

The Immediate Effects of Aligners and Aesthetic Fixed Appliances on Smiling and Perceptions in Young Adults

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ABSTRACT

AIMS

- To evaluate, in young adults, the immediate effect of clear aligners (CAs) and aesthetic fixed appliances (AFAs) on the magnitude of rest to natural and rest to maximal smile
- To evaluate, in young adults, the immediate effect of CAs and AFAs on intra-session reproducibility of rest to natural and rest to maximal smile
- To evaluate, in young adults, the immediate perception of CAs and AFAs

MATERIALS AND METHODS

Forty Caucasian subjects (20 females, 20 males), aged between 18 and 25 years, with a Class I incisor relationship and no history of orthodontic treatment were recruited. 3D stereophotogrammetric images were captured of each subject without appliances and separately, in random order with either CAs or AFAs (Session 1), at rest, natural and maximum smile (Capture A). Following a rest period of 15 minutes, the images were retaken both without and with appliances (Capture B) to assess intra-session reproducibility. Four weeks later (Session 2), the same protocol was adopted as per Session 1, except that subjects who had been randomised to the CAs were allocated to the AFAs and vice versa.

All images had 26 landmarks placed by 1 operator. The landmarking identification error was calculated by re-landmarking 10 percent of the original sample one month after initial images were landmarked and determining the difference in landmark placement. The mean magnitude of movement and reproducibility with each expression, rest to natural and rest to maximal smile, were compared and analysed across both genders. Four weeks after Session 2, a questionnaire was issued via email to all subjects to evaluate the immediate perception of CAs and AFAs.

RESULTS

The landmark identification error was 0.50 +/- 0.08 mm. For rest to natural smile, there was no significant difference in magnitude of movement with and without CAs ($p = 0.6964$). In contrast, for rest to maximal smile, the magnitude of movement differed significantly with and without CAs ($p = 0.0001$), with significantly greater movement recorded with the latter. For rest to natural and rest to maximal smile, there was a significant difference in magnitude of movement with and without AFAs ($p = 0.0024$ and $p = 0.0002$ respectively). Significantly greater mean movement occurred with AFAs, than with CAs, for both expressions. The mean magnitude for each smile was greater in males than in females ($p = 0.0109$). The order of randomisation of appliances made no difference to the mean magnitude of movement from rest to natural and rest to maximal smile ($p = 0.0939$). Without appliances, there was no significant difference in intra-session reproducibility of the magnitude of rest to natural and rest to maximal smile ($p = 0.3601$) but significant differences existed in intra-session reproducibility of the mean magnitude of each expression with appliances ($p = 0.0290$). Although statistically significant differences were recorded between appliances in magnitude and intra-session reproducibility for both expressions, these are unlikely to be of any clinical significance.

Seventy-six percent of subjects preferred CAs to AFAs as they were deemed to be more discrete (43 percent) and more comfortable (33 percent). All subjects indicated the appearance of CAs was good or very good. Ninety percent of subjects indicated that they were likely or very likely to recommend CAs.

CONCLUSIONS

- Except for rest to natural smile with CAs, both appliances had an immediate and significant impact on the mean magnitude of movement for both expressions
- CAs and AFAs had a significant immediate effect on intra-session reproducibility of rest to natural and rest to maximal smile
- Young adults' immediate perception was preference for CAs as they were reckoned to be more discrete and comfortable

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DECLARATION

I hereby declare that the work described in this thesis, except where otherwise mentioned, is my own work and has not been submitted previously as a requirement for a degree or a diploma at this or any other institution.

A handwritten signature in black ink that reads "Jackie Clune." The signature is written in a cursive style with a large initial 'J'.

Jacqueline Clune

CHAPTER ONE

INTRODUCTION

1. INTRODUCTION

The pursuit of the aesthetic smile has primarily driven the increased demand for adult orthodontics in recent years (Zachrisson, 2005). This is reflected in the growth of adult cases in North American orthodontic practices from 20 percent in 2007 to 25 percent in 2014 (Keim et al., 2007; Keim et al., 2008; Keim et al., 2014).

Adults, however, are not only concerned by the treatment outcome but also by the provision of treatment by aesthetic appliances such as tooth coloured brackets and arch wires, lingual appliances and clear aligners (Boyd, 2011; Cedro et al., 2010). In addition, how appliances will impact their smile in the short term is an important consideration.

Clear aligners (CAs) and aesthetic fixed appliances (AFAs) are 2 commonly used aesthetic appliances in adults. The percentage of US orthodontic practices undertaking clear aligner therapy (CAT) increased from 76 percent in 2008 to 89 percent in 2014 (Keim et al., 2014). The median number of cases started per annum increased from 12 to 21 over the same period of time. While the adoption of these appliances has increased significantly in recent years, their immediate effects on rest to natural and rest to maximal smile have not been explored in young adults. Their effect on the intra-session reproducibility of these expressions has not been assessed in a young adult group. Furthermore, the immediate perception of young adults of both appliances has not been reported to date. This project addresses these deficiencies in the orthodontic literature.

This study set out to evaluate, in young adults, the immediate effect of CAs and AFAs on rest, natural and maximal smile and the immediate effect of CAs and AFAs on the intra-session reproducibility of each expression. An online questionnaire also evaluated the immediate perception of these appliances in young adults.

CHAPTER TWO

LITERATURE REVIEW

2. LITERATURE REVIEW

2.1 SEARCH STRATEGY

An electronic database search was conducted for literature written in the English language and published between January 1st 1965 to February 1st 2018. The search strategy used in this literature review was conducted using Medline, Pub Med, Science Direct, Embase, Google Scholar, Cochrane Library and Academic Search. The following terms were used: ‘Prevalence of adult orthodontics’, ‘Adult orthodontics’, ‘Perceptions of orthodontics’, ‘Perception of orthodontic appliances’, ‘Evaluation of aesthetic orthodontic appliances’, ‘Cosmetic orthodontic appliances’, ‘Cosmetic braces’, ‘Aesthetic orthodontic appliances’, ‘Aesthetic brackets’, ‘Invisalign®’, ‘Orthodontic aligners’, ‘Lingual orthodontics’, ‘Short-term orthodontics’, ‘Three dimensional imaging or 3D’ or ‘Stereophotogrammetry’ AND ‘Orthodontics’, ‘Facial expressions’, ‘Smile assessment’, ‘Reproducibility of facial expressions’, ‘Reproducibility of smile’ ‘Orthodontic appliances and facial expressions’, ‘Intra-oral scanners’, ‘Digital models’ and ‘3D printing orthodontics’.

Bibliographies of key papers were screened for further publications and sourced when considered relevant.

This is a narrative, non-systematic review of the literature. Six topics are considered within the literature review. The first and second sections pertain to adult orthodontics and aesthetic appliances. The third and fourth sections relate to facial and dental imaging. The fifth section considers the smile. In the final section, recent and past literature regarding perceptions of orthodontic appliances are reviewed.

2.2 ADULT ORTHODONTICS

Adult orthodontic treatment is not new. Pierre Fauchard made the first reference to adult orthodontics in 1723. Kingsley, (1880) was credited with being one of the first dentists to consider the potential for adults to undergo orthodontic treatment (Goldstein, 1953).

This section focuses on the prevalence of adult orthodontics, including demographics and motivations for orthodontic treatment.

2.2.1 Prevalence of adult orthodontics

There has been a continuous and sustained growth in the number of adults considering orthodontic treatment in Europe and North America in the last 30 years (Thilander, 1979; Buttke and Proffit, 1999; Cedro et al., 2010; Keim et al., 2014).

In a North Carolina University clinic, the proportion of adult orthodontic patients grew from 5 percent to 25 percent from 1970 to 1990 (Buttke and Proffit, 1999). In a survey of members of the American Association of Orthodontists, a 14 percent increase in adult patients was noted between 2010 and 2012. More recent data indicates that adults account for 24 percent of a North American orthodontic practice caseload (Keim et al., 2014).

In the UK, the 2007 British Orthodontic Society survey found on average 17 percent of an orthodontist's caseload consisted of adults (BOS, 2007). More recently, adults have comprised 21 percent of NHS and 28 percent of private practice orthodontic patients (Cedro et al., 2010). These percentages need to be interpreted with caution, however, as orthodontists working in private practices tend to see the highest proportion of adults. In addition, the NHS hospital orthodontic service deals with the adult orthognathic patient caseload (Cedro et al., 2010).

The number of orthodontists in the Republic of Ireland (RoI) has grown by 400 percent over the last 25 years, making orthodontic services significantly more available (Moss, 1993; McGuinness and Collins, 2007). In 2007, over 100

orthodontists in the RoI were surveyed and the results showed that 12 percent of adults were treated in a hospital setting, compared to 28 percent in private practice (McGuinness and Collins, 2007). A 2017 questionnaire study in the RoI, reported that 95 percent of specialist orthodontists treated adults, with more patients being self-referred (McMorrow and Millett, 2017).

2.2.2 Adult demographics

Several studies have shown that females account for over 66 percent of adults who undergo orthodontic treatment (Tayer and Burek, 1981; Khan and Horrocks, 1991; Lew, 1993; Cedro et al., 2010; Keim et al., 2014). However, 23 percent of orthodontists in the RoI indicated a 40 to 60 percent male adult caseload (McMorrow and Millett, 2017).

Adults in higher socioeconomic groups also have an increased uptake, partly linked to their value systems and the associated costs involved (Whitesides et al., 2008). The 2017 RoI study found similar results, showing a ratio of 3:2 for professionals to non-professionals (McMorrow and Millett, 2017). Young adults are more likely to undergo treatments than elderly adults (Dos Santos et al., 2017).

Historically, most adult patients undergoing orthodontic treatment were in their early twenties, whereas now it is more common for adult patients to be in their late twenties and thirties. A study conducted at the Eastman Dental Hospital London in 1991 found that 41 percent of adult patients were aged between 18 to 21 years, two thirds were under the age of 26 years and nearly 4 percent were older than 42 years (Khan and Horrocks, 1991). More recently, a UK based survey showed that most adults now commence orthodontic treatment between the ages of 26 to 35 years, followed by the age group of 36 to 45 years (Cedro et al., 2010). In the RoI, a similar pattern was identified with most adult patients being within the 25 to 35 year age group (McMorrow and Millett, 2017).

2.2.3 Motivations for adult orthodontics

Adults seek orthodontic treatment for a broad variety of reasons, including aesthetic, functional, social and psychological concerns (Breece and Nieberg, 1986; Pabari et al., 2011). In the 1950s, the driving force for adults to seek treatment was to correct a facial deformity (Goldstein, 1953). In more recent years, however, the primary motivation has been to improve dental aesthetics. In addition, adults are seeking treatment for minor corrections without referral from their general dentist (Cedro et al., 2010; Pabari et al., 2011; McMorow and Millett, 2017). Improved accessibility to the internet and an increase in external marketing have improved patient education regarding the positive impact of orthodontics on dental health as well as other dental procedures (Buttke and Proffit, 1999; Christensen and Luther, 2015). Superior aesthetics of orthodontic appliances and auxiliaries have made orthodontic treatment more desirable (Proffit, 2007).

Marital status, age and oral health related quality of life (OHRQoL) were all significant variables in predicting the uptake in orthodontic treatment among UK adults in a private-practice setting (Jahal and Joury, 2015). Motivation to improve oral health has also been identified as a key motivation for seeking treatment (Andiappan et al., 2014; Choi et al., 2015).

2.3 AESTHETIC ORTHODONTIC APPLIANCES

Aesthetic orthodontic appliances comprise of CAs, aesthetic brackets and wires as well as lingual appliances (Russell, 2005; Boyd, 2011; Hennessy and Al-Awadhi, 2016; Hardwick et al., 2017).

This study evaluates the effect of CAs and labial AFAs on smiling and perception. It does not assess specific properties regarding either appliance type. As such, a brief overview will be provided with regard to these 2 aesthetic appliances. Other aesthetic systems and appliances are not considered.

2.3.1 Clear aligner therapy

2.3.1.1 Development history

Kesling (1945) developed a device to reposition teeth during the last phase of orthodontic treatment; he was aware of the limitations of the system and believed that additional tooth movements could be achieved by using several aligners. Ponitz (1971) developed the Invisible Retainer 30 years after Kesling's appliance failed. The retainer produced minimal tooth movements and the crowns were tipped to attain the desired results. In 1993, Sheridan proposed the use of clear aligners with interproximal tooth reduction to produce small tooth movements (Sheridan, 1993). In 1999, the first aligner system (Invisalign®, Align Technology Inc, USA) was developed (AlignTechnology, 2002; Hennessy and Al-Awadhi, 2016).

2.3.1.2 Prevalence

In 2017, over 305 million cases were in treatment with over 50,000 active Invisalign® clinicians including orthodontists and general dental practitioners (AlignTechnology, 2017). The geographical case mix included 62 percent from North America and the remainder related to international sales.

2.3.1.3 Invisalign® treatment process

The Invisalign® system uses CAD-CAM and stereolithography technologies to visualise treatment and fabricate custom-made clear aligners from a single impression (Kuo and Miller, 2003). Stereolithography is a technology in which a laser beam hardens successive layers of photosensitive liquid resin until a solid model is formed (Sager, 2006). Aligners are manufactured by first developing a digital model of the patient's baseline study model. This can be done either via a direct digital scan or a FlashCT (HYTEC Inc, Los Alamos, New Mexico), which is an advanced computed tomography scan of a polyvinyl siloxane (PVS) dental impression (Vardimon et al., 2010). A technician then uses 'Treat software' (Align Technology Inc, San Jose, California) to place simulated gingiva and create a virtual setup according to the required prescription. After manipulation of the digital model to incrementally align the teeth, the treatment plan is modified and approved using an online portal and ClinCheck® software (Kuo and Miller, 2003; Marti et al., 2017). Then, a series of stereolithographic models are fabricated. These are used to vacuum-form polyurethane resin custom-made aligners using a proprietary material called SmartTrack® (Wong, 2002; Keim, 2017).

The aligners are then fitted, the tooth movement monitored and necessary adjunctive procedures are performed, such as; bonding attachments; interproximal reduction and elastics. Each aligner is worn for approximately 2 weeks, for a minimum of 22 hours per day, and the aligner is removed during eating, tooth brushing and taking beverages that contain sugar (Miethke and Vogt, 2005; Kuo and Miller, 2003; Kravitz et al., 2009). The patient is evaluated periodically to ensure the teeth are tracking as predicted. When the patient has completed the programme of aligners, the clinician determines if treatment is complete or if additional refinement aligners are required (Wheeler, 2017).

2.3.1.4 Advantages and limitations

The proposed advantages of CAs are:

- *Improved oral hygiene*
 - Better for oral hygiene measures (Miethke and Brauner, 2007; Ziuchkovski et al., 2008)
- *Pain*
 - Reduced pain reported in comparison to fixed appliances (Fujiyama et al., 2014)
- *More efficient*
 - Fewer visits, a shorter treatment span, less emergency and chair time compared to fixed appliances (Buschang et al., 2014; Glassick et al., 2017; Gu et al., 2017)
- *Bruxism*
 - Treatment of choice for those with parafunctional oral habits due to aligner acting as a thin mouthguard preventing further wear to the occlusal plane (Nedwed and Miethke, 2005; Miller et al., 2007)
- *Anterior open bite*
 - Helps correct mild anterior open bite by increasing interocclusal distance introducing an intrusive effect on posterior teeth (Schupp et al., 2010)
- *Heavily-filled teeth*
 - Eliminates issues with bonding to heavily-filled teeth (Malik et al., 2013)
- *Psychosocial or functional effects*
 - Minimal adverse effects on quality of life during the initial stages of alignment (Miller et al., 2007)
 - Minimal effects during speech (Nedwed and Miethke, 2005)
- *Decreased root resorption*
 - No root resorption found in 100 consecutively treated Invisalign® cases (Boyd et al., 2006; Boyd, 2008)

Potential disadvantages of CAs include:

- *Tooth Movements*
 - Not suitable for severe anteroposterior discrepancies and orthodontic movements such as torque, extrusion and intrusion of anterior teeth (Djeu et al., 2005; Bowman et al., 2015)
 - Not the treatment of choice for extraction and deepbite cases (Lagravere and Flores-Mir, 2005)
 - Lack of robust evidence on outcome measures using precision attachments (Bowman, 2017)
 - Not as effective in achieving ‘great improvement’, as measured by an occlusal index (Djeu et al., 2005)
- *Compliance*
 - Not suitable for non-compliant patients (Baldwin et al., 2008; Kravitz et al., 2009)

Clinical studies on Invisalign® are given (**Table 2.1**). Five studies were retrospective and 5 were prospective, with subjects aged between 18 to 36 years.

Table 2.1: Studies and outcomes of Invisalign® treatment

AUTHOR YEAR	TYPE OF STUDY	SAMPLE (N)		TREATMENT DURATION (YRS)	CONCLUSIONS
		<i>Invisalign</i>	M:F MEAN AGE (YRS)		
Gu et al. (2017)	Retrospective case-control study	48 16:32 26	<u>FA</u> 48 18:30 22	1.08-1.58	- Mean PAR for Invisalign® similar to FA - Invisalign® 5.7 mts faster than FA
Hennessy et al. (2016)	Parallel-group, randomised prospective cohort trial	44 17:27 26.4		NS	No difference in amount of proclination post-tx between Invisalign® and FA
Simon et al. (2014)	Prospective cohort study	30 11:19 16.3		NS	Force change generated by Invisalign® is exponential
Krieger et al. (2012)	Retrospective cohort study	50 15:34 33		NS	3D ClinCheck predictions relative to outcome - Most accurate: moderate to severe anterior crowding - Least accurate: overbite
Pavoni et al. (2011)	Prospective cohort study	<u>Invisalign</u> 20 8:12 18	<u>FA</u> 20 11:9 15	1.5	- Invisalign® produced < arch width increase than FA - No difference in tx durations between Invisalign® and FA

AUTHOR YEAR	TYPE OF STUDY	SAMPLE (N) M:F MEAN AGE (YRS)	TREATMENT DURATION (YRS)	CONCLUSIONS
Krieger et al. (2011)	Retrospective cohort study	• 35 • 11:24 • 33	• 0.8	• ClinCheck predictions accurate relative to outcomes • Successful tooth movements: overjet and midline shift • Less successful tooth movements: vertical plane
Kravitz et al. (2009)	Prospective cohort study	• 37 • 14:23 • 31	• NS	• Mean accuracy of tooth movement: 41% • Most accurate movement: lingual constriction at 47.1 % • Least accurate movement: extrusion at 29.6%; mesiodistal tipping of mandibular canines 26.9%; and canine rotation
Kravitz et al. (2008)	Prospective cohort study	• 31 • 13:18 • 29.4	• 0.6	• Mean accuracy of canine rotation with Invisalign® 35.8% • Vertical-ellipsoid attachments and interproximal reduction did not improve accuracy of canines rotation
Baldwin et al. (2008)	Randomised cohort trial	• 24 • 6:18 • 32.8	• FA: 1.94 • Invisalign® : 1.4	• Increased tipping of mandibular teeth compared with maxillary teeth during space closure following second premolar extraction • Adjunctive use of FA to upright teeth adjacent to extraction sites effective, may require longer tx times

AUTHOR YEAR	TYPE OF STUDY	SAMPLE (N) M:F MEAN AGE (YRS)		TREATMENT DURATION (YRS)	CONCLUSIONS
Kuncio et al. (2007)	Retrospective cohort study	<u>Invisalign</u> • 11 • 1:10 • 34	<u>FA</u> • 11 • 1:10 • 27	• NS	- Changes in total alignment worse post-retention with Invisalign® - Maxillary anterior alignment worsened post-retention with Invisalign®
Lagrave and Flores-Mie (2005)	Systematic review	<u>Study 1</u> • 38 • NS • NS	<u>Study 2</u> • 51 • 15:36 • 34	<u>Study 1:</u> 1.6 – 2.6 <u>Study 2:</u> NS	- Did not quantify tx effects of Invisalign® 1 RCT - High drop-out rate - Limited evidence - no conclusion made
Djeu et al. (2005)	Retrospective cohort study	<u>Invisalign</u> • 48 • NS • 33.6	<u>FA</u> • 48 • NS • 23.7	• FA: 1.7 • Invisalign® : 1.4	13 < OGS points than FA 27% < OGS passing rate than FA - Lower scores for buccolingual inclination, - Occlusal contacts, occlusal relationships overjet - Finished 4 months sooner than FA
Key: tx = Treatment F = Female		FA = Fixed Appliance M = Male	OGS = Objective Grading System < = Less than	RCT = Root Canal Therapy NS = Not Stated mts - Months	Yrs = Years % = Percentage

2.3.2 Ceramic brackets

Ceramics are composed of aluminium oxide as monocrystalline or polycrystalline alumina. Monocrystalline brackets are produced by melting aluminium oxide at over 2100 degrees Celsius and then cooling to create the bracket material (Gautam and Valiathan, 2007). Polycrystalline brackets are created where the aluminium oxide is blended with a binder and heated to temperatures over 1800 degrees Celsius to fuse the particles (Russell, 2005). The cooled mass is then injection moulded (Jena et al., 2007). This eliminates any imperfections that are linked to the cutting process (Zinelis and Brantley, 2017).

The differences in the manufacturing process of the monocrystalline and polycrystalline ceramic brackets result in differences in the mechanical and optical properties. As Lopes Filho et al. (2012) described, the manufacturing process produces translucent brackets when monocrystalline brackets are made with the structure of a single crystal. In polycrystalline brackets, the bonding between the aluminium oxide and binder reduces the transparency (Jena et al., 2007).

2.3.1.4 Disadvantages

Despite improved aesthetics, ceramic brackets have several disadvantages:

- *Wear*
 - Abrasion of enamel and wear of opposing dentition, especially in deep bite cases (Ghafari, 1992)
- *Enamel damage during debonding*
 - Damage due to high bond strength (Macri et al., 2015; Saito et al., 2015)
- *Bracket fracture*
 - Ceramic brackets are between 20 and 40 times less tough than stainless steel; bracket breakage can be a problem for brackets placed on lower incisors (Buzzitta et al., 1982; Johnson et al., 2005; Matsui et al., 2015; Iijima et al., 2017)
 - Ceramic brackets have lower fracture resistance compared to metal brackets (Nishio et al., 2009)

- *Frictional resistance*
 - Ceramic brackets had higher static frictional resistance under laboratory conditions (Angolkar et al., 1990)
 - Incorporating a metal slot reduced frictional resistance (Cacciafesta et al., 2003)

2.4 EXTRA-ORAL 3D IMAGING

This study assessed 3D facial images, at rest and on smiling, of young adults using stereophotogrammetry. Several 3D imaging techniques have been described. These include Moire topography, CT, CBCT, structured light scanning, 3D laser scanning, MRI, 3D ultrasonography and stereophotogrammetry.

The advantages and disadvantages of each, excluding stereophotogrammetry, are summarised (**Table 2.2**). These imaging techniques will not be examined further here. Rather the focus will only be on stereophotogrammetry.

Table 2.2: 3D imaging techniques

METHOD	ADVANTAGES	LIMITATIONS
Moire topography	- Contour fringes helped improve overall image quality and texture quality (Motoyoshi et al., 1992) - One of original 3D methods - Achieves better results on smooth surfaces	- Faced challenges of feature identification and cost of set up was high (Bush and Antonyshyn, 1996) - Method does not operate successfully when capturing sharp intervals (90 degrees) - Changes in position of patient's head can adversely affect fringe pattern
Computerised Axial Tomography (CT)	- Extensive use for many dental imaging and diagnosis needs including periodontics, orthognathic surgery and dental trauma (Mota de Almeida et al., 2016) - Ease of operation	- Exposure to radiation with need for continuous assessment is a major challenge (Yamamoto, 2016) - Provides poor resolution of soft facial tissue - Metal objects such as dental fillings can disrupt the results
Cone Beam Computer Tomography (CBCT)	- Effective imaging in the maxillofacial region (Benington et al., 2010) - Rapid data acquisition (Hechler, 2008) - Reduced exposure to radiation (Silva et al., 2008) - Improvement in volumetric data identification (Scarfe et al., 2006) - Reduced costs of operation (Kau et al., 2007)	- Presence of artefacts - Time taken for assessment (Leuzinger et al., 2010) - Limited use when trying to understand the complexities of soft tissues - Struggles to convey information such as textures and colours - Unsuitable for providing detail on muscle structure or attachments

METHOD	ADVANTAGES	LIMITATIONS
Structured light scanning	• Use of light instead of radiation (Ireland et al., 2008) • Improved perioral soft tissue scanning and texture assessment (Ahn et al., 2014)	• Time taken is high (Kau et al., 2007) • Reflection-based scattering should be accounted for (Ahn et al., 2014) • Cost and training needs are present • Not possible to capture a model of patient's full face
3D laser scanning	• Wide variety of scanners available • Landmark assessment effective (Kau et al., 2005; Almukhtar, 2016)	• Concerns about landmark identification • Process can be time consuming • Requires patient to remain still during scanning stage • Technique more invasive than other methods • Fails to capture texture of soft tissue • Risk of laser beam damaging patient's eyes
Magnetic Resonance Imaging (MRI)	• Non-invasive imaging technique • Powerful 3D images with high tissue content (Papadopoulos et al., 2002)	• Very expensive • Magnetic field can interfere with objects such as implants, orthodontic appliances, pacemakers, valves and stents

METHOD	ADVANTAGES	LIMITATIONS
3D Ultrasonography	• Inexpensive and safe • Takes less time than CT or MRI techniques • Suitable for visualising soft tissue (Papadopoulos et al., 2002)	• Creates a 3D image with low accuracy • Images get distorted due to artefacts • Slow process and requires experienced operator • Requires patient to not move their head
Key: CT = computerised axial tomography	MRI = magnetic resonance imaging	

2.4.1 Stereophotogrammetry

Stereophotogrammetry is a special photography technique that uses 2 cameras with a configured stereo-pair to recover the depth of a 3D object (Hong et al., 2017). The disparity between the 2-dimensional locations helps in creating the corresponding points in the third dimension. The 2 cameras are placed at 2 ends of an imaginary triangle where the distance between the cameras is fixed based on the nature of the object to be imaged (Andrade et al., 2017). It allows simultaneous images of each side of the face to be taken, from which a 3D image is composed by capturing the surface appearance of the skin and “draping” it over a 3D wireframe model of the subject’s face (Hajeer et al., 2002; Hajeer et al., 2004). Stereophotogrammetry is more reliable and repeatable than anthropometric measurements (Ghoddousi et al., 2007) and is better than CT with respect to landmark assessment of the hairline, eyebrows and eyelids (Swennen et al., 2005).

From an analysis of 34 stereophotogrammetric images, Baysal et al. (2016) concluded that facial landmarks for soft tissues in the context of extra-oral imaging showed high reliability and moderate reproducibility. The overall differences in landmarks was less than 1 mm.

2.4.1.1 Types of stereophotogrammetry

There are 4 types of stereophotogrammetry systems: Di3D, C3D, Vectra 3D and 3dMDface (Ayoub et al., 2003; Winder et al., 2008; Othman et al., 2013; Hong et al., 2017). The Di3D system has been shown to be a valid, reproducible and accurate method to assess facial expressions (Johnston et al., 2003). The Di3D system was selected as the imaging system used in this study due to the validated accuracy of the system; due to the extensive experience of using this system within CUDSH and having a highly trained operator. The Di3D system will be discussed in detail in this section and C3D, Vectra 3D and 3dMDface systems will be considered briefly.

Di3D system

The Di3D system was developed by Dimensional Imaging, Glasgow and makes use of stereophotogrammetry to produce fully textured 3D surface contour images of the head and face (Salloum et al., 2017). This system is passive in nature and has 2 camera pods, each pod containing a pair of 10.1 megapixel colour assessment cameras. Use of a synchronised auto flash helps capture 2 stereopairs of images which can be reconstructed into 3-dimensional data by capturing matching data from each set of images (Catherwood et al., 2011). This system is found to have a typical shutter speed of 20 to 50 milliseconds when there is good lighting. The overall data reconstruction process in this tool takes less than 3 minutes (Catherwood et al., 2011).

The primary effectiveness of the Di3D system when compared to other 3D imaging systems is that it does not require any exposure to laser scanning (Almukhtar et al., 2017). This procedure is rapid and specific tests identify the overall accuracy of this tool. Winder et al. (2008) made use of a mannequin head to address the effectiveness of facial landmark assessment. The authors used colour coded surface difference images with repeated exposure. A comparison of measurements of physical linear distance with digital measurements was carried out. The findings showed that, overall, the Di3D tool had a mean error of 0.057 mm and a variance of 0.0016 mm. This indicates that overall findings show high clinical accuracy and repeatability.

Potential challenges have been linked to the operation of the Di3D capture software as its integrated image capture and 3D processing required some dynamic movement. This led to the evolution of the dynamic Di4D system, where live onscreen previews were captured with cameras that could be moved to provide a comprehensive image of the face. The choice of the dynamic software allowed viewing of more than 1 3D image and, therefore, helped in creating different 3D models based on the movement of the cameras (Hallac et al., 2017).

C3D system

This system is based on the use of digital cameras along with special texture illumination. These cameras have a capture time of 50 milliseconds (Hajeer et al., 2004). The system helps in quantifying the alteration of relevant tissues (Khambay et al., 2002).

Vectra 3D dual module system

This type of stereophotogrammetry method helps in better rotation, planning and zooming of images and is found to enhance consistency, as it makes measurement of the width of the image base and comparison possible (Othman et al., 2013).

The system requires calibration on a daily basis, which can be time-consuming (See et al., 2008).

3dMDface system

This tool is a multi-modal system, which makes use of structured light as well as stereophotogrammetry (Hong et al., 2017). Lübbers et al. (2010) showed that the overall precision and accuracy of this system is good as it is able to meet clinical needs. The mean global error of this tool is only 0.2 mm and is, therefore, well within the clinical range.

2.4.2 Landmarks

Landmarks are pre-determined points on the face used to analyse 3D images. These are identified and marked. Quantitative and qualitative assessments are then carried out (Liang et al., 2013).

Douglas (2004) reported that through 3D construction and imaging using photogrammetry and cephalometry, facial surface landmarks could be identified. Similarly, Zogheib et al., (2018) in their comparison of 3D scanning with 2D photographs, found that the use of 3D tools was better, as quantitatively better landmarks were identified. Hoevenaren et al. (2015) defined 30 landmarks based on known topographical and bone-related landmarks. The authors concluded that

when specific landmarks were previously mapped and multiple subject analysis was carried out, reproducibility and reliability were high.

Several studies have attempted to enhance 3D imaging-linked landmark assessment. According to Perakis et al., (2010) facial landmark detection methods are classified as those which are dependent on geometric information and those which are supported through the use of trained statistical methods. Seminal work on this was carried out by Lu and Jain, (2006) who identified through a fusion scheme of shape index that facial landmarks can be automatically detected using the position of the eye and the mouth. Curvature analysis, geometric methodology, deformable matching and graph-matching are alternative methodologies that can be used. Through structured learning, the authors were able to improve the overall relevance of landmark mapping (Romero-Huertas and Pears, 2008).

2.5 INTRA-ORAL 3-DIMENSIONAL IMAGING

The clear aligners used in this study were created from 3D intra-oral scans. This technology will now be reviewed.

2.5.1 Intra-oral scanners

2.5.1.1 Overview

Intra-oral scanners (IOS) are defined as devices that can help capture an optical impression. Jiang et al. (2016) report that IOS are like other digital scanners, where a light source is projected onto a scanned object to create a digital image. Most IOS are composed of a data acquisition unit that gathers information on the teeth through imaging; compatible software can then be used to design digital models which are anchored to these virtual impressions (Jiang et al., 2016). The most commonly adopted application for IOS is the preparation of digital study models (Logozzo et al., 2014; Boeddinghaus et al., 2015). Many IOS require powder and opacification (Agnini et al., 2015; Zaruba and Mehl, 2017). Efforts are being made, however, to reduce the use of these elements in order to enhance efficiency (Zimmermann et al., 2015; Park, 2016). There are differences between scanners in terms of scanning speed and the size of the scanning tip, which may impact patients' comfort (Christensen, 2008).

2.5.1.2 Types of IOS

IOS capture images of the dento-gingival tissues by utilising imaging sensors to generate point clouds. The imaging sensor gathers surface data points using laser light or white light, which are reflected to a sensor and a camera (Kravitz et al., 2014; Richert et al., 2017). The capturing of such images is based on 4 techniques, outlined below.

Active wave front sampling

This technology is used by the Trios scanner and 3 Shape software which was used in this study. According to Syrek et al., (2010) the use of this method helps obtain 3D data from a single lens imaging system, where 3 sensors capture clinical images from multiple angles at the same time. With this method, surface patches can be generated leading to reconstruction of the teeth. The Lava COS system also operates on this principle (Van der Meer et al., 2012). This system has high data redundancy due to overlapping pictures which, in turn, ensures that there is highly accurate image quality; this is known as 'point and stitch reconstruction' (Kravitz et al., 2014).

Triangulation technology

This technology uses the measurement of angles and distance from known points to scan an object. The distance between the laser sources and the sensor is known and the reflected light is analysed using the angle of reflection. The technology uses a thin coating of opaque powder to achieve the right angle of reflection. The CEREC® AC Bluecam® utilises this technology (Patzelt et al., 2014).

Parallel confocal imaging

Laser light is projected through a filtered pinhole that is near the target tissue, for example iTero. This system captures intra-oral surfaces using 100,000 points of laser light at 300 dpi focal depth of the tooth structure (Flügge et al., 2013).

Accordion fringe interferometry

This technique makes use of light sources to project 3 patterns of light, often referred to as a 'fringe' pattern, which are then recorded using video to help identify the right optical measurement (Jiang et al., 2016). The Lythos intraoral scanner, byOrmco, uses this technology (Martin et al., 2015).

2.5.1.3 Advantages of IOS

- *Comfort*
 - Less patient discomfort and high patient acceptance (Yuzbasioglu et al., 2014)
- *Efficiency*
 - Operational efficiency is higher when intra-oral scans are taken as fewer steps are necessary (Joda and Brägger, 2015)
- *Enhanced Communication*
 - Can provide real-time visualisation of patient needs and enhance patient communication (Kathariya, 2017; Mangano et al., 2018)

2.5.1.4 Disadvantages of IOS

- *Cost*
 - Expensive (Mangano et al., 2017)
- *Learning Curve*
 - Time and learning curve associated with its operation (Joda et al., 2017)
- *Acceptance by clinicians*
 - Challenges in participants' perception of ease of use (Marti et al., 2017)

2.5.2 3D printing of digital models

3D printing is a manufacturing process by which objects are fabricated by making use of a layering method where fusing of material or depositing of material takes place to create a 3D structure (Müller et al., 2003; Canstein et al., 2008). This method involves generating physical models, using digital layouts, via 3D printing techniques.

2.5.2.1 3D printing techniques

The most frequently used methods for dental 3D printers include stereolithography, triple jetting technology and fusion deposition model printing (Keyhan et al., 2016).

Stereolithography (SLA)

In this most commonly used method, an ultraviolet laser cures resins into required shapes (Kasparova et al., 2013). This process ensures that the printing plates move in small steps and the exposure of the resin to the ultraviolet laser helps create a cross-sectional layered printed model. The method continues until the entire dental model is made (Keyhan et al., 2016). The stereolithography technique applied by the Form2 3D printer was used to generate the models for this study.

Triple jetting technology/polyjet 3D printing

This method of 3D printing is akin to inkjet printing, where a printer jet layers curable liquid photopolymer onto a specific printing platform (Srivastava, 2017). This platform is used to create layered thickness, 1 layer at a time, until the entire shape has been printed. The advantage of this method is that it can facilitate the use of multiple materials to achieve the required strength and durability. This 3D printer can be easily maintained, but the cost of production is high due to the expensive raw materials (Chae et al., 2015). This method is commonly used in other biomedical applications; the quality of print can be low and it is less commonly used in dentistry (Mahamood et al., 2016).

Fused deposit modelling

This is similar to the SLA approach and has been used extensively as the time taken is relatively less (Ning et al., 2015; Mohamed et al., 2015). In this method, a melted filament of thermoplastic material is extruded using a nozzle which moves in an x-y plane. This then solidifies after being deposited onto the build plate. The build plate lowers by a set distance once every layer is done (Chia and Wu, 2015). The use of this technology provides 3D models which are comparable to plaster models and demonstrate the same occlusal relationship and dental arch morphology (Wang et al., 2017).

Comparison of techniques

Models produced by the polyjet printer were accurate irrespective of the model base design. In the SLA technique, however, only the horseshoe shaped base with a bar and the regular model were accurate (Camardella et al., 2017)

2.5.3 Digital versus non-digital models comparative studies

Evidence from comparative studies indicates:

- Digital models have better ease of access and storage (Stevens et al., 2006)
- The use of digital tools is better for treatment planning than the plaster models (Rheude et al., 2005)
- Digital and plaster models both have high levels of measurement reproducibility, but digital models have a higher degree of efficacy and effectiveness (Motohashi and Kuroda, 1999; Tomassetti et al., 2001; Bell et al., 2003; Quimby et al., 2004)
- The following features could be measured in a more accurate fashion from digital models:
 - Overbite; lower intermolar width, centreline discrepancy, lower incisor height (Abizadeh et al., 2012)
 - Mandibular intermolar width and overjet (Reuschl et al., 2015)

2.6 THE SMILE

2.6.1 Definition and relevance

This study assessed the impact of CAs and AFAs on magnitude and reproducibility of smiling. This section will define smiling and its relevance to orthodontics, then describe smile types and finally discuss methods of smile assessment.

A smile is described as the change in the facial expression of an individual through the spreading of lips to denote pleasure or happiness (Toth et al., 2016). A smile is often a result of complex neurological pathways which involve the cerebral cortex, where non-motor and motor functions are involved (Parrini et al., 2016). The interaction between the cerebral cortex and the 7th cranial nerve and the sensory feedback input from the trigeminal nerve at the premotor cortex lead to the contraction of the facial muscles, producing a smile (Lukez et al., 2015; Mora et al., 2015). Given the level of importance attributed to smiling, the key elements of orthodontic diagnosis and treatment include smile analysis and smile design (Koidou et al., 2017). An attractive smile is a motivation for individuals to seek orthodontic treatment (Lima et al., 2017).

2.6.2 Smile types

Various classifications of smiles have been reported. These are based on different aspects and described as follows:

- **Exposure, posing and spontaneity of smiling** (Patterns, 1999)
 - *Spontaneous smile*
 - Found in response to emotions, with pronounced lip elevation and lower engagement of the gingival band (Duchenne, 1862)
 - *Natural/posed smile*
 - No spontaneity and is often posed (Girard et al., 2015)
 - Can be elicited in response to the following cue ‘say cheese’ (Zachrisson, 1998)
 - *Maximal smile*

- Maximum lip corner retraction, where the elevators of the upper lip and the corners of the mouth contract simultaneously to show upper and lower teeth concurrently (Sabri, 2005)

- **Smile level or pattern**

- *Commissure smile/Mona Lisa*
 - Regularly seen when people greet one another. With this smile type, the commissures are pulled upward and the teeth are not displayed (Rubin and Rubin, 1974)
- *Cuspid smile / social smile*
 - Often seen in self-portraits, where the upper lip is drawn upward uniformly with the display of the anterior teeth (Machado, 2014)
- *Complex smile*
 - Where there is wide movement of the upper lip and lesser movement of lower lip and is often involuntary (Câmara, 2010)

- **Exposure of teeth and gingivae**

- *High smile*
 - Complete crown length of the maxillary incisors is seen along with the gingival band
- *Average smile*
 - 70 to 100 percent of maxillary incisors are visible
- *Low smile*
 - Less than 75 percent of maxillary incisors visible
- *Gummy smile*
 - Excessive exposure of the gingival band

2.6.3 Components of the smile

Lip line

When a person smiles, the level to which the maxillary central incisor teeth are exposed vertically is known as the lip line (Calamia and Wolff, 2015). When the gingival margin is touched by the upper lip, the lip line is considered to be optimal, exposing the entire length of the cervicoincisal line of the maxillary incisors with interproximal gingivae (Kallidass et al., 2017). In males, the lip line is on average 1.5 mm lower than in females, where the normal range of gingival display is 1 to 2 mm. Although some level of gingival display is acceptable and even considered youthful, a remarkably gummy smile is regarded universally as unattractive (Sabri, 2005).

Smile arc

This is the relationship of the curvature of the incisal edges of the maxillary incisors and canines to the curvature of the lower lip in the posed smile (Tjan et al., 1984; Sarver, 2001; Sabri, 2005). In an optimal smile, it is described as “consonant” if the maxillary incisal edge curvature parallels that of the lower lip (Hulsey, 1970; Sarver, 2001; Sabri, 2005). It can be unintentionally flattened during orthodontic treatment by over-intrusion of the maxillary incisors, incorrect bracket positioning and orthodontic forces affecting the cant of the occlusal plane (Sabri, 2005).

Upper lip curvature

This is a measure of the relationship of the central upper lip position to the corner of the mouth. It is ‘upward’ when the corner of the mouth is higher than the central position, ‘straight’ when the corner of the mouth and the central position are at the same level and ‘downward’ when the corner of the mouth is lower than the central position. Lip curvature cannot be improved with orthodontic treatment as it is muscle driven (Hulsey, 1970; Sabri, 2005).

Lateral negative space

Lateral negative space is the buccal corridor between the posterior teeth and the corner of the mouth in smiling (Sabri, 2005). It has also been defined as the ratio of the maxillary inter-canine distance to inter-commissure distance (Hulsey, 1970; McNamara et al., 2008).

Smile symmetry

This is the relative positioning of the corners of the mouth in the vertical plane; it is assessed by the parallelism of the commissural and pupillary lines (Sabri, 2005). Around 75 to 100 percent of the maxillary teeth lie below this line in an ideal, aesthetically pleasing, young person's smile (Morley, 1999; Morley and Eubank, 2001).

Frontal occlusal plane

Defined as the line from right and left canine cusp tips, a cant of the occlusal plane in the transverse dimension can be due to factors such as ankylosis, a digit sucking habit, differential eruption of the maxillary teeth or to a skeletal asymmetry of the mandible (Sarver and Ackerman, 2003b; Sabri, 2005).

Dental components

Size, shape, colour, alignment, crown angulation of the teeth, the midline and arch symmetry are all factors which affect the balance of the smile (Sabri, 2005).

Ideally, the lateral incisor should be 67 to 72 percent the width of the central incisor and 1 to 1.5 mm shorter (Bukhary et al., 2007). Teeth shape has been described as "square-round", "round" or "square" (Anderson et al., 2005). The maxillary central incisors tend to be the lightest teeth in the smile, while the canines characteristically have the greatest chroma and lowest value of the anterior teeth (Lombardi, 1973; Goodkind and Schwabacher, 1987; Morley and Eubank, 2001). The maxillary incisor teeth tip medially (Andrews, 1972; Morley and Eubank, 2001). This medial inclination increases as the teeth progress posteriorly from the dental midline (Morley and Eubank, 2001). Dental midlines should be coincident, parallel with each other and located in the midline of the face (Morley and Eubank, 2001). The

parallelism between the maxillary central incisor midline and the facial midline is more important than the coincidence between the dental and facial midlines (Kokich et al., 1999). A mild midline discrepancy is acceptable as long as the interproximal contact area (connector space) between the maxillary central incisors is vertical (Sabri, 2005).

Gingival components

The gingival components of the smile are the colour, contour, texture and height of the gingivae. Inflammation, blunted papillae, open gingival embrasures and uneven gingival margins detract from the aesthetic quality of the smile (Sabri, 2005).

The gingival margins of the central incisors are normally at the same level or slightly lower than those of the canines, while the gingival margins of the lateral incisors are lower than those of the central incisors (Frush and Fisher, 1958; Morley and Eubank, 2001; Sabri, 2005).

2.6.4 Smile assessment and evaluation

2.6.4.1 Clinical assessment

Existing literature (Frush et al., 1984; Schabel et al., 2008) suggests that smile assessment should be carried out as part of the comprehensive orthodontic examination. There are various static and dynamic methods of smile assessment which can be undertaken from both the patient's and the orthodontist's perspective (Sarver and Ackerman, 2003).

2.6.4.2 Photographic assessment 2D

Photography-based assessment is a commonly used 2-dimensional method of smile assessment but is limited (Ferrario, 2000). 2D photographs have been used to assess various aspects of smiling. These include: smile arc (Springer et al., 2011), buccal corridor (Springer et al., 2011), occlusal cant (Kaya and Uyar, 2016), incisor display (Kokich et al., 2006) and gingival display (Kaya and Uyar, 2013).

Assessments have been made by orthodontists, general dentists and lay people (Kokich et al., 2006). 2D photography can help identify ideal aesthetic features, which can then be verified with clinical assessment (Springer et al., 2011).

Statistically significant differences with respect to the amount of gingival display and smile attractiveness were found between various rater groups (Kaya and Uyar, 2013). The use of 2D photography, which can be digitally altered, was found to lead to subjective assessments with variations in acceptance of the ideal smile aesthetics among different raters (Kokich et al., 2006).

2.6.4.3 3D analysis

Flores-Mir et al., (2004) in their comparison of the frontal full face and lower facial third views, conclude that the use of a 3-dimensional assessment can improve overall analysis of the smile. It has been shown that maxillary incisor labiolingual inclination and antero-posterior position play an important role in the aesthetics of the smiling profile (Cao et al., 2011).

Smile aesthetics are often determined through a harmonious relationship amongst different components including the facial skeleton, musculature, fat distribution and the texture of the skin (Sforza et al., 2013). Therefore, as Robiony et al. (1998) contend, it is essential that the face is represented as a stereoscopic dynamic structure. A 3D assessment method can be effective as it can help identify the complex relationship between nose, malar zygomatics and chin-jaw lines. Additionally, a 3D configuration can also be used to assess facial proportions and asymmetry (Dibeklioglu et al., 2015).

Much of the recent research in smile evaluation has been carried out using 3D technology (Johnston et al., 2003; Sawyer et al., 2009; Campbell et al., 2012; Darby et al., 2015). The various techniques available for 3D assessment have been outlined in preceding sections.

2.6.4.4 Dynamic assessment

The use of 3D motion analysers is ideal in smile aesthetics and treatment planning as they are non-invasive in their quantification and can provide a more holistic assessment (Sforza et al., 2013). Lin et al. (2016) screened the stable and unstable points of the smile contour through the use of facial motion capture and curve fitting. The region around the corner of the mouth was the most mobile area which can help characterise smile expression.

Commonly addressed methods include video sequencing and images, as well as digital videography (Van der Geld et al., 2011; Zhang et al., 2015). Capturing high definition video can help provide an optimal treatment plan, as direct biometric measurements can be made (Husain et al., 2017). Similarly, Schabel et al. (2010) compared clinical photography with digital video clips using the Smile Mesh TM program. Digital video clips showed more validity and consistency in assessment.

2.6.4.5 Objective evaluation of the smile

Studies which assessed smiling objectively are given in **Table 2.3**.

The following observations and conclusions can be made: 6 studies have been conducted in North America, 6 in the UK, 13 in Europe and the remainder in Brazil, Turkey, Japan, Iran, Israel and India. Ethnic mix is unspecified in 17 studies and given as Caucasian or White in 16 studies. Sample size ranged from 7 to 230 subjects. The age range of adults is from 18 to 55 years in 23 studies; 7 studies exhibited a wider age range from 12 to 55, with a portion of the sample being under 18 years and 2 studies did not specify an age range. There was 1 study which solely assessed females and 5 studies relating to males only. Twenty studies evaluated a mixed group, while in 7 studies the gender was not specified.

Clinical assessment has been undertaken using many expressions, ranging from rest to natural to maximal smile and from mouth open to mouth closed.

Table 2.3: Studies of objective evaluation of the smile

AUTHOR (S)	SAMPLE (N) M:F MEAN AGE/ RANGE (YRS) ETHNICITY	2D vs 3D vs 4D SYSTEMS	EXPRESSIONS AND PARAMETERS MEASURED	CONCLUSIONS
Alagha et al. (2018)	20 3:17 23-64 Cau	4D stereo photogrammetry	• Max smile, lip purse, cheek puff, max raising of eyebrows and forceful eye closure • Reproducibility	• Lip purse, cheek puff, raising eyebrows were reproducible • Max smile and forceful eye closure not reproducible
Gibelli et al. (2017)	10 10:0 30-40 NS	4D stereo- photogrammetry	• Neutral, happy, sad and angry expressions • RMS point-to-point distance in labial area	• RMS values of facial areas differed significantly among facial expressions • Widest modifications of the lips were observed in happy expressions
Ceinos et al. (2017)	50 28:22 20-40 Cau	3D stereo photogrammetry	• Staged smile and max intercuspatation • Facial and dental landmarks, golden ratio	• Incisal edge of maxillary central incisor —lwr border of chin/sub nasal point—incisal edge of maxillary central incisor: in line with golden ratio
Duran et al. (2017)	30 16M:14 13-25rys White	3D stereo photogrammetry	• Social smile	• Social smile shows asymmetry in X, Y and Z planes • Especially corners of mouth

Ju et al. (2016)	32 16:16 18-35 yrs NS	3D stereo- photogrammetry and (2D) photogrammetry	• Max smile, lip purse and cheek puff • Speed of landmark displacement calculated	• NSS difference in smiles • Max smile highest reproducibility
Dindaroğlu et al. (2016)	80 NS 25-45 White	3D stereo- photogrammetry 2D photogrammetry	• Rest • Reproducibility	• Measurements using 3D stereophotogrammetry consistent with direct anthropometric and 2D photogrammetric measurements • Method is reproducible
Darby et al. (2015)	40 20:20 18-30 Cau	3D stereophoto- grammetry	• Rest smile • Natural smile • Max smile	• Mean landmark error low • 3D facial asymmetry scores increased in magnitude on smiling • No gender difference
Miron et al. (2012)	72 36:36 20 - 40 NS	3D Digital videography	• Social smile • Rest smile • Max smile • Upper lip and gingival changes	• Mean MAX central incisor display at rest was 1.78 mm greater in F • High smile 2.5 time more common in F
Van der Geld et al. (2011)	122 122:0 20-55 White	3D Motion analyser	• Spontaneous smile • Posed smile • Smile line assessment • Quantitative measurement vs 3-grade and 4-grade scales	• Inter- and intra-examiner reliability values high for 3 and 4 grade semi-quantitative methods • Differentiating between high and gummy smiles (4-grade scale resulted in greater inaccuracies)

				• Differentiating high, average or low smile lines (3-grade) showed high reliability close to quantitative measurements • Smile analysis performed reliably using 3-grade scale
Sforza et al. (2010)	40 20:20 20-50 NS	3D stereo-photogrammetry	• Max smile • Free smile • Surprise with mouth closed • Surprise with mouth open • Symmetrical eye closure • Right-side eye closure • Left side eye closure • Age- and sex-related characteristics in standardised facial movements (magnitude and asymmetry)	• Sex and age - limited influence on total facial motion and asymmetry in normal adult M and F
Sawyer et al. (2009)	71 38:33 21-59 Cau	3D Motion analysis scanner	• Mouth closed • Spontaneous smile (widest smile, with lips apart in response to spoken and visual stimuli) • Distances each landmark moved, from rest to smile position	• Distances landmarks moved - used to assess outcome of reanimation surgery

Popat et al. (2009)	25 13:11 21-30 Cau	2D Video clip capturing chin to nose region of face	• Max standardised smile with lips closed • Max normal smile with lips open • Reproducibility	• Verbal expressions more reproducible than nonverbal • Standardised smile more reproducible than normal smile
Desai et al. (2009)	221 89:132 15-50 NS	2D Video-sequence (in frame mode) of subject performing facial expressions	• Widest commissure-to-commissure smile • Posed smile • Upr lip length, upr lip thickness, inter-commissural width, maxillary incisal display, inter-labial gap height,	• Decrease of 1.5-2 mm in maxillary incisal display at smile with increasing age • Upr lip thickness decrease 1.5 mm with age • Smile index increased with age • No subject above 50 yrs had a high smile and no subject in the 15-19 yrs had a low smile
Houstis et al. (2009)	80 40:40 12-33 NS	3D stereo-photogrammetry	• Rest (lips closed, teeth lightly in occlusion) • Posed smile • Lip Pucker (pursing of lips, as if to give a kiss) • Effect of gender and age on facial expressions	• M had greater upward vertical movement capacity than F in posed smile and lip pucker • F had a more pronounced horizontal capacity in posed smile in posed smile • Increase in percentage change in vertical movements (more pronounced in M) • Vertical characteristics in facial expressions are not established in children
Sawyer et al. (2009)	39 21:18 21-36 White	2D Full frontal Aesthetic frame	• Repose • Raised eyebrows • Close eyes as in sleep	• Facial expressions are reproducible within a 10-20 min period

			• Close eyes as tight as possible • Smile as wide as possible with lips closed and open • Purse your lips • Show your lower teeth • Blow out the cheeks • Reproducibility	• Differences in reproducibility 4 weeks apart for certain expressions • M showed less reproducibility than F
Yang, et al. (2008)	92 19:73 23.5 NS	2D Photographs	• Posed smile • Determination of which hard and soft tissue factors relate to BC dimensions	• To control amount of BC it is necessary to observe vertical pattern of the face, amount of upper incisor exposure and the sum of tooth material
Krishnan et al. (2008)	60 M 30:30 18-25 NS	3D FACIAL CLIMA (video recording and data analysis of facial movements)	• Posed smile • Smile arc, modified smile index	• High correlation between right and left BC in M and F • F had more consonant smile arcs than M • Modified smile index showed no correlation to the facial index; there was negative correlation of modified smile index with mandibular width-facial height index
Hontanilla and Aubá, (2008)	20 0:20 21-45 NS	2D Smile photographs and slides	• Close eyes • Open eyes • Raise eyebrows	• FACIAL CLIMA could be used to assess facial paralysis reanimation surgery

			• Smile with mouth closed • Rest • Upper lip elevation • Show lwr teeth • Pucker • Amplitude of various angles, vectors, areas and velocities of movements in upper and lwr face were measured	
Popat et al. (2008)	NS NS NS NS	3D Motion-analysis	• Posed smile • Smile arch, smile index, relationship between maxillary dental arch widths and BCs	• Smile Index: Group 1: 5.37, Group 2: 7 • Upper gingival exposure: Group 1 mean: 0.16mm, Group 2 mean: 0.13mm • BC width: Group 1 mean: 0.69mm, Group 2 mean: 0.63mm • BC space: Group 1 mean: 8.47%, Group 2 mean: 7.66% • Relationship between BC width and the maxillary arch width: Group 1 mean: 35.9mm (cuspid width) and 50.6mm (first molar width)
Van der Geld122 et al. (2008)	122:0 20-55	2D Digital recordings from which frames were selected	• Posed smile • Spontaneous (Duchenne) smile	• 3dMDFace™ Dynamic system allows objective, 3D assessment of facial movement

Cau			• Lip-line height (gingival display) and smile width • Utterance: “puppy” • Facial movement	• Uttering “puppy” is more appropriate to assess facial movement than assessment of smile expression • Lip line height: Maxillary lip line height is higher during spontaneous smile than posed smile • Smile width: was greater in spontaneous smile than posed smile
Maulik et al. (2007)	230 NS 14-35 All	2D Digital video recordings from which frames were selected	• Rest • Smile • Lip-line	• Lip-line canting is affected by right and left differences in muscular activity in addition to craniofacial morphology when cant changes markedly during smiling
Van der Geld et al. (2007)	20 20:0 35-55 White	2D Digital video recordings from which frames were selected	• Posed smile • Smile arc	• Majority of subjects showed flat smile arc back to second maxillary premolar and an 11% BC • Group treated with orthodontics showed more parallel smile arc than non-expanded subjects
Holberg et al. (2006)	31 NS 26-39 NS	2D photographs	• Spontaneous smile of joy • Posed social smile • Speech • Full dentition (with aid of retractors) • Gingival and dental display, length of teeth, vertical distance from most	• Mean tooth and gingival display for maxillary central incisor is 11.2 mm for spontaneous smile and 9.7 mm for posed smile

			incisal point of each tooth and lip edge to interpupillary line	
Ritter et al. (2006)	60 30:30 8-25 Cau	2D B&W photographs	• Neutral expression • Conscious smile “on command” • “i.e. to simulate a “group picture” smile • Facial morphology	• Intra-individual variability <10% for repeated measurements of conscious smiling • Inter-individual variation was high: 28-60% depending on localisation of the measuring point • Greatest displacement in lwr facial third • Corners of mouth, lip philtrum, cheeks and side wings of nose showed highest displacements
Mashid et al. (2004)	157 82:75 18-30 NS	2D photograph Frontal smile photograph and retracted lip	• Forced smile • BC	• No differences between right and left BC • M BC larger than F BC • BC proportion to smile width was similar for M and F
Nicholls et al. (2004)	16 NS 18-48 80% European	3D Fiore	• Aesthetic smile • Golden proportion	• Golden proportion did not exist between widths of maxillary anterior teeth in individuals who do not have an aesthetic smile
Johnston et al. (2003)	30 15:15 21-30 Cau	3D Stereo- photogrammetry	• Happy expression • Sad expression • Neutral expression	• Movement of left side of the face significantly greater than movement of right side of face • Left-sided movements more pronounced for negative than positive emotions

Okada (2001)	7 NS NS NS	Laser scanning Computer graphics Lighting techniques	• Rest • Natural smile • MAX smile • Lip purse • Cheek puff • Reproducibility	• Intra-session expression reproducibility high • Inter-session expression variation minimal • Expressions not performed with same symmetry • Differences in expression reproducibility exist between M and F
Ferrario (2000)	80 40:40 19-32 Cau	3D ELITE acquisition system	• Rest • Smile • Facial contour	• Changes of angles and widths of cheek and nasal units - associated with dimensional changes imposed by action of the underlying mimetic muscles
Clark Weeden et al. (2001)	50 25:25 23-39 NS	3D Video-based tracking system	• 7 max facial movements from rest • Influence on sex and facial shape	• M>F facial movements • Facial shape had a small but significant effect on facial movement
Trotman et al. (2000)	5 2:3 26-29 NS	Video-based tracking system	• Smile • Lip purse • Cheek puff • Eye closure • Eye opening • Grimace • Identification regions of face - most mobile during some facial animations	• Smile: mid and lwr regions - greatest facial movement • Cheek puff: Similar to smile but infraorbital and chin regions - min movement • Grimace and eye closure: upr, mid-facial and upr lip regions - greatest movement • Eye opening: upr and mid-facial regions (excluding upr lip and cheek) moved most

Trotman et al. (1998)	9	Video-based tracking system with spherical retroreflective markers attached to the facial skin and maxillary dentition	• Smile	• Headcap landmarks suitable reference landmarks during smile, cheek puff, lip purse and talking • Skin landmarks not suitable reference landmarks • Valid tool to assess facial mobility		
	NS		• Lip purse			
	28-38		• Cheek puff			
	NS		• Eye closure			
			• Eye opening			
			• Grimace			
			• Assessment of a 3D tracking system to assess facial mobility			
Key:	MAX = Maximum	Tx = Treatment	Upr = Upper	RMS = Root Mean Square	B & W = Black and White	NS = Not Specified
	yrs = Years	% = Percent	Hx = History	Orth = Orthodontic	M = Male	F = Female
	BC = Buccal Corridor	No = Number	NSS = No Statistically Significant		Lwr = Lower	Cau = Caucasian

2.6.4.6 Subjective evaluation of the smile

It is the orthodontist's responsibility to guide their patients with regard to their treatment needs (Shaw, 1981; Pinho et al., 2007). From the patient's perspective, it is often the appearance on smiling that is of utmost importance (Pabari et al., 2011). This task is further complicated by the patient's perception of their own malocclusion and what they perceive as aesthetic or attractive (Shaw et al., 1975). Furthermore, laypeople may be less sensitive to dentofacial abnormalities than dental professionals (Shaw et al., 1975; Kokich et al., 2006; Pinho et al., 2007). Consequently, there is a possibility that dental professionals could overestimate the need for orthodontic treatment in this regard (Shaw et al., 1975).

2.6.5 Effect of race, age and gender on smiling

Different ethnic populations have preferences for smile aesthetics. A comparison between US Caucasians, US American Asians and Indians residing in India found buccal corridor space to be preferred by the US Indians when compared to Caucasians (Sharma et al., 2012). The maximum and ideal gingival display, however, was found to be similar across all groups. Variations also exist across the German, Russian and Turkish populations with regard to the acceptability and aesthetics of smiles (Sarver and Ackerman, 2003). Europeans display larger facial movements than Asians (Tzou et al., 2004).

Vig and Brundo, (1978) found that adult males show a larger upward vertical movement capacity than females, who show a more pronounced horizontal movement in posed smiles (Houstis and Kiliaridis, 2009). In addition, the magnitude of the facial expressions are larger in males than females (Weeden et al., 2001).

With age, there was a decrease of 1.5 to 2 mm in the maxillary incisor display during smiling (Desai et al., 2009). The smile index also increased. Most subjects were found to display an average smile height and, with age, the spontaneity of the smile also decreased. These changes are due to a combination of the loss of muscle tone and volume, increasing lip length and dental wear (Dong et al., 1999). Upper lip females and 16 to 18 years in males (Ferrario, 2000). Tarvade and Agarwal (2015)

further show that as a person ages, the smile becomes narrower vertically and wider transversely.

2.6.6 Reproducibility of expressions

Twelve studies evaluating repeatability of facial expressions in 3D indicate that there can be challenges linked to enhancing reproducibility of expression (Popat et al., 2009; Mishima et al., 2011). It is essential that variation of repeated expression mapping should be as low as possible (Popat et al., 2008). The use of stereophotogrammetry can create high inter-session reproducibility (Johnston et al., 2003). The use of 3D images, where specific patterns of smiles were used, helped enhance reproducibility within 10 to 20 minutes (Sawyer et al., 2009). For an individual expression, the maximal smile had the highest similarity value for individual landmarks (Ju et al., 2016). Through the use of 4D imaging it is possible to enhance reproducibility of the lip purse, cheek puff and eyebrow raise (Alagha et al., 2018).

2.6.7 Effect of appliances on smiling

To date, only 2 studies, 1 recording 2D data and the other using 3D data, have been carried out to ascertain the soft tissue changes produced by orthodontic appliances.

Abed et. al, (2009) evaluated the profile changes on 33 adults with regard to lip posture. Photographs, taken before and after debonding of labial fixed appliances, were analysed via Viewbox software using customised reference lines. No significant differences were found regarding lip posture between the profile photographs with or without the appliances.

Eidson et al. (2012) analysed 3D stereophotogrammetric images of 50 teenage patients with Class I occlusion, before and immediately after debonding fixed orthodontic appliances. The authors chose 6 landmarks, with proven validity, to evaluate soft tissue changes. They found considerable variations in all landmark measurement changes among subjects, but the overall mean changes seen in the perioral soft tissues, with and without appliances, were not clinically significant.

No study has assessed the effect of aesthetic orthodontic appliances on smiling in young adults. In this project, the changes of facial expressions from rest to natural smile and to maximal smile will be evaluated in relation to aesthetic appliances only.

2.7 PATIENT PERCEPTION OF ORTHODONTIC APPLIANCES

This study evaluates patient perception of 2 appliance types, CAs and AFAs, in young adults. Studies to date that have evaluated patient perception of orthodontic appliances are given in **Table 2.4**.

The following observations can be made:

- 7 studies have evaluated patient perception of orthodontic appliances
- 2 were conducted in North America; 2 in the UK, 2 in Brazil, 1 in Canada and 1 in Germany
- 4 studies evaluated young adults and older adults; 1 pertained to young adults and 1 had subjects ranging from 20 to 50 years old
- All studies except 1 had a majority of female subjects, of which 4 studies had over 70 percent females
- 3 studies considered both aligners and fixed appliances; 2 studies focused on lingual appliances; 1 related solely to Invisalign®; 1 assessed the perceived impact of fixed and clear appliances on beauty, 1 study analysed the social perception of adults wearing orthodontic appliances
- 7 studies used questionnaires and 1 used interviews to gather data

Ziuchkovski et al. (2008) assessed the aesthetics of orthodontic appliances by type using a questionnaire. From their results, they created a hierarchy of appliance types categorised by attractiveness: clear aligners, ‘alternative’, ranked higher than ceramic appliances, which in turn were perceived as more aesthetically pleasing than stainless steel and self-ligating appliances. Other studies have concurred with these findings (Jeremiah et al., 2011; Feu et al., 2012). The aesthetics of the appliances seems to play a significant role in the patient acceptance of orthodontic treatment and overall satisfaction (Rosvall et al., 2009; Rossini et al., 2014). Patients have also been shown to be attracted to clear aligner treatment because there is no metal associated with the appliances (Rosvall et al., 2009; Rossini et al., 2014).

Rosvall et al. (2009) found that patients would be willing to pay more for aesthetic orthodontics appliances, but Feu et al., (2012) in their group of Brazilian patients, found the contrary.

In recent years, lingual appliances have also been shown to have increased acceptance and uptake, due to their superior aesthetics (Ata-Ali et al., 2016). In the study by Jeramiah et al., (2011) lingual appliances ranked the highest in terms of aesthetics of all the appliances. Hardwick et al. (2017) conducted an assessment of patient expectations from lingual orthodontics. With age, there were differences in patient needs and expectations. Males less than 30 years of age wanted aesthetics-based systems but were unsure of the specifics of the system; on the other hand, women between 30 and 45 years of age were more knowledgeable and wanted to know more about the specific systems that they had researched.

A recent study from Canada investigated patient satisfaction and quality of life (QoL) changes after Invisalign® treatment in a cohort of 81 patients (29.6 percent male and 70.4 percent female). The authors reported an overall high level of satisfaction with Invisalign® treatment (Pacheco-Pereira et al., 2018).

No study has assessed the perception of CAs and AFA in young adults.

Table 2.4 Studies assessing patient perception of orthodontic appliances

AUTHOR YEAR STUDY DESIGN	TOPIC	SUBJECTS (N) M:F MEAN AGE / RANGE (YRS)	RESULTS AND COMMENTS
Pacheco-Pereira et al. (2018) Retrospective survey	Pt satisfaction following Invisalign® treatment	• 81 • 24:57 • 26	• No dissatisfaction scores noted for any factor • Most respondents responded positively in positive dimensions or neutrally in negative dimensions
Hardwick et al. (2017) Qualitative study	Lingual orthodontic treatment	• 15 • NS • 16 - 60	• M < 30 yrs wanting aesthetics-based systems but unsure of the specifics • F 30 - 45 yrs more knowledgeable and wanted more information regarding systems
Fonseca et al. (2014) Cross-sectional questionnaire	Pt perception of appliances metal vs ceramic fixed appliances	• 60 • 21:39 • 18-47	• No significant differences in how personal characteristics were assessed • Lower beauty scores assigned to metal fixed appliance • Orthodontic appliances can affect self-perception change
Feu et al. (2012) Cross-sectional questionnaire	Pt perception and economic value of orthodontic appliances	• 252 • 152:100 • 17-63	• Perception: clear aligners>ceramic appliances>sapphire appliances>self-ligating/SS appliances>gold appliances • Large sample • Aligners were assessed with anterior attachments increasing validity • Photographs depicted real scenario – not software generated

AUTHOR YEAR STUDY DESIGN	TOPIC	SUBJECTS (N) M:F MEAN AGE / RANGE (YRS)	RESULTS AND COMMENTS
Walton et al. (2010) Cross-sectional computer-based questionnaire	Orthodontic appliance preferences of children and adolescents	• 141 • 58:81 • 9-17	• 9 - 11 and 12 - 14 yrs old preferred metal orthodontic appliances with coloured elastomers • 15 - 17 yrs old preferred ceramic orthodontic appliances • Preferences of orthodontic appliances differ between children and adolescents • Large sample • Photographs were modified, not actual • Wide range of appliances assessed
Ziuchkovski et al. (2008) Cross-sectional computer-based questionnaire	Perceived attractiveness of orthodontic appliances	• 200 • 58:142 • 18 – 46+	• Attractiveness: clear aligners ‘alternative’ > ceramic appliances > stainless steel and self-ligating appliances • No significant differences in brands • Large sample • Actual representation of appliances- not a digital simulation
Fritz et al. (2002) Retrospective survey	Lingual appliances motivation and acceptance	• 100 • 26:74 • NS	• Lingual appliance appealed to F < 40 years • Positive acceptance and reduced discomfort after 3 weeks • Pt recall bias present
Key:	Pt = Patients Yrs = Years	M = Males F = Females	No: = Number < = Less than

CHAPTER THREE

AIMS AND OBJECTIVES

3. AIMS AND OBJECTIVES

3.1 AIMS

- To evaluate, in young adults, the immediate effect of clear aligners (CAs) and aesthetic fixed appliances (AFAs) on the magnitude of rest to natural and rest to maximal smile
- To evaluate, in young adults, the immediate effect of CAs and AFAs on intra-session reproducibility of rest to natural and rest to maximal smile
- To evaluate, in young adults, the immediate perception of CAs and AFAs

3.2 NULL HYPOTHESES

- There is no difference in young adults, between the immediate effect of CAs and AFAs on the magnitude of rest to natural and rest to maximal smile
- There is no difference in young adults between the immediate effect of CAs and AFAs on intra-session reproducibility of rest to natural and rest to maximal smile
- There is no difference in young adults between the immediate perception of CAs and AFAs

CHAPTER FOUR

MATERIALS AND METHODS

4. MATERIALS AND METHODS

4.1 DESIGN

This was a prospective clinical cohort study. Following the initial screening, all subjects had 3 appointments (**Figure 4.1**).

4.2 ETHICAL APPROVAL

Ethical approval was granted for this project from the Clinical Research Ethics Committee of the Cork University Teaching Hospitals (**Appendix 1**).

4.3 SAMPLE SIZE

A sample size of 40 subjects, 20 males and 20 females, was required to have an 80 percent power to detect a clinically meaningful difference of 2 mm in the magnitude of facial expressions, rest to natural smile and rest to maximal smile with $p < 0.05$ (Darby et al., 2015).

4.4 RECRUITMENT FOR THE STUDY

Subjects were recruited via email and social media. They comprised students, staff and family members of staff within Cork University Dental School and Hospital (CUDSH).

4.5 PLANNING

Several pilot studies were conducted to evaluate the methods and procedures to be used prior to commencing the main study.

A 1-day training course, provided by ESM Digital Solutions (Swords, Dublin), was undertaken. This included training in the use of the TRIOS® Impression scanner and 3Shape® software.

4.6 COMMUNICATION

All subjects were sent reminders via text message, at 48 hours and 8 hours prior to their appointments.

A comprehensive tracking spreadsheet was created listing each of the subjects and was used to record when each step of the process was completed.

4.7 CONSENT

All subjects received written and verbal information regarding the purpose, design and requirements of the study. Written consent was obtained from all subjects prior to participation.

4.8 INITIAL SCREENING

One hundred and sixty-seven subjects attended the initial clinical screening and were evaluated against the inclusion and exclusion criteria as set out below.

4.8.1 Inclusion criteria

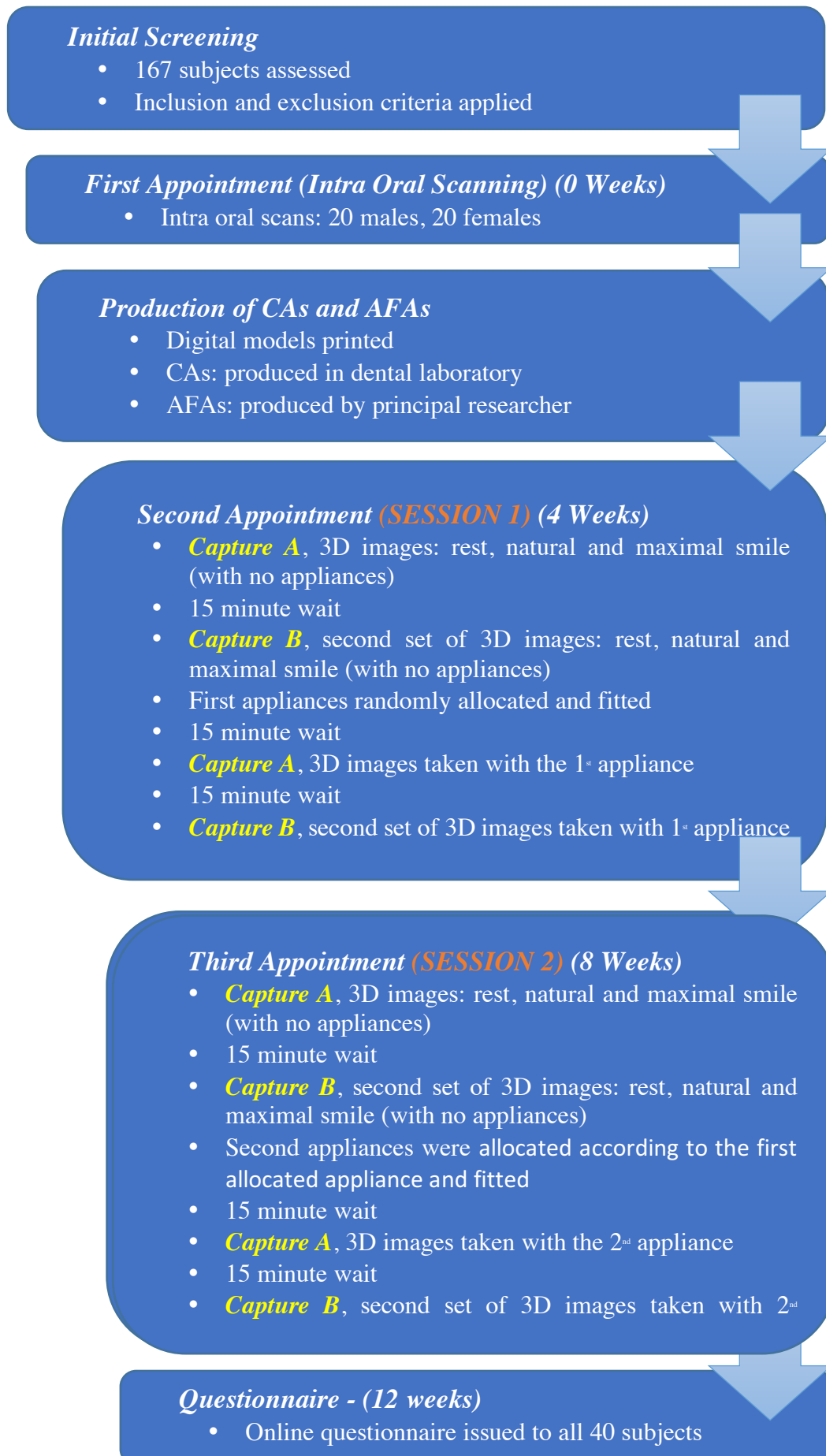
- Caucasian males and females
- Age ≥ 18 and ≤ 25 years
- Class I incisor relationship as defined by the British Standards Institute (1983)
- No history of orthodontic treatment

4.8.2 Exclusion criteria

- Non-Caucasian
- History of congenital orofacial clefting
- Subjects with suspected or identifiable syndromes, facial deformity, muscular disorders or palsy, trauma, burns, paralysis, scars, botulinum toxin injections and dermal fillers, skin disease, surgery of the facial region or gross facial asymmetry
- Missing anterior teeth
- Malocclusion other than Class I
- Previous orthodontic treatment

Following the screening processes, 40 subjects were recruited (20 males and 20 females). The study programme is shown (**Figure 4.1**).

Figure 4.1: Flow chart detailing the study programme



4.9 FIRST APPOINTMENT – INTRA ORAL SCANNING

Following informed consent, a 3D intra oral scan (**Figure 4.2**) was taken of each subject with the TRIOS® scanner (**Figure 4.3**) to allow fabrication of the CAs and AFAs.

The 3Shape TRIOS® scanner was calibrated for both colour and grey scale using the calibration heads provided. Recalibration was carried out at regular intervals throughout the project as per the manufacturer's guidelines.

Figure 4.2: Example of upper arch scan

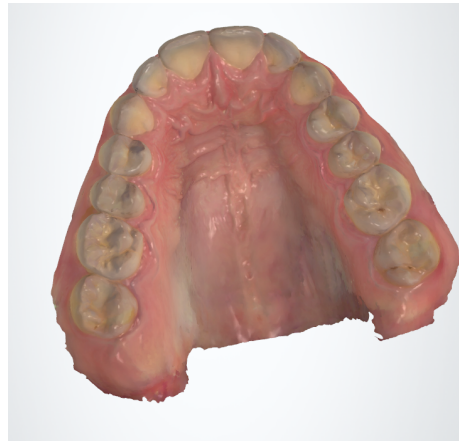


Figure 4.3: 3Shape TRIOS® scanner



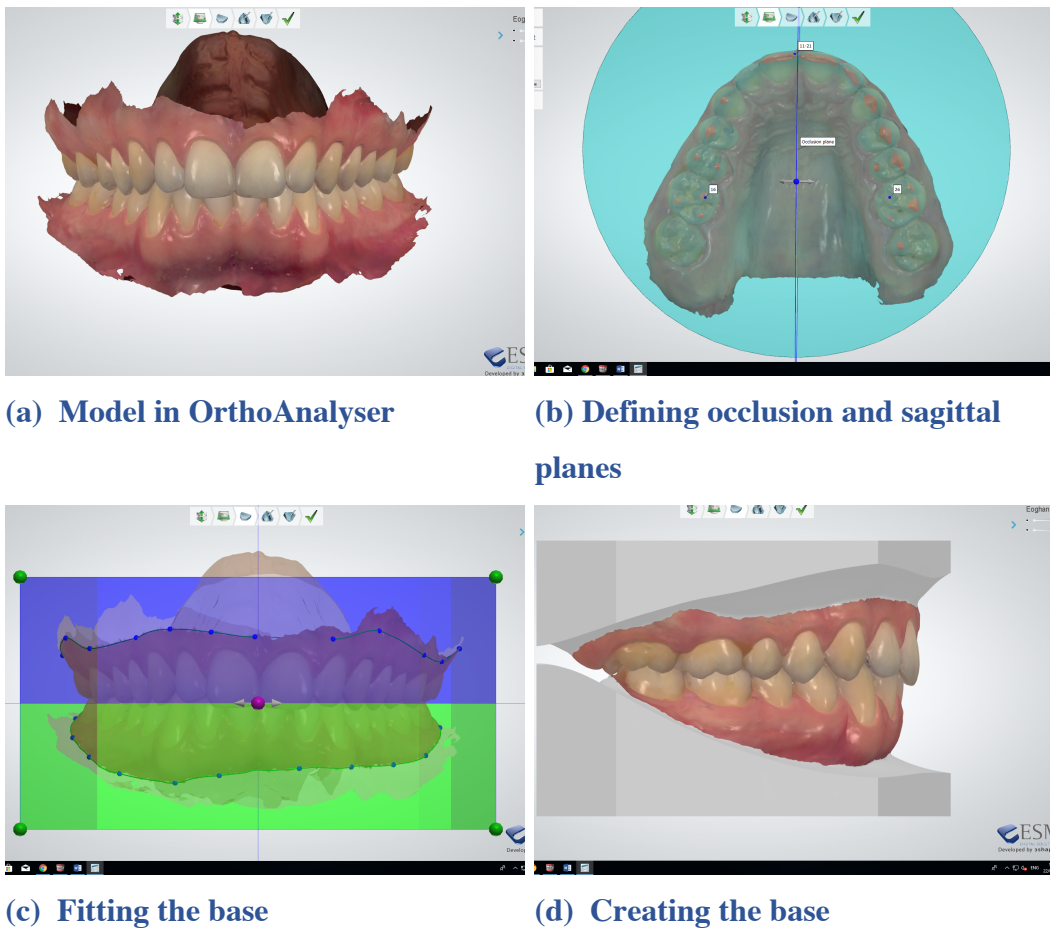
4.10 PRODUCTION OF THE CAs AND AFAs

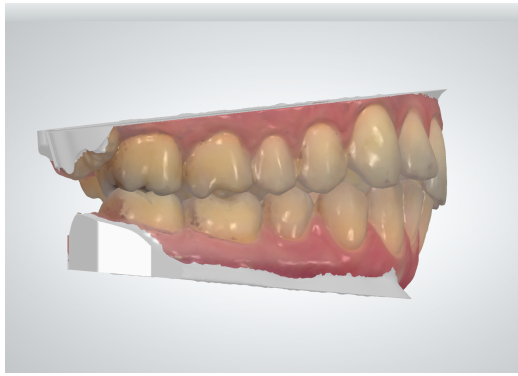
4.10.1 Production of the CAs

The digital scans of the dental arches were imported into Ortho Analyser (**Figure 4.4**), then based and imported into Appliance Designer, where they were labelled and exported as STL files.

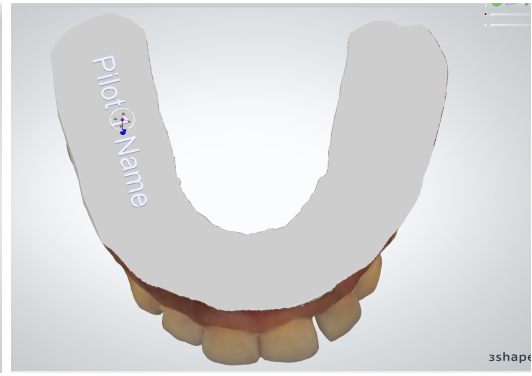
These were then imported into the Preform 3D printing software. Print supports were generated (**Figure 4.5**) and the models printed and soaked in the IPA solution. These were then dried and packaged before sending via courier to DentalTech (Dublin, Ireland) where 2 sets of CAs were made for each arch. The completed CAs were placed in individually labelled boxes.

Figure 4.4: Basing the digital models



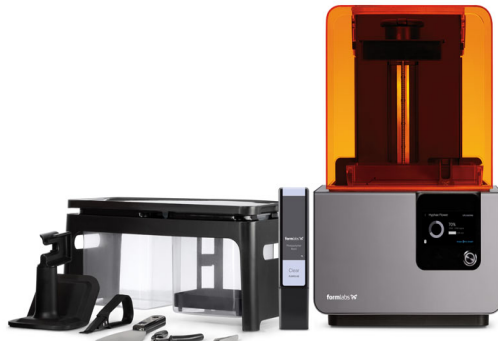


(e) Model in Appliance Designer

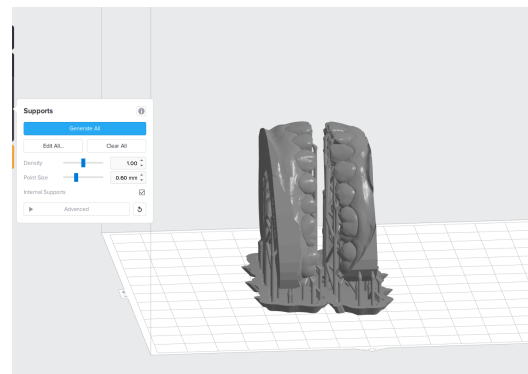


(f) Labelling model

Figure 4.5: Printing the models



(a) Form2 printer



(b) Printing model with supports



(c) Printed model (left) and model with CAs (right) on velvet background

Aligner Material

A pilot study was conducted to establish which type of aligner to use for this study. The majority of literature on CAs relates to Invisalign®. Invisalign® was unable to sponsor this project so an alternative aligner was sourced. A key characteristic of the aligner relevant for this study was the aligner thickness. A trial was conducted to compare the thickness of Invisalign® aligners to that of Zandura aligners fabricated by Dentaltech (Dublin, Ireland). A Vernier calliper was used to measure the thickness of each aligner at 12 prescribed sites (mid labial UR1, UL1; mid buccal UR3, UL3, UR5, UL5; and mid palatal UR1, UL1, UR3, UL3, UR5, UL5). The mean thickness of the Invisalign® aligners was 0.79 mm and this closely matched the mean of 0.85 mm for the Zandura aligners.

4.10.2 Production of the AFAs

The digital models in OrthoAnalyzer® were segmented, points and cut lines defined, the models sculpted and the occlusal and sagittal planes defined. After the FA points were identified on each tooth, brackets were applied and the model was imported into Appliance Designer (**Figure 4.6**). The brackets were then removed from the digital model, virtual bracket markers added and the models were printed, left to soak in IPA solution and then dried. The markers were removed with a scalpel and traced on the model with a 0.3 mm black Staedtler triplus fineliner pen (Nuremberg, Germany).

When the CAs were placed over the printed model, the black traced marker outlines could clearly be seen through the CAs and this allowed for accurate direct bonding of the brackets to the CAs to produce the AFAs (**Figure 4.7**).

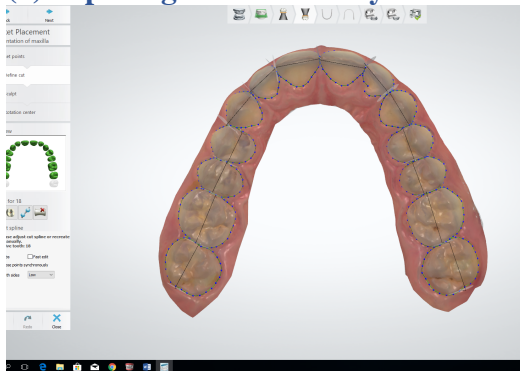
Twenty 3M APC Flash-Free Clarity Advanced MBT brackets (Unitek, St Paul, Minnesota, USA) were bonded directly onto the CAs and 3M APC Victory Superior First molar tubes were bonded to the first and second permanent molars. The upper and lower models were light-cured in a light-cure box for 20 seconds.

0.014" Nickel Titanium (Unitek, St Paul, Minnesota, USA) archwires were ligated to each tooth with clear elastomeric modules (Orthocare, West Yorkshire, UK) and the AFAs were placed in individually labelled boxes.

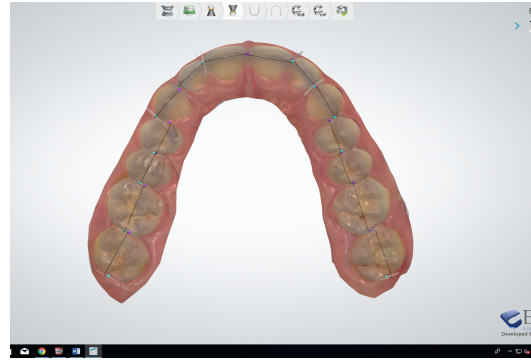
Figure 4.6: Locating brackets on digital model in OrthoAnalyzer®



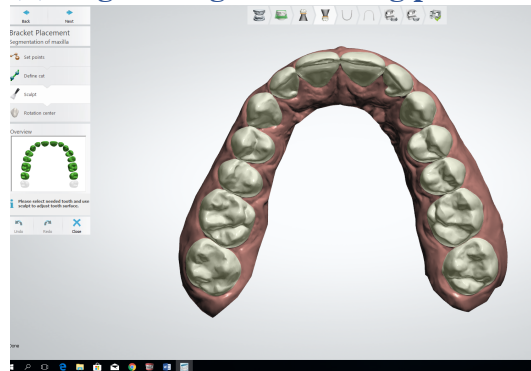
(a) Opening in OrthoAnalyzer®



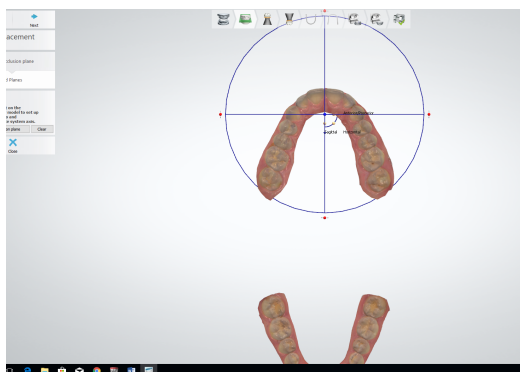
(c) Defining the cut



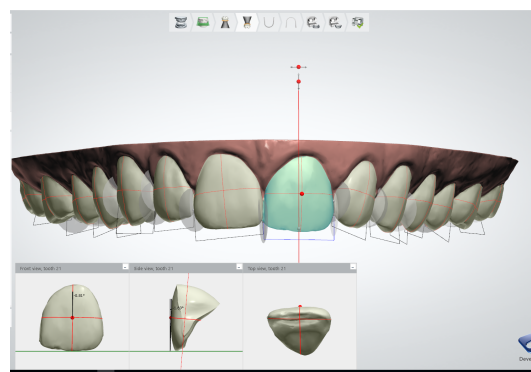
(b) Segmenting and defining points



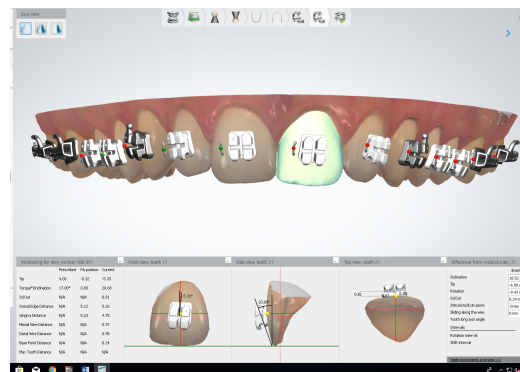
(d) Sculpting the model



(e) Define occlusal and sagittal planes



(f) Locating FA point



(g) Software applied brackets on FA points



(h) Digital model used to compare position of the brackets on CA

Figure 4.7: Direct method of bonding brackets to CAs to produce the AFAs



(a) Image of printed model with brackets removed and only bracket markers



(b) Image of printed model with markers removed and traced on model



(c) Final appliance simulation with aesthetic brackets and wires

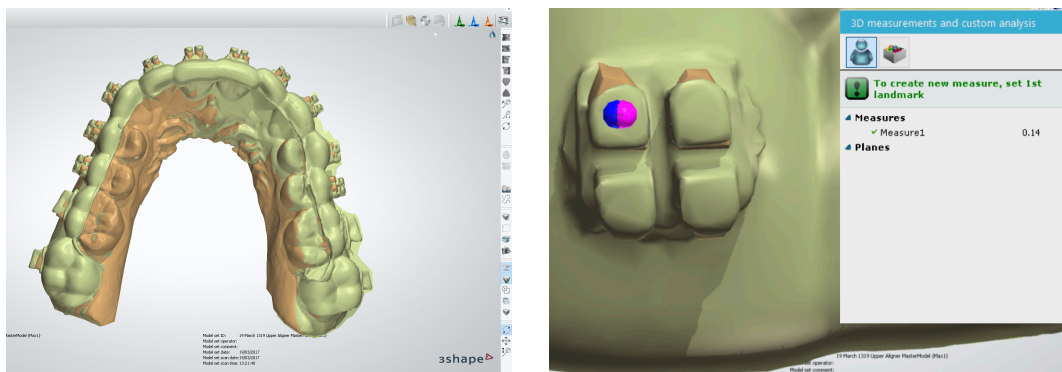
Error study

An error study was conducted to validate the accuracy of the direct bonding of the bracket onto the FA point by comparing the position of the brackets on the AFA model to the location of the brackets on the digital model using Ortho Analyzer® software (**Figure 4.8**).

The bracket displacement was measured on each tooth for 4 models (10 percent of the sample) in the error study. All measurements were within the agreed tolerance of 0.5 ± 0.05 mm (**Table 4.1**).

This measuring process requires making a judgement to determine the centre of the orientation marker on the bracket and clicking the mouse in the centre of that point in an accurate and repeatable manner. An accuracy and repeatability study was conducted for each tooth for both arches to confirm this. **Figure 4.9** shows the results of the accuracy and repeatability study on 1 tooth. The full results of the accuracy and repeatability study for all teeth are included in **Appendix 3**.

Figure 4.8: Measuring bracket position on AFAs relative to the digital model



(a) Two models superimposed: 'Best fit method'

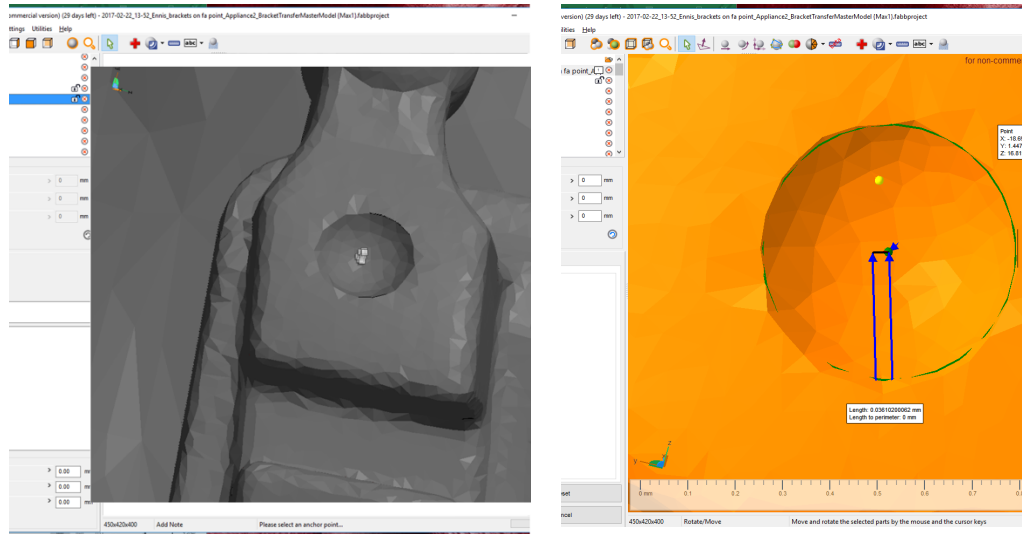
(b) Distance from orientation marker on digital model to same point on AFA

Table 4.1: Displacement measurements for all 4 models in error study

Model 1				Model 2			
Tooth Number	Δ Indication dot	Tooth Number	Δ Indication dot	Tooth Number	Δ Indication dot	Tooth Number	Δ Indication dot
1.1	0.14	2.1	0.47	1.1	0.11	2.1	0.01
1.2	0.11	2.2	0.27	1.2	0.43	2.2	0.47
1.3	0.42	2.3	0.46	1.3	0.35	2.3	0.29
1.4	0.28	2.4	0.45	1.4	0.45	2.4	0.24
1.5	0.02	2.5	0.48	1.5	0.44	2.5	0.05
1.6	0.19	2.6	0.14	1.6	0.47	2.6	0.42
1.7	0.45	2.7	0.37	1.7	0.47	2.7	0.47
Tooth Number	Δ Indication dot	Tooth Number	Δ Indication dot	Tooth Number	Δ Indication dot	Tooth Number	Δ Indication dot
4.1	0.47	3.1	0.4	4.1	0.35	3.1	0.44
4.2	0.48	3.2	0.49	4.2	0.07	3.2	0.01
4.3	0.46	3.3	0.46	4.3	0.45	3.3	0.34
4.4	0.47	3.4	0.3	4.4	0.17	3.4	0.09
4.5	0.34	3.5	0.42	4.5	0.48	3.5	0.46
4.6	0.43	3.6	0.14	4.6	0.3	3.6	0.39
4.7	0.47	3.7	0.15	4.7	0.4	3.7	0.17

Model 3				Model 4			
Tooth Number	Δ Indication dot	Tooth Number	Δ Indication dot	Tooth Number	Δ Indication dot	Tooth Number	Δ Indication dot
1.1	0.29	2.1	0.48	1.1	0.14	2.1	0.27
1.2	0.49	2.2	0.41	1.2	0.21	2.2	0.45
1.3	0.14	2.3	0.28	1.3	0.08	2.3	0.47
1.4	0.45	2.4	0.44	1.4	Tooth Missing	2.4	Tooth Missing
1.5	0.48	2.5	0.26	1.5	0.48	2.5	0.47
1.6	0.32	2.6	0.47	1.6	0.48	2.6	0.29
1.7	0.31	2.7	0.43	1.7	0.47	2.7	0.44
Tooth Number	Δ Indication dot	Tooth Number	Δ Indication dot	Tooth Number	Δ Indication dot	Tooth Number	Δ Indication dot
4.1	0.46	3.1	0.02	4.1	0.41	3.1	0.45
4.2	0.27	3.2	0.23	4.2	0.06	3.2	0.07
4.3	0.25	3.3	0.47	4.3	0.48	3.3	0.28
4.4	0.43	3.4	0.4	4.4	Tooth Missing	3.4	Tooth Missing
4.5	0.49	3.5	0.46	4.5	0.45	3.5	0.46
4.6	0.07	3.6	0.49	4.6	0.49	3.6	0.43
4.7	0.49	3.7	0.21	4.7	0.42	3.7	0.15

Figure 4.9: Using Autodesk Netfabb® software to conduct accuracy and repeatability study



(a) Repeatability selecting centre of orientation marker

(b) Accuracy: measuring distance from selected point to true centre of orientation marker

TOOTH No.	Trial No.	X (mm)	Y (mm)	Z (mm)	ΔX (mm)	ΔY (mm)	ΔZ (mm)
1.3	1	-18.7	1.43	16.8	0.01	0.02	0.02
	2	-18.71	1.46	16.79	0.02	0.01	0.03
	3	-18.71	1.45	16.78	0.02	0.00	0.04
	4	-18.7	1.49	16.79	0.01	0.04	0.03
	5	-18.71	1.44	16.79	0.02	0.01	0.03
	6	-18.71	1.49	16.78	0.02	0.04	0.04
	7	-18.7	1.6	16.8	0.01	0.05	0.02
	8	-18.7	1.46	16.8	0.01	0.01	0.02
	9	-18.7	1.44	16.81	0.01	0.01	0.01
	10	-18.7	1.49	16.8	0.01	0.04	0.02
ACTUAL		-18.693	1.447	16.819	0.011	0.024	0.025
Key: No. = Number							

(c) Repeatability study showing 10 selected points and distance to actual centre of orientation marker in XYZ planes

4.11 SECOND APPOINTMENT – SESSION 1

4.11.1 Image capture process

Subjects were required to remove all make-up, earrings and facial jewellery. Subjects with facial hair were required to shave it off and subjects with long hair were provided with standardised disposable hairbands to ensure that hair did not interfere with the images.

During the second appointment (Session 1), images were taken with each subject seated in front of the 3D imaging system. The 3D imaging assistant ensured that each subject's head was in the natural head position (NHP) by asking them to look at their eyes in a mirror.

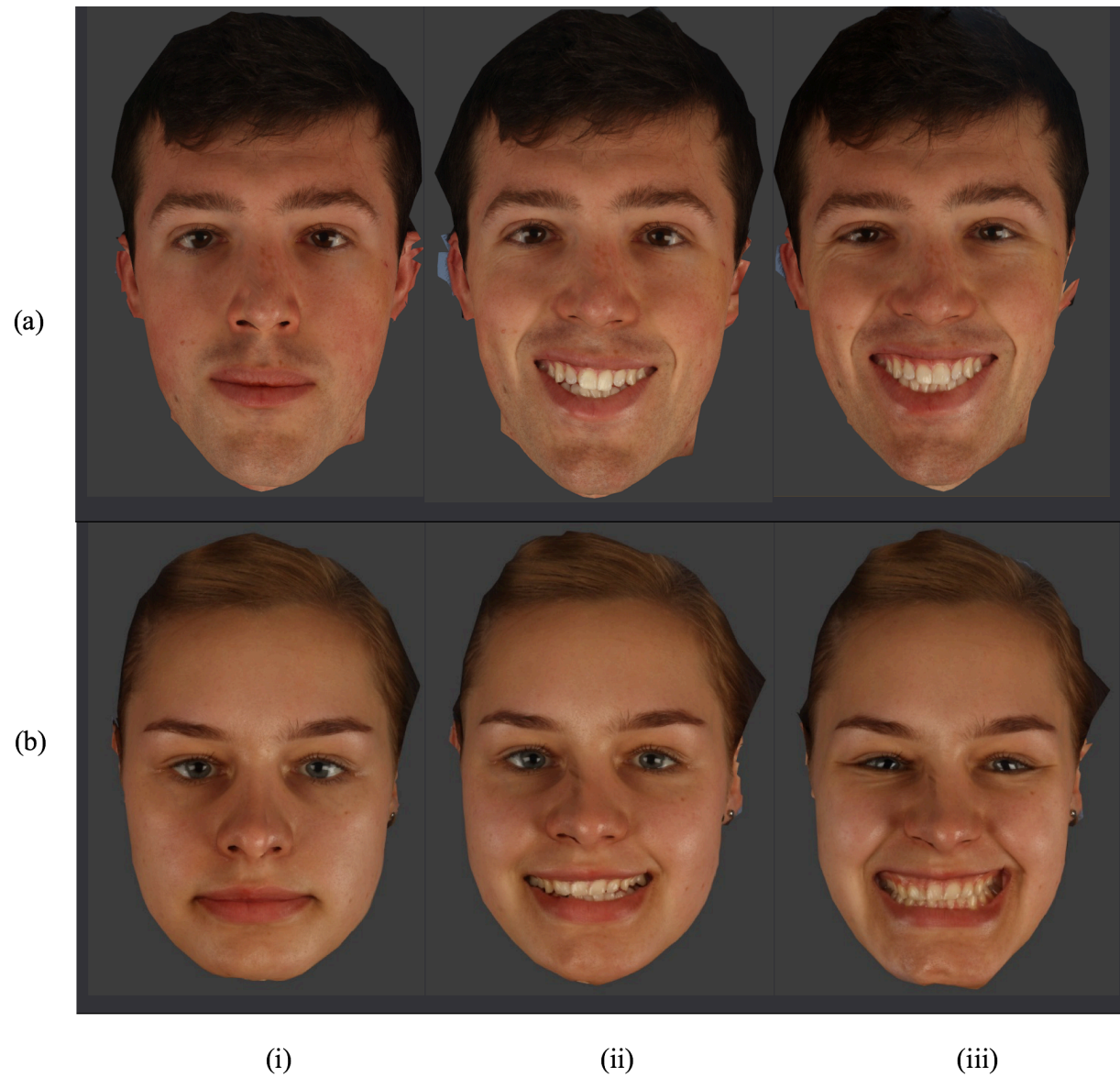
Each subject was requested to generate each expression as directed by the assistant. Each expression was practiced until the subject felt comfortable performing it.

The following facial expressions, using the verbal cues described by Zachrisson, (1998) were recorded:

- Rest position
 - a. Instruct the subject to say “Mississippi”
 - b. Then instruct the subject to swallow
 - c. Then instruct the subject to say “N”
 - d. Check the patient's position twice to ensure that the incisor display represents the true rest position of the lips
 - e. Then take the 3D image
- Natural smile
 - a. Instruct the subject to bite their teeth gently together and say “Cheese”
 - b. Check that the smile is natural and full
 - c. Then take the 3D image
- Maximal smile
 - a. Instruct the subject to bite their teeth gently together and smile maximally
 - b. The assistant takes the 3D image

3D images were taken preforming each of the expressions (Capture A) as described above without any appliances in place (**Figure 4.10**). Following a 15-minute wait, a second set of images was recorded (Capture B). The 3D imaging assistant reviewed each image during each session and if any image was distorted or incorrect, it was discarded and a new image was captured.

Figure 4.10: 3D images of (a) male and (b) female subject: (i) at rest, (ii) natural smile and (iii) maximal smile



4.11.2 Imaging equipment set up

The Postgraduate Orthodontic Unit at Cork University Dental School and Hospital has a dedicated imaging room suitable for 3D stereophotogrammetry (**Figure 4.11**). The 3D stereophotogrammetry system uses 4 Canon EOS 100D digital cameras with 2 Esprit 500 DX digital flashes.

A purpose-built assembly fixture has been built to mount the cameras 850 mm apart in the horizontal direction. The cameras were connected to a DELL Dimension 8400 computer on which Di3D software (Dimensional Imaging Ltd) was used to capture the images (**Figure 4.12**).

For each point imaged in the left camera, the corresponding point in the right camera is determined and the output of this process is recorded as x and y coordinates of each pixel on the face. From this, the third dimension of each pixel can be calculated, resulting in a high-quality 3D photorealistic model (Ayoub et al., 1998; Leung et al., 2016).

Figure 4.11: Imaging room



Figure 4.12: Stereophotogrammetry equipment



Randomisation procedure

The CAs and AFAs were assigned to subjects in a random order by the 3D Imaging Assistant. A random number generator software was used to assign a random number, 0 or 1, to each subject: 0 = CAs; 1 = AFAs. The randomised selection was concealed in brown envelopes.

Fitting the appliances

Subjects were taken to the Postgraduate Orthodontic Clinic to have the allocated appliances (CAs or AFAs) fitted by the principal researcher. Subjects were then taken to the waiting area and instructed not to remove the appliances while waiting.

Image capture with appliances

Following a 15-minute wait with the appliances in situ, 3D images at rest, natural and maximal smile were recorded (Capture A). After a further 15-minute interval, with the appliances in situ, a second set of 3D images was captured of the same expressions (Capture B) (**Figure 4.13**). The appliances were then removed and the subject discharged.

4.12 THIRD APPOINTMENT – SESSION 2

Session 2 was scheduled for the same week day and the same time of day, morning or afternoon, 4 weeks after Session 1. 3D images were captured at rest, natural and maximal smile with no appliances in place (Capture A). After a 15-minute wait, a further set of 3D images were captured with no appliances in place (Capture B).

Subjects who had been randomised to the CAs at Session 1, were now allocated the AFAs and vice versa; the allocated appliances were fitted. Following a 15 minute wait, 3D images at rest, natural and maximal smile were recorded (Capture A). After a further 15-minute interval, a second set of 3D images were captured (Capture B) of the same expressions (**Figure 4.13**). The appliances were then removed and the subject discharged.

Figure 4.13: Facial images of a female subject at rest and natural smile, without and with, CAs and AFAs



(a) Facial images of a female subject with no appliances in situ: at rest and natural smile



(b) Facial images of a female subject with CAs in situ: at rest and natural smile



(c) Facial images of a female subject with AFAs in situ: at rest and natural smile

4.13 LANDMARKS

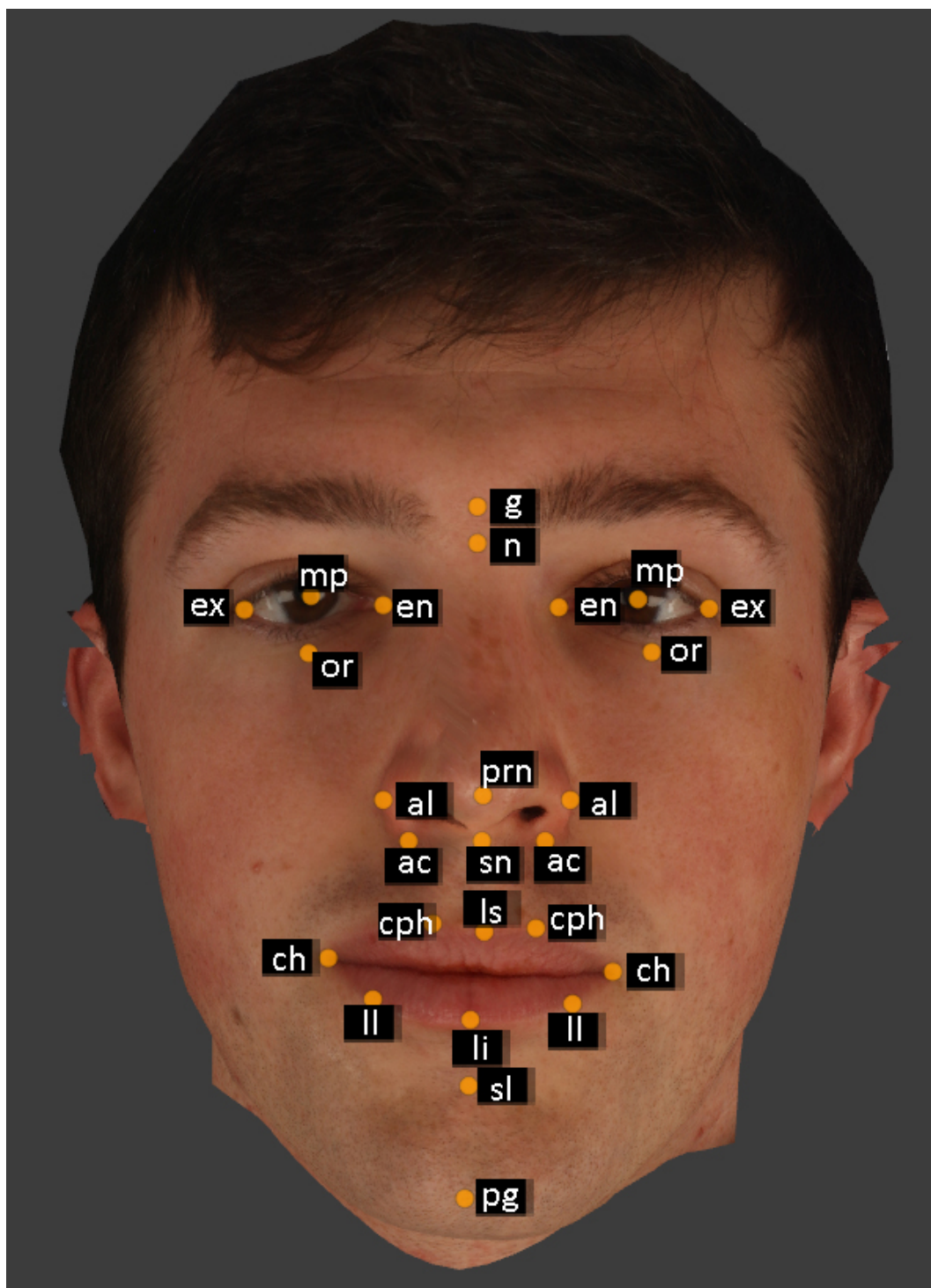
After all of the images were captured, the following landmarks, as defined by Farkas, (1994) were placed on each image (**Table 4.2**). They are shown on a model in **Figure 4.14**. The lower face landmarks are denoted in blue.

Table 4.2: Table detailing the landmarks as defined by Farkas

LANDMARK	DEFINATION
Glabella (g)	Most prominent midline point between eyebrows
Nasion (n)	Point in the midline of both nasal root and nasofrontal suture
Right exocanthion (exR)	Outermost point on the commissure of the right eye fissure
Mid pupil right (mpR)	Centre point of the right pupil
Orbitale right (oR)	Lowest point on the lower margin of the right orbit
Endocanthion right (enR)	Innermost point on the commissure of the right eye fissure
Endocathion left (enL)	Innermost point on the commissure of the left eye fissure
Mid pupil left (mpL)	Centre point of the left pupil
Orbitale left (oL)	Lowest point on the lower margin of the left orbit
Exocanthion left (exL)	Outer most point on the commissure of the right eye fissure
Pronasale (prn)	Most protruded point of the apex nasi identified in the lateral view of the rest position of the head
Subnasale (sn)	Midpoint of the angle where the lower nasal septum and the lips meet (the base of Columella)
Alar curvature right (acR)	Most lateral point in the curved base line of the right ala
Alar curvature left (acL)	Most lateral point in the curved base line of the left ala
Alare right (aR)	Most lateral point on the right alar contour
Alare left (aL)	Most lateral point on the left alar contour
Cheilion right (chR)	Outermost point of the right lip commissure
Christa philltri right (cphR)	Point on the right elevated margin of the philtrum just above the vermillion line
Labiale superius (ls)	Midpoint on the upper vermillion border

Christa philltri left (cphL)	Point on the left elevated margin of the philtrum just above the vermillion line
Cheilion left (chL)	Outermost point of the left lip commissure
Labiale inferius (li)	Lower border of the lower lip
Lower lip right (llR)	Point located midway between cheilion right and labiale inferius
Lower lip left (llL)	Point located midway between cheilion left and labiale inferius
Sublabiale (sl)	Lower border of the lower lip or the upper border
Pogonion (pg)	Most anterior midpoint on the chin

Figure 4.14: All 26 facial landmarks indicated on a male subject



4.14 STATISTICAL ANALYSIS

The average range of movement was calculated for the rest to natural and rest to maximal smile over all landmarks and for the lower facial landmarks separately. Results for the CAs were compared to those of the AFAs. Movements were analysed using an analysis of variance model for repeated measures.

Appliance, capture, expression, gender and the sequence of fitting the appliances were included as factors in the model. Two-way interactions between appliances as well as capture, expression and gender were also included. An unstructured Analysis of Covariance (ANCOVA) model was applied. Residual analyses were performed to confirm the suitability of the ANCOVA model. Appropriate comparisons were performed using linear contrasts estimated from the model. In the statistical data, for presentation purposes, the sessions were standardised so that all data relating to the CAs was designated as Session 1 and all data relating to the AFAs as Session 2, irrespective of which appliances the subject received at each session.

The level of significance used was 5 percent and all statistical analyses were performed in SAS® (Version 9.4).

To access intra-observer reproducibility in landmark placement, a random sample of 10 percent of the images was selected and re-landmarked by the same operator 1 month after initial landmarking. The 3D coordinates for the first set of values were compared to the second set (Johnston et al., 2003).

4.15 FOLLOW-UP QUESTIONNAIRE

A questionnaire was developed and piloted among 20 members of staff from CUDSH. The pilot group was briefed about the context and nature of the research project and was asked about ease of comprehension and ambiguity.

Following feedback, 1 question was changed and the revised questionnaire was distributed to a further 10 members of staff from CUDSH. No further amendments were required. The finalised questionnaire (**Appendix 2**) was then transformed into a digital version and was sent to each subject via email 4 weeks after the third appointment.

CHAPTER FIVE

RESULTS

5. RESULTS

5.1 SUBJECT DETAILS

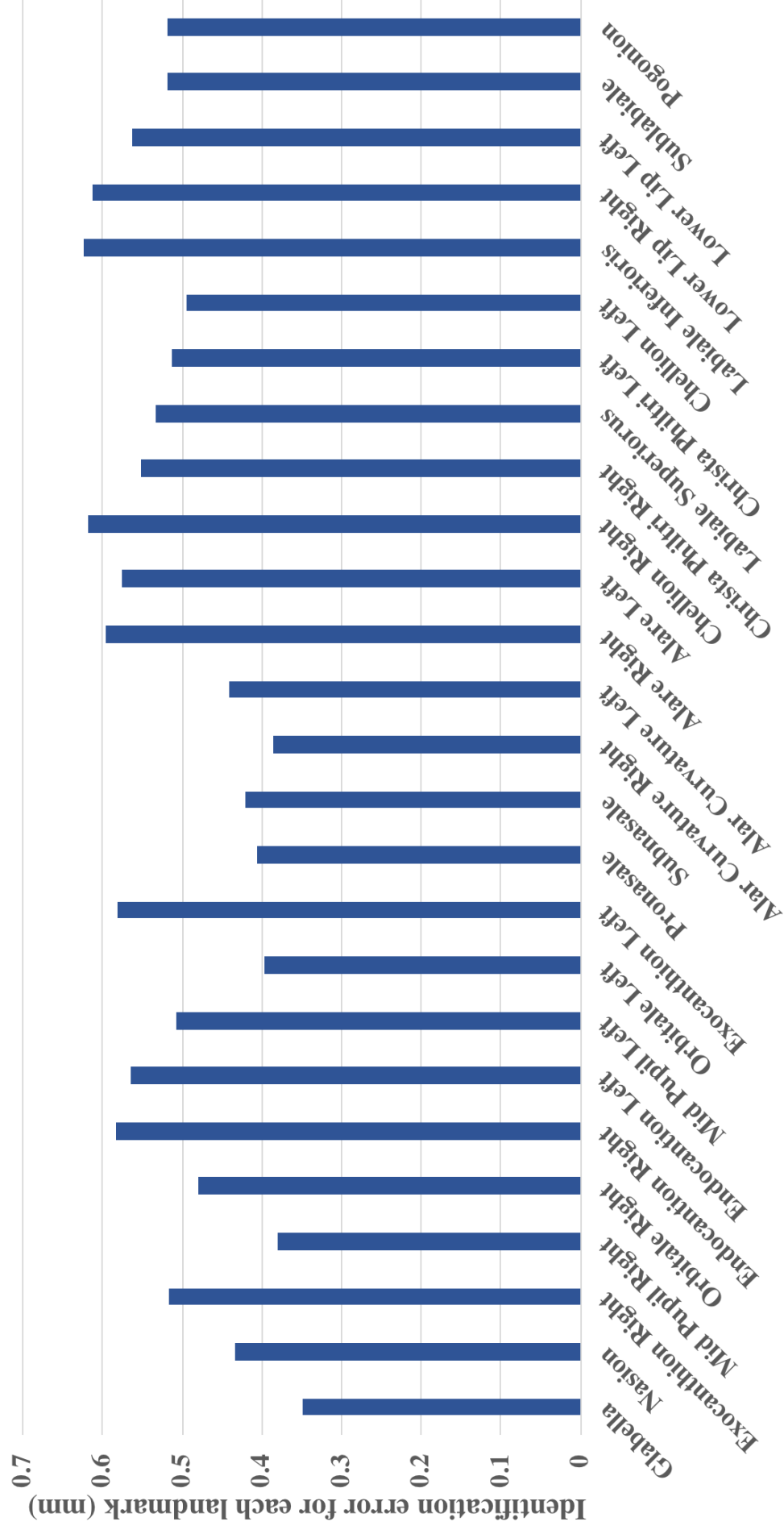
Forty Caucasian subjects with a Class I incisor relationship (BSI, 1983) and no history of orthodontic treatment took part in this study; 20 males (mean age 20.80 ± 1.54 years) and 20 females (mean age 21.15 ± 1.35 years). The mean overjet for males was 2.0 ± 0.9 mm and for females was 2.6 ± 0.6 mm.

5.2 LANDMARK IDENTIFICATION ERROR

Each subject had 24 images captured. This resulted in 960 images for the 40 subjects. Each image had 26 landmarks identified. Ten percent of the images were landmarked a second time and their coordinates compared to the originals. The mean landmark identification error for each landmark is the mean difference between the 2 sets of landmark placement coordinates (**Figure 5.1**).

The overall mean landmark error was 0.50 ± 0.08 mm. This was determined to be acceptable (Gwilliam, 2006).

Figure 5.1: Mean landmark identification error for each landmark



5.3 LANDMARK MEAN DIFFERENCE ANALYSIS

During Session 1, 3D facial images were recorded at rest, natural and maximal smile without an appliance (Capture A) and repeated again after a 15-minute interval (Capture B). The subject was allocated CAs or AFAs and Captures A and B were repeated. This was repeated during image Session 2 with the other appliance. To determine the reproducibility of the expressions in this study, the mean difference between each landmark for each image between Capture A and B was calculated. The percentage of landmarks where the mean difference was less than 1.5 mm was established, as this has been used formerly as the limit of what is acceptable and reproducible (Popat et al., 2008). All expressions had between 75 and 84 percent of landmarks with a mean difference less than 1.5 mm.

Figure 5.2 represents the mean landmark difference by appliance type while **Figure 5.3** represents the data by expression type. The percentage of landmarks with intra-session mean difference less than 1.5 mm was greater for CAs than for AFAs for all expressions, while the natural smile type had the least percentage of landmarks with intra-session mean differences less than 1.5 mm.

Figure 5.2: Percentage of landmarks with intra-session mean difference less than 1.50 mm by appliance type

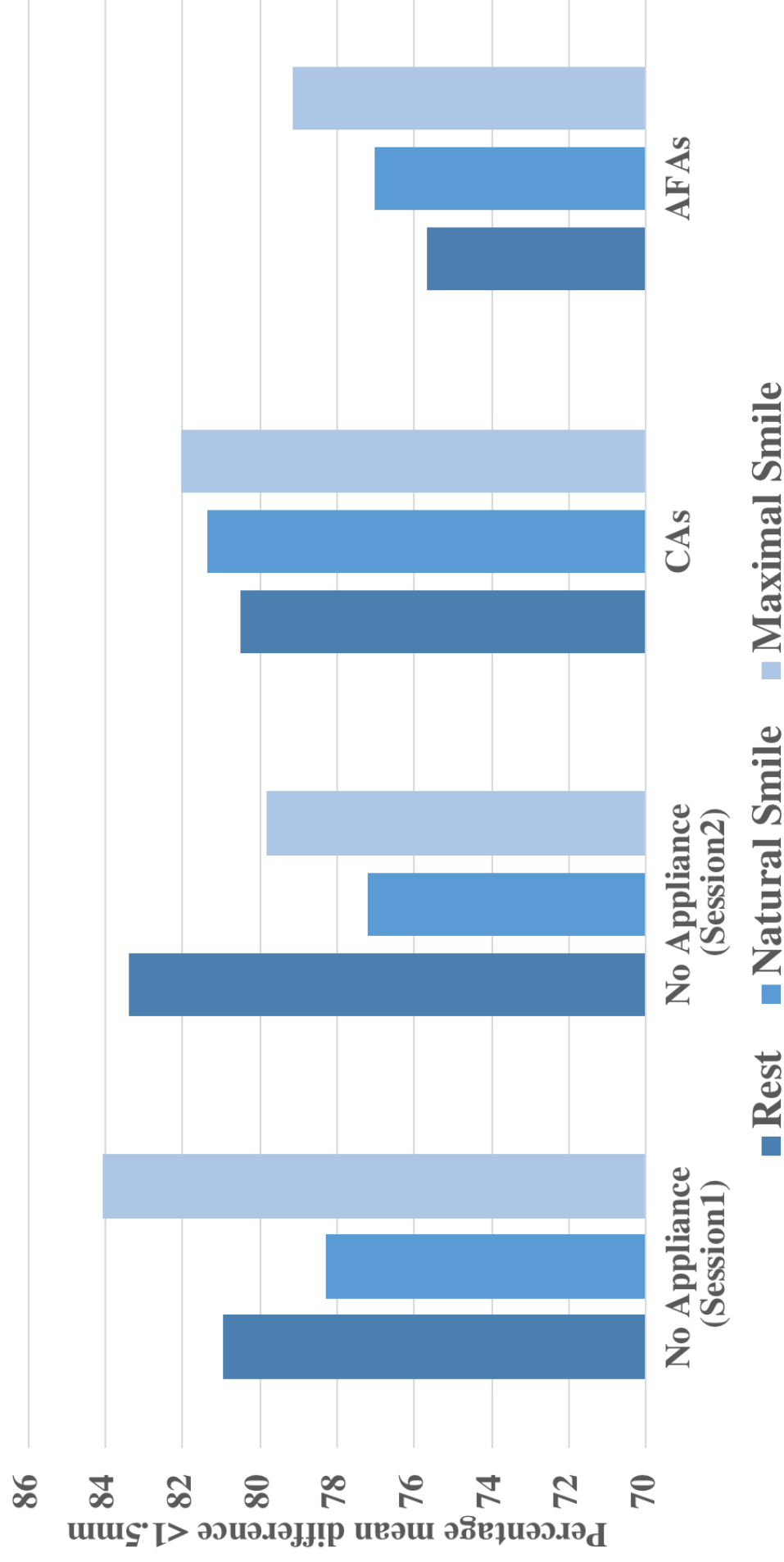
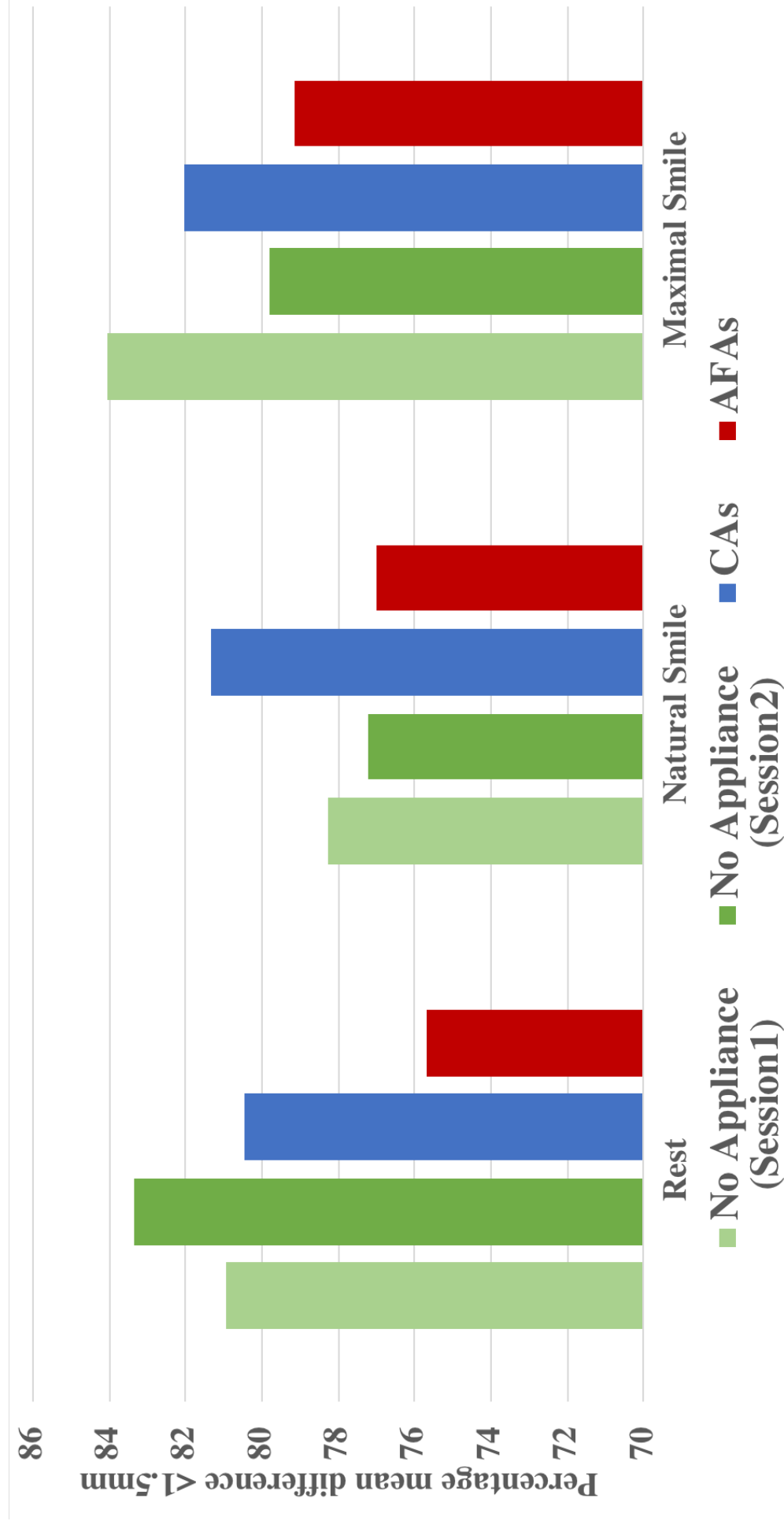


Figure 5.3: Percentage of landmarks with intra-session mean difference less than 1.50 mm by expression



5.4 MAGNITUDE OF SMILE

CAs

For rest to natural smile, there was no significant difference in mean magnitude of movement with and without CAs ($p = 0.6964$) (**Table 5.1**). **Table 5.2** and **Figure 5.4** show a mean magnitude of movement of 5.02 ± 1.3 mm from rest to natural smile with no appliance and a mean magnitude of movement of 4.97 ± 1.28 mm from rest to natural smile with CAs.

In contrast, for rest to maximal smile, the mean magnitude of movement differed significantly with and without CAs ($p = 0.0001$) (**Table 5.1**), with significantly greater movement recorded with the latter. Mean magnitude of movements of 6.06 ± 1.26 mm and 6.36 ± 1.27 mm were recorded for no appliances and with CAs respectively (**Table 5.2**).

AFAs

For rest to natural and rest to maximal smile, there was a significant difference in mean magnitude of movement with and without AFAs ($p = 0.0024$ and $p = 0.0002$ respectively) (**Table 5.1**). Significantly greater mean magnitude of movement occurred, with AFAs for both expressions, 5.28 ± 1.33 mm for rest to natural smile and 6.43 ± 1.61 mm for rest to maximal smile. The mean magnitude of movement without AFAs was 4.85 ± 1.18 mm for rest to natural smile and 6.02 ± 1.36 mm for rest to maximal smile (**Table 5.2**).

Gender

The mean magnitude of movement for each smile was significantly different between males and females ($p = 0.0109$) (**Table 5.4**). Greater total mean magnitude of movement was observed in males, 4.75 ± 1.02 mm to 5.31 ± 1.44 for rest to natural smile and 5.86 ± 1.23 mm to 6.58 ± 1.44 mm for rest to maximal smile (**Table 5.3**) (**Figure 5.5**).

The combined type of appliance the subject wore and gender ($p = 0.0620$) (**Table 5.4**) had no significant effect on the mean magnitude of movement of either smile. The mean magnitude of movement for females for rest to natural smile

was 4.61 ± 1.08 mm for CAs and 5.10 ± 1.03 mm for AFAs and this compared to 5.32 ± 1.38 mm and 5.46 ± 1.56 mm respectively for males. Similarly, the smile magnitude for rest to maximal smile in females was 6.04 ± 1.14 mm for CAs and 6.15 ± 1.46 mm for AFAs; and this compared to 6.67 ± 1.32 mm and 6.71 ± 1.73 mm in males.

Sequence

The order of appliance randomisation had no significant effect on the mean magnitude of movement of either smile ($p = 0.0939$) (**Table 5.4**).

Table 5.1: Pair-wise comparisons of mean magnitude of movements for appliance, smile and capture

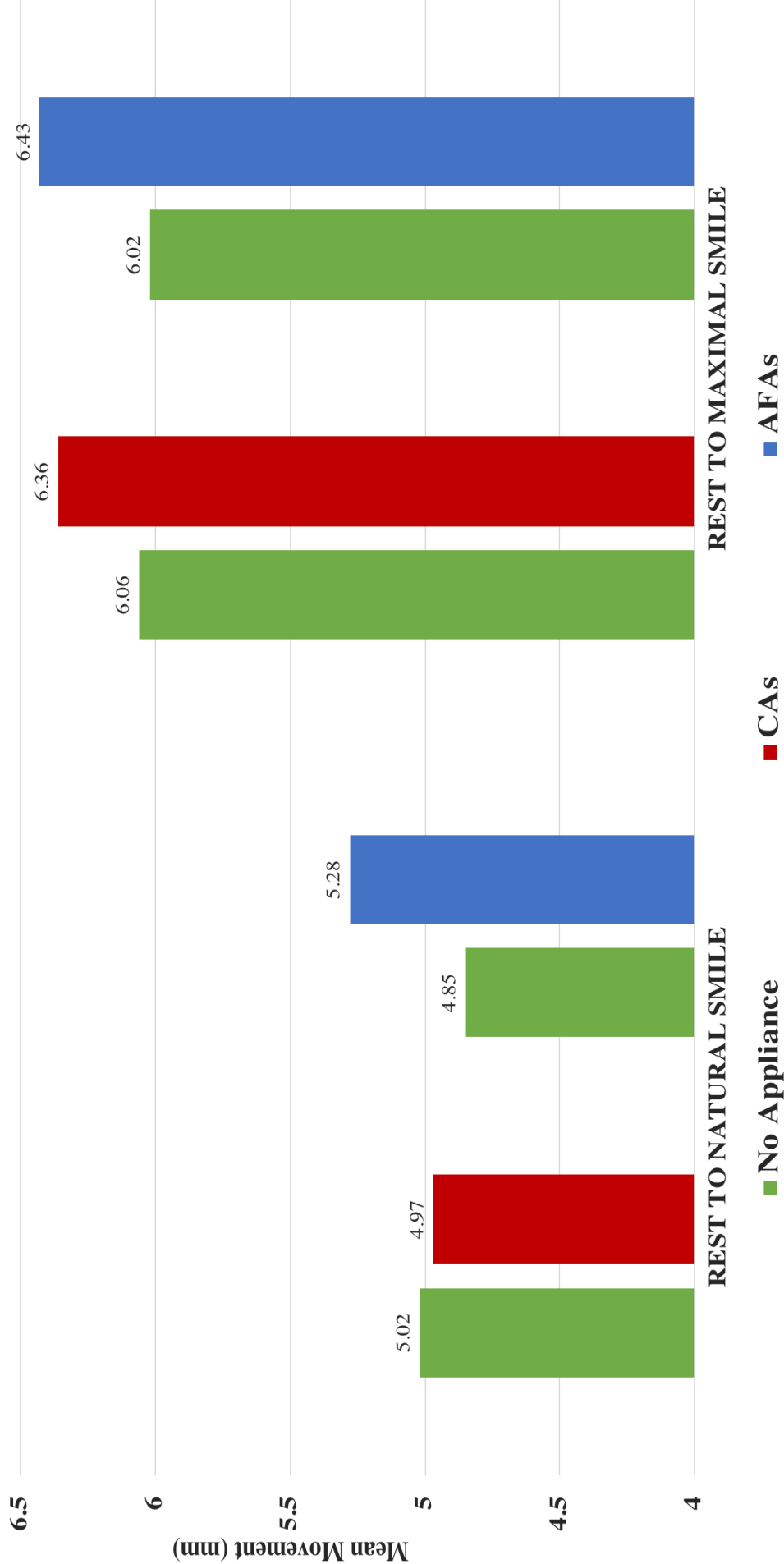
COMPARISON	t Value	P Value
CAs V None (Natural)	-0.39	0.6964
CAs V None (Maximal)	4.33	0.0001
AFAs V None (Natural)	3.25	0.0024
AFAs V None (Maximal)	4.19	0.0002
CAs V None (Capture A)	0.85	0.3984
CAs V None (Capture B)	2.76	0.0090
AFAs V None (Capture A)	2.70	0.0104
AFAs V None (Capture B)	4.46	< 0.0001

Table 5.2: Mean magnitude of movements across all landmarks for females and males combined for each expression with CAs and AFAs

FEMALES AND MALES COMBINED		CAPTURE					
		REST TO NATURAL SMILE			REST TO MAXIMAL SMILE		
APPLIANCE	CAPTURE	n	MEAN	SD	n	MEAN	SD
Without CAs	A	40	5.05	1.30	40	6.06	1.21
	B	40	4.99	1.32	40	6.05	1.33
	Total	80	5.02	1.30	80	6.06	1.26
Without AFAs	A	40	4.92	1.20	40	6.03	1.43
	B	40	4.78	1.17	40	6.00	1.30
	Total	80	4.85	1.18	80	6.02	1.36
CAs	A	40	4.99	1.25	40	6.21	1.32
	B	40	4.94	1.33	40	6.50	1.21
	Total	80	4.97	1.28	80	6.36	1.27
AFAs	A	40	5.17	1.35	40	6.48	1.51
	B	40	5.39	1.31	40	6.39	1.73
	Total	80	5.28	1.33	80	6.43	1.61
Total	A	160	5.03	1.27	160	6.19	1.37
	B	160	5.03	1.29	160	6.24	1.41
	Total	320	5.03	1.28	320	6.22	1.39

Figure 5.4: Mean magnitude of movements across all landmarks for females and males combined for each expression with CAs and AFAs

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**Table 5.3: Mean magnitude of movements across all landmarks separated by
(a) females, (b) males for each expression with CAs and AFAs**

(A)

FEMALES		CAPTURE					
		REST TO NATURAL SMILE			REST TO MAXIMAL SMILE		
APPLIANCE	CAPTURE	n	MEAN	SD	n	MEAN	SD
Without CAs	A	20	4.57	1.11	20	5.50	1.05
	B	20	4.66	1.14	20	5.54	1.21
	Total	40	4.62	1.11	40	5.52	1.12
Without AFAs	A	20	4.75	0.89	20	5.64	1.20
	B	20	4.56	0.70	20	5.77	1.08
	Total	40	4.65	0.79	40	5.70	1.13
CAs	A	20	4.63	1.07	20	5.93	1.14
	B	20	4.59	1.13	20	6.15	1.15
	Total	40	4.61	1.08	40	6.04	1.14
AFAs	A	20	5.04	0.98	20	6.18	1.42
	B	20	5.16	1.10	20	6.13	1.53
	Total	40	5.10	1.03	40	6.15	1.46
Total	A	80	4.75	1.01	80	5.81	1.22
	B	80	4.74	1.04	80	5.90	1.26
	Total	160	4.75	1.02	160	5.86	1.23

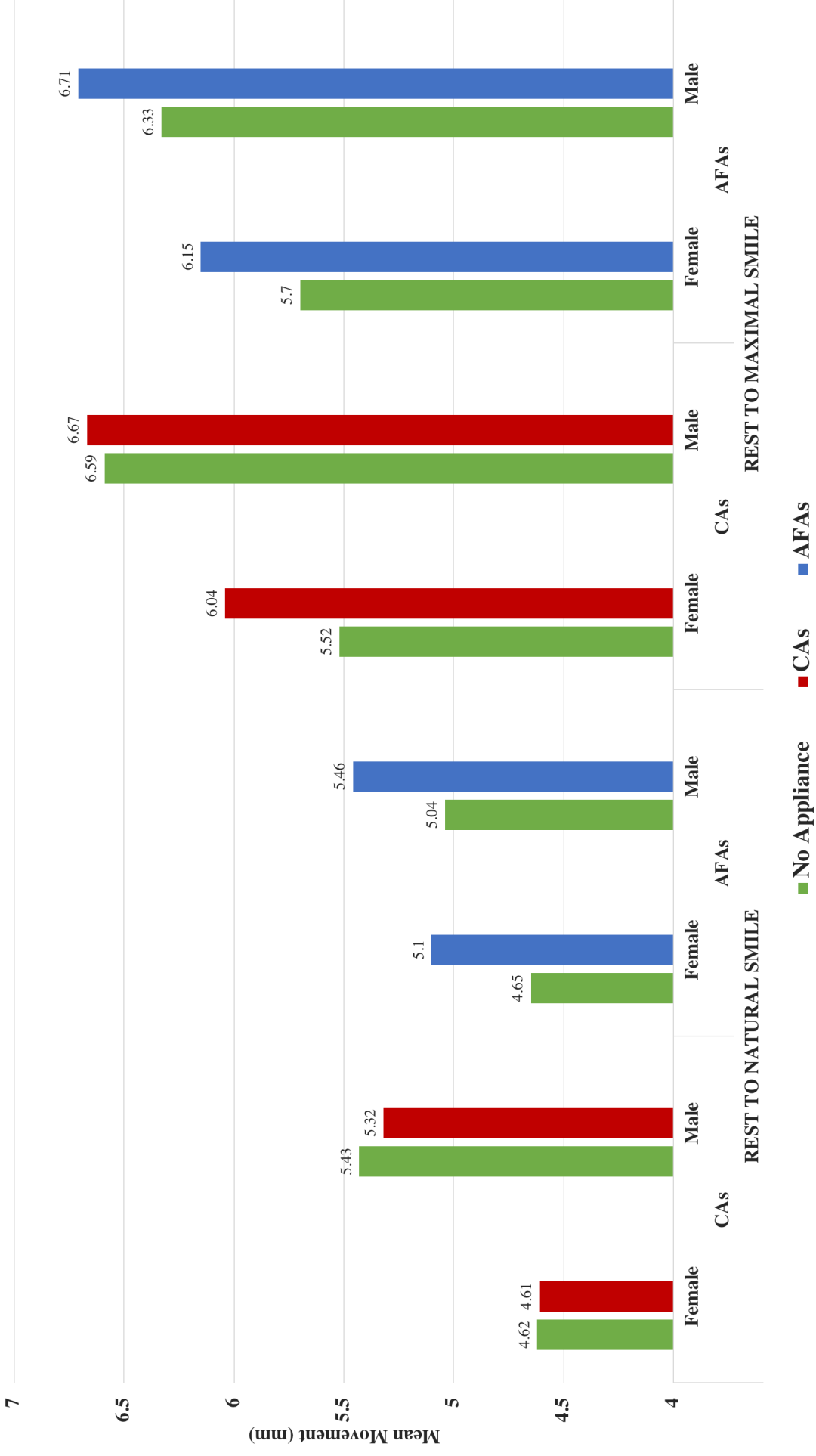
(B)

MALES		CAPTURE					
		REST TO NATURAL SMILE			REST TO MAXIMAL SMILE		
APPLIANCE	CAPTURE	n	MEAN	SD	n	MEAN	SD
Without CAs	A	20	5.54	1.32	20	6.61	1.13
	B	20	5.32	1.43	20	6.56	1.27
	Total	40	5.43	1.37	40	6.59	1.19
Without AFAs	A	20	5.09	1.45	20	6.42	1.56
	B	20	5.00	1.49	20	6.24	1.47
	Total	40	5.04	1.45	40	6.33	1.50
CAs	A	20	5.35	1.35	20	6.49	1.44
	B	20	5.30	1.44	20	6.85	1.20
	Total	40	5.32	1.38	40	6.67	1.32
AFAs	A	20	5.29	1.66	20	6.77	1.58
	B	20	5.62	1.48	20	6.66	1.91
	Total	40	5.46	1.56	40	6.71	1.73
Total	A	80	5.32	1.43	80	6.57	1.42
	B	80	5.31	1.45	80	6.58	1.48
	Total	160	5.31	1.44	160	6.58	1.44

Table 5.4: Formal statistical analysis of mean magnitude of movements of smile by capture, gender and appliance

EFFECT	NUM DF	DEN DF	F VALUE	P VALUE
Appliance	3	37	7.82	0.0004
Capture (A/B)	1	37	0.86	0.3601
Expression	1	37	97.12	< 0.0001
Gender	1	37	7.18	0.0109
Sequence	1	37	2.96	0.0939
Appliance* Capture	3	37	3.36	0.0290
Appliance* Expression	3	37	5.96	0.0020
Appliance*Gender	3	37	2.67	0.0620

Figure 5.5: Mean magnitude of movements across all landmarks separated by (a) females, (b) males for each expression with CAs and AFAs



5.5 REPRODUCIBILITY OF SMILE MAGNITUDE

The following can be concluded regarding the effect the appliances had on the reproducibility of magnitude of each smile.

Intra-session reproducibility without appliances

There was no significant difference in intra-session reproducibility of the magnitude of rest to natural and rest to maximal smile without CAs or AFAs ($p = 0.3601$) (**Table 5.4**).

This is reflected in the mean magnitude of movement without CAs of the rest to natural smile for Capture A (first set of images taken in each session) of 5.05 ± 1.30 mm, and 4.99 ± 1.32 mm for Capture B (second set of images taken in each session) (**Table 5.2**). Similarly, the mean magnitude of movement without AFAs was 6.03 ± 1.43 mm for Capture A and 6.05 ± 1.33 mm for Capture B when performing the rest to maximal smile (**Table 5.2**).

Intra-session reproducibility with appliances

There was a significant difference in the reproducibility of smile magnitude between Capture A and Capture B for the two appliance types ($p = 0.0290$).

The mean magnitude of movement with CAs for rest to maximal smile at Capture A and Capture B was 6.21 ± 1.32 mm and 6.50 ± 1.21 mm respectively (**Table 5.2**). With AFAs the mean magnitude of movement from rest to natural smile for Capture A was 5.17 ± 1.35 mm and 5.39 ± 1.31 mm for Capture B; additionally, the mean magnitude for rest to maximal smile for Capture A was 6.48 ± 1.51 mm and 6.39 ± 1.73 mm for Capture B (**Table 5.2**).

With regards to Capture A, the reproducibility of the mean magnitude of each smile did not differ significantly with (4.99 ± 1.25 mm) and without CAs (5.05 ± 1.30 mm) ($p = 0.3984$) for rest to natural smile, but did with (5.17 ± 1.35 mm) and without AFAs (4.92 ± 1.20 mm) ($p = 0.0104$), the mean smile magnitude being greater with the latter (**Table 5.1** and **Table 5.2**).

With regards to Capture B, the reproducibility of the mean magnitude of each smile differed significantly with (6.50 ± 1.21 mm) and without (6.05 ± 1.33 mm) CAs for rest to maximal smile ($p = 0.0090$) and with (6.39 ± 1.73 mm) and

without AFAs (6.00 ± 1.30 mm) ($p < 0.0001$), with mean smile magnitude being greater for both CAs and AFAs (**Table 5.1** and **Table 5.2**).

5.6 ANALYSIS OF LOWER FACIAL LANDMARKS

Whilst the focus of this analysis relates to movements averaged over all 26 facial landmarks, movement over the 10 lower-face landmarks is considered briefly (Table 5.5).

The appliance type the subject wore and the subject's gender ($p = 0.0346$) had a statistically significant effect on the mean magnitude of movement of both smiles. The appliance type and the capture session did not have a statistically significant effect on the mean magnitude of movement of rest to natural and rest to maximal smile.

These findings contrast with the findings of the overall analysis of the 26 landmarks.

Table 5.5: Formal statistical analysis of mean magnitude of movements for 10 lower landmarks and all landmarks

EFFECT	10 LOWER LANDMARKS			
	NUM DF	DEN DF	F VALUE	P VALUE
Appliance	3	37	4.29	0.0108
Capture (A/B)	1	37	0.13	0.7238
Expression	1	37	69.33	< 0.0001
Gender	1	37	9.18	0.0044
Sequence	1	37	1.09	0.3042
Appl*Capture	3	37	1.12	0.3524
Appl*Expression	3	37	5.70	0.0026
Appl*Gender	3	37	3.19	0.0346

5.7 QUESTIONNAIRE SURVEY

A questionnaire survey was conducted to evaluate, in young adults, the immediate perception of CAs and AFAs. Thirty-three subjects completed the questionnaire, 16 females (mean age 20.86 ± 1.63 years) and 17 males (mean age 20.94 ± 1.39 years). The results for each question are shown graphically below (**Figure 5.6** to **Figure 5.14** inclusive).

The survey showed 76 percent of subjects preferred CAs (**Figure 5.6**). All subjects indicated the appearance of the CAs as being good or very good, while only 60 percent of subjects reported likewise about the AFAs (**Figure 5.7**). Eighty-two percent reported the CAs were 'Comfortable' or 'Very Comfortable' to wear and only 48 percent denoted the same about the AFAs; this increased to 88 percent and 55 percent respectively when the subject was smiling (**Figure 5.8**).

The CAs were perceived to have very little impact on bite, lips, cheek and tongue as well as minimal impact on study, working or social environment (**Figure 5.9** and **Figure 5.10** respectively). Seventy-six percent of subjects advised they were 'Likely' or 'Very Likely' to wear CAs if undergoing orthodontic treatment and this compared to just 39 percent for AFAs (**Figure 5.11**). Only 27 percent of subjects intimated they would be willing to wear the CAs for more than 12 months and this compared to just 17 percent for AFAs (**Figure 5.12**).

Forty-eight percent of subjects were 'Likely' and a further 42 percent were 'Very Likely' to recommend CAs to a friend but only 18 percent and 36 percent respectively reported likewise with AFAs (**Figure 5.13**). The perceived reasons for recommending CAs included discretion and comfort while the perceived benefits of AFAs included 'shorter treatment time', 'easier to comply with' and 'less hassle' (**Figure 5.14**).

Figure 5.6: Preference for each appliance type (%)

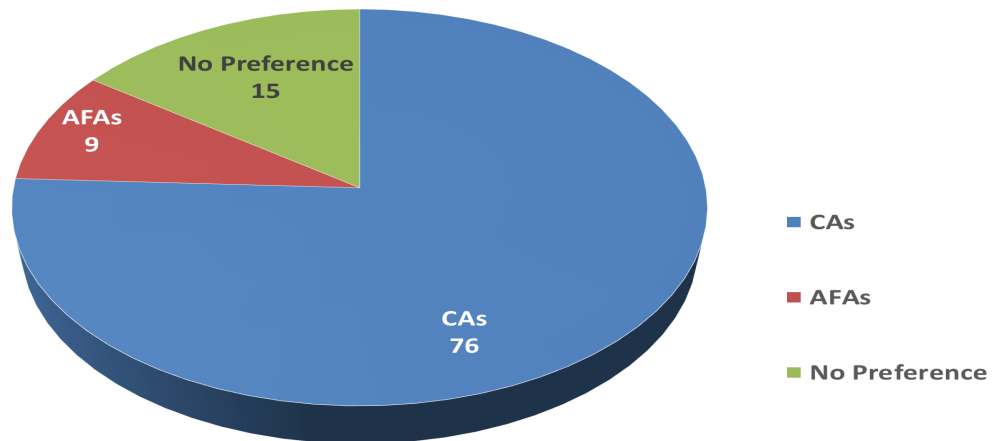


Figure 5.7: Subjects' perceptions of appearance of appliances (%)

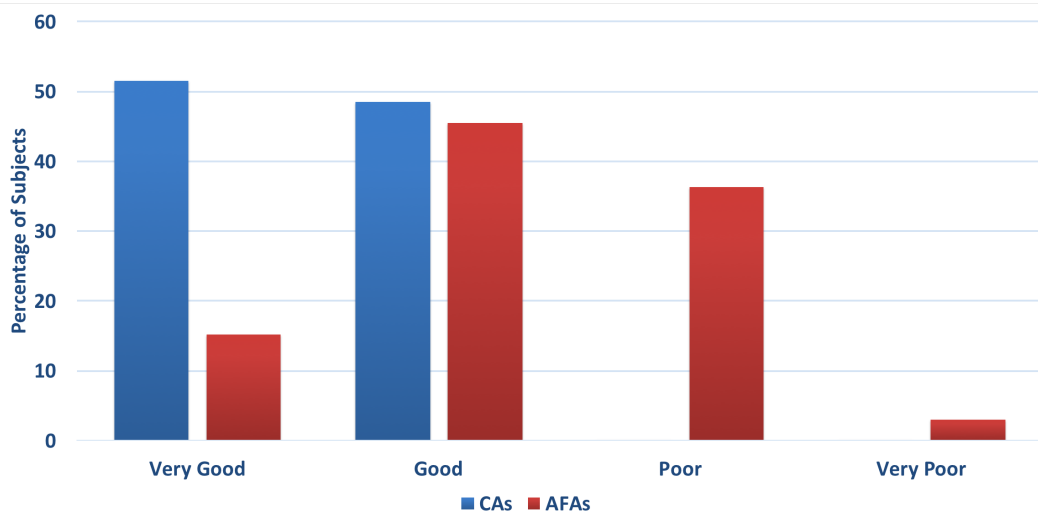


Figure 5.8: Subjects' perceptions of how comfortable each appliance was when wearing and smiling (%)

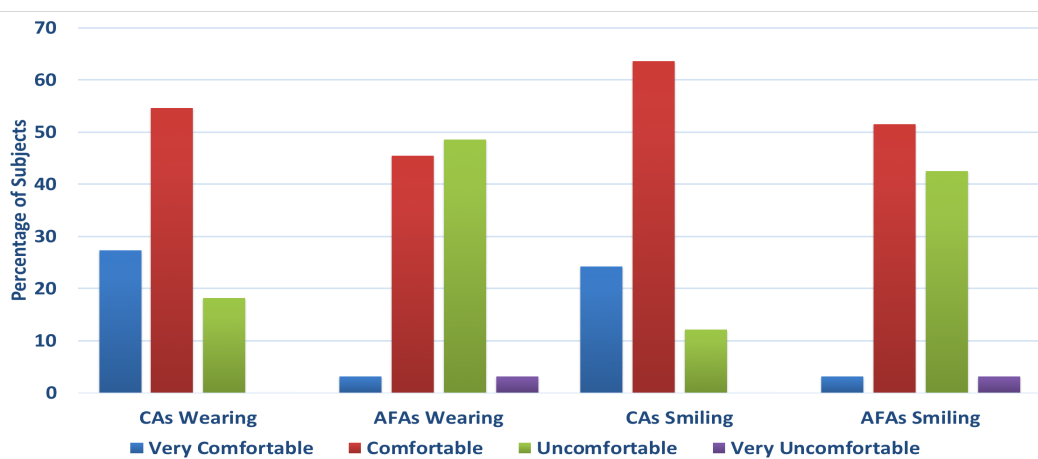


Figure 5.9: Subjects' perceptions of how their bite, lips, cheeks and tongue were affected by each appliance (%)

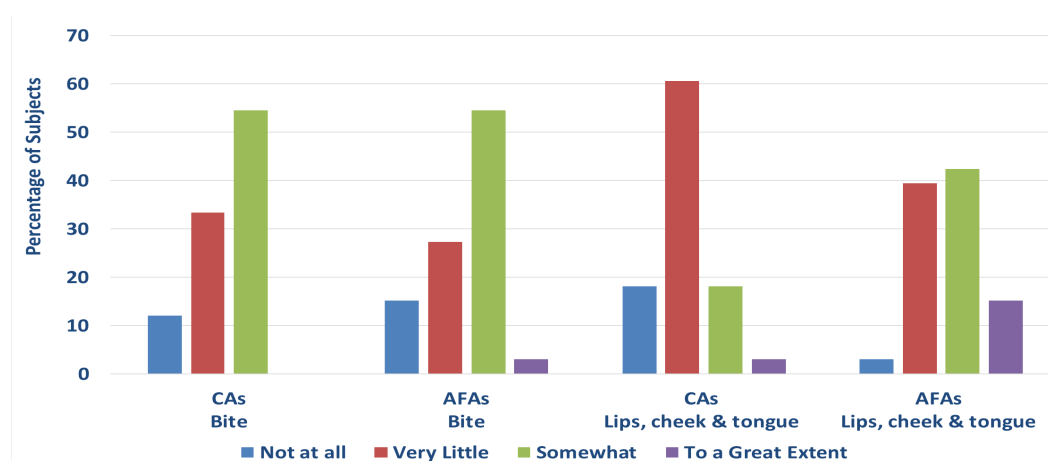


Figure 5.10: Subjects' perceptions of how each appliance would affect them when studying/working and in social life (%)

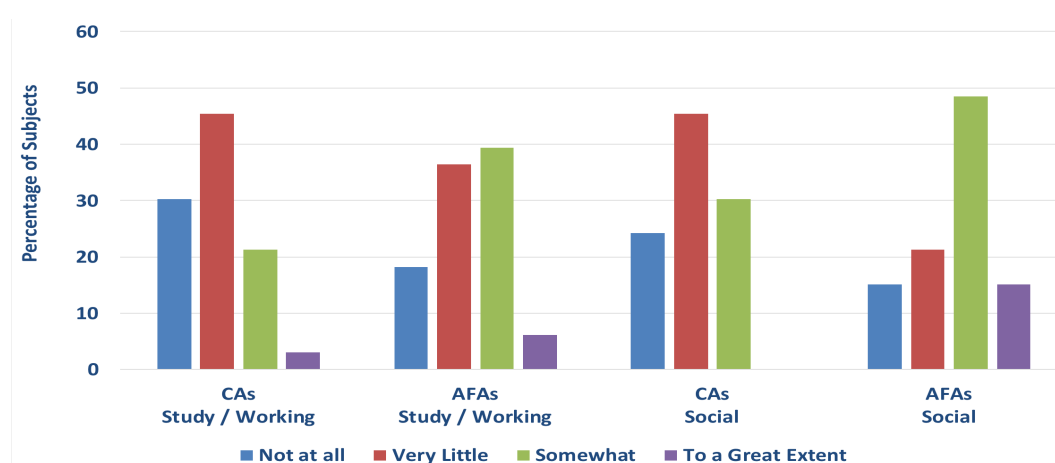


Figure 5.11: Likelihood of subjects accepting orthodontic treatment (%)

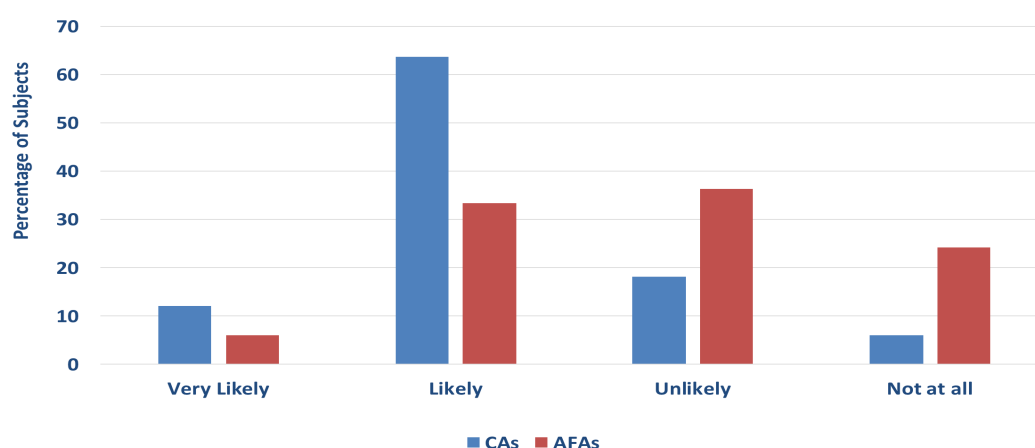


Figure: 5.12: Length of time subjects would be prepared to wear each appliance (%)

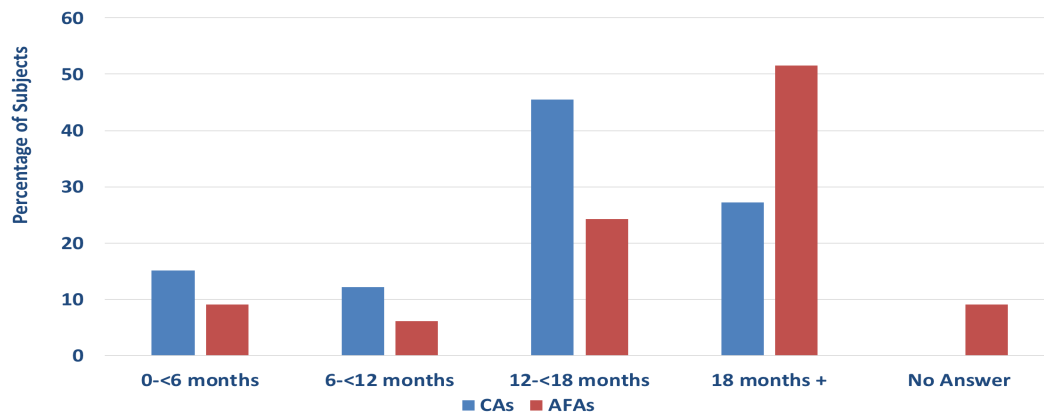


Figure 5.13: Likelihood of subject recommending orthodontic treatment to a friend (%)

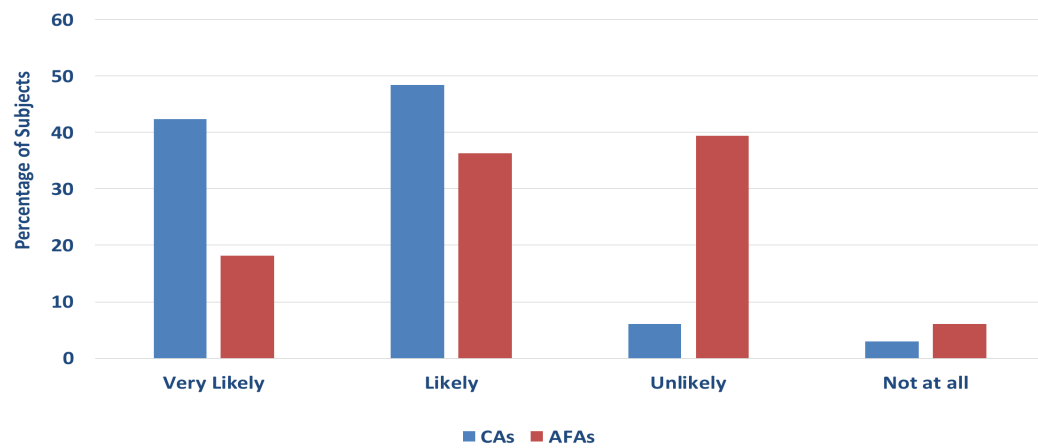
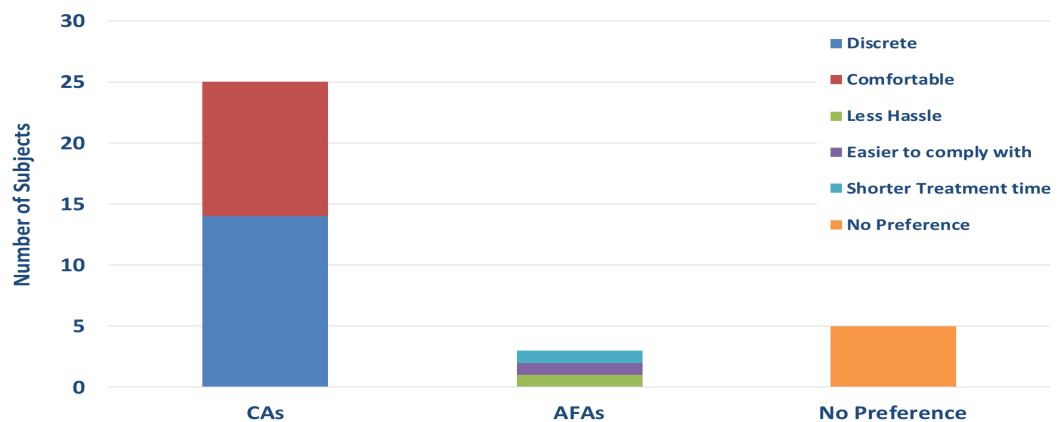


Figure 5.14: Reasons given for preferences for preferred appliances



CHAPTER SIX

DISCUSSION

6. DISCUSSION

This would appear to be the first study to report in young adults the immediate effects of CAs and AFAs on the magnitude of rest to natural and rest to maximal smile. This study is also the first to report in young adults the immediate effects of CAs and AFAs on the intra-session reproducibility of these expressions and the immediate perception of young adults of both appliances. This chapter will discuss the study design and its findings in more detail.

6.1 STUDY DESIGN

This was a prospective clinical cohort study assessing the effects of CAs and AFAs on linear soft tissue changes. The method of evaluation was by 3D imaging, using a DI3D stereophotogrammetry system, which has been shown to be a valid, reproducible and accurate method to assess facial expressions (Johnston et al., 2003). Previous prospective 3D cohort studies, similar to this study design, were undertaken by Johnston et al. (2003), Campbell et al. (2012), Darby et al. (2015) and Salloum et al. (2017). They differed, however, from this study in the following aspects: Johnston et al. (2003) evaluated the reproducibility of facial expressions only; Campbell et al. (2012) assessed the effect of overjet on the magnitude and reproducibility of smiling in an older female group, mean age 30.1 years; Darby et al. (2015) evaluated the effect of smiling on facial asymmetry in a similar age cohort to the present study; and Salloum et al. (2017) assessed both volumetric and soft tissue profile changes of a twin-block appliance in a younger age group, mean age 13.4 years.

Previous prospective 3D and 2D cohort studies, which assessed soft tissue change from orthodontic fixed appliances, were undertaken by Eidson et al. (2012) and Abed et al. (2009) respectively. This study differed from the former study as Eidson et al. (2012) utilised only 6 lower face landmarks only to assess lip position. In the latter study, the authors carried out an assessment of changes in lip posture was undertaken using 2D profile cephalometric landmarks of the upper and lower face. In the current study, all subjects were evaluated in 3D using 26 facial landmarks spanning the upper and lower face.

6.2 SAMPLE SIZE AND CHARACTERISTICS

A sample size of 30 subjects with 15 males and 15 females per group was previously determined to have a power of 80 percent to detect differences of 0.5 mm between similar expressions (Johnston et al., 2003). In the present study, 20 subjects per gender group were recruited to allow for potential attrition. This sample size is comparable to studies in which 3D stereophotogrammetry was used to assess soft facial expressions in adults (Campbell et al., 2011; Darby et al., 2015).

A p value < 0.05 was used to detect a change of 1 mm in any landmark position, similar to the studies by Johnston et al. (2003), Gwilliam et al. (2006) and Titiz et al. (2012). The selection criteria used in this study allowed standardisation of the groups. The limitations of previous studies in terms of age range (Popat et al., 2008), malocclusion type (Johnston et al., 2003), gender (Holberg et al., 2006) and ethnicity (Yang et al., 2008; Krishnan et al., 2008) were addressed. Some previous studies have also failed to disclose the orthodontic treatment status of the subjects included (Hontanilla and Auba, 2008; Gruebler and Suzuki, 2010), while this study only included subjects who had not previously received orthodontic treatment.

Equal numbers of male and female subjects were recruited. The male and female groups were of similar age. The average age of the males was 20.8 ± 1.54 years, while that of the females was 21.15 ± 1.35 years. These characteristics of the sample minimise the effect of bias on the results. Samples of similar gender balance and age were recruited by Johnston et al. (2003) and Darby et al. (2015) with 15 males and 15 females (age range of 20 to 30 years) for the former, and 20 males and 20 females (age range of 18 to 30 years) for the latter. In contrast, the sample evaluated by Campbell et al. (2012) included females only, although the age group was slightly older than in the present study (mean age of 30.1 ± 6.4 years).

All of the subjects in the present study had a Class I occlusion and were of Caucasian origin which is comparable to the studies by Johnston et al. (2003) and Darby et al. (2015) and similar to the control group in the study by Campbell et al. (2012).

6.3 FACIAL EXPRESSIONS AND CUES

To address some of the limitations of previous studies, which failed to detail the cues used to elicit the facial expressions (Trotman et al., 1998b; Sawyer et al., 2010), the current study used standardised prompts. The same prompts were used in some previous studies (Johnston et al., 2003; Campbell et al., 2011; Darby et al., 2015), which allows inter-study comparison.

6.4 LANDMARK IDENTIFICATION ERROR

The mean intra-observer landmark identification error was 0.50 ± 0.08 mm, which compared favourably with similar 3D stereophotogrammetry studies: 0.49 mm (Johnston et al., 2003); 0.79 mm (Ayoub et al., 2003); 0.57 mm (Campbell et al., 2011); and 0.41 mm (Darby et al., 2015). It is also below the threshold level of 2 mm formerly proposed as acceptable in terms of reproducibility by Weinberg et al. (2004). Hajeer et al., (2004) reported that a landmark can be considered highly reproducible if the landmark identification error is below 0.5 mm.

6.5 IMMEDIATE EFFECT OF CAs AND AFAs ON REST TO NATURAL AND REST TO MAXIMAL SMILE

The assessment of changes in the magnitude of the smile when CAs or AFAs are worn has not been reported previously in the orthodontic literature. Changes in lip posture (Abed et al., 2009) and lip position (Eidson et al., 2012) following debonding of buccal fixed appliances have been assessed.

The findings in this study show that when CAs were in situ, there was an effect on the mean magnitude of movement of facial landmarks from rest to maximal smile only ($p = 0.0001$). With AFAs, there was an effect on the magnitude for both smiles, rest to natural and rest to maximal smile ($p = 0.0024$ and $p = 0.0002$ respectively). In contrast, previous studies (Abed et al., 2009; Eidson et al. 2012) have reported no significant changes in lip posture and lip position with the presence of buccal fixed appliances. Abed et al., (2009) in a cephalometric study, comparing pre- and post debond lip soft tissue movement, reported changes of 0.38 mm and 0.07 mm for movement of the upper and lower vermillion border respectively; this was further validated by non-significant findings for the same points with their photographic analysis. Edison et al., (2012) showed that from before to after appliance removal, all landmarks moved in a posterior direction but to a clinically insignificant amount (set at 1.5 mm). The current study differs, as only the immediate effect of appliances on smile magnitude was assessed in a simulation scenario, showing a total mean magnitude of movement with AFAs from rest to maximal smile of approximately 0.41 mm.

Comparing CAs and AFAs, the current study found a difference in mean magnitude of movement between appliances, from rest to natural smile, of approximately 0.31 mm and from rest to maximal smile of 0.07 mm. These differences are so small as to infer that there would be no clinically significant difference in mean magnitude of movement for either smile with either appliance in young adults.

Greater mean magnitude of movement was, however, observed with AFAs. This may have been due to the added bulk with AFAs, thereby requiring larger facial

movements to reach the required smile than with CAs, which were of a smaller diameter.

With no appliance, mean magnitude of movement for both smiles was greater in males than females ($p = 0.0109$). This contrasts with the study by Darby et al., (2015) which did not find a statistically significant difference in the smile magnitude between genders ($p = 0.4238$).

With either appliance, the mean magnitude of movement for both smiles did not differ significantly between males and females ($p = 0.0620$). No inter-study comparisons can be made relating to gender differences, as gender was not specified in the North Carolina study by Eidson et al. (2012) and there was a gender imbalance in the 2D study by Abed et al. (2009).

6.6 IMMEDIATE EFFECT OF CAs AND AFAs ON THE REPRODUCIBILITY OF REST TO NATURAL AND REST TO MAXIMAL SMILE

The present study found that CAs and AFAs had a statistically significant effect on the intra-session reproducibility of the mean magnitude of movement of rest to natural and rest to maximal smile ($p = 0.0290$).

In contrast, Eidson et al. (2012) found the intra-session reproducibility of 3D images of the poses ‘lips sealed before’ and ‘repose before’ over 6 lower face landmarks to be highly reproducible. The study by Abed et al. (2009) also found the mean intra-session reproducibility of their 2D profile photographs to be statistically insignificant. Both these studies, however, considered only the reproducibility of a static expression whereas the current study evaluated movement from rest position to natural and maximal smile.

6.7 IMMEDIATE PERCEPTION IN YOUNG ADULTS OF CAs AND AFAs

Few previous studies which assessed the perception of orthodontic appliances have specifically used subjects that have worn the appliance (Fritz et al., 2002; Pacheco-Pereira et al., 2018). Furthermore, some studies evaluated individual appliances only; Fritz et al. (2002) examined lingual appliances and Pacheco-Pereira et al. (2018) included only those with Invisalign®. In the current study, both CAs and AFAs were evaluated after the appliances were worn. Two studies concerned with the perception of orthodontic appliances used questionnaire surveys based on a photograph of a subject wearing different appliances (Ziuchkovski et al., 2008; Feu et al., 2012) and the remainder used digitally altered photographs to depict the different appliance types (Walton et al., 2010; Jeremiah et al., 2010; Fonseca et al., 2014). In the present study, 76 percent of subjects preferred CAs. This finding is consistent with studies by Ziuchkovski et al. (2008), Feu et al. (2012) and Jeremiah et al. (2010).

One study investigated patient comfort related to Invisalign® and showed an overall satisfaction rate of 70 percent (Pacheco-Pereira et al., 2018). A further study by

Shalish et al. (2012), found levels of oral symptoms were significantly lower with Invisalign® compared to buccal fixed appliances. The current study found that 82 percent of respondents indicated that CAs were comfortable or very comfortable and only 48 percent denoted the same about AFAs. No other study has assessed patient perception of comfort relating to AFAs after fitting. While patient perception of comfort with non-aesthetic buccal fixed appliances has been evaluated (Scott et al., 2010, Shalish et al., 2012), no study has evaluated perception of comfort with AFAs.

No previous study has reported on the perceived reasons for recommending orthodontic appliances. In this study, 48 percent of subjects were ‘Likely’ and a further 42 percent were ‘Very Likely’ to recommend CAs to a friend, while only 18 percent and 36 percent respectively reported likewise with AFAs. This might imply that patients would have a greater willingness to have treatment with CAs than AFAs. This is corroborated by 76 percent of subjects who advised that they were ‘Likely’ or ‘Very Likely’ to wear CAs if undergoing orthodontic treatment compared to just 39 percent for AFAs.

6.8 STRENGTHS OF THE STUDY

- This study was a prospective 3D study that investigated several new aspects in relation to CAs and AFAs
- The study used in-vivo representation of CAs and AFAs, fabricated to standardised design, allowing accurate assessments of patient perception regarding the appliances
- Male and female groups were of the same ethnicity, well matched for age, as well as standardised in terms of occlusal relationship and no previous orthodontic treatment.
- Images were taken by a single trained 3D Imaging Assistant, ensuring standardisation of image capture, in a dedicated 3D imaging room with the equipment calibrated daily and shown previously to be accurate and reproducible
- Defined facial expressions were assessed with standardised cues and time between sessions also standardised with CAs and AFAs allocated in a random order
- The results could potentially be used for informed consent and treatment planning in orthodontic management of adults requiring treatment with CAs or AFAs

6.9 SHORTCOMINGS OF THE STUDY

- Selection criteria were based on the BSI classification of incisor relationship, overjet and overbite measurements. No consideration was given to the underlying skeletal relationship of the volunteers
- The immediate effects of CAs and AFAs were assessed. There is potential that patient perception of the appliance would differ if the appliances were worn for a longer period of time
- The CAs used in this study did not contain attachments; these are widely used in Invisalign® appliances today

6.10 SUGGESTIONS FOR FUTURE WORK

This study investigated the immediate effects of CAs and AFAs on smiling and perceptions in young adults. The findings presented here could be used for comparative purposes for future longer-term studies on the effect of these or other aesthetic orthodontic appliances on facial expressions and patient perceptions.

CHAPTER SEVEN

CONCLUSIONS

7. CONCLUSIONS

AIM 1:

To evaluate, in young adults, the immediate effect of clear aligners (CAs) and aesthetic fixed appliances (AFAs) on the magnitude of rest to natural and rest to maximal smile.

CONCLUSION:

Except for rest to natural smile with CAs, both appliances had an immediate and significant impact on the mean magnitude of movement for both expressions.

AIM 2:

To evaluate, in young adults, the immediate effect of CAs and AFAs on the intra-session reproducibility of rest to natural and rest to maximal smile.

CONCLUSION:

CAs and AFAs had a significant immediate effect on intra-session reproducibility of rest to natural and rest to maximal smile.

AIM 3:

To evaluate, in young adults, the immediate perception for CAs and AFAs.

CONCLUSION:

Young adults' immediate perception was preference for CAs as they were reckoned to be more discrete and comfortable.

NULL HYPOTHESES

NULL HYPOTHESIS 1:

There is no difference in young adults between the immediate effect of CAs and AFAs on the magnitude of rest to natural and rest to maximal smile.

This null hypothesis is rejected.

NULL HYPOTHESIS 2:

There is no difference in young adults between the immediate effect of CAs and AFAs on the intra-session reproducibility of rest to natural and rest to maximal smile.

This null hypothesis is rejected.

NULL HYPOTHESIS 3:

There is no difference in young adults between the immediate perception of CAs and AFAs.

This null hypothesis is rejected.

CHAPTER EIGHT

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8 BIBLIOGRAPHY

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CHAPTER NINE

APPENDICES

APPENDIX 1 – CONSENT

CONSENT FORM: Clinical Research Ethics Committee Of The Cork Teaching Hospitals

CONSENT BY SUBJECT FOR PARTICIPATION IN RESEARCH PROTOCOL

Section A

Protocol Number: _____

Patient Name: _____

Title of Protocol: The immediate effects of simulation with Invisalign and fixed appliances on facial expressions in adults.

Doctor(s) Directing Research: (Prof D Millett)

Phone: (021 4901139)

You are being asked to participate in a research study. The doctors at University College Cork study the nature of disease and attempt to develop improved methods of diagnosis and treatment. In order to decide whether or not you want to be a part of this research study, you should understand enough about its risks and benefits to make an informed judgment. This process is known as informed consent. This consent form gives detailed information about the research study, which will be discussed with you. Once you understand the study, you will be asked to sign this form if you wish to participate.

Section B

I. NATURE AND DURATION OF PROCEDURE(S):

We want to see if there is a difference in your smile when wearing two different types of braces. At the first visit we will take a scan of your teeth and take 3D pictures without any brace. Four weeks later we will take these photos again without any brace in and with one of the braces. Four weeks later again we will take these photos without any brace in and with the other brace. Each time we take these pictures, we will take them again 15 minutes later.

II. POTENTIAL RISKS AND BENEFITS:

There are no risks associated with having your 3D pictures taken. The information we collect during the study will help us understand how good you are at repeating the same smile with different braces. This will allow us to better plan orthodontic treatment in the future.

III. POSSIBLE ALTERNATIVES:

It is your choice to take part in this study or not. You can withdraw at any time without giving a reason.

Section C

AGREEMENT TO CONSENT

The research project and the treatment procedures associated with it have been fully explained to me. All experimental procedures have been identified and no guarantee has been given about the possible results. I have had the opportunity to ask questions concerning any and all aspects of the project and any procedures involved. I am aware that participation is voluntary and that I may withdraw my consent at any time. I am aware that my decision not to participate or to withdraw will not restrict my access to health care services normally available to me. Confidentiality of records concerning my involvement in this project will be maintained in an appropriate manner. When required by law, the records of this research may be reviewed by government agencies and sponsors of the research.

I understand that the sponsors and investigators have such insurance as is required by law in the event of injury resulting from this research.

I, the undersigned, hereby consent to participate as a subject in the above described project conducted at the Cork Teaching Hospitals. I have received a copy of this consent form for my records. I understand that if I have any questions concerning this research, I can contact the doctor(s) listed above. If I have further queries concerning my rights in connection with the research, I can contact the Clinical Research Ethics Committee of the Cork Teaching Hospitals, Lancaster Hall, 6 Little Hanover Street, Cork.

After reading the entire consent form, if you have no further questions about giving consent, please sign where indicated.

Doctor: _____

Guardian
minor, if applicable)

Witness: _____
_____AM (Circle) PM

Signature of Subject, Parent or
(include a separate line for assent of

Date: _____ Time: _____

APPENDIX 2 – POST STUDY QUESTIONNAIRE

Survey of perception of Invisalign versus Fixed Appliances

* 1. How would you rate the appearance of each type of brace?

	Very Good	Good	Poor	Very Poor
Clear Braces	☐	☐	☐	☐
Fixed Braces	☐	☐	☐	☐

* 2. How comfortable did you find each type of brace to wear?

	Very Comfortable	Comfortable	Uncomfortable	Very Uncomfortable
Clear Braces	☐	☐	☐	☐
Fixed Braces	☐	☐	☐	☐

* 3. How comfortable did you find each type of brace for smiling?

	Very Comfortable	Comfortable	Uncomfortable	Very Uncomfortable
Clear Braces	☐	☐	☐	☐
Fixed Braces	☐	☐	☐	☐

* 4. How much was your bite affected by each type of brace?

	Not at all	Very Little	Somewhat	To a Great Extent
Clear Braces	☐	☐	☐	☐
Fixed Braces	☐	☐	☐	☐

* 5. How much were your lips, cheek and tongue affected by each type of brace?

	Not at all	Very Little	Somewhat	To a Great Extent
Clear Braces	☐	☐	☐	☐
Fixed Braces	☐	☐	☐	☐

* 6. How much do you think your study/working life would be affected by each type of brace?

	Not at all	Very Little	Somewhat	To a Great Extent
Clear Braces	☐	☐	☐	☐
Fixed Braces	☐	☐	☐	☐

* 7. How much do you think your social life would be affected by each type of brace?

	Not at all	Very Little	Somewhat	To a Great Extent
Clear Braces	☐	☐	☐	☐
Fixed Braces	☐	☐	☐	☐

* 8. How likely do you think you would be to have orthodontic treatment with either type of brace?

	Very Likely	Likely	Unlikely	Not at all
Clear Braces	☐	☐	☐	☐
Fixed Braces	☐	☐	☐	☐

* 9. If you are Very Likely or Likely to have treatment, how long would you be prepared to wear each type of brace?

	0-<6 months	6-<12 months	12-<18 months	18 months +
Clear Braces	☐	☐	☐	☐
Fixed Braces	☐	☐	☐	☐

* 10. How likely are you to recommend treatment with either type of brace to a friend?

	Very Likely	Likely	Unlikely	Not at all
Clear Braces	☐	☐	☐	☐
Fixed Braces	☐	☐	☐	☐

* 11. Overall, which type of brace did you prefer?

- ☐ Clear Braces
- ☐ Fixed Braces
- ☐ No Preference

* 12. Please give a reason for your response to Q11.

Survey of perception of Invisalign versus Fixed Appliances

* 13. Which type of brace did you wear first?

- ☐ Clear Braces
- ☐ Fixed Braces

* 14. Do you know of anyone who is currently wearing CLEAR BRACES?

- ☐ Yes
- ☐ No

15. If Yes to Q14, please indicate the age range and gender of people you know. Select as many as required

	10-14 years	15-19 years	20-24 years	25-29 years	30+ years
Male	☐	☐	☐	☐	☐
Female	☐	☐	☐	☐	☐

* 16. Do you know of anyone who is currently wearing FIXED BRACES?

- ☐ Yes
- ☐ No

17. If Yes to Q16, please indicate the age range and gender of people you know. Select as many as required

	10-14 years	15-19 years	20-24 years	25-29 years	30+ years
Male	☐	☐	☐	☐	☐
Female	☐	☐	☐	☐	☐

* 18. Please indicate your gender.

- ☐ Male
- ☐ Female

* 19. Please indicate your age

* 20. Please enter your initials

APPENDIX 3 – RESULTS OF THE ORIENTATION MARKER SELECTION REPEATABILITY STUDY

PILOT 1 - 3Shape Model - Brackets on FA Point

1.7	1.6	1.5	1.4	1.3	1.2	1.1	2.1	2.2	2.3	2.4	2.5	2.6	2.7
4.7	4.6	4.5	4.4	4.3	4.2	4.1	3.1	3.2	3.3	3.4	3.5	3.6	3.7

Tooth Number	Trial No.	X (mm)	Y (mm)	Z (mm)	Δ X (mm)	Δ Y (mm)	Δ Z (mm)
1.7	1	-31.73	-2.87	-12.76	0.00	0.05	0.00
	2	-31.73	-2.83	-12.76	0.00	0.01	0.00
	3	-31.74	-2.88	-12.79	0.01	0.06	0.03
	4	-31.72	-2.84	-12.74	0.01	0.02	0.02
	5	-31.73	-2.83	-12.76	0.00	0.01	0.00
	6	-31.74	-2.86	-12.78	0.01	0.04	0.02
	7	-31.74	-2.84	-12.78	0.01	0.02	0.02
	8	-31.72	-2.87	-12.75	0.01	0.05	0.01
	9	-31.74	-2.84	-12.78	0.01	0.02	0.02
	10	-31.74	-2.87	-12.79	0.01	0.05	0.03
Actual		-31.728	-2.820	-12.756	0.008	0.033	0.017

Tooth Number	Trial No.	X (mm)	Y (mm)	Z (mm)	Δ X (mm)	Δ Y (mm)	Δ Z (mm)
1.6	1	-27.07	-3.35	-2.67	0.01	0.01	0.01
	2	-27.07	-3.34	-2.67	0.01	0.00	0.01
	3	-27.08	-3.36	-2.68	0.02	0.02	0.02
	4	-27.08	-3.35	-2.68	0.02	0.01	0.02
	5	-27.08	-3.34	-2.68	0.02	0.00	0.02
	6	-27.08	-3.35	-2.68	0.02	0.01	0.02
	7	-27.07	-3.36	-2.67	0.01	0.02	0.01
	8	-27.08	-3.34	-2.68	0.02	0.00	0.02
	9	-27.08	-3.35	-2.69	0.02	0.01	0.03
	10	-27.08	-3.34	-2.68	0.02	0.00	0.02
Actual		-27.063	-3.339	-2.655	0.014	0.009	0.023

Tooth Number	Trial No.	X (mm)	Y (mm)	Z (mm)	Δ X (mm)	Δ Y (mm)	Δ Z (mm)
1.5	1	-23.44	-1.50	5.19	0.00	0.01	0.01
	2	-23.44	-1.50	5.19	0.00	0.01	0.01
	3	-23.44	-1.50	5.19	0.00	0.01	0.01
	4	-23.44	-1.50	5.20	0.00	0.01	0.00
	5	-23.44	-1.50	5.20	0.00	0.01	0.00
	6	-23.44	-1.51	5.20	0.00	0.02	0.00
	7	-23.44	-1.50	5.20	0.00	0.01	0.00
	8	-23.44	-1.51	5.19	0.00	0.02	0.01
	9	-23.44	-1.50	5.19	0.00	0.01	0.01
	10	-23.44	-1.51	5.20	0.00	0.02	0.00
Actual		-23.443	-1.493	5.195	0.003	0.010	0.005

Tooth Number	Trial No.	X (mm)	Y (mm)	Z (mm)	Δ X (mm)	Δ Y (mm)	Δ Z (mm)
1.4	1	-21.4	-0.27	11.32	0.01	0.01	0.00
	2	-21.4	-0.27	11.32	0.01	0.01	0.00
	3	-21.41	-0.27	11.31	0.00	0.01	0.01
	4	-21.41	-0.27	11.31	0.00	0.01	0.01
	5	-21.41	-0.28	11.31	0.00	0.00	0.01
	6	-21.4	-0.28	11.33	0.01	0.00	0.01
	7	-21.4	-0.27	11.32	0.01	0.01	0.00
	8	-21.41	-0.28	11.32	0.00	0.00	0.00
	9	-21.41	-0.28	11.31	0.00	0.00	0.01
	10	-21.41	-0.27	11.31	0.00	0.01	0.01
Actual		-21.408	-0.279	11.317	0.004	0.006	0.006

Tooth Number	Trial No.	X (mm)	Y (mm)	Z (mm)	Δ X (mm)	Δ Y (mm)	Δ Z (mm)
1.3	1	-18.7	1.43	16.8	0.01	0.02	0.02
	2	-18.71	1.46	16.79	0.02	0.01	0.03
	3	-18.71	1.45	16.78	0.02	0.00	0.04
	4	-18.7	1.49	16.79	0.01	0.04	0.03
	5	-18.71	1.44	16.79	0.02	0.01	0.03
	6	-18.71	1.49	16.78	0.02	0.04	0.04
	7	-18.7	1.5	16.8	0.01	0.05	0.02
	8	-18.7	1.46	16.8	0.01	0.01	0.02
	9	-18.7	1.44	16.81	0.01	0.01	0.01
	10	-18.7	1.49	16.8	0.01	0.04	0.02
Actual		-18.693	1.447	16.819	0.011	0.024	0.025

Tooth Number	Trial No.	X (mm)	Y (mm)	Z (mm)	Δ X (mm)	Δ Y (mm)	Δ Z (mm)
1.2	1	-11.37	0.43	23.06	0.01	0.00	0.01
	2	-11.37	0.44	23.05	0.01	0.01	0.02
	3	-11.37	0.43	23.06	0.01	0.00	0.01
	4	-11.37	0.44	23.05	0.01	0.01	0.02
	5	-11.38	0.44	23.05	0.02	0.01	0.02
	6	-11.37	0.44	23.06	0.01	0.01	0.01
	7	-11.37	0.45	23.05	0.01	0.02	0.02
	8	-11.37	0.45	23.05	0.01	0.02	0.02
	9	-11.38	0.45	23.05	0.02	0.02	0.02
	10	-11.38	0.45	23.04	0.02	0.02	0.03
Actual		-11.358	0.431	23.067	0.015	0.011	0.015

Tooth Number	Trial No.	X (mm)	Y (mm)	Z (mm)	Δ X (mm)	Δ Y (mm)	Δ Z (mm)
1.1	1	-3.45	-0.76	25.49	0.00	0.05	0.01
	2	-3.46	-0.74	25.49	0.01	0.07	0.01
	3	-3.46	-0.75	25.49	0.01	0.06	0.01
	4	-3.46	-0.76	25.49	0.01	0.05	0.01
	5	-3.46	-0.74	25.49	0.01	0.07	0.01
	6	-3.47	-0.76	25.49	0.02	0.05	0.01
	7	-3.45	-0.75	25.49	0.00	0.06	0.01
	8	-3.46	-0.74	25.49	0.01	0.07	0.01
	9	-3.46	-0.75	25.49	0.01	0.06	0.01
	10	-3.47	-0.76	25.49	0.02	0.05	0.01
Actual		-3.452	-0.812	25.495	0.009	0.061	0.005

Tooth Number	Trial No.	X (mm)	Y (mm)	Z (mm)	Δ X (mm)	Δ Y (mm)	Δ Z (mm)
2.1	1	7.39	0.3	24.68	0.00	0.01	0.00
	2	7.4	0.31	24.68	0.01	0.00	0.00
	3	7.39	0.31	24.68	0.00	0.00	0.00
	4	7.4	0.3	24.68	0.01	0.01	0.00
	5	7.39	0.29	24.68	0.00	0.02	0.00
	6	7.39	0.3	24.68	0.00	0.01	0.00
	7	7.4	0.3	24.68	0.01	0.01	0.00
	8	7.41	0.3	24.68	0.02	0.01	0.00
	9	7.4	0.29	24.68	0.01	0.02	0.00
	10	7.41	0.3	24.68	0.02	0.01	0.00
Actual		7.390	0.306	24.683	0.008	0.008	0.003

Tooth Number	Trial No.	X (mm)	Y (mm)	Z (mm)	Δ X (mm)	Δ Y (mm)	Δ Z (mm)
2.2	1	14.84	1.57	20.33	0.01	0.02	0.01
	2	14.85	1.56	20.33	0.00	0.01	0.01
	3	14.84	1.56	20.34	0.01	0.01	0.00
	4	14.84	1.57	20.34	0.01	0.02	0.00
	5	14.84	1.57	20.33	0.01	0.02	0.01
	6	14.85	1.56	20.33	0.00	0.01	0.01
	7	14.85	1.57	20.32	0.00	0.02	0.02
	8	14.85	1.57	20.32	0.00	0.02	0.02
	9	14.85	1.56	20.33	0.00	0.01	0.01
	10	14.86	1.56	20.32	0.01	0.01	0.02
Actual		14.847	1.549	20.339	0.006	0.016	0.010

Tooth Number	Trial No.	X (mm)	Y (mm)	Z (mm)	Δ X (mm)	Δ Y (mm)	Δ Z (mm)
2.3	1	20.11	3.86	14.97	0.00	0.01	0.00
	2	20.11	3.86	14.98	0.00	0.01	0.01
	3	20.11	3.86	14.99	0.00	0.01	0.02
	4	20.12	3.86	14.96	0.01	0.01	0.01
	5	20.11	3.87	14.97	0.00	0.00	0.00
	6	20.11	3.87	14.97	0.00	0.00	0.00
	7	20.12	3.85	14.98	0.01	0.02	0.01
	8	20.12	3.86	14.96	0.01	0.01	0.01
	9	20.12	3.87	14.95	0.01	0.00	0.02
	10	20.12	3.85	14.96	0.01	0.02	0.01
Actual		20.110	3.871	14.970	0.005	0.010	0.009

Tooth Number	Trial No.	X (mm)	Y (mm)	Z (mm)	Δ X (mm)	Δ Y (mm)	Δ Z (mm)
2.4	1	23.76	3.54	5.94	0.00	0.00	0.01
	2	23.76	3.54	5.94	0.00	0.00	0.01
	3	23.76	3.54	5.95	0.00	0.00	0.00
	4	23.76	3.54	5.95	0.00	0.00	0.00
	5	23.76	3.54	5.96	0.00	0.00	0.01
	6	23.76	3.53	5.95	0.00	0.01	0.00
	7	23.76	3.54	5.96	0.00	0.00	0.01
	8	23.76	3.53	5.94	0.00	0.01	0.01
	9	23.76	3.53	5.95	0.00	0.01	0.00
	10	23.77	3.53	5.94	0.01	0.01	0.01
Actual		23.758	3.542	5.949	0.003	0.006	0.006

Tooth Number	Trial No.	X (mm)	Y (mm)	Z (mm)	Δ X (mm)	Δ Y (mm)	Δ Z (mm)
2.5	1	24.58	1.51	-0.3	0.01	0.02	0.03
	2	24.58	1.52	-0.29	0.01	0.03	0.02
	3	24.58	1.52	-0.29	0.01	0.03	0.02
	4	24.58	1.51	-0.3	0.01	0.02	0.03
	5	24.58	1.51	-0.29	0.01	0.02	0.02
	6	24.58	1.52	-0.28	0.01	0.03	0.01
	7	24.58	1.50	-0.29	0.01	0.01	0.02
	8	24.58	1.51	-0.29	0.01	0.02	0.02
	9	24.58	1.51	-0.28	0.01	0.02	0.01
	10	24.58	1.52	-0.28	0.01	0.03	0.01
Actual		24.593	1.490	-0.266	0.013	0.023	0.023

Tooth Number	Trial No.	X (mm)	Y (mm)	Z (mm)	Δ X (mm)	Δ Y (mm)	Δ Z (mm)
2.6	1	26.72	1.30	-6.86	0.01	0.02	0.04
	2	26.71	1.30	-6.84	0.00	0.02	0.02
	3	26.71	1.30	-6.82	0.00	0.02	0.00
	4	26.72	1.28	-6.85	0.01	0.00	0.03
	5	26.71	1.28	-6.83	0.00	0.00	0.01
	6	26.71	1.29	-6.82	0.00	0.01	0.00
	7	26.72	1.26	-6.85	0.01	0.02	0.03
	8	26.72	1.29	-6.85	0.01	0.01	0.03
	9	26.72	1.27	-6.84	0.01	0.01	0.02
	10	26.71	1.29	-6.84	0.00	0.01	0.02
Actual	26.707	1.279	-6.810	0.008	0.012	0.022	

Tooth Number	Trial No.	X (mm)	Y (mm)	Z (mm)	Δ X (mm)	Δ Y (mm)	Δ Z (mm)
4.7	1	-29.92	-7.82	-14.60	0.01	0.02	0.02
	2	-29.92	-7.83	-14.61	0.01	0.03	0.01
	3	-29.93	-7.84	-14.62	0.02	0.04	0.00
	4	-29.93	-7.84	-14.60	0.02	0.04	0.02
	5	-29.92	-7.83	-14.61	0.01	0.03	0.01
	6	-29.92	-7.83	-14.59	0.01	0.03	0.03
	7	-29.93	-7.84	-14.60	0.02	0.04	0.02
	8	-29.92	-7.84	-14.58	0.01	0.04	0.04
	9	-29.93	-7.85	-14.60	0.02	0.05	0.02
	10	-29.93	-7.84	-14.61	0.02	0.04	0.01
Actual		-29.911	-7.796	-14.617	0.014	0.040	0.015

Tooth Number	Trial No.	X (mm)	Y (mm)	Z (mm)	Δ X (mm)	Δ Y (mm)	Δ Z (mm)
4.6	1	-26.07	-7.90	-5.81	0.00	0.01	0.02
	2	-26.07	-7.89	-5.81	0.00	0.00	0.02
	3	-26.07	-7.90	-5.82	0.00	0.01	0.01
	4	-26.07	-7.89	-5.82	0.00	0.00	0.01
	5	-26.07	-7.90	-5.8	0.00	0.01	0.03
	6	-26.07	-7.89	-5.82	0.00	0.00	0.01
	7	-26.07	-7.90	-5.83	0.00	0.01	0.00
	8	-26.07	-7.88	-5.83	0.00	0.01	0.00
	9	-26.07	-7.90	-5.82	0.00	0.01	0.01
	10	-26.07	-7.89	-5.84	0.00	0.00	0.01
Actual		-26.069	-7.889	-5.827	0.001	0.007	0.011

Tooth Number	Trial No.	X (mm)	Y (mm)	Z (mm)	Δ X (mm)	Δ Y (mm)	Δ Z (mm)
4.5	1	-23.31	-9.24	2.58	0.00	0.00	0.01
	2	-23.31	-9.24	2.59	0.00	0.00	0.00
	3	-23.31	-9.25	2.59	0.00	0.01	0.00
	4	-23.31	-9.25	2.59	0.00	0.01	0.00
	5	-23.31	-9.25	2.58	0.00	0.01	0.01
	6	-23.31	-9.24	2.58	0.00	0.00	0.01
	7	-23.32	-9.25	2.57	0.01	0.01	0.02
	8	-23.31	-9.24	2.58	0.00	0.00	0.01
	9	-23.32	-9.25	2.57	0.01	0.01	0.02
	10	-23.31	-9.25	2.58	0.00	0.01	0.01
Actual		-23.310	-9.244	2.588	0.002	0.005	0.008

Tooth Number	Trial No.	X (mm)	Y (mm)	Z (mm)	Δ X (mm)	Δ Y (mm)	Δ Z (mm)
4.4	1	-19.99	-8.75	9.58	0.01	0.00	0.02
	2	-19.99	-8.75	9.57	0.01	0.00	0.01
	3	-19.99	-8.75	9.58	0.01	0.00	0.02
	4	-20	-8.75	9.56	0.00	0.00	0.00
	5	-19.99	-8.74	9.57	0.01	0.01	0.01
	6	-19.99	-8.74	9.57	0.01	0.01	0.01
	7	-20	-8.74	9.56	0.00	0.01	0.00
	8	-20	-8.74	9.57	0.00	0.01	0.01
	9	-20	-8.75	9.56	0.00	0.00	0.00
	10	-20	-8.76	9.55	0.00	0.01	0.01
Actual		-19.996	-8.752	9.559	0.005	0.007	0.010

Tooth Number	Trial No.	X (mm)	Y (mm)	Z (mm)	Δ X (mm)	Δ Y (mm)	Δ Z (mm)
4.3	1	-15.18	-7.33	15.44	0.02	0.01	0.04
	2	-15.18	-7.33	15.45	0.02	0.01	0.03
	3	-15.18	-7.33	15.44	0.02	0.01	0.04
	4	-15.17	-7.33	15.45	0.01	0.01	0.03
	5	-15.17	-7.34	15.46	0.01	0.02	0.02
	6	-15.18	-7.34	15.45	0.02	0.02	0.03
	7	-15.18	-7.34	15.45	0.02	0.02	0.03
	8	-15.18	-7.34	15.45	0.02	0.02	0.03
	9	-15.18	-7.34	15.45	0.02	0.02	0.03
	10	-15.17	-7.34	15.46	0.01	0.02	0.02
Actual		-15.157	-7.324	15.482	0.020	0.012	0.032

Tooth Number	Trial No.	X (mm)	Y (mm)	Z (mm)	Δ X (mm)	Δ Y (mm)	Δ Z (mm)
3.2	1	-8.59	-7.05	20.79	0.02	0.00	0.00
	2	-8.6	-7.05	20.78	0.03	0.00	0.01
	3	-8.6	-7.04	20.78	0.03	0.01	0.01
	4	-8.59	-7.06	20.78	0.02	0.01	0.01
	5	-8.6	-7.06	20.78	0.03	0.01	0.01
	6	-8.6	-7.05	20.78	0.03	0.00	0.01
	7	-8.6	-7.06	20.78	0.03	0.01	0.01
	8	-8.59	-7.05	20.78	0.02	0.00	0.01
	9	-8.59	-7.06	20.78	0.02	0.01	0.01
	10	-8.59	-7.05	20.78	0.02	0.00	0.01
Actual		-8.574	-7.050	20.789	0.021	0.005	0.008

Tooth Number	Trial No.	X (mm)	Y (mm)	Z (mm)	Δ X (mm)	Δ Y (mm)	Δ Z (mm)
4.1	1	-2.63	-5.85	21.95	0.01	0.02	0.01
	2	-2.63	-5.86	21.95	0.01	0.01	0.01
	3	-2.63	-5.85	21.95	0.01	0.02	0.01
	4	-2.64	-5.86	21.94	0.00	0.01	0.00
	5	-2.64	-5.85	21.95	0.00	0.02	0.01
	6	-2.65	-5.86	21.94	0.01	0.01	0.00
	7	-2.64	-5.85	21.95	0.00	0.02	0.01
	8	-2.65	-5.85	21.94	0.01	0.02	0.00
	9	-2.65	-5.85	21.95	0.01	0.02	0.01
	10	-2.63	-5.85	21.95	0.01	0.02	0.01
Actual		-2.645	-5.865	21.941	0.009	0.012	0.007

Tooth Number	Trial No.	X (mm)	Y (mm)	Z (mm)	Δ X (mm)	Δ Y (mm)	Δ Z (mm)
3.1	1	2.09	-5.97	22.37	0.00	0.01	0.00
	2	2.08	-5.97	22.37	0.01	0.01	0.00
	3	2.09	-5.98	22.37	0.00	0.00	0.00
	4	2.09	-5.97	22.37	0.00	0.01	0.00
	5	2.08	-5.98	22.37	0.01	0.00	0.00
	6	2.09	-5.98	22.37	0.00	0.00	0.00
	7	2.08	-5.98	22.37	0.01	0.00	0.00
	8	2.09	-5.99	22.37	0.00	0.01	0.00
	9	2.08	-5.97	22.37	0.01	0.01	0.00
	10	2.08	-5.98	22.37	0.01	0.00	0.00
Actual		2.087	-5.983	22.369	0.005	0.007	0.001

Tooth Number	Trial No.	X (mm)	Y (mm)	Z (mm)	Δ X (mm)	Δ Y (mm)	Δ Z (mm)
3.2	1	9.04	-5.08	20.72	0.01	0.04	0.01
	2	9.03	-5.07	20.72	0.00	0.03	0.01
	3	9.03	-5.08	20.72	0.00	0.04	0.01
	4	9.03	-5.08	20.72	0.00	0.04	0.01
	5	9.02	-5.08	20.72	0.01	0.04	0.01
	6	9.03	-5.08	20.72	0.00	0.04	0.01
	7	9.03	-5.09	20.71	0.00	0.05	0.02
	8	9.03	-5.08	20.72	0.00	0.04	0.01
	9	9.03	-5.09	20.72	0.00	0.05	0.01
	10	9.03	-5.08	20.72	0.00	0.04	0.01
Actual		9.034	-5.041	20.730	0.006	0.040	0.011

Tooth Number	Trial No.	X (mm)	Y (mm)	Z (mm)	Δ X (mm)	Δ Y (mm)	Δ Z (mm)
3.3	1	16.82	-4.98	16.21	0.00	0.02	0.00
	2	16.82	-4.98	16.21	0.00	0.02	0.00
	3	16.82	-4.97	16.21	0.00	0.03	0.00
	4	16.82	-4.98	16.21	0.00	0.02	0.00
	5	16.81	-4.97	16.21	0.01	0.03	0.00
	6	16.82	-4.98	16.21	0.00	0.02	0.00
	7	16.81	-4.98	16.22	0.01	0.02	0.01
	8	16.81	-4.97	16.22	0.01	0.03	0.01
	9	16.81	-4.98	16.22	0.01	0.02	0.01
	10	16.82	-4.97	16.21	0.00	0.03	0.00
Actual		16.823	-4.996	16.206	0.007	0.020	0.007

Tooth Number	Trial No.	X (mm)	Y (mm)	Z (mm)	Δ X (mm)	Δ Y (mm)	Δ Z (mm)
3.4	1	22.54	-6.28	10.98	0.00	0.00	0.01
	2	22.54	-6.27	10.98	0.00	0.01	0.01
	3	22.54	-6.28	10.99	0.00	0.00	0.02
	4	22.54	-6.27	10.99	0.00	0.01	0.02
	5	22.54	-6.27	10.99	0.00	0.01	0.02
	6	22.54	-6.27	10.98	0.00	0.01	0.01
	7	22.54	-6.27	10.98	0.00	0.01	0.01
	8	22.53	-6.28	10.99	0.01	0.00	0.02
	9	22.53	-6.27	10.99	0.01	0.01	0.02
	10	22.54	-6.27	10.98	0.00	0.01	0.01
Actual		22.543	-6.284	10.972	0.005	0.011	0.013

Tooth Number	Trial No.	X (mm)	Y (mm)	Z (mm)	Δ X (mm)	Δ Y (mm)	Δ Z (mm)
3.5	1	23.37	-5.02	3.16	0.01	0.02	0.01
	2	23.37	-5.02	3.3	0.01	0.02	0.13
	3	23.37	-5.01	3.17	0.01	0.01	0.00
	4	23.37	-5.01	3.16	0.01	0.01	0.01
	5	23.37	-5.02	3.17	0.01	0.02	0.00
	6	23.37	-5.01	3.16	0.01	0.01	0.01
	7	23.37	-5.01	3.16	0.01	0.01	0.01
	8	23.37	-5.01	3.17	0.01	0.01	0.00
	9	23.37	-5.01	3.16	0.01	0.01	0.01
	10	23.37	-5.02	3.16	0.01	0.02	0.01
Actual		23.364	-5.002	3.166	0.006	0.012	0.018

Tooth Number	Trial No.	X (mm)	Y (mm)	Z (mm)	Δ X (mm)	Δ Y (mm)	Δ Z (mm)
3.6	1	25.22	-3.92	-5.71	0.00	0.02	0.00
	2	25.22	-3.91	-5.72	0.00	0.01	0.01
	3	25.23	-3.93	-5.71	0.01	0.03	0.00
	4	25.23	-3.92	-5.72	0.01	0.02	0.01
	5	25.23	-3.93	-5.70	0.01	0.03	0.01
	6	25.22	-3.91	-5.71	0.00	0.01	0.00
	7	25.22	-3.92	-5.70	0.00	0.02	0.01
	8	25.22	-3.92	-5.71	0.00	0.02	0.00
	9	25.22	-3.92	-5.70	0.00	0.02	0.01
	10	25.23	-3.92	-5.71	0.01	0.02	0.00
Actual		25.217	-3.902	-5.711	0.007	0.018	0.006

Tooth Number	Trial No.	X (mm)	Y (mm)	Z (mm)</
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PILOT 1 - Aligner Model - Brackets on FA Point

1.7	1.6	1.5	1.4	1.3	1.2	1.1	2.1	2.2	2.3	2.4	2.5	2.6	2.7
4.7	4.6	4.5	4.4	4.3	4.2	4.1	3.1	3.2	3.3	3.4	3.5	3.6	3.7

Tooth Number	Trial No.	X (mm)	Y (mm)	Z (mm)	Δ X (mm)	Δ Y (mm)	Δ Z (mm)
1.7	1	-32.24	1.41	-14.03	0.03	0.05	0.10
	2	-32.26	1.41	-14.07	0.05	0.05	0.14
	3	-32.24	1.37	-14.01	0.03	0.09	0.08
	4	-32.25	1.37	-14.05	0.04	0.09	0.12
	5	-32.25	1.38	-14.05	0.04	0.08	0.12
	6	-32.25	1.38	-14.05	0.04	0.08	0.12
	7	-32.25	1.38	-14.03	0.04	0.08	0.10
	8	-32.25	1.37	-14.03	0.04	0.09	0.10
	9	-32.25	1.38	-14.04	0.04	0.08	0.11
	10	-32.25	1.39	-14.04	0.04	0.07	0.11
Actual		-32.208	1.460	-13.932	0.041	0.076	0.108

Tooth Number	Trial No.	X (mm)	Y (mm)	Z (mm)	Δ X (mm)	Δ Y (mm)	Δ Z (mm)
1.6	1	-27.63	-0.32	-3.3	0.03	0.03	0.05
	2	-27.65	-0.34	-3.33	0.05	0.01	0.08
	3	-27.62	-0.35	-3.28	0.02	0.00	0.03
	4	-27.63	-0.36	-3.3	0.03	0.01	0.05
	5	-27.63	-0.35	-3.3	0.03	0.00	0.05
	6	-27.63	-0.35	-3.31	0.03	0.00	0.06
	7	-27.63	-0.35	-3.3	0.03	0.00	0.05
	8	-27.62	-0.34	-3.29	0.02	0.01	0.04
	9	-27.63	-0.34	-3.31	0.03	0.01	0.06
	10	-27.63	-0.35	-3.3	0.03	0.00	0.05
Actual		-27.596	-0.348	-3.245	0.034	0.007	0.057

Tooth Number	Trial No.	X (mm)	Y (mm)	Z (mm)	Δ X (mm)	Δ Y (mm)	Δ Z (mm)
1.5	1	-24.28	0.71	4.55	0.00	0.02	0.01
	2	-24.31	0.70	4.53	0.03	0.03	0.03
	3	-24.28	0.70	4.56	0.00	0.03	0.00
	4	-24.28	0.70	4.55	0.00	0.03	0.01
	5	-24.28	0.71	4.56	0.00	0.02	0.00
	6	-24.28	0.70	4.56	0.00	0.03	0.00
	7	-24.28	0.69	4.56	0.00	0.04	0.00
	8	-24.29	0.70	4.55	0.01	0.03	0.01
	9	-24.28	0.71	4.55	0.00	0.02	0.01
	10	-24.29	0.70	4.55	0.01	0.03	0.01
Actual		-24.281	0.731	4.565	0.006	0.029	0.013

Tooth Number	Trial No.	X (mm)	Y (mm)	Z (mm)	Δ X (mm)	Δ Y (mm)	Δ Z (mm)
1.4	1	-22.24	1.42	11.18	0.00	0.02	0.03
	2	-22.26	1.38	11.21	0.02	0.02	0.00
	3	-22.27	1.39	11.18	0.03	0.01	0.03
	4	-22.25	1.41	11.19	0.01	0.01	0.02
	5	-22.22	1.44	11.18	0.02	0.04	0.03
	6	-22.26	1.39	11.19	0.02	0.01	0.02
	7	-22.22	1.45	11.19	0.02	0.05	0.02
	8	-22.22	1.46	11.19	0.02	0.06	0.02
	9	-22.22	1.45	11.19	0.02	0.05	0.02
	10	-22.22	1.46	11.2	0.02	0.06	0.01
Actual		-22.237	1.405	11.207	0.018	0.031	0.018

Tooth Number	Trial No.	X (mm)	Y (mm)	Z (mm)	Δ X (mm)	Δ Y (mm)	Δ Z (mm)
1.3	1	-19.56	2.44	16.48	0.00	0.02	0.02
	2	-19.56	2.42	16.58	0.00	0.00	0.08
	3	-19.56	2.43	16.47	0.00	0.01	0.03
	4	-19.56	2.44	16.47	0.00	0.02	0.03
	5	-19.56	2.44	16.47	0.00	0.02	0.03
	6	-19.56	2.43	16.48	0.00	0.01	0.02
	7	-19.55	2.45	16.48	0.01	0.03	0.02
	8	-19.56	2.45	16.47	0.00	0.03	0.03
	9	-19.57	2.44	16.46	0.01	0.02	0.04
	10	-19.56	2.45	16.47	0.00	0.03	0.03
Actual		-19.561	2.416	16.505	0.003	0.023	0.037

Tooth Number	Trial No.	X (mm)	Y (mm)	Z (mm)	Δ X (mm)	Δ Y (mm)	Δ Z (mm)
1.2	1	-12.05	0.49	23.3	0.05	0.01	0.06
	2	-12.04	0.48	23.31	0.04	0.00	0.05
	3	-12.06	0.49	23.3	0.06	0.01	0.06
	4	-12.07	0.49	23.3	0.07	0.01	0.06
	5	-12.05	0.48	23.3	0.05	0.00	0.06
	6	-12.09	0.49	23.29	0.09	0.01	0.07
	7	-12.07	0.51	23.29	0.07	0.03	0.07
	8	-12.06	0.48	23.3	0.06	0.00	0.06
	9	-12.1	0.47	23.3	0.10	0.01	0.06
	10	-12.08	0.5	23.29	0.08	0.02	0.07
Actual		-12.002	0.477	23.356	0.065	0.012	0.058

Tooth Number	Trial No.	X (mm)	Y (mm)	Z (mm)	Δ X (mm)	Δ Y (mm)	Δ Z (mm)
1.1	1	-4.26	-1.52	25.87	0.10	0.04	0.05
	2	-4.3	-1.52	25.86	0.14	0.04	0.06
	3	-4.28	-1.54	25.86	0.12	0.02	0.06
	4	-4.3	-1.55	25.87	0.14	0.01	0.05
	5	-4.28	-1.53	25.86	0.12	0.03	0.06
	6	-4.3	-1.53	25.86	0.14	0.03	0.06
	7	-4.29	-1.54	25.86	0.13	0.02	0.06
	8	-4.26	-1.53	25.87	0.10	0.03	0.05
	9	-4.27	-1.54	25.87	0.11	0.02	0.05
	10	-4.3	-1.54	25.86	0.14	0.02	0.06
Actual		-4.161	-1.556	25.920	0.123	0.022	0.056

Tooth Number	Trial No.	X (mm)	Y (mm)	Z (mm)	Δ X (mm)	Δ Y (mm)	Δ Z (mm)
2.1	1	6.67	-1.04	25.67	0.04	0.02	0.05
	2	6.65	-1.05	25.68	0.06	0.01	0.04
	3	6.67	-1.05	25.67	0.04	0.01	0.05
	4	6.66	-1.07	25.68	0.05	0.01	0.04
	5	6.66	-1.05	25.67	0.05	0.01	0.05
	6	6.66	-1.03	25.68	0.05	0.03	0.04
	7	6.66	-1.06	25.67	0.05	0.00	0.05
	8	6.65	-1.05	25.68	0.06	0.01	0.04
	9	6.68	-1.03	25.67	0.03	0.03	0.05
	10	6.64	-1.04	25.68	0.07	0.02	0.04
Actual		6.712	-1.063	25.721	0.052	0.017	0.046

Tooth Number	Trial No.	X (mm)	Y (mm)	Z (mm)	Δ X (mm)	Δ Y (mm)	Δ Z (mm)
2.2	1	15.9	-0.26	21.39	0.04	0.02	0.15
	2	15.89	-0.28	21.4	0.05	0.04	0.16
	3	15.86	-0.27	21.43	0.08	0.03	0.19
	4	15.9	-0.30	21.39	0.04	0.06	0.15
	5	15.88	-0.32	21.42	0.06	0.08	0.18
	6	15.89	-0.28	21.41	0.05	0.04	0.17
	7	15.86	-0.30	21.43	0.08	0.07	0.19
	8	15.88	-0.27	21.41	0.06	0.03	0.17
	9	15.87	-0.31	21.43	0.07	0.07	0.19
	10	15.88	-0.29	21.42	0.06	0.05	0.18
Actual		15.937	-0.236	21.242	0.056	0.052	0.171

Tooth Number	Trial No.	X (mm)	Y (mm)	Z (mm)	Δ X (mm)	Δ Y (mm)	Δ Z (mm)
2.3	1	22.17	1.84	15.9	0.07	0.02	0.13
	2	22.18	1.84	15.87	0.06	0.02	0.10
	3	22.17	1.83	15.9	0.07	0.01	0.13
	4	22.18	1.82	15.87	0.06	0.00	0.10
	5	22.18	1.82	15.86	0.06	0.00	0.09
	6	22.18	1.83	15.87	0.06	0.01	0.10
	7	22.18	1.83	15.86	0.06	0.01	0.09
	8	22.18	1.82	15.87	0.06	0.00	0.10
	9	22.18	1.82	15.87	0.06	0.00	0.10
	10	22.18	1.83	15.88	0.06	0.01	0.11
Actual		22.240	1.822	15.771	0.062	0.008	0.104

Tooth Number	Trial No.	X (mm)	Y (mm)	Z (mm)	Δ X (mm)	Δ Y (mm)	Δ Z (mm)
2.4	1	25.53	2.24	6.04	0.00	0.00	0.05
	2	25.54	2.21	6.04	0.01	0.03	0.05
	3	25.54	2.21	6.03	0.01	0.03	0.06
	4	25.54	2.21	6.03	0.01	0.03	0.06
	5	25.56	2.17	6.02	0.03	0.07	0.07
	6	25.56	2.16	6.29	0.03	0.08	0.20
	7	25.57	2.15	6.08	0.04	0.09	0.01
	8	25.58	2.14	6.03	0.05	0.10	0.06
	9	25.55	2.18	6.08	0.02	0.06	0.01
	10	25.56	2.18	6.03	0.03	0.06	0.06
Actual		25.528	2.237	6.087	0.025	0.053	0.060

Tooth Number	Trial No.	X (mm)	Y (mm)	Z (mm)	Δ X (mm)	Δ Y (mm)	Δ Z (mm)
2.5	1	26.68	1.08	0.02	0.02	0.04	0.01
	2	26.7	1.04	0.01	0.00	0.00	0.00
	3	26.68	1.07	0.01	0.02	0.03	0.00
	4	26.69	1.05	0.02	0.01	0.01	0.01
	5	26.69	1.07	0.03	0.01	0.03	0.02
	6	26.7	1.06	0.04	0.00	0.02	0.03
	7	26.7	1.04	0.03	0.00	0.00	0.02
	8	26.7	1.04	0.03	0.00	0.00	0.02
	9	26.7	1.04	0.03	0.00	0.00	0.02
	10	26.7	1.05	0	0.00	0.01	0.01
Actual		26.696	1.037	0.011	0.007	0.017	0.014

Tooth Number	Trial No.	X (mm)	Y (mm)	Z (mm)	Δ X (mm)	Δ Y (mm)	Δ Z (mm)
2.6	1	29.19	0.16	-6.81	0.19	0.08	0.06
	2	29.19	0.17	-6.78	0.19	0.07	0.03
	3	29.18	0.16	-6.77	0.20	0.08	0.02
	4	29.19	0.20	-6.78	0.19	0.04	0.03
	5	29.17	0.18	-6.74	0.21	0.06	0.01
	6	29.18	0.18	-6.77	0.20	0.06	0.02
	7	29.17	0.17	-6.74	0.21	0.07	0.01
	8	29.18	0.16	-6.76	0.20	0.08	0.01
	9	29.18	0.17	-6.76	0.20	0.07	0.01
	10	29.18	0.18	-6.77	0.20	0.06	0.02
Actual	29.375	0.239	-6.746	0.194	0.066	0.025	

Tooth Number	Trial No.	X (mm)	Y (mm)	Z (mm)	Δ X (mm)	Δ Y (mm)	Δ Z (mm)
4.7	1	-30.51	-0.98	-15.11	0.10	0.07	0.15
	2	-30.51	-0.98	-15.09	0.10	0.07	0.13
	3	-30.50	-0.98	-15.10	0.09	0.07	0.14
	4	-30.50	-0.97	-15.10	0.09	0.08	0.14
	5	-30.51	-0.98	-15.11	0.10	0.07	0.15
	6	-30.50	-0.97	-15.11	0.09	0.08	0.15
	7	-30.50	-0.97	-15.09	0.09	0.08	0.13
	8	-30.50	-0.97	-15.10	0.09	0.08	0.14
	9	-30.50	-0.96	-15.11	0.09	0.09	0.15
	10	-30.50	-0.97	-15.12	0.09	0.08	0.16
Actual		-30.414	-1.046	-14.955	0.089	0.073	0.149

Tooth Number	Trial No.	X (mm)	Y (mm)	Z (mm)	Δ X (mm)	Δ Y (mm)	Δ Z (mm)
4.6	1	-26.28	-0.17	-6.86	0.16	0.05	0.19
	2	-26.27	-0.13	-6.87	0.15	0.09	0.20
	3	-26.27	-0.15	-6.86	0.15	0.07	0.19
	4	-26.27	-0.14	-6.84	0.15	0.08	0.17
	5	-26.27	-0.14	-6.86	0.15	0.08	0.19
	6	-26.27	-0.14	-6.86	0.15	0.08	0.19
	7	-26.27	-0.15	-6.85	0.15	0.07	0.18
	8	-26.27	-0.14	-6.86	0.15	0.08	0.19
	9	-26.27	-0.15	-6.87	0.15	0.07	0.20
	10	-26.27	-0.15	-6.85	0.15	0.07	0.18
Actual		-26.121	-0.217	-6.671	0.150	0.071	0.187

Tooth Number	Trial No.	X (mm)	Y (mm)	Z (mm)	Δ X (mm)	Δ Y (mm)	Δ Z (mm)
4.5	1	-24.51	-0.77	1.24	0.16	0.10	0.06
	2	-24.51	-0.76	1.22	0.16	0.11	0.08
	3	-24.51	-0.75	1.26	0.16	0.12	0.04
	4	-24.51	-0.74	1.25	0.16	0.13	0.05
	5	-24.51	-0.74	1.23	0.16	0.13	0.07
	6	-24.51	-0.75	1.24	0.16	0.12	0.06
	7	-24.51	-0.75	1.23	0.16	0.12	0.07
	8	-24.51	-0.76	1.23	0.16	0.11	0.07
	9	-24.51	-0.75	1.23	0.16	0.12	0.07
	10	-24.51	-0.77	1.23	0.16	0.10	0.07
Actual		-24.351	-0.870	1.304	0.159	0.116	0.068

Tooth Number	Trial No.	X (mm)	Y (mm)	Z (mm)	Δ X (mm)	Δ Y (mm)	Δ Z (mm)
4.4	1	-21	0.48	8.96	0.15	0.06	0.02
	2	-20.99	0.52	8.96	0.14	0.10	0.02
	3	-20.98	0.52	8.9	0.13	0.10	0.08
	4	-20.99	0.51	8.97	0.14	0.09	0.01
	5	-20.99	0.54	8.98	0.14	0.12	0.00
	6	-20.99	0.54	8.96	0.14	0.12	0.02
	7	-20.99	0.53	8.95	0.14	0.11	0.03
	8	-21	0.51	8.95	0.15	0.09	0.03
	9	-20.99	0.53	8.97	0.14	0.11	0.01
	10	-21	0.53	8.95	0.15	0.11	0.03
Actual		-20.853	0.424	8.980	0.139	0.097	0.025

Tooth Number	Trial No.	X (mm)	Y (mm)	Z (mm)	Δ X (mm)	Δ Y (mm)	Δ Z (mm)
4.3	1	-16.33	1.96	15.28	0.13	0.13	0.12
	2	-16.34	1.96	15.27	0.14	0.13	0.13
	3	-16.34	1.97	15.27	0.14	0.14	0.13
	4	-16.34	1.96	15.27	0.14	0.13	0.13
	5	-16.34	1.97	15.26	0.14	0.14	0.14
	6	-16.34	1.97	15.26	0.14	0.14	0.14
	7	-16.34	1.98	15.26	0.14	0.15	0.14
	8	-16.34	1.97	15.26	0.14	0.14	0.14
	9	-16.34	1.98	15.26	0.14	0.15	0.14
	10	-16.34	1.97	15.26	0.14	0.14	0.14
Actual		-16.197	1.827	15.398	0.142	0.142	0.133

Tooth Number	Trial No.	X (mm)	Y (mm)	Z (mm)	Δ X (mm)	Δ Y (mm)	Δ Z (mm)
4.2	1	-9.35	2.62	21.07	0.06	0.11	0.12
	2	-9.34	2.64	21.06	0.05	0.13	0.13
	3	-9.35	2.64	21.06	0.06	0.13	0.13
	4	-9.33	2.63	21.07	0.04	0.12	0.12
	5	-9.33	2.64	21.06	0.04	0.13	0.13
	6	-9.34	2.64	21.06	0.05	0.13	0.13
	7	-9.34	2.64	21.06	0.05	0.13	0.13
	8	-9.34	2.64	21.06	0.05	0.13	0.13
	9	-9.34	2.63	21.07	0.05	0.12	0.12
	10	-9.33	2.64	21.07	0.04	0.13	0.12
Actual		-9.285	2.508	21.190	0.054	0.128	0.126

Tooth Number	Trial No.	X (mm)	Y (mm)	Z (mm)	Δ X (mm)	Δ Y (mm)	Δ Z (mm)
4.1	1	-4.13	3.91	22.25	0.13	0.09	0.15
	2	-4.12	3.93	22.24	0.12	0.11	0.16
	3	-4.13	3.92	22.23	0.13	0.10	0.17
	4	-4.12	3.94	22.23	0.12	0.12	0.17
	5	-4.14	3.94	22.23	0.14	0.12	0.17
	6	-4.15	3.92	22.23	0.15	0.10	0.17
	7	-4.13	3.93	22.23	0.13	0.11	0.17
	8	-4.13	3.93	22.23	0.13	0.11	0.17
	9	-4.12	3.94	22.23	0.12	0.12	0.17
	10	-4.14	3.93	22.23	0.14	0.11	0.17
Actual		-3.997	3.823	22.396	0.134	0.106	0.163

Tooth Number	Trial No.	X (mm)	Y (mm)	Z (mm)	Δ X (mm)	Δ Y (mm)	Δ Z (mm)
3.1	1	0.57	3.64	23.24	0.17	0.08	0.06
	2	0.58	3.65	23.24	0.16	0.09	0.06
	3	0.57	3.66	23.24	0.17	0.10	0.06
	4	0.59	3.66	23.25	0.15	0.10	0.05
	5	0.6	3.65	23.25	0.14	0.09	0.05
	6	0.59	3.67	23.25	0.15	0.11	0.05
	7	0.58	3.67	23.25	0.16	0.11	0.05
	8	0.57	3.67	23.24	0.17	0.11	0.06
	9	0.59	3.64	23.25	0.15	0.08	0.05
	10	0.59	3.68	23.25	0.15	0.12	0.05
Actual		0.736	3.558	23.298	0.153	0.101	0.052

Tooth Number	Trial No.	X (mm)	Y (mm)	Z (mm)	Δ X (mm)	Δ Y (mm)	Δ Z (mm)
3.2	1	8.12	3.71	21.86	0.15	0.02	0.09
	2	8.16	3.71	21.86	0.11	0.02	0.09
	3	8.1	3.71	21.87	0.17	0.02	0.08
	4	8.09	3.71	21.87	0.18	0.02	0.08
	5	8.09	3.72	21.87	0.18	0.03	0.08
	6	8.1	3.72	21.86	0.17	0.03	0.09
	7	8.08	3.71	21.87	0.19	0.02	0.08
	8	8.1	3.71	21.87	0.17	0.02	0.08
	9	8.09	3.73	21.87	0.18	0.04	0.08
	10	8.09	3.71	21.87	0.18	0.02	0.08
Actual		8.266	3.692	21.953	0.164	0.022	0.086

Tooth Number	Trial No.	X (mm)	Y (mm)	Z (mm)	Δ X (mm)	Δ Y (mm)	Δ Z (mm)
3.3	1	16.64	2.84	17.71	0.09	0.07	0.23
	2	16.62	2.85	17.72	0.11	0.06	0.22
	3	16.63	2.84	17.72	0.10	0.07	0.22
	4	16.63	2.85	17.72	0.10	0.06	0.22
	5	16.62	2.85	17.72	0.11	0.06	0.22
	6	16.63	2.86	17.71	0.10	0.05	0.23
	7	16.63	2.85	17.71	0.10	0.06	0.23
	8	16.62	2.86	17.72	0.11	0.05	0.22
	9	16.62	2.85	17.72	0.11	0.06	0.22
	10	16.62	2.84	17.72	0.11	0.07	0.22
Actual		16.726	2.905	17.937	0.100	0.056	0.220

Tooth Number	Trial No.	X (mm)	Y (mm)	Z (mm)	Δ X (mm)	Δ Y (mm)	Δ Z (mm)
3.4	1	22.85	0.54	12.76	0.15	0.13	0.10
	2	22.83	0.54	12.77	0.17	0.13	0.09
	3	22.86	0.56	12.75	0.14	0.11	0.11
	4	22.84	0.57	12.77	0.16	0.10	0.09
	5	22.83	0.56	12.79	0.17	0.11	0.07
	6	22.86	0.58	12.76	0.14	0.09	0.10
	7	22.84	0.56	12.77	0.16	0.11	0.09
	8	22.83	0.56	12.78	0.17	0.11	0.08
	9	22.84	0.55	12.77	0.16	0.12	0.09
	10	22.83	0.55	12.77	0.17	0.12	0.09
Actual		23.002	0.671	12.858	0.161	0.114	0.089

Tooth Number	Trial No.	X (mm)	Y (mm)	Z (mm)	Δ X (mm)	Δ Y (mm)	Δ Z (mm)
3.5	1	24.36	1.44	4.9	0.16	0.04	0.09
	2	24.33	1.45	4.94	0.19	0.03	0.05
	3	24.34	1.46	4.92	0.18	0.02	0.07
	4	24.33	1.45	4.93	0.19	0.03	0.06
	5	24.33	1.46	4.93	0.19	0.02	0.06
	6	24.33	1.46	4.92	0.19	0.02	0.07
	7	24.32	1.46	4.94	0.20	0.02	0.05
	8	24.33	1.45	4.93	0.19	0.03	0.06
	9	24.32	1.45	4.94	0.20	0.03	0.05
	10	24.32	1.46	4.94	0.20	0.02	0.05
Actual		24.520	1.479	4.986	0.189	0.025	0.057

Tooth Number	Trial No.	X (mm)	Y (mm)	Z (mm)	Δ X (mm)	Δ Y (mm)	Δ Z (mm)
3.6	1	26.87	1.27	-4.38	0.26	0.01	0.22
	2	26.87	1.27	-4.40	0.26	0.01	0.24
	3	26.88	1.28	-4.42	0.25	0.00	0.26
	4	26.88	1.28	-4.43	0.25	0.00	0.27
	5	26.87	1.28	-4.42	0.26	0.00	0.26
	6	26.88	1.27	-4.43	0.25	0.01	0.27
	7	26.87	1.28	-4.43	0.26	0.00	0.27
	8	26.87	1.28	-4.44	0.26	0.00	0.28
	9	26.88	1.28	-4.44	0.25	0.00	0.28
	10	26.87	1.28	-4.41	0.26	0.00	0.25
Actual	27.128	1.276	-4.160	0.254	0.005	0.260	