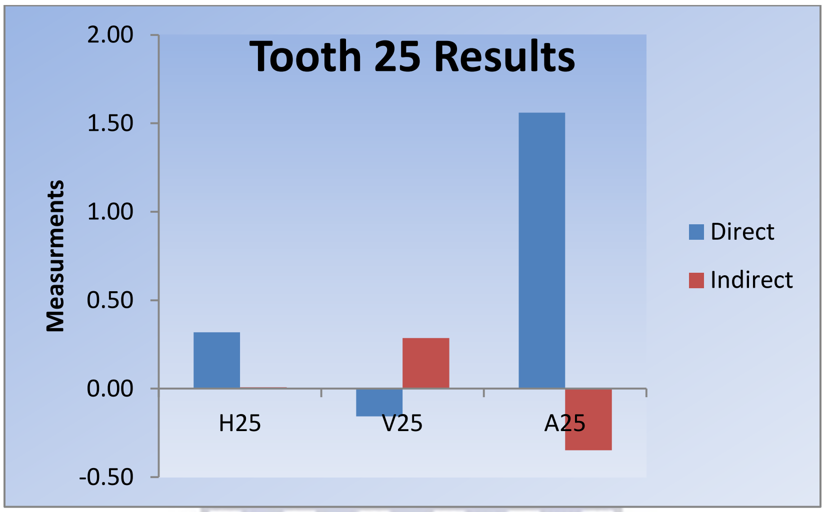

Figure 4.10: Mean height, vertical and angle results of Tooth #25

Table 4.12: Resultant measurements for Tooth #25

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	Direct	Indirect	P	
H25	0.32	0.01	P=0.0159	H_1
V25	-0.16	0.29	P=0.0063	H_1
A25	1.56	-0.35	P=0.4049	H_0

Mean Square/deviation 25

H25 = 0.481

V25 = 0.490

A25 = 18.202

4.4.11 Tooth #31

For Tooth #31, the mean values for the horizontal measurement were positive for direct and negative for indirect, showing more mesial displacement for direct and distal displacement indirect. The

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standard deviation was 0.548 and the *p* value = 0.139H value 1, therefore indicating statistical significance ($p < 0.05$).

The mean values for the vertical measurement were positive showing more coronal displacement direct. The standard deviation was 0.011 and the *p* value = 0.9037H value 1, therefore indicating no statistical significance ($p < 0.05$).

The mean values for the angular measurement were positive for direct and indirect, showing more mesial angle displacement. The standard deviation was 46.048 and the *p* value = 0.0088H value 1, therefore indicating statistical significance ($p < 0.05$).

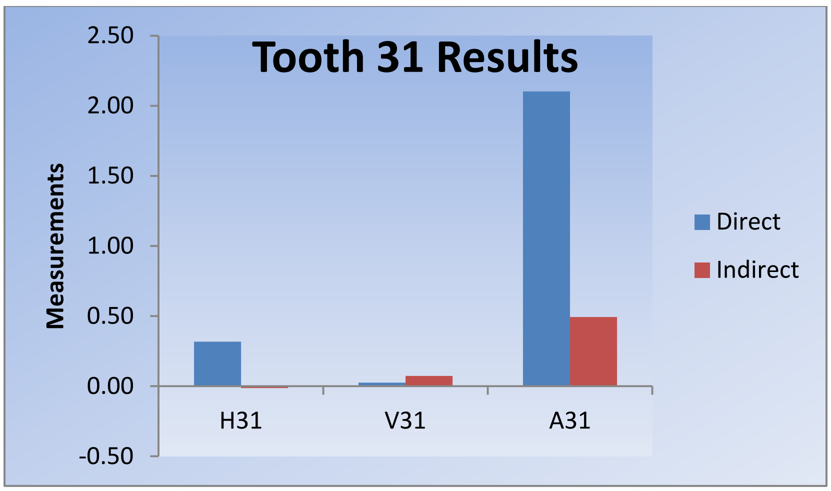

Figure 4.11: Mean height, vertical and angle results of Tooth #31

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Table 4.13: Resultant measurements for Tooth 331

	Direct	Indirect		
H31	0.32	-0.01	P=0.139	H_0
V31	0.03	0.07	P=0.9037	H_0
A31	2.10	0.49	P=0.0088	H_1

Mean Square/deviation 31

H31 = 0.548

V31 = 0.011

A31 = 46.048

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4.4.12 Tooth #32

For Tooth #32, the mean values for the horizontal measurement were positive for direct and for indirect, showing more mesial displacement. The standard deviation was 0.544 and the *p* value = 0.0002 H value 1, therefore indicating statistical significance ($p < 0.05$).

The mean values for the vertical measurement were negative for direct and positive for indirect, showing more coronal displacement direct and apical displacement for indirect. The standard deviation was 0.359 and the *p* value = 0.139 H value 0, therefore indicating no statistical significance ($p < 0.05$).

The mean values for the angular measurement were positive for direct and indirect, showing more mesial angle displacement. The standard deviation was 9.072 and the *p* value = 0.4049H value 0, therefore indicating no statistical significance ($p < 0.05$).

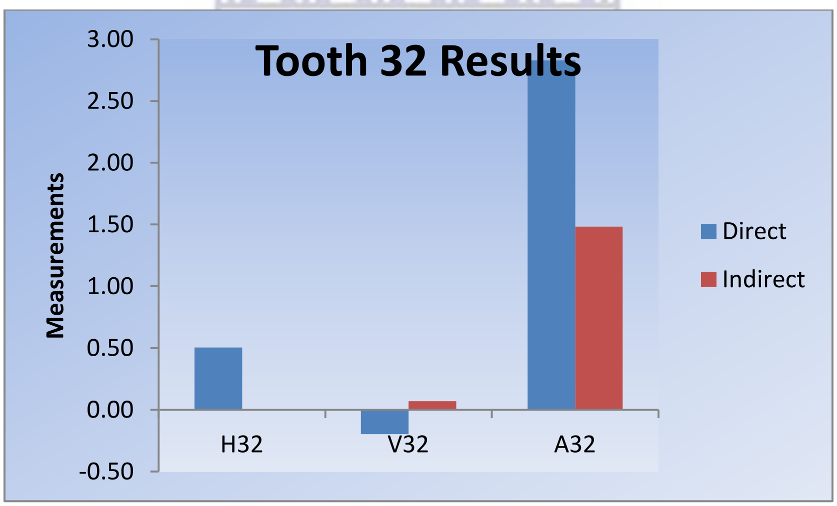

Figure 4.12: Mean height, vertical and angle results of Tooth #32

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Table 4.14: Resultant measurements for Tooth #32

	Direct	Indirect		
H32	0.50	0.00	P=0.0002	H_1
V32	-0.20	0.07	P=0.139	H_0
A32	2.83	1.48	P=0.4647	H_0

Mean Square/deviation 32

H32 = 0.544

V32 = 0.359

A32 = 9.072

4.4.13 Tooth #33

For Tooth #33, the mean values for the horizontal measurement were positive for direct and indirect, showing more mesial displacement. The standard deviation was 0.039 and the p value = 0.6341 H value 0, therefore indicating no statistical significance ($p < 0.05$).

The mean values for the vertical measurement were negative for direct and positive for indirect, showing more coronal displacement direct and apical displacement for indirect. The standard deviation was 1.105 and the p value = 0.0013 H value 1, therefore indicating statistical significance ($p < 0.05$).

The mean values for the angular measurement were positive for direct and for indirect, showing more mesial angle displacement. The standard deviation was 0.080 and the p value = 0.8558 H value 0, therefore indicating no statistical significance ($p < 0.05$).

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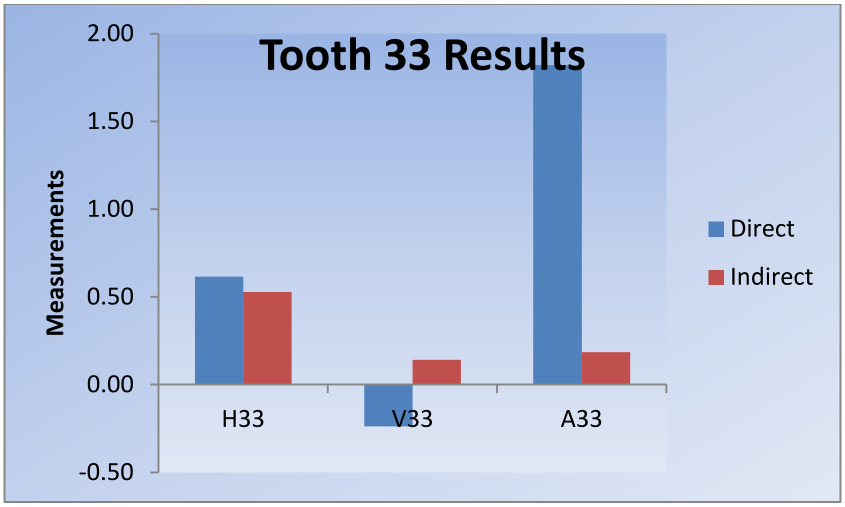

Figure 4.13: Mean height, vertical and angle results of Tooth #33

Table 4.15: Resultant measurements for Tooth #33

	Direct	Indirect	P	H
H33	0.62	0.53	P=0.6341	H_0
V33	-0.24	0.14	P=0.0013	H_1
A33	1.82	0.19	P=0.8558	H_0

Mean Square/deviation 33

H33 = 0.039

V33 = 1.105

A33 = 0.080

4.4.14 Tooth #34

For Tooth #34, the mean values for the horizontal measurement were positive for both direct and indirect, showing more mesial placement. The standard deviation was 0.001 and the *p* value = 0.9594 H value 0, therefore indicating no statistical significance ($p < 0.05$).

The mean values for the vertical measurement were negative for the direct and negative for indirect amounts, showing more apical placement for direct and coronal displacement for indirect. The standard deviation was 0.445 and the *p* value = 0.1031 H value 0, therefore indicating no statistical significance ($p < 0.05$).

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The mean values for the angular measurement were negative for both the direct and indirect amounts, showing more distal angle. The standard deviation was 13.041 and the *p* value = 0.1294 H value 0, therefore indicating no statistical significance ($p < 0.05$).

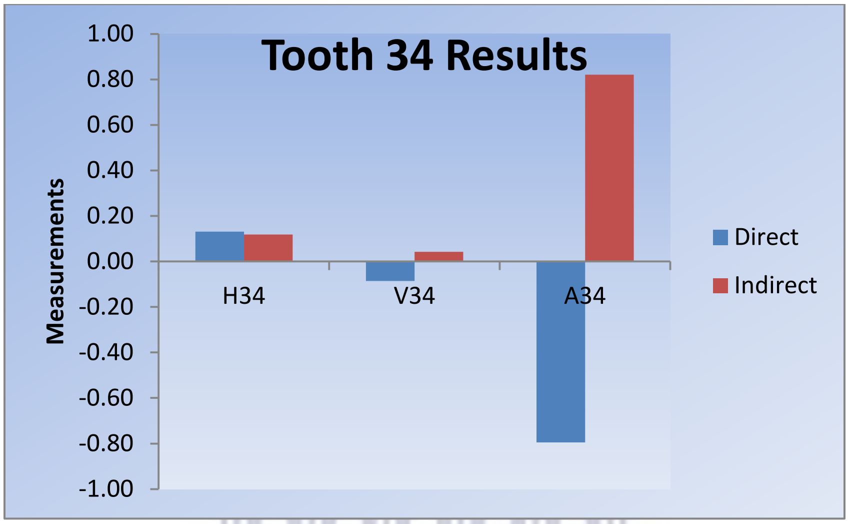

Figure 4.14: Mean height, vertical and angle results of Tooth #34

Table 4.16: Resultant measurements for Tooth #34

	Direct	Indirect	P	
H34	0.13	0.12	P=0.9594	H_0
V34	-0.09	0.04	P=0.1031	H_0
A34	-0.80	0.82	P=0.1294	H_0

Mean Square/deviation 34

H34 = 0.001

V34 = 0.445

A34 = 13.041

4.4.15 Tooth #35

For Tooth #35, the mean values for the horizontal measurement were negative for direct and positive for indirect, showing more distal displacement for direct and mesial displacement for indirect. The

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standard deviation was 0.200 and the *p* value = 0.1444 H value 0, therefore indicating no statistical significance ($p < 0.05$).

The mean values for the vertical measurement were positive for direct and positive for indirect, showing more coronal displacement for direct and indirect. The standard deviation was 0.041 and the *p* value = 0.5402 H value 0, therefore indicating no statistical significance ($p < 0.05$).

The mean values for the angular measurement were positive for direct and for indirect, showing more mesial angle displacement. The standard deviation was 15.611 and the *p* value = 0.4562 H value 0, therefore indicating no statistical significance ($p < 0.05$).

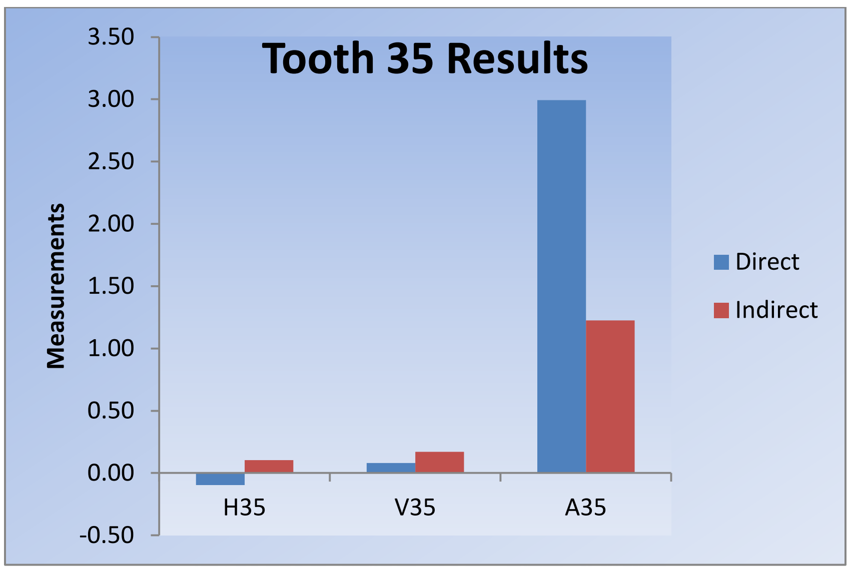

Figure 4.15: Mean height, vertical and angle results of Tooth #35

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Table 4.17: Resultant measurements for Tooth #35

	Direct	Indirect	P	
H35	-0.10	0.10	P=0.1444	H_0
V35	0.08	0.17	P=0.5402	H_0
A35	2.99	1.23	P=0.4562	H_0

Mean Square/deviation35

H35 = 0.200

V35 = 0.041

A35 = 15.611

4.4.16 Tooth #41

For Tooth #41, the mean values for the horizontal measurement were a positive amount showing more mesial displacement. The standard deviation was 0.010 and the *p* value = 0.6178 H value 0, therefore indicating no statistical significance ($p < 0.05$).

The mean values for the vertical measurement were positive for direct and positive for indirect, showing more coronal displacement for direct and indirect. The standard deviation was 0.047 and the *p* value = 0.5895 H value 0, therefore indicating no statistical significance ($p < 0.05$).

The mean values for the angular measurement were positive for direct and negative for indirect, showing more mesial angle displacement for direct and distal angle displacement for indirect. The standard deviation was 8.337 and the *p* value = 0.309 H value 0, therefore indicating no statistical significance ($p < 0.05$).

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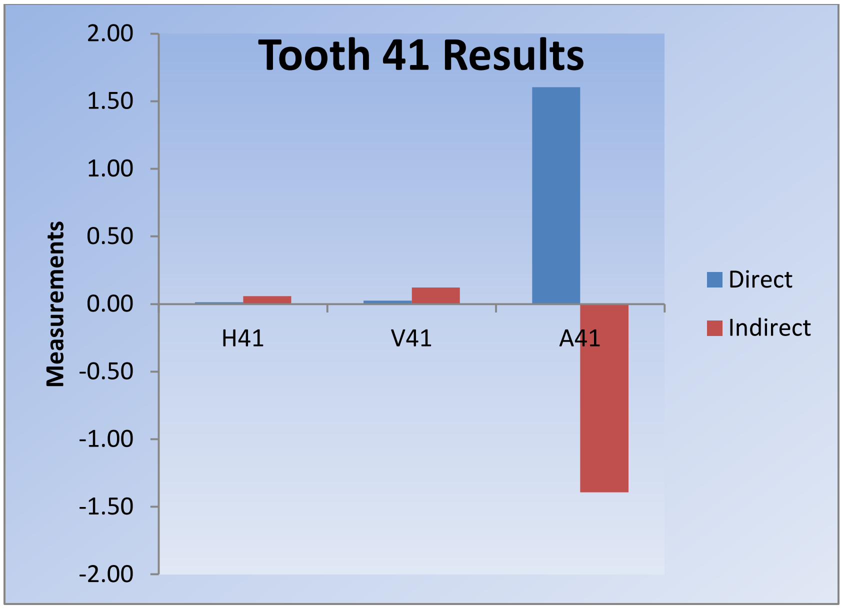

Figure 4.16: Mean height, vertical and angle results of Tooth #41

Table 4.18: Resultant measurements for Tooth #41

	Direct	Indirect	P	
H41	0.01	0.06	P=0.6178	H_0
V41	0.02	0.12	P=0.5895	H_0
A41	1.60	-1.39	P=0.309	H_0

Mean Square/deviation41

H41 = 0.010

V41 = 0.047

A41 = 8.337

4.4.17 Tooth #42

For Tooth #42, the mean values for the horizontal measurement were negative for direct and positive for indirect, showing more mesial displacement for direct and distal displacement for indirect. The standard deviation was 0.005 and the *p* value = 0.8107 H value 0, therefore indicating no statistical significance ($p < 0.05$).

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The mean values for the vertical measurement were negative for direct and indirect, showing more apical displacement. The standard deviation was 0.545 and the *p* value = 0.1663 H value 0, therefore indicating no statistical significance ($p < 0.05$).

The mean values for the angular measurement were negative for direct and positive for indirect, showing more distal angle displacement for direct and mesial angle displacement for indirect. The standard deviation was 4.714 and the *p* value = 0.5056 H value 0, therefore indicating no statistical significance ($p < 0.05$).

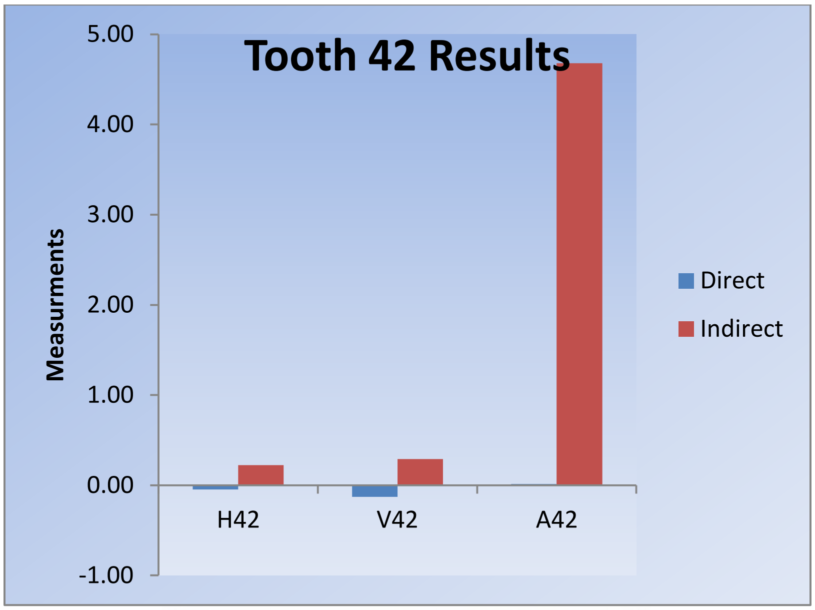

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Figure 4.17: Mean height, vertical and angle results of Tooth #42

Table 4.19: Resultant measurements for Tooth #42

	Direct	Indirect		
H42	-0.05	0.22	P=0.8107	H_0
V42	-0.13	0.29	P=0.1663	H_0
A42	0.01	4.68	P=0.5056	H_0

Mean Square/deviation42

H42 = 0.005

V42 = 0.545

A42 = 4.714

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4.4.18 Tooth #43

For Tooth #43, the mean values for the horizontal measurement were positive for direct and for indirect, showing more mesial displacement for indirect. The standard deviation was 0.123 and the *p* value = 0.4868 H value 0, therefore indicating no statistical significance ($p < 0.05$).

The mean values for the vertical measurement were negative for direct and positive for indirect, showing more coronal displacement for direct and apical displacement for indirect. The standard deviation was 1.794 and the *p* value = 0.0159 H value 1, therefore indicating statistical significance ($p < 0.05$).

The mean values for the angular measurement were positive for direct and negative for indirect, showing more mesial angle displacement for direct and distal angle displacement for indirect. The standard deviation was 74.459 and the *p* value = 0.1837 H value 0, therefore indicating no statistical significance ($p < 0.05$).

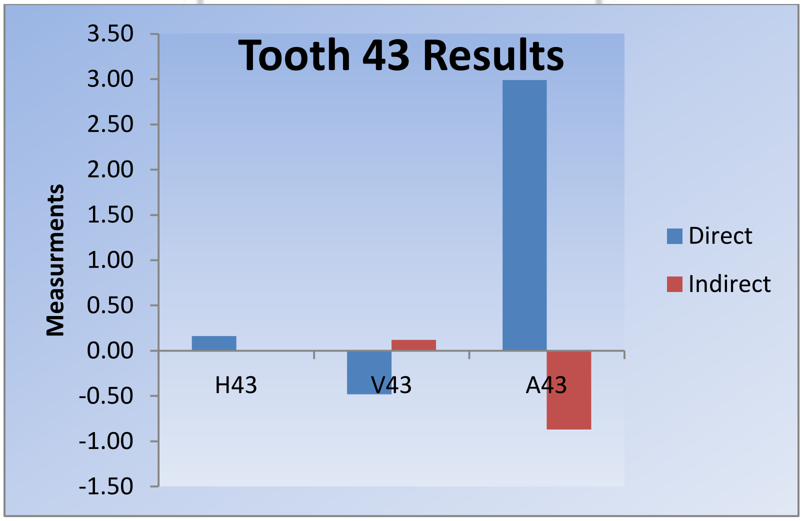

Figure 4.18: Mean height, vertical and angle results of Tooth #43

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Table 4.20: Resultant measurements for Tooth #43

	Direct	Indirect	P value	Hypothesis
H43	0.16	0.01	P=0.4868	H_0
V43	-0.48	0.12	P=0.0159	H_1
A43	2.99	-0.87	P=0.1837	H_0

Mean Square/deviation43

H43 = 0.123

V43 = 1.794

A43 = 74.459

4.4.19 Tooth #44

For Tooth #44, the mean values for the horizontal measurement were a positive amount showing more mesial displacement. The standard deviation was 0.117 and the *p* value = 0.3489H value 0, therefore indicating no statistical significance ($p < 0.05$).

The mean values for the vertical measurement were positive for direct and positive for indirect, showing more coronal displacement for direct and indirect. The standard deviation was 0.015 and the *p* value = 0.7773H value 0, therefore indicating no statistical significance ($p < 0.05$).

The mean values for the angular measurement were positive for direct and negative for indirect, showing more mesial angle displacement for direct and distal angle displacement for indirect. The standard deviation was 26.519 and the *p* value = 0.1766 H value 0, therefore indicating no statistical significance ($p < 0.05$).

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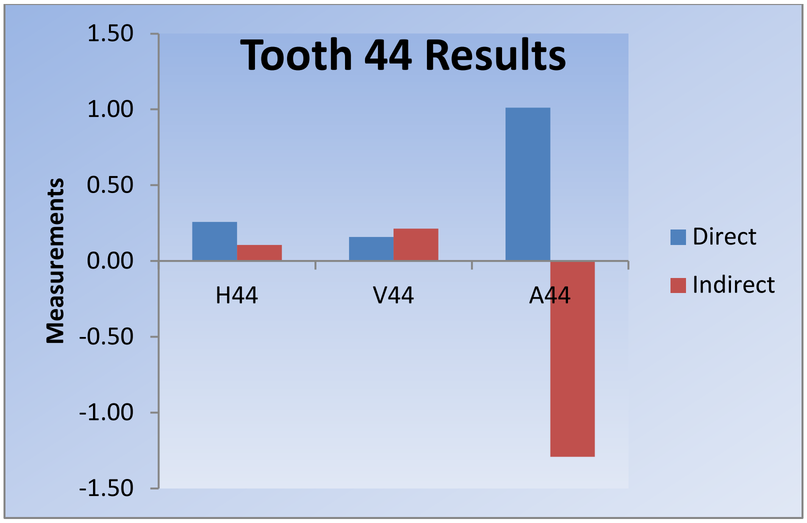

Figure 4.19: Mean height, vertical and angle results of Tooth #44

Table 4.21: Resultant measurements for Tooth #44

	Direct	Indirect		
H44	0.26	0.11	P=0.3489	H_0
V44	0.16	0.21	P=0.7773	H_0
A44	1.01	-1.29	P=0.1766	H_0

Mean Square/deviation44

H44 = 0.117

V44 = 0.015

A44 = 26.519

4.4.20 Tooth #45

For Tooth #45, the mean values for the horizontal measurement were negative for direct and positive for indirect, showing more distal displacement for direct and mesial displacement for indirect. The standard deviation was 0.381 and the *p* value = 0.1229 H value 0, therefore indicating no statistical significance ($p < 0.05$).

The mean values for the vertical measurement were positive for direct and indirect, showing more coronal displacement. The standard deviation was 0.000 and the *p* value = 0.9342 H value 0, therefore indicating no statistical significance ($p < 0.05$).

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The mean values for the angular measurement were negative for direct and indirect, showing more distal angle displacement for indirect. The standard deviation was 65.921 and the *p* value = 0.6262 H value 0, therefore indicating no statistical significance ($p < 0.05$).

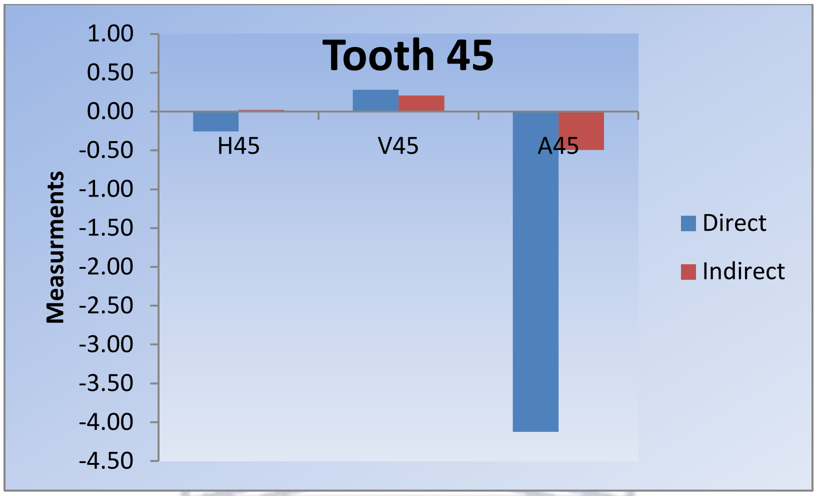

Figure 4.20: Mean height, vertical and angle results of Tooth #45

Table 4.22: Resultant measurements for Tooth #45

	Direct	Indirect		
H45	-0.26	0.02	P=0.1229	H_0
V45	0.28	0.21	P=0.9342	H_0
A45	-4.12	-0.49	P=0.6262	H_0

Mean Square/deviation 45

H45 = 0.381

V45 = 0.000

A45 = 65.921

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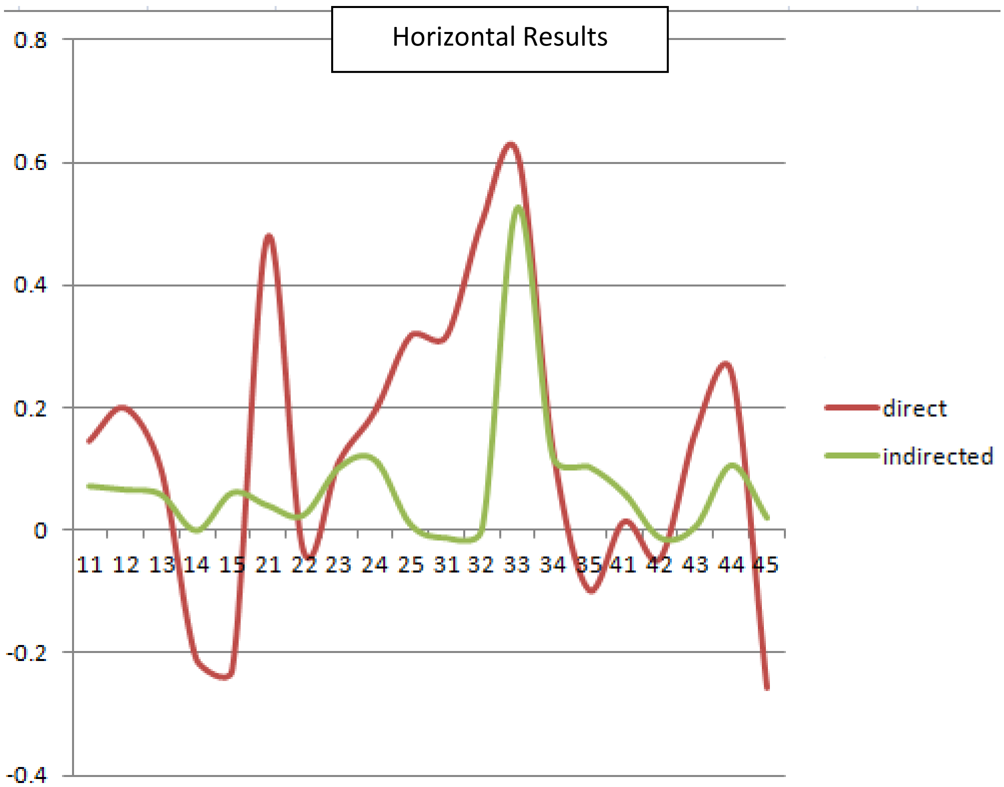

Figure 4.21: Combined results – horizontal

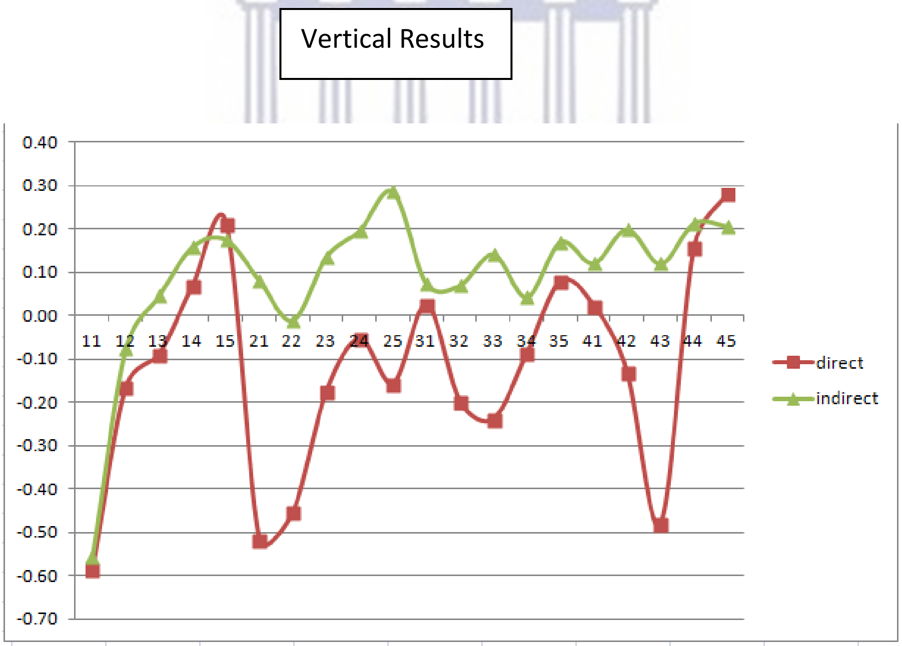

Figure 4.22: Combined results – vertical

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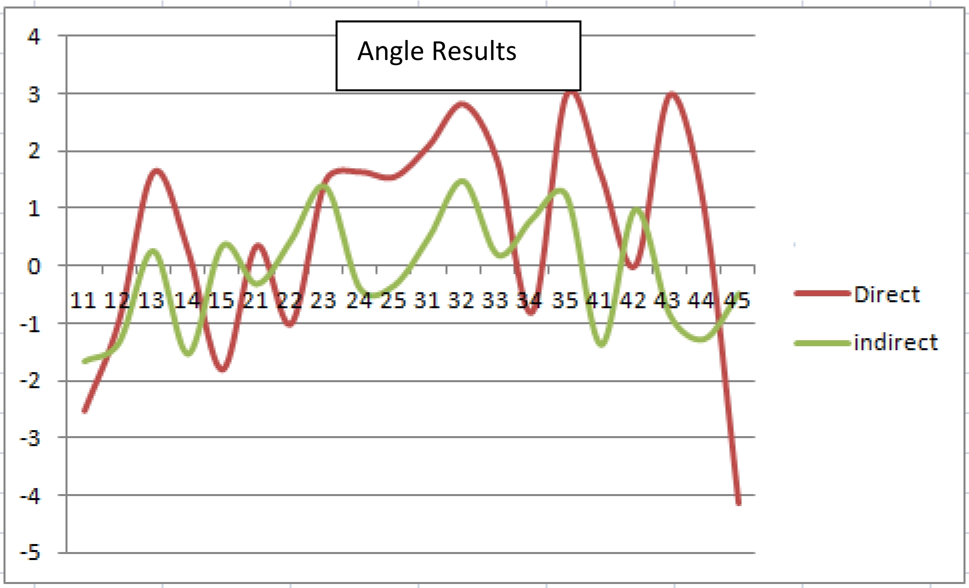

Figure 4.23: Combined results – angle

4.5 SUMMARY OF THE RESULTS

A statistically significant difference was found in terms of the height of Tooth #21 H21 (p=0.018), vertical dimensions of Tooth #21 V21 (p=0.018), height of Tooth #25 H25 (p=0.0159), vertical dimensions of Tooth #25 V25 (p=0.0063), angle of Tooth #31 A31 (p=0.0088), height of Tooth #32 H32 (p=0.002), vertical dimensions of Tooth #33 V33 (p=0.0013) and vertical dimensions of Tooth #43 V43 (p=0.0159) in the experiment on all the models.

Horizontal #21 favoured the indirect method, 0.48 to 0.04, with both brackets moving mesially.

In the vertical aspect, #21 indirect favoured -0.52 to -0.08 with both brackets showing a more lower or apical placement.

The horizontal aspect of #25 indirect favoured 0.32 to 0.01, which means that both brackets were placed slightly more mesially.

Surprisingly, vertical #25 favoured the direct method with -0.16 to 0.29. The direct was slightly more apical whereas the indirect was more coronal. This is in line with a study showing that the direct method is more accurate at the mandibular premolars (Hocevar, 1988; Hodge *et al*., 2004; Prasad & Varatharajan, 2011).

The angle of #31 indirect favoured 2.10 to 0.49. Here, both brackets showed a more mesial tilt.

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Horizontal #32 showed 0.50 to 0.00. Here, the indirect was exact on target. The direct was more mesially placed.

The vertical measurement of #33 favoured the indirect method with -0.24 to 0.14 where the direct was more placed apically and the indirect more placed incisally.

The vertical measurement of Tooth #43 changed from -0.48 to 0.12, favouring the indirect method while the direct method favoured the apical movement and the indirect the more coronal placement.

In the **horizontal** measurements, the exact target was only found with the indirect (ID) method with the result being 0.00. This was found on Tooth #14 and Tooth #32.

The direct (D) method was better on the height on Tooth #41 with a measurement of 0.01mm.

Large deviations were found between D and ID on Tooth #14 (0.21mm difference), Tooth #21 (0.44mm difference), Tooth #25 (0.31mm difference), Tooth #31(0.31mm) and Tooth #32 (0.50mm difference) – all favouring the indirect method, which is close to zero.

Tooth #32 was farthest, presenting itself with highest values (0.62 direct and 0.53 indirect), with indirect being closest to optimal on this tooth.

In total, ID was 74.67% closer to zero/optimal compared directly to D in height.

The measurements showed the brackets favoured a more mesial displacement except for indirect on Teeth #14, #15, #22, #35, #42 and #45, and indirect on Teeth #31 and #42 favouring mesial displacement. Tooth #42 in both direct and indirect favoured distal displacement.

In the **vertical** dimension, none reached zero.

Closest to zero were Tooth #22 (-0.01mm) indirect, Tooth #41 (0.02mm) direct, Tooth #31 (0.03mm) direct, Tooth #34 (0.04mm) indirect, Tooth #13 (0.05mm) indirect and Tooth #24 (-0.05mm) direct.

Large deviations were found Teeth 21 (0.44mm), 22 (0.44mm) and 43 (0.36mm).

Farthest off zero were Teeth 11 (-0.59d -0.56id), 21 (-0.52d 0.08id), 22 (-0.45d -0.01id) and also 43 (-0.43d 0.12id).

The total was D 4.18mm from zero, ID 3.08mm from zero, and ID 57.6% closer to zero/optimal.

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The measurements showed the brackets favoured direct apical (negative) except for: 14, 15, 31, 35, 41, 44 and 45 which expressed themselves more coronally (positive). Indirect expressed more coronal displacement (positive) except for 11, 12 and 22 which expressed more apical (negative) displacement.

In the **angle** dimensions, none of the exact targets was reached.

Closest to zero was Tooth #42 with 0.01d 0.99id.

Large deviations were found in Tooth #45 (3.63deg), Tooth #43 (2.12deg), Tooth #35 (1.76deg), Tooth #32 (1.35deg), Tooth #31 (1.61deg), Tooth #25 (1.21deg), Tooth #24 (1.24deg), Tooth #15 (1.45deg), Tooth #14 (1.27deg) and Tooth #13 (1.38deg).

Farthest from zero was Tooth #45 with -4.12d -0.49id.

The total was D 33.52mm from zero, ID was 17.33mm from zero, and ID was 65.91% closer to zero/optimal.

The measurements showed the brackets favoured mesial deviation in direct methods except for Teeth #11, #12, #15, #22, #34 and #45 distal displacement. Teeth #11, #12 and #45 correlated with distal displacement. The indirect test showed a 50/50 distribution.

When the totals were added together removing the negative values, direct scored 41.88 and indirect 21.9.

52.31% indirect being closer to zero ratio of direct being more accurate 2:1.

Tooth #11 showed major displacements in the vertical and angular measurements both direct and indirect. Tooth #21 showed major displacements in the direct method for vertical and horizontal, while Tooth #45 presented with the most frequent direct in horizontal both direct and indirect in vertical and direct in angular readings. Tooth 33 showed major displacements indirect in the horizontal plane and direct in angular plane. Other notable displacements included Teeth #14, #15 and #25 indirect in the horizontal plane, Tooth #24 indirect in the vertical plane, and Tooth #32 and Tooth #35 in direct method in the angular plane.

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4.6 CONCLUSION

This study attempted to compare the efficacy of direct and indirect orthodontic bracket placements. The results were displayed graphically with a short description of each pair of measurements. A pair consisted of the mean average of the results comparing direct and indirect results as the actual outcome measurement. In the next chapter, the results will be discussed and conclusions drawn.

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CHAPTER 5

DISCUSSON OF RESULTS

5.1 INTRODUCTION

In the previous chapter, the results of the comparison between the direct and indirect method of orthodontic bracket placements were portrayed. In this chapter, the results will be discussed.

5.2 DISCUSSION OF RESULTS

Proffit *et al*. (2018) described “effectiveness and efficiency” as accomplishing a preferred outcome without wasting the time of the orthodontist and patient. In 1972, Archibald Cochrane published a monograph entitled “Effectiveness and Efficiency,” which challenged the medical community to use medical evidence-based procedures to incorporate the best research supported by clinical expertise and patient values (Rinchuse & Cozzani, 2015).

The present study attempted to compare the efficacy of direct and indirect orthodontic bracket placements. Neither the direct method nor indirect method was completely accurate, which correlates with the findings of Aguirre *et al*. (1982). In line with Aguirre *et al.* (1982), the upper 3s favoured closer constant values across the board with angles still showing great variations, which may lead to using canines as a standard to measure accuracy. The indirect method was also closer to the ideal position. In their research, Nichols *et al*. (2013) used the indirect method and also found that canines in both the maxillary and mandibular arches were closer to the ideal.

Orthodontists are constantly investigating ways to improve treatment efficiency by reducing the orthodontic treatment time and the length of orthodontic appointments, as well as to obtain the best possible treatment results (Stolzenberg, 1935).

The indirect method is more accurate at the second maxillary premolar and lower left central incisors while the direct method is more accurate at the mandibular premolars and upper right lateral. The theory would be to combine both systems’ strong points in order to increase accuracy and decrease treatment time (Hocevar, 1988; Hodge *et al.*, 2004; Prasad & Varatharajan, 2011).

In Koo’s study (1999), indirect bonding showed better height placement on the upper right second premolar, which correlates with our study, and lower left incisor, which does not correlate with our study. Except for the lower left central incisor, the indirect method was better in the horizontal plane

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than in the mesio-distal plane. Direct bonding showed better placement, which does not correlate with our study. Angulations direct showed better placement in the upper right lateral incisors, which correlated with our studies. Neither techniques yielded ideal bracket placement.

Direct placement performed well horizontally: 35 and 41, vertically: 14, 24, 25, 31, 35, 41, 42 and 44, and angularly performed well with 12, 34, 42 and 44. It seems fair that this research correlates with that of Aguirre *et al*. (1982) who stated that the direct method performed better in the second premolar area in the lower arch. The great angular variations were also noted by Aguirre *et al.* (1982). This is predicted to be due to the difficulty of placing the brackets at the correct angles. The direct placement also performed better leaning to the left-side arch, not only the upper arch but both the upper and lower arches correlated with the study of Aguirre *et al*. (1982), stating that the upper left and the lower right were more accurate.

According to Hodge *et al*. (2004), there is no overall difference in accuracy, which does not correlate with our study as we found marked differences. However, interestingly, Hodge *et al*. (2004) found direct to be favouring gingival placement, which correlates with our study. Hodge *et al*. (2004) stated that the vertical plane was greater than the mesio-distal plane while we found both to have discrepancies in placement.

According to Shpack and his co-researchers, the greatest inaccuracies occurred with the direct method, specifically in terms of the maxillary second premolars and mandibular centrals (Shpack *et al*., 2007).

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A possible reason for Tooth #5 acting so poorly is attributed to the difficulty of placing brackets due to the location anatomically in the oral environment. Tooth #11 could be attributed to the misconception and/or optical distortion of placing the bracket in the correct planes. Armstrong *et al*. (2007) as well as Shpack *et al*. (2007) likened this to the Ponzo illusion (where two identically-sized lines appear to be different sizes when placed over parallel lines that seem to converge as they recede into the distance). However, Shpack *et al*. (2007) noted a distal placement where we noted a more mesial placement. This directly correlates with the study by Hocevar (1988) showing the direct method to be more accurate in the mandibular premolar area as well as the upper right areas. The indirect method has been shown to be more accurate in the second canines, the second premolar and lower left central incisors (Hocevar, 1988).

Based on the outcomes of this study, the evidence suggests that the indirect method of bracket placement is more accurate and predictable.

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5.3 CONCLUSION

It was expected that the direct and indirect methods would have very similar if not the same values. This was not the case in our study. A possible reason for this is because of the difficultly of placing the brackets in a simulation, which is a more accurate presentation of the clinical effects than doing it on a model. However, it has been stressed that efforts are still needed to improve the accuracy and reliability of the indirect method and to include the consideration of, as with this study, changes in soft tissue tension and muscle strain. The accuracy of this system in simulation with soft tissue should therefore be carefully interpreted.

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CHAPTER 6

CONCLUSION AND RECOMMENDATIONS

6.1 INTRODUCTION

Various studies have been done on the advantages of the three bonding methods for orthodontic brackets: direct, indirect and the combination method.

The purpose of this comparative experimental study was to compare the accuracy of direct versus indirect orthodontics because the more accurate the initial bracket placement is the less time will be needed in terms of overall treatment.

6.2 MAIN FINDINGS

With the advancement of 3D technology, the accuracy of measurements has surpassed previous measurement techniques, giving a much more accurate look at the micro measurements of orthodontic methods and the differences between the various methods. This can help to set the standard for future orthodontic evaluations and measuring techniques.

Planning the exact final placement outcome, especially onto the teeth, would be extremely beneficial to the orthodontic profession. Not only does it assist with the accurate treatment procedure, it also helps the practitioner to visualise the final placement result. Based on this study, it can be noted that the indirect method of bracket placement in orthodontics is statistically better at accurate placement outcome than the direct method.

Some studies found no significant difference between the direct and indirect methods of bracket placement. However, in some studies, the indirect method did perform better in height (Hodge *et al*., 2004; Koo, 1999; Zilberman *et al*., 2003). Therefore, based on this study, it appears that the indirect method is a better form of bracket placement for the dental professional. It is, however, recommended that further studies with a larger sample size and more practitioners be undertaken in order to evaluate the difference between the two methods as there is a deficiency, as quoted in the literature.

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The indirect method was the only method to produce a perfect or "ideal" result with no deviation in measurement being 0.0, for instance. This was found on Teeth #14 and #32. Otherwise, no technique yielded the ideal bracket placement.

Therefore, based on the results of the experiment, there is strong evidence to suggest that the indirect method is more accurate and predictable in its entirety, which means it can be recommended for future orthodontic bracket placement technique.

The findings of the study can be useful to clinicians when deciding which bonding methods to utilise.

6.3 LIMITATIONS OF THE STUDY

The lack of study models is one possible limitation of the study. During the sample collection, a lack of study models was discovered due to difficulties in finding molar Class I models which were archived incorrectly. Thus, the lack of Class I models influenced the sample size. The original proposed study of 40 models was therefore abandoned. The final study consisted of 10 models done in random order. However, this is still statistically relevant as the arbitrary nature of the experiments was respected.

6.4 FUTURE RESEARCH

To help clarify which of the direct and indirect methods of orthodontic bracket placement is indeed more efficient in terms of improved patient care and comfort, it is suggested that future research focuses on, among others, orthodontic bonding and accuracy.

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