DO PATIENTS WITH FACIAL DSYMORPHOLOGY RECOGNISE THEMSELVES IN PROFILE?

by

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In keeping with the University of Birmingham 'Alternative format thesis guidelines' [regulation 7.4.1 (g)] I declare that the findings of this study and relevant sections of this report have been recently published in a peer-reviewed journal.

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Abstract

Aims: The purpose of this investigation was to determine whether pre-operative Class III skeletal patients, who require orthognathic surgical correction, were able to accurately identify the site and extent of their dento-facial dysmorphology. As such determining whether 2D photo-cephalometric planning is a valid form of communication tool.

In addition the study questioned patients whether they would prefer to see a three-dimensional reconstruction (rather than a 2D profile view) during orthognathic surgery treatment planning; and if patients would be willing to accept an increased radiation exposure to facilitate seeing themselves in 3D.

Design: Single center, prospective cross-sectional study.

Materials and methods: Twenty adults with a Class III dento-facial malocclusion, were recruited from the Birmingham Dental Hospital, United Kingdom. The participants used 'Computer-Assisted Simulation System for Orthognathic Surgery' (CASSOS) (SoftEnable Technology Ltd.) software package to manipulate a distorted digital construction of their soft tissue profile; to assess whether they have an accurate perception of their lateral profile. Patients were able to move their upper lip and lower lip/chin backwards and forwards. As well as the lower lip/chin up and down. Differences in linear horizontal distance between the patient-perceived position of the upper lip (Labrale superious) and chin (Pogonion) and the actual position of their upper lip and chin were measured. The subjects also completed a 'Participant Questionnaire'.

Results: Intra-patient reproducibility was found to be excellent (intra-class correlation coefficient score 0.93 to 0.98). The mean difference in upper lip position was -2.3 ± 3.0mm (95% CI -3.7mm to -0.9mm) (p=0.001). Mean differences in AP chin position and vertical chin position were 0.8 ± 3.7m (95% CI -0.9mm to 2.5mm) (p=0.334) and 4.7 ± 4.2mm (95% CI 2.7mm to 6.6mm) (p=0.001) respectively. All absolute mean differences were greater than 3.0mm, these differences would be deemed clinically significant.

Conclusions: In this present study approximately half of patients could not correctly identify their current pre-surgical facial profile. Patients were able to determine their anterior-posterior chin position with greater accuracy than their upper lip position. There was a tendency to produce a retrusive upper lip position, exaggerating the extent of their Class III skeletal pattern. In the vertical direction there was a tendency to position the chin more inferiorly, producing a longer face. Patients were able to consistently reproduce their perception of their facial soft tissue profile on a second attempt. Given the lack of awareness of their own profile, this questions the validity of using profile planning as a tool for patient communication and informed consent.

LIST OF FIGURES

LIST OF TABLES

Contents

CHAPTER 1

LITERATURE REVIEW

1.1 ORTHOGNATHIC SURGERY

Orthognathic surgery is undertaken to correct an aberrant skeletal base relationship; this involves surgery that is generally limited to repositioning the mandible, maxilla or both jaws (Cunningham and Johal, 2015). One of the main objectives of orthognathic surgery is to 'normalise' the patient's facial morphology (Vittert et al., 2018). Orthognathic treatment generally combines pre-surgical orthodontics and maxillofacial surgery (Malik, 2016). Alternative approaches include surgery before orthodontic treatment and surgery without orthodontic therapy (Naini and Gill, 2017). Orthognathic surgery may be undertaken to correct skeletal discrepancies in the antero-posterior, vertical and/or transverse plane. Orthognathic surgery is not limited only to problems of dento-skeletal disharmony but may also address problems arising from conditions such as temporomandibular joint disorders, sleep apnoea and syndromes affecting the facial complex, for example hemifacial microsomia (Cunningham and Johal, 2015).

1.2 PATIENT MOTIVATIONS FOR SEEKING SURGICAL TREATMENT

Patients are motivated towards seeking treatment where they have aesthetic concerns; functional concerns, such as masticatory difficulties; issues with speech or due to the psychological impact of their skeletal malformation (Finlay et al., 1995; Proothi et al., 2010). Motivating factors towards surgery vary and are individual to each patient, but common themes include the social impact of the malocclusion, the patient's self perception of their appearance, and the effect their malocclusion has on their self-esteem and quality of life (Rivera et al., 2000; Cunningham and Johal, 2015). It has also been stated that patients affected by 'Body Dysmorphic Disorder'

(BDD) are likely to seek orthognathic treatment, at a disproportionately high rate (Rosten et al., 2018).

1.2.1 Facial aesthetic concerns

Perception of facial attractiveness has been acknowledged as a motivating factor for patients seeking treatment (Johnston et al., 2010). Vittert et al. (2018) describes patients as being motivated “predominantly by aesthetics” (Vittert et al., 2018). Previous evidence has suggested that 70% of prospective patients report facial aesthetics as an influencing factor towards seeking orthognathic surgery (Sinclair et al., 1995).

Cunningham et al. (2000) investigated the psychological profile of orthognathic patients, at the start of treatment, prior to any active treatment / pre-surgical orthodontics. Orthognathic patients were generally found to have a lower body image and ‘facial body image’. In addition, the self-esteem of these patients was shown to be lower, although the significance of this was borderline. Further research has shown that orthognathic treatment can improve the psycho-social well-being and quality of life (QoL) for patients with dento-facial problems (Lee et al., 2007; Ryan et al., 2012).

The importance of facial appearance should not be underestimated in the current social climate. Facial attractiveness has been shown to increase selection amongst potential dating partners and increase the likelihood of being hired for employment; having been perceived as having greater interpersonal skills (Riggio and Woll, 1984; Cash and Kilcullen, 1985). More worryingly, facial attractiveness has the potential to reduce sentences awarded to criminal defendants, with more lenient sentencing given to attractive defendants (Sigall and Ostrove, 1975). As such, it is not surprising that patients with visible facial difference are motivated towards seeking these reported social advantages offered to attractive individuals.

Societies increasing use of social media should not be overlooked with regards to its effects on self-perception and perceived attractiveness. Dissatisfaction with facial and body aesthetics and the pursuit of attractiveness is rising and can be linked to the increasing use of social media (Fardouly and Vartanian, 2016). Greater social media photograph viewing activity amongst adolescent females has been shown to correlate with body image concerns (Meier and Gray, 2014; de Vries et al., 2014). A similar effect on self-perception is seen following exposure to the faces of others rated as highly attractive; with a resultant negative impact on participants, demonstrating increased dissatisfaction with their own facial appearance (Newton and Minhas, 2005). Increased social media usage has also been linked to a rise in the 'desire to undergo cosmetic surgery' (de Vries et al., 2014; Walker et al., 2019).

1.3 PERCEPTION OF FACIAL APPEARANCE

1.3.1 An individual's perception of profile

There has been some debate in the literature regarding the ability of an individual to recognise their facial profile. Some authors feel that individuals do not often see themselves in profile and are therefore unfamiliar with their lateral facial profile appearance (Bonetti et al., 2011). Johnston et al. (2010) asked 319 study participants whether they had seen their own face in profile; 51% of the sample were patients identified as candidates for orthognathic treatment, the remaining 49% formed the control group. Surprisingly, the results showed that only 67.2% of skeletal class II patients, 77.9% of class III patients and 67.5% of the control group reported they had seen themselves in profile. Although based on a large sample size, this study asked whether individuals had “seen” themselves in profile, with no further follow-up questions i.e. would they recognise their own facial profile, and to what degree of accuracy? Given the fact that individuals are not accustomed to viewing themselves in profile this may highlight a generalised difficulty for individuals to identify their own facial profile. Interestingly the study did demonstrate an increased awareness of facial profile amongst Class III patients.

Similar findings have been found for patients undergoing orthodontic treatment. Hershon and Giddon (1980), in a cross-sectional prospective cohort study, investigated how accurately 84 orthodontic patients and non-orthodontic controls could subjectively identify their profile, compared to an objective measure of their profile derived from a lateral photograph. Both groups of subjects were unable to accurately determine the protrusiveness of their lips, with both groups over exaggerating their lip prominence. However, these results are disputed by researchers who found orthodontic patients and non-orthodontic controls to be equally accurate in the self-perception of their profiles (Kitay et al., 1999).

The ability of children to recognise their facial profile has also been investigated. A group of 24 children, aged 8-15years, were tested on the accuracy with which they could determine their profile (Miner et al., 2007). In this study the position of the mandible was varied between “retrusive and protrusive extremes”, as a moving animation. The position of chin point (Pogonion) was taken to represent mandibular change. Children were able to reproduce the position of their mandible to a mean accuracy of 1.7mm. To put this into context, the treating clinicians, undertaking the same task of assessing patient profile, were able to determine the profile to a mean accuracy of 0.9 mm. The study concluded that children were not accurately aware of their actual pre-treatment profiles. A tendency to over exaggerate the protrusion of the mandible was found; which is consistent with the results of previous studies for adults (Hershon and Giddon, 1980; Bell et al., 1985).

Interestingly the ability for individuals to accurately perceive facial profile has been shown to alter with age; with older patients experiencing greater difficultly in accurately determining their profile (Bullen et al., 2014). Based on silhouette profiles showing incremental protrusion and retrusion of the upper and lower lips; 15 to 25 year olds were able to estimate their profile more accurately than 26 to 55 year olds, who tended to over exaggerate their lip protrusion (Bullen et al., 2014).

1.3.2 The effect of education on the perception of facial profile

It has been established that the perception of facial profiles, with regard to aesthetics and treatment need differs between laypeople and dental specialists (Peck and Peck, 1970; Tufekci et al., 2008). This may be due to their professional experience in the analysis of profiles, whilst diagnosing and treatment planning. The level of education has been shown to influence the perception of facial profiles (Falkensammer et al., 2014). Using facial profiles that had been manipulated in the sagittal and vertical dimensions, 304 ‘non-academic laypeople’, ‘academic laypeople’, dental students, orthodontists and maxillofacial surgeons were asked to assess the attractiveness and treatment need based on a series of facial profiles. The level of education significantly influenced perception of facial profiles and ‘attractiveness score’. The orthodontists and maxillofacial surgeons reported the highest need for treatment. This is supported by the findings of Phillips et al. (1992), who also found the level of dental training affected how facial attractiveness was rated.

It should be acknowledged there is a difference in how dental professional groups and laypeople perceive the attractiveness of facial profiles that deviate from a Class I pattern, with average vertical proportions. For example, for males with “convex, high angle” profiles only 34% of laypeople perceived a need for correction, compared with 71% of orthodontists (Falkensammer et al., 2014). This is consistent with other investigations, which found significant differences in perceived need for treatment between laypeople and dental professionals; with orthodontists recommending treatment significantly more often than general dental practitioners or laypeople (Prahl-Anderson et al., 1979). Interestingly there is also a difference in perceived orthodontic treatment need between professional groups (Bell et al., 1985). Although orthodontists and surgeons assessed profiles similarly, when looking at facial aesthetics alone, without assessment of occlusal relationships, surgeons recommended surgical treatment need significantly more.

1.3.3 Influence of exposure to pre-treatment photographs on perception of profile

Pretreatment photographs are used in the assessment, diagnosis and treatment planning of orthognathic cases. These photographs can be a useful aid for communication with the patient (Sarver et al.,1988; Sarver,1996).

Participants exposed to their own pretreatment profile photographs have been shown to have a reduction in satisfaction with their facial appearance post viewing (Bonetti et al., 2011). As a result patients were more likely to be willing to undergo treatment to change their appearance. The effect was significant, with 50% of the study group experiencing a decrease in satisfaction in their profile and an increase of 34% of participants willing to undergo surgery to change their profile as a result. Whereas in the control group, who were not shown their pretreatment profile photograph, there was no significant change in the outcome. The study concluded that laypeople generally are not aware of their facial profiles (Bonetti et al., 2011).

The 'mere-exposure' hypothesis (Zajonc, 1968) states that repeated exposure to a stimulus is required for an individual to sufficiently evaluate it. It would correlate that for patients to have an accurate perception of themselves or recognise themselves in lateral profile, this would require them to be familiar with this view. Mita et al. (1977) investigated the mere-exposure effect in relation to the self-perception of frontal facial images. Participants were given photographs representing a mirror image of themselves, and 'true' photographs of themselves, they expressed a preference for the mirror image. The study also assessed whether the friends of the participants preferred the mirror or true photographs of the participant; as suspected the friend preferred the true image over the mirror image.

1.3.4 The perceived need for surgery based on perception of profile

The perceived need for surgery has been shown to vary between clinicians and patients (Bell et al., 1985). In a study investigating this, an oral surgeon and orthodontist agreed, based on facial profiles, that a group of 80 patients were candidates for orthognathic surgery; 62% were skeletal class II and 9% skeletal class III. Despite the professional judgment that surgery would be required for these patients, only 40 of the patients (50%) had opted for surgery, with the remaining half of the sample declining surgical intervention. The patients who had decided against surgery perceived their profiles to be within the ‘normal’ range, based on a 9 point rating scale of facial outlines. Despite patients having a treatment need, recommended by professional opinion and cephalometric parameters, patients may still have a self-perception of normality which ultimately governs their decision making process (Vargo et al., 2003).

However, the validity of the study may be questioned, as the author’s report an “equal treatment need” based on cephalometric values. Whereas significant differences were reported in the mean ANB of the patient group undergoing surgical treatment, compared to those who decided against; with a mean ANB value of 5.8^{o} and 4.0^{o} respectively. Also noting the mean soft tissue AN-Pogonion angle to be greater in the orthognathic patient group, with a mean of 9.8^{o}, compared to 7.4^{o} in the non-surgical group. As such patients opting against surgery had smaller anteroposterior discrepancies and this could account for why they opted against surgery, as they were more likely to perceive themselves to be ‘normal’ on the ratings scales.

1.4 FACIAL DISHARMONY (Patients with a visible facial difference)

The incidence of individuals with a visible facial difference has been reported as 5% of the population in the United States (Vig and Ellis, 1990). The prevalence of ‘disfiguring’ dento-facial disharmonies possibly requiring orthognathic surgery in the

United States is around 2% of the population (Profitt et al., 1998; Hupp et al., 2019). In the United Kingdom, Brook and Shaw (1989) reported 5-19% of adolescents presenting for orthodontic assessment had a malocclusion that was significantly severe, that it could not be treated with orthodontics only; as such potentially needing orthognathic surgery. The British Association of Oral and Maxillofacial Surgeons reported 2718 orthognathic surgeries were performed in England in 2012, in a population size of approximately 53 million. Many authors agree that there is a sparsity of accurate evidence reporting the prevalence of dento-facial deformity and the incidence requiring orthognathic surgery; believing current statistics may be an underestimation (Naini and Gill, 2017, Hupp et al., 2019).

1.5 SURGICAL TECHNIQUES

Surgical correction varies dependent on the aetiology of the dento-facial deformity. Examples of surgical techniques include - Le fort I osteotomy, sagittal split osteotomy and bimaxillary osteotomies.

A Le Fort I osteotomy is indicated for the correction of maxillary position, mainly in the anterior-posterior and vertical directions. The maxilla can be advanced forwards, by separating the maxilla from the skull base, zygomatic buttress and pterygoid plates. In cases of vertical maxillary excess, the maxilla can be impacted anteriorly; and conversely posterior impaction can be utilised for the correction of anterior open bites.

Bilateral sagittal split mandibular osteotomies are undertaken to correct retrognathic mandibles, mandibular prognathism and mandibular asymmetries. For example, the treatment of a severe skeletal class II relationship may be treated with mandibular advancement surgery; patients with a severe class III may require a mandibular set back. Repositioning of the bony segments is guided by a pre-fabricated occlusal wafer, which indicates the intermediate and planned final position of the jaw bones following the surgical movements. The bone segments are then fixated and stabilised with cortical plates and screws. Patients will be monitored during the healing and recovery period and return for post-surgical orthodontics for finishing and detailing of the occlusion (Cunningham and Johal, 2015; Hupp et al., 2019).

1.6 PROFILE PREDICTION PLANNING

1.6.1 History of profile prediction planning

Prior to carrying out orthognathic surgery a detailed clinical history, assessment and series of special investigations are essential to reach the correct diagnosis and resulting treatment plan. Ideally this relies on creating a “virtual patient” which allows confirmation of the plan and rehearsal of the procedure. The aim of the virtual patient is take the individual components parts i.e. the skeletal, soft tissues and dental tissues, and combine them together to allow planning to take place. The conventional method of predication planning is an augmentation of profile prediction planning and model surgery. The profile prediction plan allows prediction of the hard and soft tissues, as well as the occlusion, only in two dimensions - in the anterior-posterior and vertical directions, but not in the transverse direction. ‘Model surgery’ is undertaken, translating the movements of the photo-cephalometric prediction to the dental casts. This model surgery indicates the planned dental and skeletal surgical movements. However, this model set up does not relate back to any soft tissue change that will occur.

The first reported method of planning used, manual manipulation of line drawings obtained from acetate tracings (McNeil et al., 1972). The hard tissue segments were moved to simulate the potential surgical treatment. The soft tissue profile would then be predicted using accepted ratios that translated the effect of skeletal repositioning to the degree of soft tissue change. This technique produced a prediction given in the form of a simple line drawing of the predicted soft tissue outline, with no soft tissue texture. It also had the disadvantage of being time consuming and technique sensitive (Harradine and Birnie, 1985).

The next advancement superimposed black and white photographs over the cephalogram and was known as 1:1 prediction planning (Henderson, 1974). This technique involved taking a profile photograph and a lateral cephalogram. The profile photograph was then rescaled to match the lateral cephalogram and the two were superimposed manually. Following this, the skeletal tissue on the cephalogram was cut (with scissors) and repositioned based on the clinical assessment, into the "correct" position. Then the overlying profile soft tissue photographic image was cut into the appropriate sections e.g. upper lip, lower lip and chin. These would then be repositioned according to the underlying hard tissue changes based either on the surgeons' experience of the anticipated changes or on ratios based on the literature. The loose sections would be stuck down with adhesive tape and the final "collage", complete with gaps, would be shown to the patient. However, both methods had their limitations; the accepted ratios for soft tissue change do not account for individual variation in soft tissue thickness and tonicity (Sinclair et al., 1995). Whilst crude manipulation of photographic segments resulted in gaps and step defects in the image generated (Henderson, 1974; Sarver, 1996); as well as poor representation of how soft tissues would change in response to the hard tissue adjustments (Proffit and Epker, 1980). This method was based on “cut and paste” and over time the adhesive would deteriorate meaning it was often not possible to go back after some time to audit or change the prediction.

Early computer technology, and digital cephalometry allowed single line profile outlines of the soft tissue to be “morphed” with the underlying hard tissue changes, based on computer algorithms. Sarver (1996) stated that “*whilst these profile outlines may prove useful to surgeons and orthodontists, they may hold little ‘cognitive value’ to patients”*. Highlighting the fact that patients are not familiar with seeing their profiles redacted and reduced to a simple outline tracing.

1.6.2 Patient Involvement in prediction planning

Further advances in video-imaging enabled the superimposition of colour digital lateral profile photographs with digital lateral cephaolgrams. As with conventional 1:1 planning this allowed movement of the hard tissue with the overlying soft tissues. This time in a digital environment, allowing real-time morphing of the soft tissue without the need to “cut and paste”. These photo-cephalometeric simulations were easier for patients to comprehend than a single facial outline (Sinclair et al., 1995; Sarver, 1996). The use of imaging technology in the discussion of treatment plans and the counselling of patients was reported to have a number of advantages. These included improved soft tissue profile planning prediction, increased and more precise clinician to patient communication in a way that verbal description alone could not achieve (Sarver, 1996).

Anecdotally surgeons are reluctant to show patients, their post surgery predictions, as it is reportedly believed this may result in unrealistic expectations and subsequent dissatisfaction if the prediction exaggerates the possible outcome; or if this outcome is not achieved post treatment (Sarver et al., 1988). This assumption has not been formally proven; although Sarver et al. (1988) found patients did report heightened aesthetic expectations after seeing their imaging predictions. Although these results should be viewed with caution owing to a small sample size.

Sarver (1996) described surgical patients as ‘very motivated’ toward knowing their likely appearance after surgery. The evidence shows, contrary to the surgeon’s concerns, that where surgery had been planned with ‘video imaging technology’, 89% of post surgery patients reported that they felt the prediction was realistic and the ‘desired result’ had been achieved (Sarver et al., 1988). Involving patients in the treatment planning process, including discussion of treatment options has been shown to increase patients’ acceptance of the outcome (Sinclair et al., 1995). In patient groups where the surgical prediction images had not been shared approximately 45% reported satisfaction (Kiyat et al., 1991) compare to 89% in the patient group who had been shown the prediction (Sarver et al., 1988). This would suggest that involving patients in the process and sharing the surgical prediction may instead better manage their expectations. The predictions have a role as a communication tool to illustrate to patients the surgical plan. It has been suggested that treatment should not begin until all the treatment options and expected outcomes have been discussed (Vig and Ellis, 1990). However, this relies on the assumption that patients accurately recognise their own lateral profile view and that the prediction plans are valid and accurate as a starting point for the conversation.

1.6.3 Validity and accuracy of photo-cephalometric planning

The validity and accuracy of the prediction plans will in part be determined by how accurately the investigations that inform the treatment plan are performed and interpreted. Cephalometric radiographs are obviously key to photo-cephalometric planning, but they are prone to error. These errors may occur during cephalometric analysis for multiple reasons; for example, incorrect head position (Houston, 1986; Malkoc et al., 2005), landmark validity (Houston, 1983) tracing method (Sandler, 1988; Chen et al., 2004; Sayinsu et al., 2007; Naoumova and Lindman, 2009) and clinician experience (Baumrind and Frantz, 1971; Gravely and Benzies, 1974).

Since photo-cephalometric planning predictions are just one element in the formulation of an orthognathic treatment plan, alongside clinical examination and use of articulated study models, the impact of errors in cephalometric analyses on treatment outcome can not be accurately determined in isolation (Durao et al., 2015).

1.6.4 Accuracy of two-dimensional (2D) photo-cephalometric soft tissue predictions

The accuracy of two-dimensional computer-generated photo-cephalometric surgical soft tissue predictions has been investigated by comparing post-surgical outcomes, with pre-surgical predictions. (Sinclair et al., 1995; Aharon et al., 1997; Mankad et al., 1999). These studies concluded that antero-posterior movements were predicted with greater accuracy than those in the vertical plane. (Sinclair et al., 1995; Aharon et al., 1997; Mankad et al., 1999; Pektas et al., 2007). Percentage errors in vertical movements were demonstrated to be approximately 12 times greater than in the horizontal plane (Aharon et al., 1997). Inaccuracies were seen in the prediction of soft tissue Pogonion and soft tissue Menton, with both being placed more superiorly than the patients' resulting surgical outcome (Mankad et al., 1999). It was reported that the greatest discrepancy in the predictions was seen to be in the labiomental fold (Sinclair et al., 1995).

When examining the computer-generated prediction of lip profile, it was shown that a more retrusive and thinner lower lip was predicted, than was actually achieved. (Sinclair et al., 1995). For 20% of the predictions a discrepancy of over 2mm was observed, which would be deemed clinically significant. Multiple studies have found photo-cephalometric predictions to be inaccurate at determining the lower lip position. With this consistently being reported as the soft tissue region showing the greatest discrepancy between predications and the post-surgical result (Sinclair et al.,1995; Lu, 2003; Pektas et al., 2007,).

With regards to the chin (soft tissue Pogonion) 71% of predictions were deemed to be accurate/acceptable if undertaking mandibular advancement only (Sinclair et al., 1995). This figure decreased to 53% with the addition of a genioplasty procedure. However, the results of this study should be viewed with caution as they employed a subjective grading system, simply ranking the similarity between the pre-treatment prediction and post treatment outcome as poor / fair / good / very good / excellent, rather than using an objective linear measure.

1.6.5 Limitations of two-dimensional photo-cephalometric planning

Lateral cephalograms may be of limited value in the planning of surgery for patients with a facial asymmetry. These asymmetries cannot be clearly demonstrated in a lateral cephalogram. As such additional radiographic imaging is required, for example by the supplementation of posteroanterior cephalograms (Leonardi et al., 2008). However, these are still subject to error (Trpkova et al., 2003), whilst exposing the patient to further radiographic exposure. Investigation has shown where discrepancies have been found between the visual treatment objective predictions and the surgical outcome, this could be attributed to the surgical correction of asymmetries (Gossett et al., 2005). It was deemed that asymmetric surgical movements, be it setbacks or advancements cannot be accurately predicted due the limitations of two-dimensional planning.

Subsequent examination of photo-cephalometric predictions found their accuracy was limited to antero-posterior and vertical movements (Rustemeyer et al., 2010). The authors recommended that in planning transverse corrections/ transverse hard tissue movements, three-dimensional planning would be favourable

1.7 THREE-DIMENSIONAL (3D) PLANNING OF ORTHOGNATHIC SURGERY

Three-dimensional (3D) planning, also referred to as ‘computer-assisted surgical planning’, has been shown to improve predictions of orthognathic surgery outcomes (Lin et al., 2018). However, as yet, in the United Kingdom 3D orthognathic surgical planning has not been universally adopted (Cevidanes et al., 2010). During 3D planning, as with 2D photo-cephalometric planning, a surgical prediction is generated by the integration of records of the patient’s soft tissue morphology, hard tissues and dental relationship. However, the key difference being that these are all recorded in three dimensions (Xia et al., 2000; Ayoub et al., 2014).

Technological advances now allow capture of three-dimensional representations of the patient's soft tissue features and skeletal pattern reproducibly; with the use of stereophotogrammetry and cone beam computerised tomography (CBCT) (Ayoub et al., 2014). CBCT captures dental tissues, skeletal hard tissue and soft tissues simultaneously (Kim et al., 2013). The dental hard tissues may be of low or poor quality, due to scatter producing 'streak artefacts', commonly seen in the presence of metal restorations or appliances (Cevidanes et al., 2010; Stokbro et al., 2014). As such a three-dimensional virtual dental model needs to be obtained and aligned to replace the otherwise distorted dental tissues. To capture and register the dentition there are various protocols described in the literature. These include a CBCT scan undertaken of the patient with occlusal registration devices in situ (Nairn et al., 2013); the 'triple scan procedure', which involves additional CBCT exposure (Swennen et al., 2009); intra oral scans of the dentition (Hernandez-Alfaro and Guijarro-Martinez, 2013); in addition conventional plaster models may also be CBCT or laser scanned (Stokbro et al., 2018).

Stereophotogrammetry or laser scanning replaces the extra oral photographs used in conventional 2D planning, capturing a three-dimensional photorealistic representation of the soft tissues (Ayoub et al., 1998). 3D stereophotogrammetry has the advantage over laser scanning of reduced motion artifacts (Dindaroglu et al., 2016). This is required as CBCT imaging does not produce a skin coloured / textured image (Benington et al., 2010). Superimposition of the photorealistic stereophotogrammetry image aids visual assessment, interpretation and patient communication.

Previous studies have investigated the accuracy of three-dimensional surgical planning, comparing predictions to the post-surgical result. However, it is difficult to draw conclusions on the accuracy of 3D surgical planning, due to variances in surgical protocol e.g. single jaw vs bimaxillary surgery; methods of superimposition; the variety of software programs, each have differing software algorithms, with varying degrees of accuracy; the outcome measure of accuracy varies between studies, some looking at the resultant position of hard tissue structures comparative to the predictions, whilst others compare soft tissue form (Stokbro et al., 2014).

1.8 VIEWING IMAGES IN THREE DIMENSIONS

The human face is three dimensional, as such it correlates that this information should be seen in 3D (Dindaroglu et al., 2016). Research has found that viewing facial characteristics in a 3D format, as opposed to 2D images is also the preferred method among clinicians; as it was deemed to provide greater clinical information (Zhu et al., 2018).

Facial asymmetry cannot be accurately assessed and surgically planned with two-dimensional photo-cephalometric profile planning (Gossett et al., 2005; Rustemeyer et al., 2010; Cevidanes et al., 2010); nor can it predict post-surgical soft tissue changes from a frontal view (De Riu et al., 2018). In conventional 2D planning posterior-anterior cephalograms are used to assess facial asymmetry relative to the midfacial axis or mid sagittal plane (Cevidanes et al., 2010). However, the validity of this has been called into question (Ferrario et al., 1994; Garrahy, 2002). It was found that landmarks used to denote the mid facial plane, for example Nasion, Subnasale, Labrale Superius, Labrale Inferius, did not actually lie on the midline, and as such the assumption could not be made that using these points would divide the face into two equal halves; nor could they be deemed to represent an 'axis of symmetry' (Ferrario et al., 1994; Garrahy, 2002). As well as this, measuring facial asymmetry by medio-lateral deviation to a midfacial plane does not fully represent the extent of three-dimensional morphometric issues apparent in facial asymmetry (Hajeer et al., 2004). Clinicians are familiar with viewing two-dimensional patient photographs, however the process of viewing 3D images and using these for assessment and diagnosis, cannot be assumed to be the same (Zhu et al., 2017). Capturing patients in 3D, but then viewing them in a 2D format on a screen may result in a degradation of the available information, such as depth perception; alteration in size projection; variations in texture gradient and distortion in lighting and shading (Zhu et al., 2017).

These problems can be overcome, rather than rendering the 3D image into a 2D viewing format resulting in monocular visual cues; use of 'stereoscopic viewers' can simulate binocular vision and 3D projection (Volbracht et al., 1996; Held and Hui, 2011). Zhu et al. (2017) found that assessment of facial characteristics that are not depth dependent such as proportions of facial height, do not show clinically significant variation in reliability between being viewed in 2D or in 3D projections. However, assessment of features that require perception of depth, such as facial profile retrusion/protrusion are more reliably undertaken with 3D stereoscopic projection. A disadvantage of this method would be the increase in equipment required, and the associated costs.

1.9 SUMMARY OF LITERATURE REVIEW

Patients seek orthognathic surgery for aesthetic and functional concerns. Individuals with a visible facial difference were generally found to have a lower body image and ‘facial body image’ (Cunningham et al., 2000). Following surgical treatment there is a positive effect on the quality of life for these individuals (Lee et al., 2007; Ryan et al., 2012). From a clinical perspective a full three-dimensional assessment of the facial form is undertaken. However, from a surgical planning perspective the lateral facial profile is at present the standard view. The profile view of the face is a view clinicians are very familiar with; whilst frontal mirrored views are the most “recognised” view for lay individuals. There has been some debate in the literature regarding the ability of an individual to recognise their facial profile. The attractiveness of an individual’s facial profile is to some extent subjective and depends on who is viewing the image, layperson or professional? In addition age and exposing individuals to their own pretreatment profile photographs has been shown to coincide with a reduction in satisfaction with their facial appearance post viewing (Bonetti et al., 2011). All these factors will have an effect on the perceived need for surgery between clinicians and patients (Bell et al., 1985).

Surgeons are anecdotally reluctant to show patients, their post surgery predictions, as it is reportedly believed this may result in unrealistic expectations and subsequent dissatisfaction (Sarver et al., 1988). This however needs to be weighed against the need for “informed consent”. Especially given the elective nature of orthognathic surgery and the risks involved.

At present the two-dimensional profile prediction is the most common method of planning and potential patient communication. For the 2D profile prediction to be a valid tool for patient commination, the premise must be that patients know what they look like in profile pre-treatment. If they do not know what they look like in profile i.e. the severity of their facial disharmony, basing a discussion and informed consent around the post-surgical prediction will be of limited value.

CHAPTER 2

AIMS AND NULL HYPOTHESIS

2.1 AIMS OF THE STUDY

The primary aim of this study was to investigate whether pre-operative class III patients have an accurate perception of themselves in profile. This was determined by whether participants could accurately identify the position and severity of their facial dysmorphology; recreating this by manipulation of 2D profile photographs on two occasions. This was defined as patients being able to reproduce

- the horizontal position (x) of the upper lip (Labrale superious, Ls).
- the horizontal (x) and vertical (y) position of the chin - soft tissue pogonion (Pogonion, Pog).

The outcome measures were:

1. The difference in linear horizontal distance (mm) between the patient-perceived position of the upper lip (Labrale superious) and the actual position of their upper lip.
2. The difference in linear horizontal distance (mm) between the patient-perceived position of the chin (Pogonion) and the actual position of their chin.
3. The difference in linear vertical distance (mm) between the patient-perceived position of the chin (Pogonion) and the actual position of their chin.
4. The linear relative horizontal difference (mm) between the patient-perceived position of the lip-chin relationship and the actual lip-chin relationship.
5. The linear relative vertical difference (mm) between the patient-perceived position of the lip-chin relationship and the actual lip-chin relationship.

Differences of 3.0mm and greater were deemed to be clinically significant.

The study also aimed to determine whether patients would prefer to see a three-dimensional reconstruction (rather than a 2D profile view) when treatment planning orthognathic surgery. As well as whether patients would be willing to accept an increased radiation exposure to facilitate seeing themselves in 3D.

2.2 NULL HYPOTHESIS

There were no statistically significant differences ($p<0.05$) in the absolute mean difference in patient-perceived horizontal and vertical positions of the upper lip (Labrale superious) and chin (Pogonion) and the actual position of their upper lip and chin. Any differences would not be 3.0mm or above, and therefore would not be of clinical significance.

CHAPTER 3

MATERIALS AND METHODS

3.1 ETHICAL APPROVAL

Approval for this study was granted by the Health Research Authority (IRAS No: 231259). The research protocol was given approval from the University of Birmingham.

3.2 STUDY PARTICIPANTS

This was a prospective cross sectional study of adult patients with a Class III dento-facial malocclusion, who were attending the joint orthodontic-orthognathic multidisciplinary clinics, between July 2018 and November 2019, at the Birmingham Dental Hospital. Patients who met the inclusion criteria were invited to participate in the study. The inclusion criteria for the study were as follows:

- Clinically confirmed diagnosis of Class III profile having undergone a full orthodontic assessment.
- Planned for joint orthodontic and orthognathic surgical treatment following agreement on a joint orthodontic-orthognathic multidisciplinary clinic.
- Patients aged between 17 and 55 years of age.
- Standardised clinically acceptable lateral cephalogram and right lateral profile photograph, taken at the same time point.
- Competent to consent.
- English speaking.
- Non-syndromic.

The exclusion criteria for in the study were as follows:

- Unwilling to participate in the study.
- Post orthognathic surgical correction.
- Poor quality cephalogram.
- Dense facial hair or beard that would prevent accurate plotting of the underlying soft tissue profile.

The following clinical information was recorded:

- Presenting malocclusion (*Skeletal pattern, incisor relationship, OJ/ROJ, SNA, SNB, ANB, MMPA, LFH)*
- Provisional surgical plan

3.3 SAMPLE SIZE CALCULATION

To obtain a significance level of $\alpha = 0.05$ with a power of 80%, using a standard deviation of 4.5mm a minimum of 20 patients would be necessary to detect a clinically significant difference of 3.0mm (Jones et al., 2007).

3.4 MATERIALS AND METHODS

A computer software package, Computer-Assisted Simulation System for Orthognathic Surgery (CASSOS) (SoftEnable Technology Ltd., Hong Kong) was used to produce a morphable profile image for each patient. CASSOS was originally developed for orthognathic surgery prediction planning and allowed manipulation of the maxillary and mandibular skeletal bases to produce a soft tissue profile prediction. In this study patients were able to manipulate the hard tissue, which they could not see, to produce a soft tissue profile they could easily visualise.

To produce a morphable image in CASSOS the following steps were necessary:

1. *Lateral cephalogram uploading and digitisation.*
2. *Right lateral portrait photograph uploading and digitisation.*
3. *Lateral cephalogram and portrait photograph "matching".*

3.4.1 Lateral cephalogram uploading and digitisation

Lateral cephalograms were quality assured and met the following criteria:

- Correctly positioning with Frankfort Plane parallel to the floor.
- Lips in repose.
- Teeth in intercuspal position (ICP).
- Appropriate contrast and brightness to facilitate location of landmarks.

Lateral cephalogram radiographs were obtained prospectively during pre-treatment record collection, as part of the patients' routine care, for diagnosis and treatment planning. No additional ionising radiation exposures were undertaken for the purposes of this study. The standardised lateral cephalograms were downloaded from a picture archiving and communication system (PACS) and re-sized to maintain the original aspect ratio/dimensions of the digital film (avoiding distortion, with an accepted 10% magnification); aspect ratio 0.84 using Adobe Photoshop (Adobe Photoshop v7.0, Adobe Systems Inc., USA). The radiographs were saved at 300dpi and 24-bit sRGB JPG file formats and uploaded into CASSOS. Seventy-one pre-determined hard and soft tissue landmarks utilised by CASSOS (Appendix 1) were identified on the lateral cephalograms to generate a 'tracing', Figure 3.1.

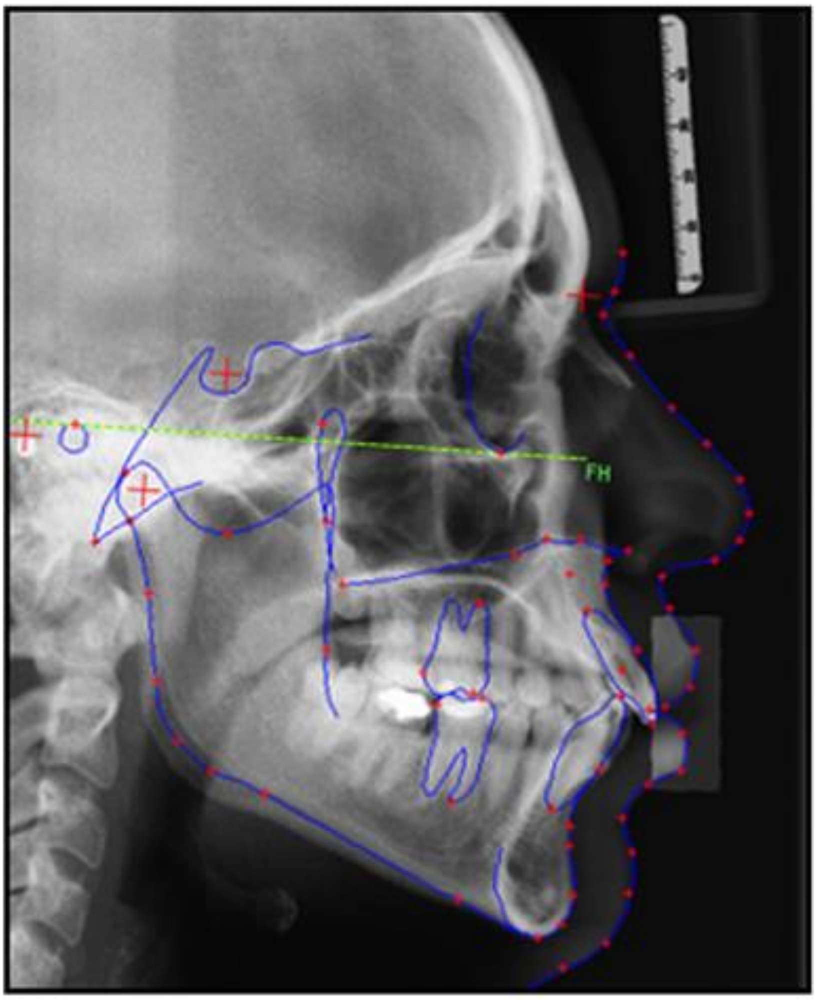

Figure 3.1 Lateral cephalogram seventy-one pre-determined hard and soft tissue landmarks utilised by CASSOS

The lateral cephalogram was exported from CASSOS and imported into Microsoft Paint (Microsoft Paint v1703, Windows 10. (2017) Microsoft Corporation, USA). A line was drawn from Subnasale posteriorly and all informed below this line was replaced with a filled rectangle, Figure 3.2. All the visual information below this line was redacted to remove any indicators that would aid the patient in determining their profile. The redacted lateral cephalogram was uploaded back into CASSOS and replaced the original lateral cephalogram. This meant that when the “match” was opened in CASSOS the redacted lateral cephalogram would still be aligned with the profile photograph. In addition, outlines of the skeletal hard tissue and the dentition were removed from the tracing Figure 3.3. This again ensured that the patients could not use the bone or teeth as indirect cues to generate their perceived soft tissue profile.

3.4.2 Right lateral portrait photograph uploading and digitisation

The profile photographs, were downloaded from the hospital’s secure image data base and uploaded into Adobe Photoshop, saved at 300dpi 24-bit sRGB JPG file and uploaded into CASSOS. Twenty-eight pre-defined landmarks were identified on the lateral profile photograph (Appendix 2).

Lateral photographs were quality assured and met the following criteria:

- Correctly positioning with Frankfort Plane parallel to the floor.
- Lips in repose.
- Taken on the same day as the lateral cephalogram.
- No hair or obstructions which would prevent location of landmarks.

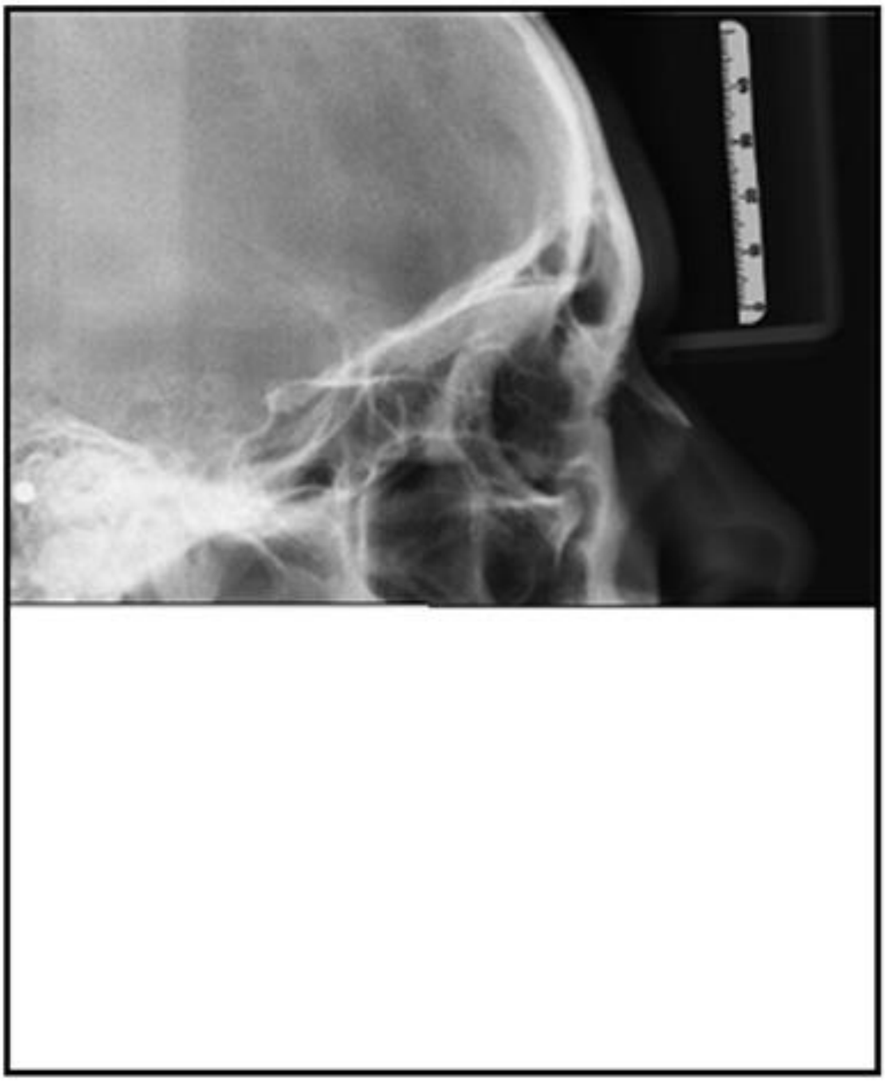

Figure 3.2 Lateral cephalogram redacted below Subnasale.

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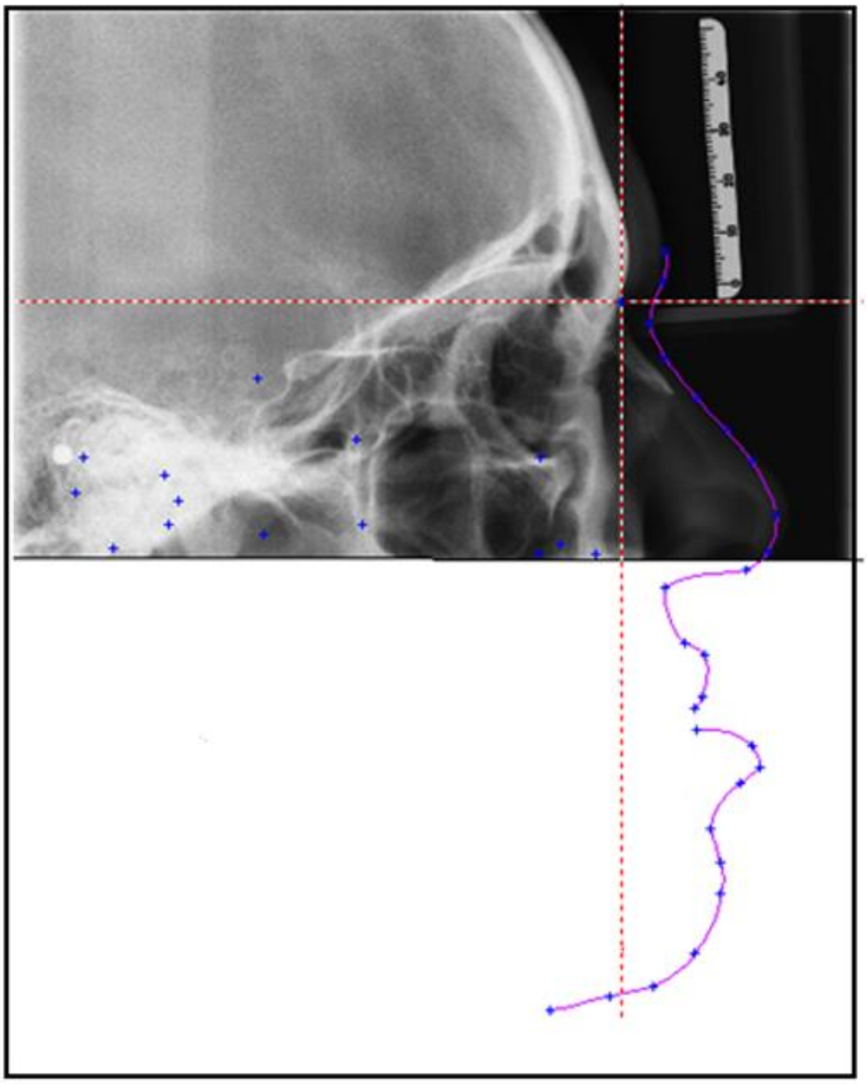


Figure 3.3 Lateral cephalogram redacted below Subnasale. showing soft tissue outline with hard tissue and dental structures removed.

3.4.3 Lateral cephalogram and portrait photograph “matching

Once landmarking of the both the lateral cephalogram and lateral photograph was completed CASSOS automatically generated a ‘matched image’, by superimposing the lateral cephalogram and profile photograph, Figure 3.4.

3.4.4 Patient generated profile

Prior to asking the patients to undertake the study they were told the outcome of their attempts would have no influence on their treatment or surgical plan and there was no time constraint for manipulating their image.

The patient’s matched image was loaded into CASSOS, which had been installed on a Dell Latitude 3340 Intel Core i3 13.3’ screen Laptop (Dell). The soft tissue profile was morphed using the CASSOS surgical planning tools. For standardisation and consistency, the starting point of each soft tissue profile outline was altered by the same amount. Each lateral cephalogram was manipulated so the mandibular skeletal tissue was translated anteriorly horizontally (x-axis) by +10mm and vertically/inferiorly (y-axis) by +10mm. The maxillary skeletal tissue was translated horizontality posteriorly by -10mm. With these hard tissue changes CASSOS repositioned the soft tissue outline appropriately, Figure 3.5. The first image the patients saw of themselves was the altered image, they never saw their actual profile image at any point in the study.

Patients were shown a demonstration of the process they would be undertaking using a mock profile of the researcher (SF). They were shown how to manipulate the profile soft tissue using the keyboard arrow keys. The patient was asked to

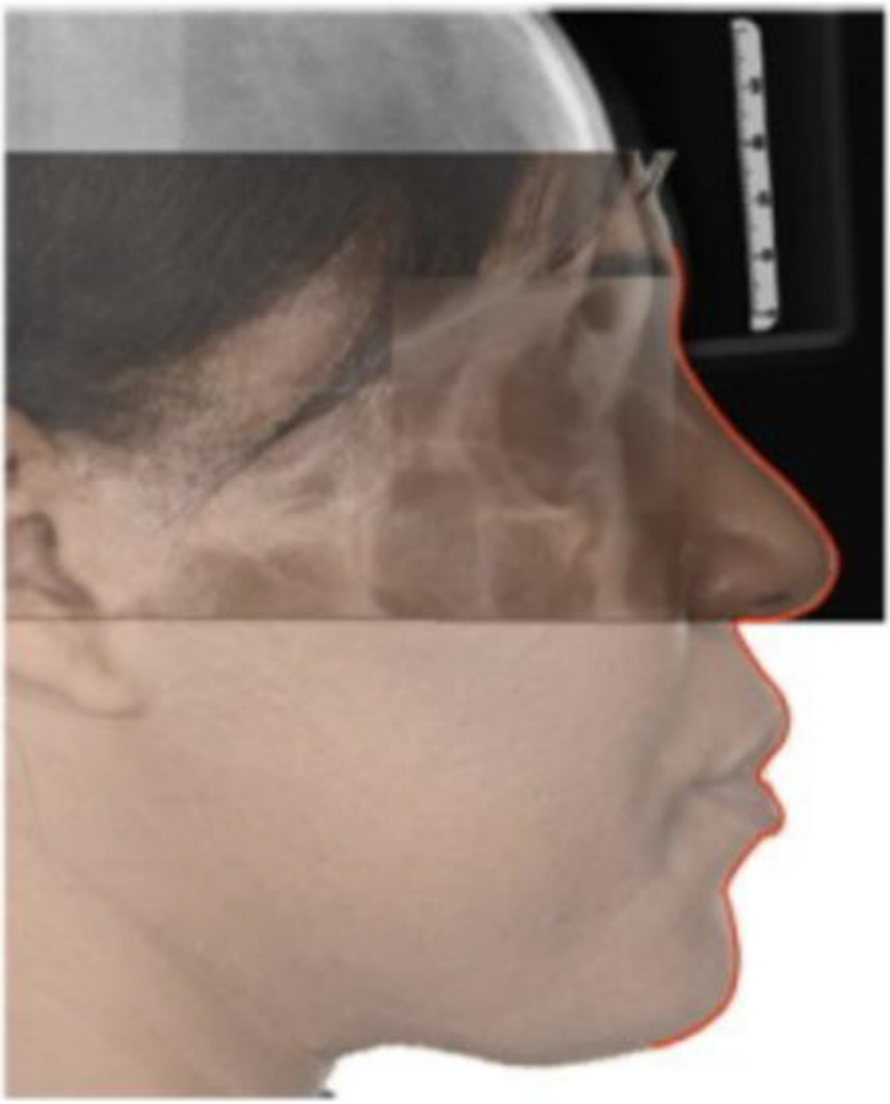
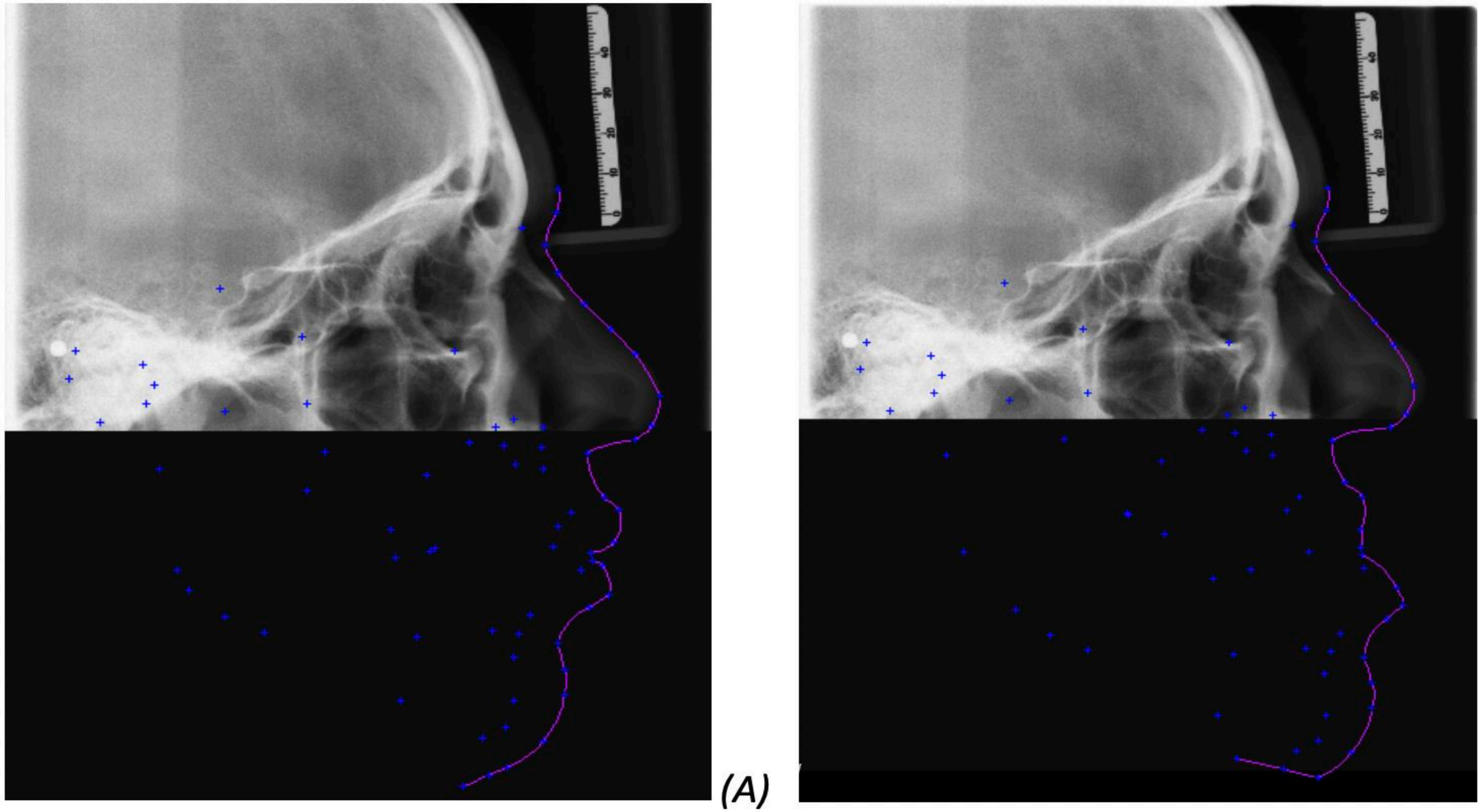


Figure 3.4 Lateral cephalogram and portrait photograph “matching” - Matched lateral cephalogram with the lower half redacted and soft tissue profile (red line) with right profile photograph superimposed



(A) (B)

Figure 3.5 (A) Traced lateral cephalogram landmarked (blue crosses), generating a soft tissue profile outline (purple line) for a non class III individual used in demonstration.

(B) Lateral cephalogram showing distorted soft tissue profile outline; the mandible is repositioned anteriorly and inferiorly (+10mm along both X and Y axis), the maxilla is translated posteriorly (-10mm on X axis).

manipulate the profile outline visible on screen, until they felt it resembled their current soft tissue profile. Patients were informed that they could move the upper lip “backward and forwards” using the keyboard arrow keys. The lower lip and chin would move simultaneously, and could be moved “backwards and forwards, up and down” using the arrow keys. The alterations made to the soft tissue outline produced a ‘simulation’ lateral profile image of the patient. Once the patient was happy with the simulation image they were asked to confirm that they thought this was an accurate representation of their current facial profile, Figure 3.6. Patients were instructed that they could make further adjustments as many times as they felt necessary, until they were satisfied the simulation image was accurate and represented their current profile.

The operator remained present only to assist in using CASSOS. Once the patient had started to manipulate their profile image, only set questions were asked, so as not to introduce any bias. For example, once shown the simulation, the patient would only be asked “Do you think this is an accurate representation of your profile”, “would you like to make any further changes”. Once the patient was satisfied with the soft tissue profile it was saved within CASSOS (T_1). The initial altered image was then reloaded into CASSOS.

Following a 15 minute break each patient was asked to repeat the procedure and the second ‘simulation’ lateral profile image saved (T_2). This particular version of CASSOS had been modified by the developers to record the changes of all 71 landmarks in the x (horizontal) and y (vertical) direction relative to Nasion (0, 0). It was therefore possible to determine the differences in specific landmarks in the x

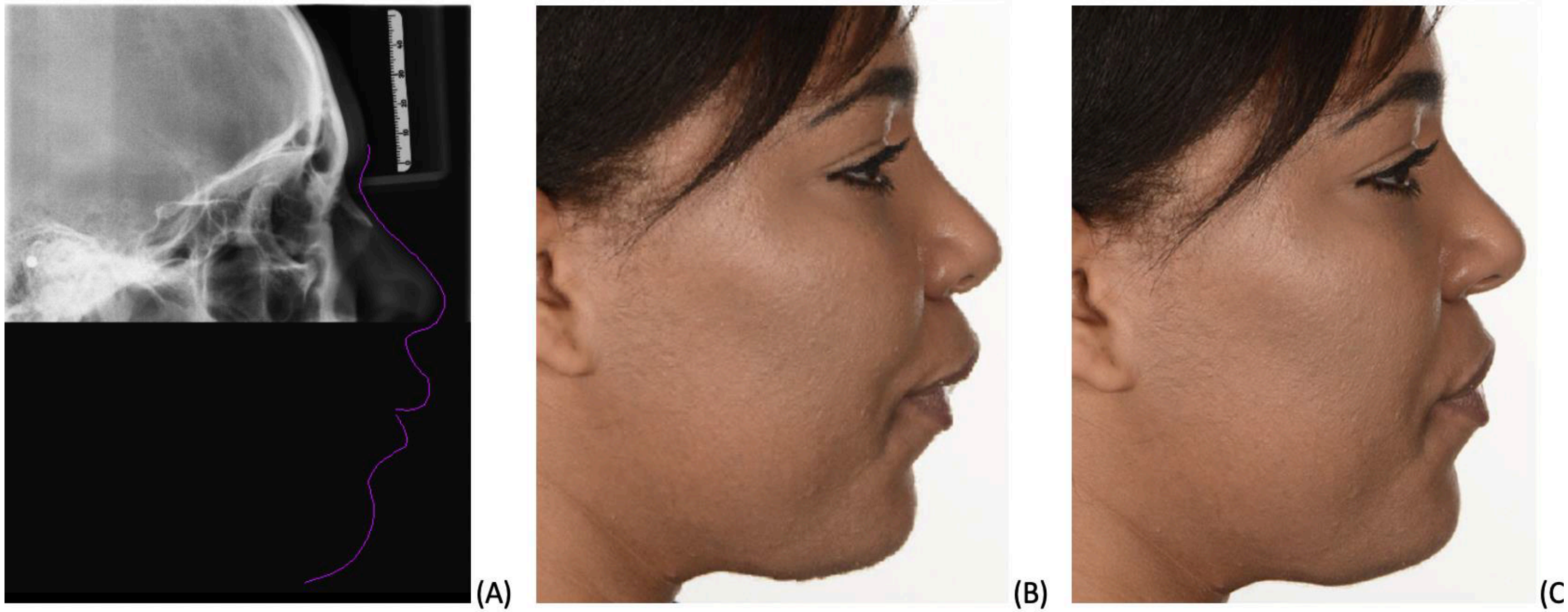


Figure 3.6 (A) Lateral cephalogram showing patient manipulated soft tissue profile outline
(B) Resultant 'simulation' of profile, based on the patient-perceived appearance of the soft tissue profile outline.
(C) Right lateral photograph, to demonstrate how the simulation compares to the original.

and y directions between the original (actual) patient profile and their perceived profile. For instance, the greater the differences in linear measurements in Labrale superious (Ls) and Pogonion (Pog), the greater the inability of the patient to place their upper lip and chin in the correct position. A negative value indicates the patient perceived landmark is more posterior or more superior in the x and y direction respectively, than the actual cephalometric landmark. A positive value indicates the patient perceived landmark is more anterior or more inferior in the x and y direction respectively, than the actual cephalometric landmark.

Each patient was asked to anonymously answer questions 1 and 2 of the self-completed 'Participant Questionnaire' (Appendix 3). This was completed on the clinic at the time of participation in the study.

Question 1. Would you find it more helpful to see a 3D image of your face or a 2D profile image during the surgical planning stage?

Question 2. Do you think the extra radiation exposure during the 3D scan (CBCT) would be "worth it" if it allowed you to see yourself in 3D before surgery?

3.5 ANALYSIS

The linear difference in absolute distance between the patient derived landmarks and the actual cephalometric landmark position were calculated, in both the X axis and Y axis.

The outcome measures were:

1. The difference in linear horizontal distance (mm) between the patient-perceived position of the upper lip (Labrale superious) and the actual position of their upper lip.
2. The difference in linear horizontal distance (mm) between the patient-perceived position of the chin (Pogonion) and the actual position of their chin.
3. The difference in linear vertical distance (mm) between the patient-perceived position of the chin (Pogonion) and the actual position of their chin.
4. The linear relative horizontal difference (mm) between the patient-perceived position of the lip-chin relationship and the actual lip-chin relationship.
5. The linear relative vertical difference (mm) between the patient-perceived position of the lip-chin relationship and the actual lip-chin relationship.

Differences in Labrale superious (Ls) and Pogonion (Pog), in the x and y directions, between the actual patient profile and their perceived profile were extracted relative to Nasion (0, 0). The data was tested for normality and found to be normally distributed based on the Anderson-Darling test.

To determine intra-patient reproducibility, the anterior-posterior (AP) and vertical position of Labrale superious (Ls) and Pogonion (Pog) were assessed for the two attempts using the Intraclass Correlation Coefficient (ICC).

A paired Students t-test was used to determine if the mean differences, in the anterior-posterior (AP) direction, between the actual upper lip position (Ls), and the patient-perceived upper lip position, was statistically significantly different ($p<0.05$). In addition a paired Students t-test was used to determine if the mean differences, in the AP direction, between the actual chin position (Pog), and the patient-perceived chin position, was statistically significantly different ($p<0.05$). This was repeated for Pogonion in the vertical direction.

To test for clinical significance, a one-sample t-test was performed to determine whether the actual and perceived lip and chin position, in both the AP direction and vertical directions were greater than 3.0mm, based on the absolute mean difference. A Bland Altman analysis was also carried out to show the bias and levels of agreement (LoA) between the mean differences in actual upper lip and chin position and patient-perceived position in the anterior-posterior (AP) direction and vertical directions. The Bland Altman analysis reports the direction of the bias between mean differences (Giavarian, 2015), showing the trend of the data, and quantifying the agreement between two quantitative measurements (Bland and Altman, 1999).

The results from the questionnaires were collated and analysed.

CHAPTER 4

RESULTS

4.1 RESULTS

4.1.1 Demographics of the sample

Participants were recruited between July 2018 to November 2019 at Birmingham Dental Hospital. Volunteers were patients recruited from the joint orthodontic-orthognathic multidisciplinary clinic, planned for surgical correction of their class III dento-facial malocclusion, Table 4.1. All patients took part in the study pre-treatment.

In total twenty patients were included in the study, 13 males and 7 females. The patients' ages ranged from 16 to 35 years, with a mean age of 22.0 years.

4.1.2 Intra-patient reproducibility

The analysis of intra-patient reproducibility assesses the variation in measurements at different timepoints. This is used to demonstrate how well participants were able to repeat the profile reconstruction between attempts (T_1 – T_2). Reproducibility was assessed by examination of the landmarks for perceived upper lip horizontal position and perceived chin, both horizontal and vertical co-ordinates.

The intra-patient reproducibility for perceived upper lip (Ls), chin (Pog) horizontal and vertical position, were found to be excellent (Koo and Li, 2016), as shown by an intra-class correlation coefficient score range of 0.93 to 0.98. Based on a paired t-test the mean differences in upper lip antero-posterior (AP), chin AP and vertical position between the two attempts (T_1 – T_2) were not statistically significantly different, Table 4.2. Therefore, the measurements at both attempts for each group were averaged.

Cephalometric values	Mean value	SD
SNA (°)	79.2	3.4
SNB (°)	83.1	3.7
ANB (°)	-4.0	2.8
MMPA (°)	27.2	8.0
Wits (mm)	-9.7	3.2

Table 4.1 Shows the mean values of the sample's presenting skeletal features.

Landmark	Mean Difference (mm)	SD (mm)	Absolute Mean Difference (mm)	SD (mm)
Ls (AP)	0.9	2.7	1.8	2.1
Pog (AP)	0.2	3.2	2.2	2.2
Pog (Vertical)	-0.2	2.3	1.8	1.4

Table 4.2 Shows the mean differences and absolute mean differences for the landmark positions between attempts ($T_1 - T_2$).

4.2 UPPER LIP POSITION

4.2.1 Horizontal direction

The mean actual AP position of the upper lip (Ls), relative to Nasion, was 13.4 ± 3.2mm, whilst the mean patient-perceived position was 11.1 ± 4.0mm, Table 4.3. The mean difference in the horizontal position of the upper lip was -2.3 ± 3.0mm. The upper limit of the 95% confidence interval for the mean difference was -0.9mm, and -3.7mm for the lower limit. The mean difference of the actual AP position of the upper lip and the patient-perceived position was statistically significant (p=0.001), Table 4.4.

The absolute mean difference between the actual position and the patient-perceived position of the upper lip (Ls) horizontally was 3.1 ± 2.2mm. The upper limit of the 95% confidence interval for the absolute mean difference was 4.1mm and 2.1mm for the lower limit. The absolute mean difference between the actual position and the patient-perceived position of the upper lip (Ls) horizontally was not statistically significantly different to 3.0mm (p=0.860), Table 4.4. The absolute mean difference was greater than 3.0mm, which would deemed clinically significant; but caution should be taken in the interpretation of this, as it was only marginally over the threshold set for clinical significance.

The Bland-Altman plot shows the bias towards under advancing the upper lip and producing a more retrusive upper lip, Figure 4.1. The wide limit of agreement from 3.7mm to -8.2mm indicates the large variability for patients to correctly identify their actual in upper lip AP position. The -3.7mm lower limit 95% confidence interval suggests that this difference could be clinically significant in the wider population.

Landmark	Actual position		Patient-perceived position	
	Mean (mm)	SD (mm)	Mean (mm)	SD (mm)
Ls (AP)	13.4	3.2	11.1	4.0
Pog (AP)	13.1	5.6	13.9	6.0
Pog (Vertical)	102.4	8.5	107.0	9.5
Ls – Pog (AP)	0.3	4.4	-2.7	5.4
Ls – Pog (Vertical)	-39.4	4.5	-43.8	6.3

Table 4.3 Landmark identification: the mean actual landmark position and the mean patient-perceived landmark positions (relative to Nasion 0,0).

Landmark	(Patient-perceived position) – (Actual position)									
	Mean Difference					Absolute Mean Difference				
	Mean (mm)	SD (mm)	95% CI for the difference (mm)		p-value	Mean (mm)	SD (mm)	95% CI for the difference (mm)		p-value
			Lower limit	Upper limit				Lower limit	Upper limit	
Ls (AP)	-2.3	3.0	-3.7	-0.9	0.001^	3.1	2.2	2.1	4.1	0.860
Pog (AP)	0.8	3.7	-0.9	2.5	0.811	3.1	2.0	2.2	4.0	0.811
Pog (Vertical)	4.7	4.2	2.7	6.6	0.001^	5.1	3.6	3.4	6.8	0.017*
Ls – Pog (AP)	3.1	3.9	-0.1	6.3	0.057	3.2	2.5	2.1	4.4	0.749
Ls – Pog (Vertical)	4.4	3.9	0.9	7.9	0.015^	4.4	3.9	0.9	7.9	0.015*

^ Following a paired Students *t*-test ($p<0.05$)
* Following a one sample *t*-test with a hypothesised mean of 3.0mm ($p<0.05$)

Table 4.4 The mean and absolute mean differences between the upper lip (Ls), chin (Pog) and lip-chin relationship (Ls – Pog), in the antero-posterior (AP) and vertical directions, between the actual patient profile and the patient-perceived profiles.

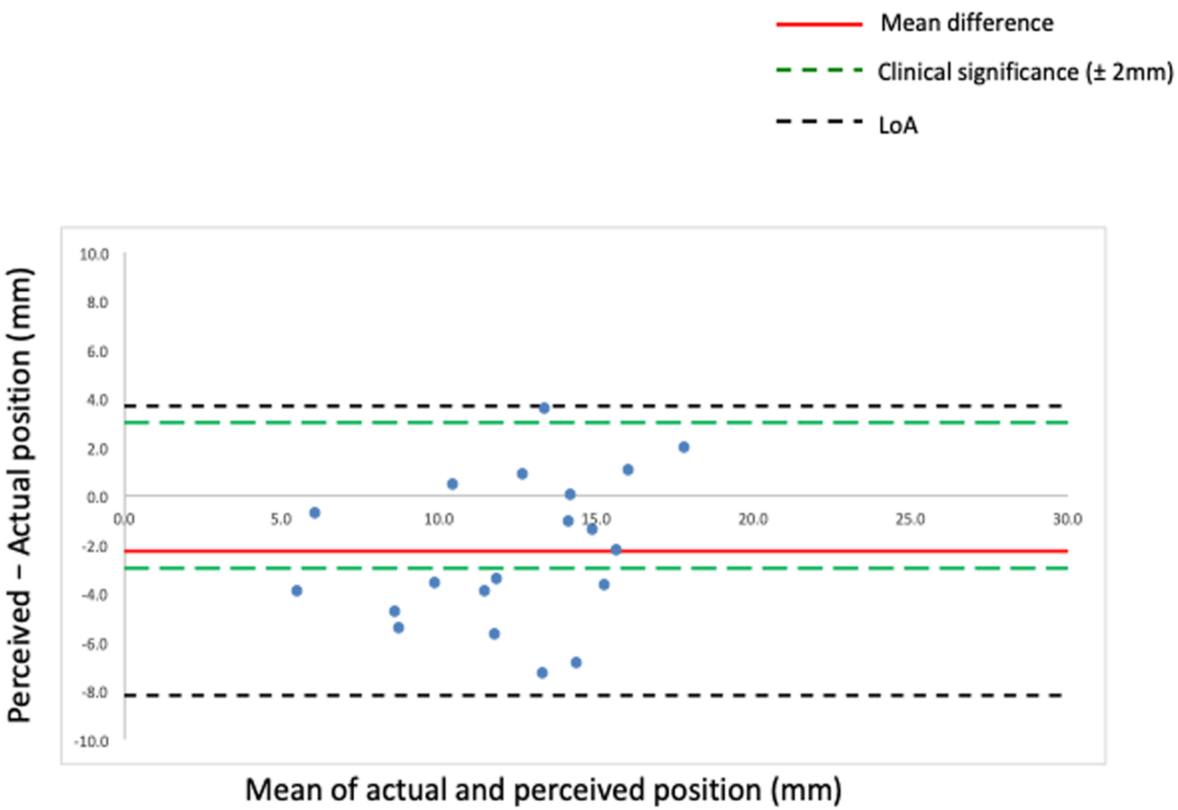


Figure 4.1 Bland-Altman plots for patient-perceived and actual antero-posterior upper lip (Ls) position.

4.3 CHIN POSITION

4.3.1 Horizontal direction

The mean actual AP position of the chin (Pog), relative to Nasion, was 13.1 ± 5.6mm, whilst the mean patient-perceived position was 13.9 ± 6.0mm, Table 4.3. The mean difference in the horizontal position of the chin was 0.8 ± 3.7mm. The upper limit of the 95% confidence interval for the mean difference was 2.5mm, and -0.9mm for the lower limit. The mean difference in the actual AP position of the chin and the patient-perceived position was not statistically significantly different (p=0.334), Table 4.4.

The absolute mean difference between the actual position and the patient-perceived chin (Pog) position horizontally was 3.1 ± 2.0mm. The upper limit of the 95% confidence interval for the mean difference was 4.0mm and 2.2mm for the lower limit. This absolute mean difference was not statistically significantly different to 3.0mm (p=0.811); however, it is over the threshold set for clinical significance. Again, this should be view with caution, given that it is only marginally over the threshold.

The Bland-Altman plot shows the bias towards over advancing the chin, producing a more protrusive chin position, Figure 4.2. The wide limit of agreement from 8.0mm to -6.3mm suggests a large variation in perceived AP chin position. Regarding anterior-posterior chin position, the mean actual position of soft tissue pogonion and the patient-perceived position were similar with the 95% confidence interval less than 3.0mm, suggesting that this difference may not be clinically significant in the larger population.

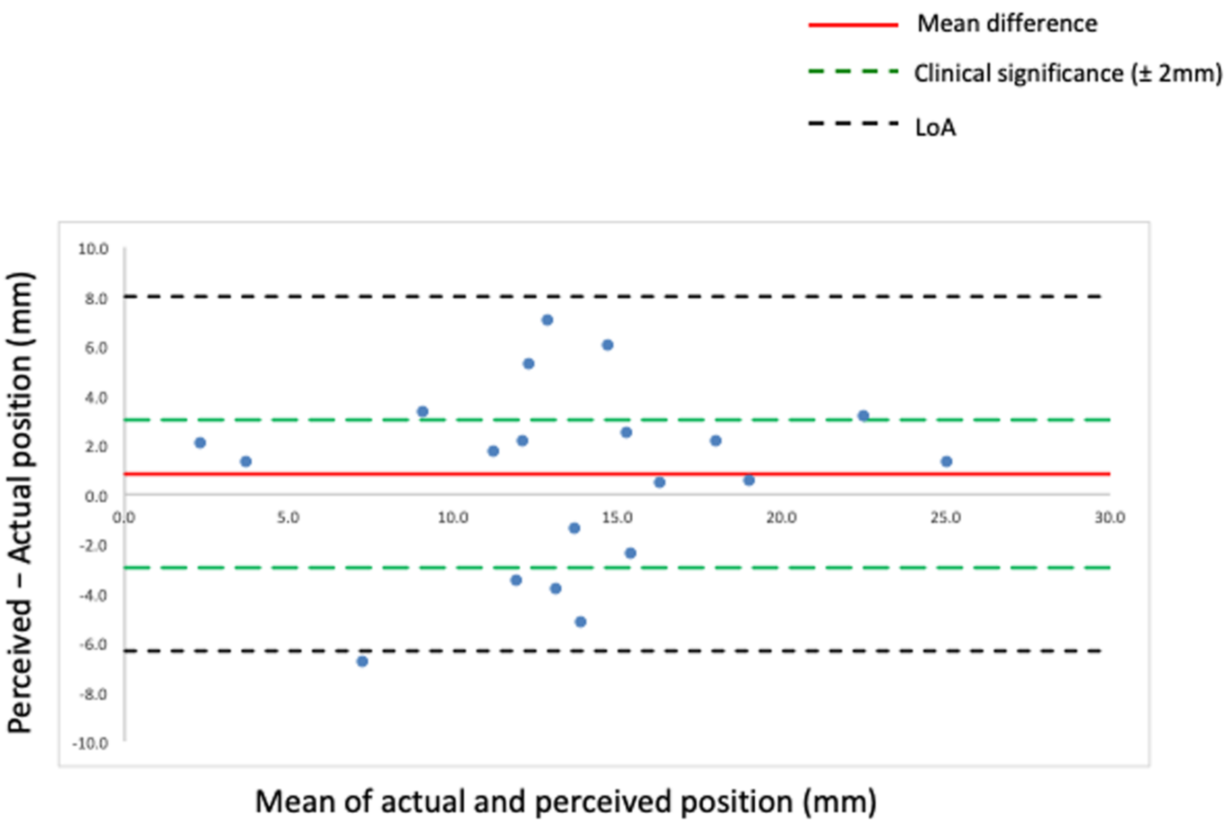


Figure 4.2 Bland-Altman plots for patient-perceived and actual antero-posterior chin (Pog) position.

4.3.2 Vertical direction

The mean actual AP position of the chin point (Pog), relative to Nasion, was 102.4 ± 8.5mm, whilst the patient-perceived position was 107.0 ± 9.5mm, Table 4.3. The mean difference in the vertical position of the chin was 4.7 ± 4.2mm. The upper limit of the 95% confidence interval for the mean difference was 6.6mm, and 2.7mm for the lower limit. The mean difference in the actual vertical position of the chin and the patient-perceived position was statistically significantly different (p=0.001), Table 4.4.

The absolute mean difference between the actual position and the patient-perceived chin (Pog) position vertically was was 5.1 ± 3.6mm. The upper limit of the 95% confidence interval for the mean difference was 6.8mm, and 3.4mm for the lower limit. This absolute mean difference was statistically significantly greater than 3.0mm (p=0.017).

The Bland-Altman plot shows the bias towards placing Pogonion more inferiorly, Figure 4.3. Again, in addition the wide limit of agreement from 12.8mm to -3.5mm suggests a large variation in perceived vertical chin position.

4.4 INTER LIP-CHIN RELATIONSHIP

The horizontal and vertical distances of the upper lip (Ls) to the chin point (Pog) were used to measure the relative position of the chin to the upper lip. The mean actual AP distance of the upper lip to chin point (Ls-Pog) was 0.3 ± 4.4mm; the mean patient-perceived measurement, was -2.7 ± 5.4mm, Table 4.3. The mean difference between these measurements was not statistically significantly different (p=0.057), Table 4.4.

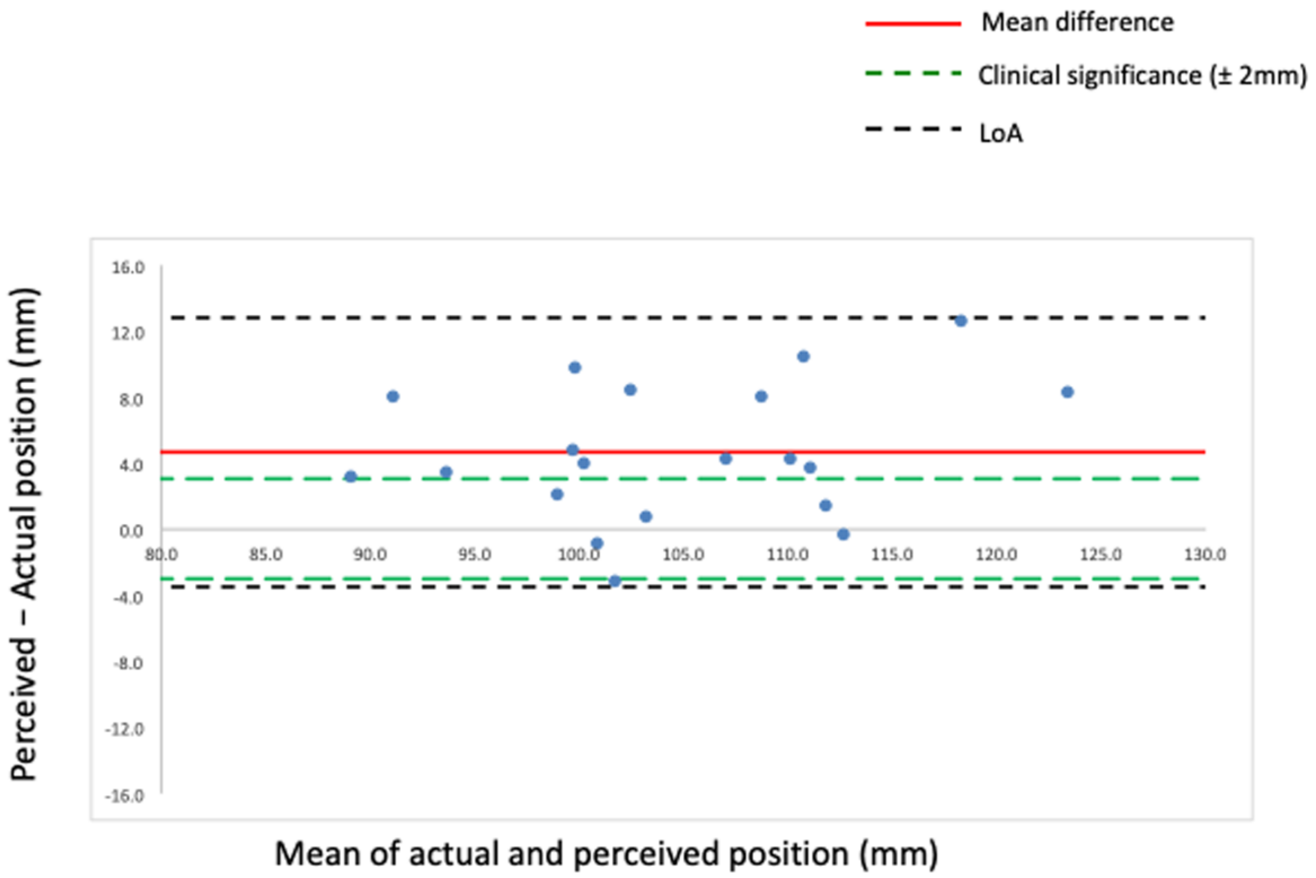


Figure 4.3 Bland-Altman plots for patient-perceived and actual vertical chin (Pog) position.

The absolute mean difference between the actual Ls-Pog horizontal distance and the patient-perceived distance was 3.2 ± 2.5mm. The upper limit of the 95% confidence interval for the mean difference was 4.4mm, and 2.1mm for the lower limit. This absolute mean difference was not statistically significantly greater than 3.0mm (p=0.749).

The mean actual vertical distance of the upper lip to chin point (Ls-Pog) was -39.4 ± 4.5mm, whilst the mean patient-perceived measurement, was -43.8 ± 6.3mm, Table 4.3. The mean difference between these measurements was statistically significantly different (p=0.001), Table 4.4.

The absolute mean difference between the actual Ls-Pog vertical distance and the patient-perceived distance was 4.8 ± 3.4mm. The upper limit of the 95% confidence interval for the mean difference was 6.4mm, and 3.3mm for the lower limit. This absolute mean difference was statistically significantly greater than 3.0mm (p=0.025).

The Bland-Altman plots show the wide limit of agreements, Figure 4.8 and Figure 4.9.

4.5 RESPONSES TO THE PARTICIPANT QUESTIONNAIRE

Each patient was asked to anonymously answer Questions 1 and 2 of the self-completed ‘Participant Questionnaire’ (Appendix 3). The results of the questionnaire showed that 65% of the study participants would have preferred a 3D image of themselves. However, 20% of the study participants reported that they were concerned regarding the additional radiation exposure needed for a CBCT scan, to produce a 3D prediction, Table 4.5.

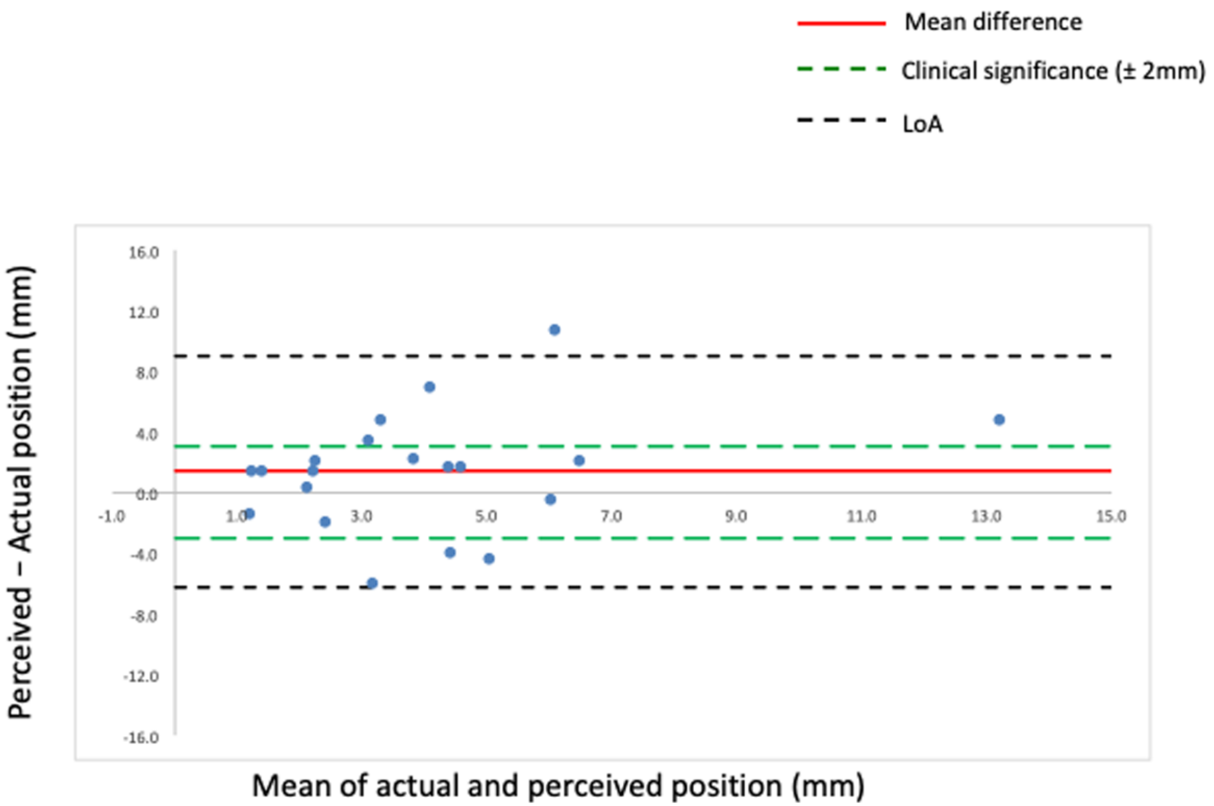


Figure 4.4 Bland-Altman plots for patient-perceived and actual anterior=posterior inter lip-chin (Ls-Pog) relationship.

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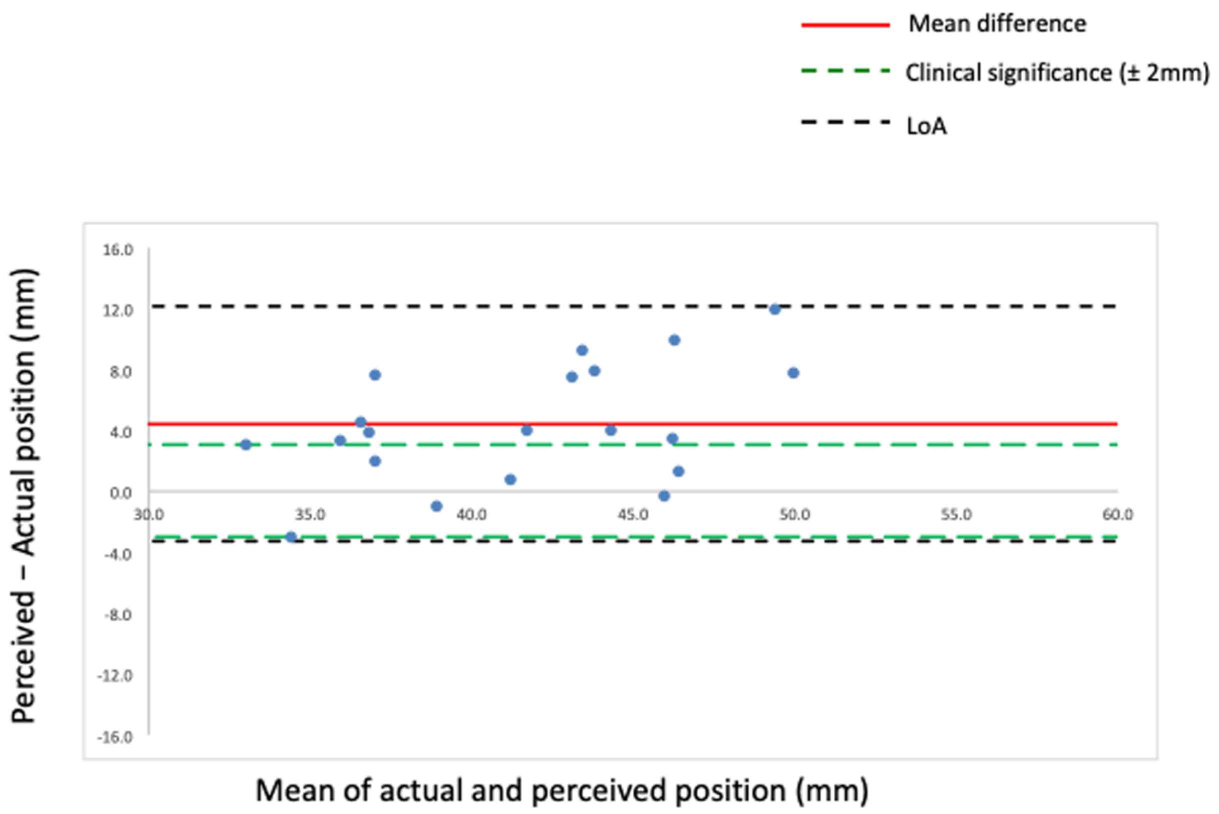


Figure 4.5 Bland-Altman plots for patient-perceived and actual vertical inter lip-chin (Ls-Pog) relationship

Question 1 *Would you find it more helpful to see a 3D image of your face or a 2D profile image during the surgical planning stage?*		
Response	Total	%
Yes	13	65
No	4	20
Don't Know	3	15
Question 2 *Do you think the extra radiation exposure during the 3D scan (CBCT) would be "worth it" if it allowed you to see yourself in 3D before surgery?*		
Response	Total	%
Yes	11	55
No	4	20
Don't Know	5	25
Of those answering 'Yes' to Question 1, how many would accept the increased radiation exposure		
Response	Total	%
Yes	10	77
No	1	8
Don't Know	2	15

Table 4.5 Shows the results of the participant questionnaire.

CHAPTER 5

DISCUSSION

5.1 DISCUSSION

The aim of the present study was to determine whether patients with facial dysmorphology recognise themselves in profile, measured at landmarks for the upper lip (Ls), chin (Pog) and the inter lip-chin relationship. A prospective cross-sectional study was undertaken at Birmingham Dental Hospital, utilising a convenience sample of 20 pre-treatment patients with Class III dento-facial malocclusion, presenting at the Orthognathic Clinic. The inclusion and exclusion criteria were in keeping with similar previous studies (Jones et al., 2007). To reduce bias and confounding variables patients with underlying conditions or syndromes such as cleft and craniofacial abnormality; and patients post orthognathic surgical correction were omitted. Patients were selected at the same stage in the Orthognathic Multidisciplinary Clinic treatment pathway to produce a homogenous sample. In the present study a 3.0mm difference was set as the threshold for clinical significance, based on the findings of Jones et al. (2007). The authors had previously conducted a pilot study (Jones, 2005) to determine the change in horizontal position of the maxilla and mandible needed for laypeople to detect a difference in soft tissue profile.

A limitation of the present study is the short interval of time between the two attempts at which the patient recreated their soft tissue profile (T_1-T_2). This may lead to memory bias, recreating the simulation at the first attempt, rather than recreating their perception of profile. However, it was felt it would be unethical and harder to recruit patients if they needed to attend additional appointments solely for participation in the study. Due to the nature of the waiting list times, the next opportunity to meet with the patient may have been a number of years later.

Patients with a facial disharmony or visible difference often seek treatment to improve their facial appearance with an underlying desire to look “normal” and improve their quality of life (Rivera et al., 2000; Vittert et al., 2018). Patients may present with concerns regarding specific features of their face they feel require correction, which do not match the clinical assessment. For instance, patients often present with hypoplastic or retrusive maxilla’s and normally positioned mandibles, but they are under the impression that their mandible requires a setback procedure (Maxwell and Kiyak, 1991). Patients are obviously unaware of subtle clinical features that guide the clinical decision-making process, for example the para-nasal deficiency associated with a hypoplastic or retrusive maxilla.

At present, in the United Kingdom (U.K.), the majority of orthognathic prediction planning utilises model surgery to plan the dental occlusion and post-operative skeletal change (Anwar and Harris, 1990). This method cannot simulate the changes that will result in the overlying soft tissues. As such this method of planning is of limited value from a patient’s perspective and not a useful communication tool to convey the plan to patients, apart from showing them how their teeth will look after surgery. The use of digital computerised orthognathic surgery planning software can overcome this, by generating a lateral profile soft tissue prediction, based on the planned skeletal and dental changes (Sarver, 1996). This soft tissue profile prediction can be used as a tool to communicate the plan to patients, involving them in the treatment planning process. Communication with patients is vital, not only from the perspective of informed consent, but it has also been shown that patients who are involved in the treatment decision-making process are more satisfied with the post surgical outcome (Sinclair et al., 1995; Cunningham and Johal, 2015). Therefore, the soft tissue profile should be used as a communication tool, before surgery, to demonstrate the site and severity of the facial disharmony; as well as the post surgical prediction, to manage their expectations of the outcome.

Anecdotally, some surgeons are uncomfortable showing patients their predictions; as they feel it may lead to an increase in patient expectations (Sarver et al., 1988). This creates an interesting dilemma, the patient is undergoing an elective procedure to address their facial disharmony, to improve their facial appearance, but the surgeons are unwilling to show them the outcome. This could be seen as a paternalistic approach to treatment where the patient has no option but assume the surgeon "knows best". This approach to treatment is no longer acceptable from a legal perspective and is by no means informed consent. Patients need to be given the relevant information to make an informed decision (McKinnon et al., 2018). For profile assessment and predication to be of benefit from a patient's perspective, the baseline assumption must be that these individuals know what they look like in profile before treatment. If this were not the case the use of the profile facial image would not be valid for either purpose. Therefore, this study was undertaken to determine whether pre-operative class III patients could recreate the severity of their facial dysmorphology based on their profile soft tissue photograph.

To be a useful communication tool with patients, to both convey the treatment plan and gain informed consent, the assumption is that patients are aware of what they look like and have an accurate perception of themselves profile; as the starting point in both conversations and in order to understand and fully comprehend the predicted changes then demonstrated to them. This would not be the case if the patient had a distorted perception of their profile, or if the patients are not familiar with this view of themselves. A distorted perception of their facial appearance could be part of a larger body dysmorphic disorder or more specifically a facial dysmorphic disorder. ‘Body Dysmorphic Disorder’ (BDD) is characterised by an excessive “preoccupation with perceived defects or flaws in physical appearance, that are not observable or appear slight to others” (American Psychiatric Association, 2013). The term “facial dysmorphic syndrome” is a less recognised entity, but is face specific (MacCorquodale, 1999). The assumption for the patients in the present study was that they were not suffering from any form of body or facial dysmorphophobia. In the present clinical situation, it is worth noting that this was based on an assessment made by the orthognathic team rather than a clinical psychologist.

Based on the mean differences between the actual and perceived lip and chin positions the results of the present study showed that out of the 20 class III patients, 9 patients (45%) correctly identified the anterior-posterior (AP) position of their upper lip and 11 patients (55%) correctly identified their AP chin position to within the 3.0mm clinical threshold (Jones et al., 2007). Of these, only 5 patients correctly identified both their AP upper lip and chin positions. There was a tendency for patients to under advance their upper lip i.e. positioning it more retrusive than it was in reality (-2.3 ± 3.0mm) whilst positioning their chin in approximately the correct AP position (0.8 ± 3.7mm). This is more accurate than the findings reported by Miner et al. (2007) who found participants overestimated protrusion of the mandible by approx. 1.7mm. Twelve patients correctly identified their anterior-posterior upper lip to chin relationship. In the vertical direction, only 6 patients (30%) were able to position their chin correctly to within the 3.0mm clinical threshold. There was tendency for patients to position their chin more inferiorly than in reality i.e. positioned as having longer faces.

One possible explanation as to why patients were more aware of their AP chin position may be due the journey the patients have taken to access the clinic. This usually involves the patient being referred by their general dental practitioner to a specialist, in a secondary care setting, and then being referred onwards again to a tertiary care provider in a hospital setting (Cunningham and Johal, 2015). Each time the healthcare professional possibly reinforcing the patient's belief and awareness that their "chin sticks out". Even prior to this, patients may have been subject to comments from peers and family (Seehra et al., 2011). Patients will often report that their profile concerns stem from comments regarding a "strong jaw", "protrusive chin" or words to similar effect (O'Keefe and Sinnott, 2016). The patient has been repeatedly educated by comments and discussions with lay people (peers, friends, family), dentists and orthodontists that they have an issue with the AP position of their chin. If the patients believe this narrative and internalise it, this may lead them to focus primarily on the AP position of their chin over other facial features (such as the upper lip or vertical proportions) or develop an exaggerated perception of their profile and the severity of their skeletal pattern. The results of the present study suggest that patients are more aware of their antero-posterior chin position rather than its vertical position. The lack of vertical chin position perception may be due to the fact that the patients focus on what they perceive to be predominantly an AP discrepancy, their focus was not on correcting the vertical component, and so did not recognise this as aberrant.

As patients progress through the orthognathic treatment planning pathway, they will have an increased exposure to their pretreatment photographs; and their level of education with regards to their skeletal pattern and dentofacial malocclusion will increase. As discussed earlier, the theory of '*mere exposure'* suggests that increased exposure to an image leads to increased familiarity (Zajonc, 1968). As such for the purpose of the current investigation, it was deemed appropriate to assume that patients new to the orthognathic pathway, may differ in their ability to recognise their profiles, as well as differing in their perception of their profiles, comparative to patients in treatment. As such patients were recruited from the same stage in the orthognathic treatment pathway, to avoid introducing confounding variables.

Regarding the linear measurement, the use of mean values should be viewed with caution as any positive and negative values will cancel each out and produce a mean difference of zero. For instance, if 10 patients were to place their chin more retrusively, each by 5mm, than the mean difference between the actual and perceived chin positions would be -5mm, the negative sign (-) indicating the retrusion. If the remaining 10 patients over advanced their chin position each by 5mm, then the mean difference between the actual and perceived chin positions would be +5mm, the positive sign (+) indicating the protrusion. For all 20 patients the mean difference would be zero, meaning they were perfect at positioning the chin as a group of 20 patients. Even though this is mathematically correct, it is not clinically correct.

The use of the *absolute mean difference* between the actual and perceived lip and chin positions is more clinically meaningful. These differences provide the magnitude of the difference rather than the direction. Based on the above example, the mean absolute difference between the actual and perceived lip and chin position, for all 20 patients would be 5mm. Even though the magnitude of error/difference is known the direction is not. A combination of the two, mean and absolute mean values provides a more meaningful clinically valid outcome measure. In the present study the absolute mean difference between the actual and perceived lip and chin positions for all measurements were 3.0mm or greater. These differences would be deemed to be clinically significant.

Interestingly the results showed that although there were inaccuracies reproducing their facial soft tissue profile the patients consistently reproduced their perceived profile on a second attempt. This would suggest that patients do have an idea of their facial profile as was reproducible, but it is not the correct perception. One possible explanation for better AP chin point position may be that the chin is well defined and is an isolated feature, whist the perception of upper lip position may be influenced by the surrounding soft tissue i.e. nasal tip position, columella inclination or malar projection. There may be several reasons why patients produce a soft tissue profile that exaggerates their AP class III skeletal pattern and increased vertical dimension. It could be that patients do not know what they look like in profile, patients have a distorted view of themselves, or patients may be trying to guarantee acceptance for treatment or guide the surgical plan. Reassuring the patients their identified images would not be used in the surgical decision-making process would have hopefully negated the effect of the later. Clear instructions were given that participation in this study would not alter their treatment.

The results show that patients overestimated the severity of the class III skeletal pattern, this could be for several reasons. Individuals do not view themselves in direct lateral profile view nor do they commonly see themselves in profile in photographs. Despite being the most photographed generation of all time due to the ease of access to digital photography, photographs are rarely taken of us from a vantage point that demonstrates our lateral profile; and “selfies” are also not taken in profile view. Individuals are more accustomed to viewing our faces in frontal view, and more specifically a mirror reversed reflection (Mita et al., 1977). de Runz et al. (2016) reported a significant preference for mirror-reversed photographs over standard photographs among female patients who are undergoing facial aesthetic surgery. This could also be of significance in orthognathic patients seeking correction of a mandibular asymmetry. The study acknowledges that there may be a difference in facial perception between males and females and possibly between racial groups but was beyond the scope of this study, but does warrant further investigation.

Patients may have a facial dysmorphic self-image, perceiving something different, due to a distorted view of themselves. Previous research investigating Body Dysmorphic Disorder has used a similar methodology (Neyret et al., 2020). Study participants were 3D scanned to produce a 3D avatar, which was manipulated to recreate the patients’ subjective body representation. The results found that 37% of individuals were not able to correctly identify their actual body shape. This may suggest that patients with body dysmorphia have a warped perception of their shape and size; this may also present in patients with facial dysmorphia. The results of the present study showed an even greater level of inaccuracy.

A limitation of this study is that in order to obtain a homogeneous sample, the study participants were selected from a patient cohort who all presented with a class III skeletal pattern. It would be interesting to repeat this study and evaluate whether similar results and findings were shown for patients presenting with a class II skeletal base. The present sample of Class III patients were shown to over advance the mandible (based on the absolute mean differences); this may reflect their view that the source of their facial dysmorphology is the chin being too prominent. If Class II patients were also seen to over advance the mandible, the conclusion could be drawn that the tendency to position the mandible too far forward is not because of the way they view their facial disharmony; instead, this would show that all patients simply do not recognise the position of their chin relative to the rest of the facial structures; as such the findings would be that patients do not recognise themselves in profile. If however class II patients were to under advance the mandible, this may confirm the tendency for patients to exaggerate the extent of their dysmorphology. Again, it would be interesting to repeat this study with a cohort of patients whose complaint was that of a “long face” presenting with increased vertical proportions; or conversely presenting with a reduced vertical proportions. Commonly patients with a class II skeletal pattern due to a hypoplastic mandible complain of a “small jaw” and are able to articulate that they feel their chin is both less prominent and of a reduced height vertically. Perhaps if the primary presenting complaint and motivation for treatment was to correct a vertical discrepancy, this may be the patient focus when recreating a simulation of their profile; and so the vertical component may be more accurately recorded, than was found in this present study. Further investigation is required to explore this hypothesis.

Previous studies have used silhouettes to assess facial attractiveness (Tufekci et al., 2008; Trehan et al., 2011; Naini et al., 2012; Bullen et al., 2014). Whilst others assessed profile perception with crude simulation devices, resembling puzzle like pieces to obtain a "best fit" (Hershon and Giddon, 1980). Use of a discrete rather than continuous scale, may limit the value or the results. The present study used the patient's actual soft tissue profile, which could be "morphed", in real-time, in CASSOS. This allowed the individual to move their soft tissue and produce a smooth photorealistic image of their profile. Using conventional photo-editing software would have produced an image, that would have had gaps, and steps that could distract from the final image, similar to the 1:1 profile predications (Henderson, 1974; Sarver, 1996). Previous studies have reported that only 42% of lay people were able to choose the correct silhouette, which best represented their facial profile (Tufekci et al., 2008; Trehan et al., 2011) This means over 50% of lay people are unable to recognise themselves in profile.

The direction and amount the pre-surgical image was manipulated may have affected the patient's ability to accurately recreate the various soft tissue positions. A future study could involve manipulating the pre-surgical images to both extremes, making a class III patient look class II versus an exaggerated class III. Further investigation is required to explore how this could affect the results; this was beyond the scope of the present study.

In an attempt to utilise technological advances, an additional questionnaire asked whether patients would prefer to see a 3D image of their face during surgical planning. The results of the questionnaire showed that 65% of the study participants would have preferred a 3D image of themselves. The questionnaire did not explore in detail why a 3D simulation would have been preferred. However, there may be several reasons. This may be a reflection of the way in which modern media is presented, with technological advances meaning television, movies, video games, advertisements, even social media emojis and 'filters' utilise sophisticated photorealistic 3D animation. A 3D facial image can be rotated and repositioned to allow the viewer to orientate the image to a position that is more familiar to them. The advent of mobile phone cameras started the phenomenon of "selfies". Although far from standardised, there is a common vantage point from which these images are taken; from a high angle and close distance. Interestingly, research has shown that the increase in selfies has lead to increased dissatisfaction with mid face features, commonly the nose (Ward et al., 2018). This has led to an increase in patients seeking cosmetic surgery, following increasing dissatisfaction with their actual facial features (Shome et al., 2020; Tremblay et al., 2020). A 3D facial image that could be repositioned and reorientated would allow the patient to view their simulation and surgical prediction from a vantage point that may be more familiar and may be more preferred. This would be of benefit for patients with asymmetry, a discrepancy in the transverse plane, which may not be clearly demonstrated in lateral profile view. A 3D image may be preferred as it better represents the face as a multifaceted anatomical structure, with many recesses, projections and curvatures making it a complex 3D shape. The benefit of a 3D versus 2D image is the ability to render depth of field (Zhu et al., 2017), which increases photorealism (Benington et al., 2010).

The patients' ability to correctly identify their profile and the severity of their facial dysmorphology may instead reflect the limitations of presenting a 2D medium to demonstrate a 3D structure, rather than being due to patients having an inaccurate perception of their profile. As such a lateral profile photograph and subsequent simulation in profile view may not be the correct way to demonstrate to the patient the extent of their facial disharmony. If this is true, then 2D photo-cephalometeric prediction planning cannot be considered to be not a useful tool for patient communication, in the treatment planning process or to gain informed consent. Whether patients would be better able to identify the severity of their Class III skeletal pattern if this study were repeated using a 3D simulation would require further investigation.

The patient questionnaire also asked whether the study participants would be willing to accept the additional radiation dose required for a CBCT, to facilitate a 3D image of surgical planning. Three-dimensional orthognathic planning is routinely available in many centres outside of the UK, however many NHS orthognathic teams do not have access to this method of planning, either due to cost, lack of specialised equipment or lack of expertise. In addition to this, there are concerns regarding the additional radiation exposure during the CBCT scan and the perceived advantages of using 3D orthognathic planning techniques. The dosage exposure from a lateral cephalogram is approximately 0.0022 – 0.0056 millisieverts (mSv) comparative to a large volume CBCT which is 0.03 – 1.1 mSv. (Isaacson et al., 2015). This is important to consider as the stochastic effect of exposure to ionising radiation carries a risk of cancer induction. The comparative risk of cancer is approximately 13 times greater with a CBCT than with a lateral cephalogram. However, only four out of twenty patients reported that they were concerned regarding the additional radiation exposure needed for a CBCT scan, to produce a 3D prediction.

CHAPTER 6

CONCLUSIONS

6.1 CONCLUSIONS

In this present study approximately half of patients could not correctly identify their current pre-surgical facial profile. Patients were able to consistently reproduce their perception of their facial soft tissue profile on a second attempt. Patients were able to determine their anterior-posterior chin position with greater accuracy than their upper lip position. There was a tendency to produce a retrusive upper lip position, exaggerating the extent of their class III skeletal pattern. In the vertical direction there was a tendency to position the chin more inferiorly, producing a longer face.

Given the lack of awareness of their profile, this questions the validity of using two-dimensional photo-cephalometeric planning as a tool for patient communication and informed consent. The information provided by a lateral view of their soft tissue profile predication may not be in a format that the patients can understand or relate to; and therefore may not be relevant information or the ideal media for them to make an informed decision. This risks invalidating the informed consent process. The profile predictions maybe of some limited benefit in explaining an overview of the general surgical plan to the patient, but their use as an absolute indicator of outcome may be of little benefit.

The results of the patient questionnaire found that patients would have preferred a 3D image of themselves during surgical planning, with the vast majority of patients willing to accept the additional radiographic exposure and the associated risks of this, to facilitate seeing themselves in 3D. Generating a 3D facial soft tissue prediction may be more useful as a patient information tool, but this requires further investigation.

CHAPTER 7

REFERENCES

7.1 REFERENCES

Aharon, P. A., Eisig, S., Cisneros, G. J. (1997). Surgical prediction reliability: a comparison of two computer software systems. *Int J Adult Orthodon Orthognath Surg.*, *12*(1), 65-78.

American Psychiatric Association. (2013). *Diagnostic and statistical manual of mental disorders : DSM-5.* (Fifth edition). Washington, District of Columbia: American Psychiatric Publishing.

Anwar, M., Harris, M. (1990). Model surgery for orthognathic planning. *Br J Oral Maxillofac Surg*, *28*(6), 393-397.

Ayoub, A. F., Khambay, B. S., Benington, P. (2014). *Handbook of Orthognathic Treatment, a team approach*. Chichester: Wiley Blackwell.

Ayoub, A. F., Siebert, P., Moos, K. F., Wray, D., Urquhart, C., Niblett, T. B. (1998). A vision-based three-dimensional capture system for maxillofacial assessment and surgical planning. *Br J Oral Maxillofac Surg*, *36*(5), 353-357.

Baumrind, S., Frantz, R. C. (1971). The reliability of head film measurements: 1. Landmark identification. *Am J Orthod*, *60*(2), 111-127.

Bell, R., Kiyak, H. A., Joondeph, D. R., McNeill, R. W., Wallen, T. R. (1985). Perceptions of facial profile and their influence on the decision to undergo orthognathic surgery. *Am J Orthod*, *88*(4), 323-332.

Benington, P (2010). An overview of three-dimensional imaging in dentistry. *Dent Update*, *37*(8), 494-501.

Bland, J. M., Altman, D. G. (1999). Measuring agreement in method comparison studies. *Stat Methods Med Res*, *8*(2), 135-160.

Bonetti, G. A., Alberti, A., Sartini, C., Parenti, S. I. (2011). Patients' self-perception of dentofacial attractiveness before and after exposure to facial photographs. *Angle Orthod*, *81*(3), 517-524.

Brook, P. H., Shaw, W. C. (1989). The development of an index of orthodontic treatment priority. *Eur J Orthod*, *11*(3), 309-320.

Bullen, R. N. (2014). Self-perception of the facial profile: an aid in treatment planning for orthognathic surgery. *J Oral Maxillofac Surg*, *72*(4), 773-779.

Cash, T. F., Kilcullen, R. N. (1985). The Aye of the Beholder: Susceptibility to Sexism and Beautyism in the Evaluation of Managerial Applicants. *J Applied Soc Psychol*, *15*(4), 591-605.

CASSOS Manual, Part IV Appendix, Chapter 1, 2. (2000-2004). Hong Kong: SoftEnable Technology Ltd.

Cevidanes, L. H. C., Tucker, S., Styner, M., Kim, H., Chapuis, J., Reyes, M., Proffit, W., Turvey, T., Jaskolka, M. (2010). Three-dimensional surgical simulation. *Am J Orthod Dentofacial Orthop*, *138*(3), 361-371.

Chen, Y.-J., Chen, S.-K., Yao, J. C.-C., Chang, H.-F. (2004). The effects of differences in landmark identification on the cephalometric measurements in traditional versus digitized cephalometry. *Angle Orthod*, *74*(2), 155-161.

Cunningham, S. J., Gilthorpe, M. S., Hunt, N. P. (2000). Are orthognathic patients different? *Eur J Orthod*, *22*(2), 195-202.

Cunningham, S. J., Johal, A. (2015). Orthognathic correction of dento-facial discrepancies. *Br Dent J*, *218*(3), 167-175.

De Riu, G., Virdis, P. I., Meloni, S. M., Lumbau, A., Vaira, L. A. (2018). Accuracy of computer-assisted orthognathic surgery. *J Craniomaxillofac Surg*, *46*(2), 293-298.

de Runz, A., Boccara, D., Chaouat, M., Locatelli, K., Bertheuil, N., Claudot, F., Bekara, F., Mimoun, M. (2015). Female plastic surgery patients prefer mirror-reversed photographs of themselves: A prospective study. *J Plast Reconstr Aesthet Surg*, *69*(1), 122-127.

de Vries, D. A., Peter, J., Nikken, P., de Graaf, H. (2014). The effect of social network site use on appearance investment and desire for cosmetic surgery among adolescent boys and girls. *Sex roles*, *71*(9-10), 283-295.

Dindaroğlu, F., Kutlu, P., Duran, G. S., Görgülü, S., Aslan, E. (2016). Accuracy and reliability of 3D stereophotogrammetry: A comparison to direct anthropometry and 2D photogrammetry. *Angle Orthod*, *86*(3), 487-494.

Durao, A. P. R., Morosolli, A., Pittayapat, P., Bolstad, N., Ferreira, A. P., Jacobs, R. (2015). Cephalometric landmark variability among orthodontists and dentomaxillofacial radiologists: a comparative study. *Imaging Sci Dent*, *45*(4), 213-220.

Falkensammer, F., Loesch, A., Krall, C., Weiland, F., Freudenthaler, J. (2014). The Impact of Education on the Perception of Facial Profile Aesthetics and Treatment Need. *Aesthetic Plast Surg*, *38*(4), 620-631.

Fardouly, J., Vartanian, L. R. (2016). Social Media and Body Image Concerns: Current Research and Future Directions. *Curr Opin Psychol*, *9*, 1-5.

Ferrario, V. F., Sforza, C., Poggio, C. E., Tartaglia, G. (1994). Distance from symmetry: A three-dimensional evaluation of facial asymmetry. *J Oral Maxillofac Surg*, *52*(11), 1126-1132.

Finlay, P. M., Atkinson, J. M., Moos, K. F. (1995). Orthognathic surgery, patient expectations, psychological profile and satisfaction with outcome. *Br J Oral Maxillofac Surg*, *33*(1), 9-14.

Franks, S. L., Bakshi, A., Khambay, B. S. (2021). The validity of using profile predictions for class III patients planned for bimaxillary orthognathic surgery. *Br J Oral Maxillofac Surg.*

Garrahy, A. (2002). *3D assessment of cleft and non-cleft children.* PhD thesis, University of Glasgow.

Giavarina, D. (2015). Understanding Bland Altman analysis. *Biochem Med (Zagreb)*, *25*(2), 141-151.

Gossett, C. B., Preston, C. B., Dunford, R., Lampasso, J. (2005). Prediction accuracy of computer-assisted surgical visual treatment objectives as compared with conventional visual treatment objectives. *J Oral Maxillofac Surg.*, *63*(5), 609-617.

Gravely, J. F., Benzies, P. M. (1974). The clinical significance of tracing error in cephalometry. *Br J Orthod.*, *83*, 382-390.

Hajeer, M. Y., Ayoub, A. F., Millett, D. T. (2004). Three-dimensional assessment of facial soft-tissue asymmetry before and after orthognathic surgery. *Br J Oral Maxillofac Surg*, *42*(5), 396-404.

Harradine, N. W., Birnie, D. J. (1985). Computerized prediction of the results of orthognathic surgery. *J Maxillofac Surg*, *13*(6), 245-249.

Held, R. T. (2011). A Guide to Stereoscopic 3D Displays in Medicine. *Acad Radiol*, *18*(8), 1035-1049.

Henderson, D. (1974). Assessment of bony deformities of the middle and lower face. *Br J Plast Surg*, *27*, 287-296.

Hernández-Alfaro, F., Guijarro-Martínez, R. (2013). New protocol for three-dimensional surgical planning and CAD/CAM splint generation in orthognathic surgery: an in vitro and in vivo study. *Int J Oral Maxillofac Surg*, *42*(12), 1547-1556.

Hershon, L. E., Giddon, D. B. (1980). Determinants of facial profile self-perception. *Am J Orthod*, *78*(3), 279-295.

Houston, W. J. (1983). The analysis of errors in orthodontic measurements. *Am J Orthod*, *83*(5), 382-390.

Houston, W. J., Maher, R. E., McElroy, D., Sherriff, M. (1986). Sources of error in measurements from cephalometric radiographs. *Eur J Orthod*, *8*(3), 149-151.

Hupp, J. R., Ellis, E., Tucker, M. R. (2019). *Contemporary oral and maxillofacial surgery* (Seventh edition). Philadelphia, PA: Elsevier.

Isaacson, K. G., Thom, A. R., Atack, N. E. (2015). *Orthodontic radiographs: guidelines* (Fourth edition). London: British Orthodontic Society.

Johnston, C., Hunt, O., Burden, D., Stevenson, M., Hepper, P. (2010). Self-perception of dentofacial attractiveness among patients requiring orthognathic surgery. *Angle Orthod*, *80*(2), 361-366.

Jones, R. M. (2005). *The validity of computer assisted simulation system for orthognathic surgery (CASSOS) for planning the surgical correction of facial deformity.* MSc, University of Glasgow.

Jones, R. M., Khambay, B. S., McHugh, S., Ayoub, A. F. (2007). The validity of a computer-assisted simulation system for orthognathic surgery (CASSOS) for planning the surgical correction of class III skeletal deformities: single-jaw versus bimaxillary surgery. *Int J Oral Maxillofac Surg*, *36*(10), 900-908.

Kim, D. S., Huh, K. H., Lee, S. S., Heo, M. S., Choi, S. C., Hwang, S. J., Yi, W. J. (2013). The relationship between the changes in three-dimensional facial morphology and mandibular movement after orthognathic surgery. *J Craniomaxillofac Surg*, *41*(7), 686-693.

Kitay, D. (1999). Computer-animated comparison of self-perception with actual profiles of orthodontic and non-orthodontic subjects. *Int J Adult Orthodon Orthognath Surg*, *14*(2), 125-135.

Kiyak H. A., Bell R. (1991). *Psychosocial considerations in surgery and orthodontics*. In: Proffit WR, White RP, eds. *Surgical orthodontic treatment*. St Louis: Mosby Year Book, 71-95.

Koo, T. K., Li, M. Y. (2016). A Guideline of Selecting and Reporting Intraclass Correlation Coefficients for Reliability Research. *J Chiropr Med*, *15*(2), 155-163.

Lee, S., McGrath, C., Samman, N. (2007). Quality of life in patients with dentofacial deformity: a comparison of measurement approaches. *Int J Oral Maxillofac Surg*, *36*(6), 488-492.

Leonardi, R., Annunziata, A., Caltabiano, M. (2008). Landmark identification error in posteroanterior cephalometric radiography. A systematic review. *Angle Orthod*, *78*(4), 761-765.

Lin, H. H., Lonic, D., Lo, L. J. (2018). 3D printing in orthognathic surgery − A literature review. *J Formos Med Assoc*, *117*(7), 547-558.

Lu, C. (2003). The accuracy of video imaging prediction in soft tissue outcome after bimaxillary orthognathic surgery. *J Oral & Maxillofac Surg*, *61*(3), 333-343.

MacCorquodale, D. W. (1999). The young woman with a wart on her nose. *BMJ*, *319*(7221), 1349-1349.

Malik, N. (2016). *Textbook of Oral and Maxillofacial Surgery* (Fourth edition). Jaypee Brothers Medical Publishers.

Malkoc, S., Sari, Z., Usumez, S., Koyuturk, A. E. (2005). The effect of head rotation on cephalometric radiographs. *Eur J Orthod*, *27*(3), 315-321.

Mankad, B. (1999). Prediction accuracy of soft tissue profile in orthognathic surgery. *Int J Adult Orthodon Orthognath Surg*, *14*(1), 19-27.

Maxwell, R., Kiyak, H. A. (1991). Dentofacial appearance: a comparison of patient self-assessment techniques. *Int J Adult Orthodon Orthognath Surg*, *6*(2), 123-131.

McKinnon, C., Loughran, D., Finn, R., Coxwell-Matthewman, M., Jeyaretna, D. S., Williams, A. P. (2018). Surgical consent practice in the UK following the Montgomery ruling: A national cross-sectional questionnaire study. *Int J Surg*, *55*, 66-72.

McNeill, R. W., Proffit, W. R., White, R. P. (1972). Cephalometric prediction for orthodontic surgery. *Angle Orthod*, *42*(2), 154-164.

Meier, E., Gray, J. (2014). Facebook photo activity associated with body image disturbance in adolescent girls. *Cyberpsychol Behav Soc Netw.*, *17*(4), 199-206.

Miner, R. M., Anderson, N. K., Evans, C. A., Giddon, D. B. (2007). The perception of children's computer-imaged facial profiles by patients, mothers and clinicians. *Angle Orthod*, *77*(6), 1034-1039.

Miner, R. M., Anderson, N. K., Evans, C. A., Giddon, D. B. (2007). The perception of children's computer-imaged facial profiles by patients, mothers and clinicians. *Angle Orthod*, *77*(6), 1034-1039.

Mita, T. H., Dermer, M., Knight, J. (1977). Reversed facial images and the mere-exposure hypothesis. *J Pers Soc Psychol*, *35*(8), 597-601.

Naini, F. B., Donaldson, A. N. A., Cobourne, M. T., McDonald, F. (2012). Assessing the influence of mandibular prominence on perceived attractiveness in the orthognathic patient, clinician, and layperson. *Eur J Orthod*, *34*(6), 738-746.

Naini, F. B., Gill, D. S. (2017). *Orthognathic surgery: principles, planning and practice.* Chichester, England : Wiley Blackwell, 2017.

Nairn, N. J., Ayoub, A. F., Barbenel, J., Moos, K., Naudi, K., Ju, X., Khambay, B. S. (2013). Digital replacement of the distorted dentition acquired by cone beam computed tomography (CBCT): a pilot study. *Int J Oral Maxillofac Surg*, *42*(11), 1488-1493.

Naoumova, J., Lindman, R. (2009). A comparison of manual traced images and corresponding scanned radiographs digitally traced. *Eur J Orthod*, *31*(3), 247-253.

Newton, J. T. (2005). Exposure to 'ideal' facial images reduces facial satisfaction: an experimental study. *Community Dent Oral Epidemiol*, *33*(6), 410-419.

Neyret, S., Bellido Rivas, A. I., Navarro, X., Slater, M. (2020). Which Body Would You Like to Have? The Impact of Embodied Perspective on Body Perception and Body Evaluation in Immersive Virtual Reality. *Front Robot AI*, *7*, 31-31.

O'Keefe, C., Sinnott, P. (2016). Early orthognathic surgery in response to bullying due to malocclusion. *J Ir Dent Assoc*, *62*(6), 343-347.

Peck, H., Peck, S. (1970). A concept of facial esthetics. *Angle Orthod*, *40*(4), 284-318.

Pektas, Z. Ö., Kircelli, B. H., Cilasun, Ü., Uckan, S. (2007). The accuracy of computer-assisted surgical planning in soft tissue prediction following orthognathic surgery. *Int. J. Med. Robotics Comput. Assist. Surg*, *3*(1), 64-71.

Phillips, C., Tulloch, C., Dann, C. (1992). Rating of facial attractiveness. *Community Dent Oral Epidemiol*, *20*(4), 214-220.

Prahl-Andersen, B., Boersma, H., Van der Linden, F., Moore, A. (1979). Perceptions of dentofacial morphology by laypersons, general dentists, and orthodontists. *J Am Dent Assoc, 98*(2), 209-212.

Profitt, W. R., Fields Jr, H. W., Moray, L. J. (1998). Prevalence of malocclusion and orthodontic treatment need in the United States: estimates from the NHANES III survery. *Int J Adult Orthodon Orthognath Surg*, *13*(2), 97-106.

Profitt, W. R., Epker, B. N. (1980). In: Bell et al., *Surgical correction of dentofacial deformities.* Philadelphia: Saunders.

Proothi, M. (2010). Motivating factors for patients undergoing orthognathic surgery evaluation. *J Oral & Maxillofac Surg*, *68*(7), 1555-1559.

Riggio, R. E., Woll, S. B. (1984). The Role of Nonverbal Cues and Physical Attractiveness in the Selection of Dating Partners. *J Soc Pers Relat*, *1*(3), 347-357.

Rivera, S. M., Hatch, J. P., Dolce, C., Bays, R. A., Van Sickels, J. E., Rugh, J. D. (2000). Patients' own reasons and patient-perceived recommendations for orthognathic surgery. *Am J Orthod Dentofacial Orthop*, *118*(2), 134-140.

Rosten, A., Cunningham, S., Newton, J. T. (2018). Body dysmorphic disorder: a guide to identification and management for the orthodontic team. *J Orthod*, *45*(3), 163-168.

Rustemeyer, J., Groddeck, A., Zwerger, S., Bremerich, A. (2010). The accuracy of two-dimensional planning for routine orthognathic surgery. *Br J Oral Maxillofac Surg*, *48*(4), 271-275.

Ryan, F. S., Barnard, M., Cunningham, S. J. (2012). Impact of dentofacial deformity and motivation for treatment: A qualitative study. *Am J Orthod Dentofacial Orthop*, *141*(6), 734-742.

Sandler, P. J. (1988). Reproducibility of cephalometric measurements. *Br J Orthod*, *15*, 105-110.

Sarver, D. M. (1996). Video cephalometric diagnosis (VCD): A new concept in treatment planning? *Am J Orthod Dentofacial Orthop*, *110*(2), 128-136.

Sarver, D. M., Johnston, M. W., Matukas, V. J. (1988). Video imaging for planning and counseling in orthognathic surgery. *J Oral Maxillofac Surg*, *46*(11), 939-945.

Sayinsu, K., Isik, F., Trakyali, G., Arun, T. (2007). An evaluation of the errors in cephalometric measurements on scanned cephalometric images and conventional tracings. *Eur J Orthod*, *29*(1), 105-108.

Seehra, J., Fleming, P. S., Newton, T., DiBiase, A. T. (2011). Bullying in orthodontic patients and its relationship to malocclusion, self-esteem and oral health-related quality of life. *J Orthod*, *38*(4), 247-256.

Shome, D., Vadera, S., Male S.R,, Kapoor, R. (2020). Does taking selfies lead to increased desire to undergo cosmetic surgery*. J Cosmet Dermatol*, *19(8), 2*025-2032.

Sigall, H., Ostrove, N. (1975). Beautiful but dangerous: Effects of offender attractiveness and nature of the crime on juridic judgment. *J Pers Soc Psychol*, *31*(3), 410-414.

Sinclair, P. M., Kilpelainen, P., Phillips, C., White, R. P., Rogers, L., Sarver, D. M. (1995). The accuracy of video imaging in orthognathic surgery. *Am J Orthod Dentofacial Orthop*, *107*(2), 177-185.

Stokbro, K., Aagaard, E., Torkov, P., Bell, R. B., Thygesen, T. (2014). Virtual planning in orthognathic surgery. *Int J Oral Maxillofac Surg*, *43*(8), 957-965.

Swennen, G. R. (2009). Three-dimensional treatment planning of orthognathic surgery in the era of virtual imaging. *J Oral Maxillofac Surg*, *67*(10), 2080-2093.

Trehan, M., Naqvi, Z. A., Sharma, S. (2011). Perception of Facial Profile: How You Feel About Yourself. *Int J Clin Pediatr Dent*, *4*(2), 109-111.

Tremblay, S. C., Essafi Tremblay, S., Poirier, P. (2020). From filters to fillers: an active inference approach to body image distortion in the selfie era. *AI & society*, *36*(1), 33-48.

Trpkova, B., Prasad, N. G., Lam, E. W., Raboud, D., Glover, K. E., Major, P. W. (2003). Assessment of facial asymmetries from posteroanterior cephalograms: validity of reference lines. *Am J Orthod Dentofacial Orthop*, *123*(5), 512-520.

Tufekci, E., Jahangiri, A., Lindauer, S. J. (2008). Perception of profile among laypeople, dental students and orthodontic patients. *Angle Orthod*, *78*(6), 983-987.

Vargo, J. K., Gladwin, M., Ngan, P. (2003). Association between ratings of facial attractiveness and patients' motivation for orthognathic surgery. *Orthod Craniofac Res*, *6*(1), 63-71

Vig, K., & Ellis, E. (1990). Diagnosis and treatment planning for the surgical-orthodontic patient. *Dent Clin North Am, 34*(2), 361-384.

Vittert, L., Katina, S., Ayoub, A. F., Khambay, B. S., Bowman, A. W. (2018). Assessing the outcome of orthognathic surgery by three-dimensional soft tissue analysis. *Int J Oral Maxillofac Surg*, *47*(12), 1587-1595.

Volbracht, S., Shahrbabaki, K., Domik, G., Fels, G. (1996). Perspective viewing, anaglyph stereo or shutter glass stereo? *Proc IEEE Symp on Visual Languages.*, 192-193.

Walker, C. E. (2019). Effects of social medi Perspective viewing, anaglyph stereo or shutter glass stereo? a use on desire for cosmetic surgery among young women. *Curr Psychol*, *40*(7), 3355-3365.

Ward, B., Ward, M., Fried, O., Paskhover, B. (2018). Nasal Distortion in Short-Distance Photographs: The Selfie Effect. *JAMA Facial Plast Surg.*, *20*(4), 333-335.

Xia, J., Samman, N., Yeung, R. W., Wang, D., Shen, S. G., Ip, H. H., Tideman, H. (2000). Computer-assisted three-dimensional surgical planning and simulation. 3D soft tissue planning and prediction. *Int J Oral Maxillofac Surg*, *29*(4), 250-258.

Zajonc, R. B. (1968). Attitudinal effects of mere exposure. *J Pers Soc Psychol*, *9*(2, part 2), 1-27.

Zhu, S., Yang, Y., Khambay, B. S. (2016). A study to evaluate the reliability of using two-dimensional photographs, three-dimensional images, and stereoscopic projected three-dimensional images for patient assessment. *Int J Oral Maxillofac Surg*, *46*(3), 394-400.

CHAPTER 8

APPENDICES

8.1 Appendix 1

71 pre-determined hard and soft tissue cephalometric landmarks utilised by CASSOS.

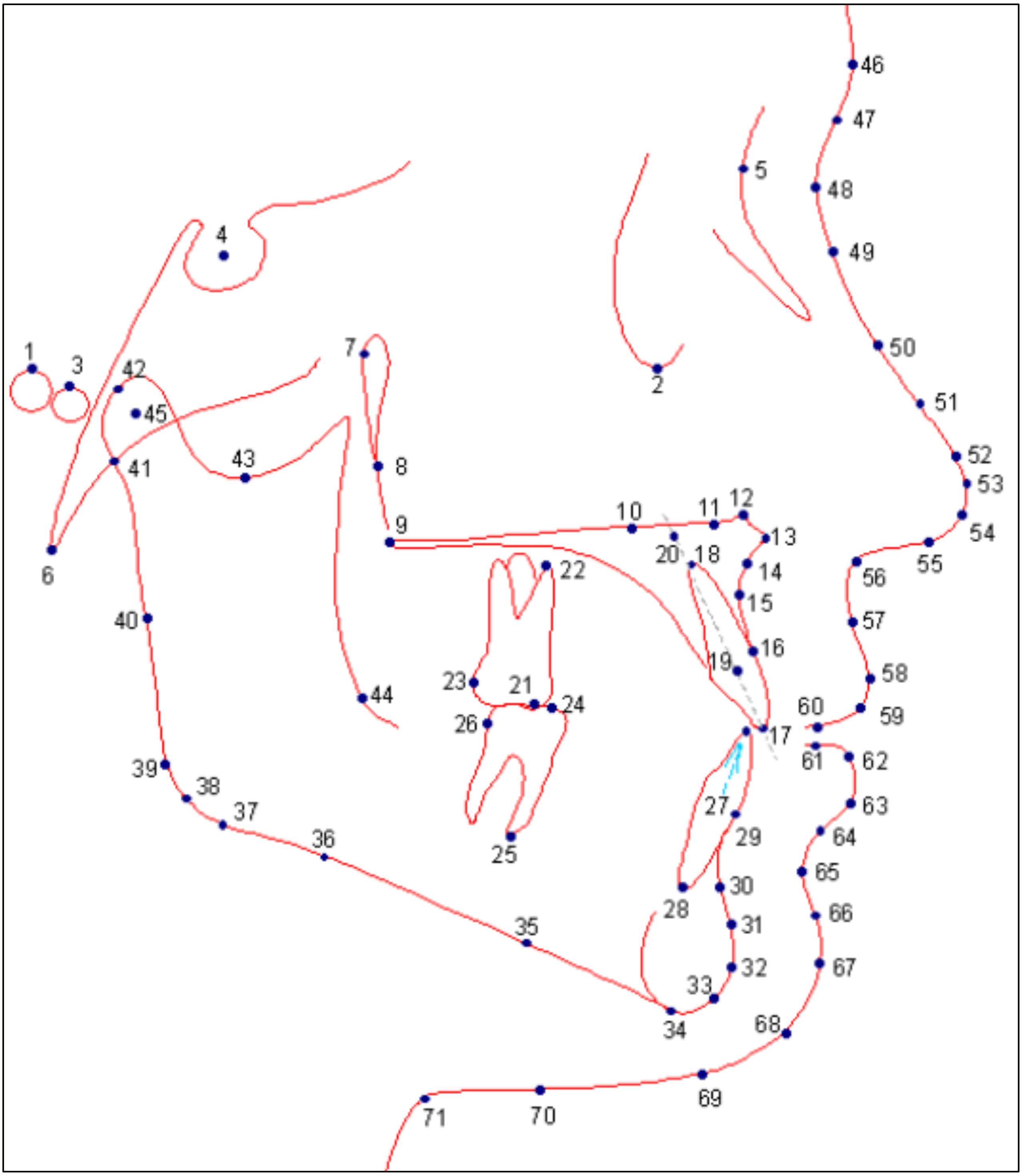
Reproduced from CASSOS Manual, Part IV Appendix, Chapter 1 'Built-In Lateral X-ray Landmark Library' (CASSOS 2000-2004, SoftEnable Technology Ltd., Hong Kong).

1. Porion (Po), the most superior point of the external auditory canal (*anatomic Porion*). If the Frankfort Horizontal Plane is constructed on Machine Porion and Orbitale, this landmark should be then digitized at the Machine Porion's position, and overlapping on the landmark of Machine Porion (MaPo).
2. Orbitale (Or), the most inferior point on the infraorbital rim.
3. Machine Porion (MaPo), the mid point of the most superior contour of the metal ear rod of the cephalometer or cephalostat (*Machine Porion*). This landmark will be used for matching color portrait to X-ray film.
4. Sella (S), the midpoint of the sella turcica, a constructed radiological point in the median plane
5. Nasion (N), the junction of the frontal and nasal bones at the naso-frontal suture.
6. Basion (Ba), the most inferior point on the anterior margin of foramen magnum, at the base of the clivus.
7. Pterygoid (Pt), a landmark at 11 o'clock of the posterior shadow of Ptyerygo-maxillary Fissure, a bilateral teardrop-shaped area of radiolucency, the posterior of the shadow of which represents the pterygoid plates, whereas the anterior shadow of which represents the posterior surfaces of the tuberosities of the maxilla.
8. Pterygo-maxillary Fissure (Ptm), a landmark at the six o'clock position of the mid-planed contour of the pterygo-maxillary fissure, at the junction of the pterygoid plates and the maxilla.
9. Posterior Nasal Spine (PNS), the posterior limit of the floor of the nose, at the tip of the posterior nasal spine.
10. Anterior Maxillary Osteotomy Point, a landmark on the superior surface of the maxilla, delimiting posterior and anterior maxillary segments in segmental maxillary osteotomy simulations.
11. Posterior Nasal Crest Point, a landmark on the superior surface of the maxilla before it turns upwards to form Nasal Crest.
12. Nasal Crest Point, a most superior landmark on the superior surface of the maxilla which turns upwards as it extends anteriorly, forming the Nasal Crest.
13. Anterior Nasal Spine (ANS), the anterior limit of the floor of the nose, at the tip of the anterior nasal spine.
14. Sub-ANS, a point located on the anterior surface of the maxilla near ANS, at a point where its supero-inferior thickness is 3 mm.
15. Point A (Subspinale), the deepest point in the concavity of the anterior maxilla between the anterior nasal spine and the alveolar crest.
16. Prosthion (Pr), alveolar rim of the maxilla; the lowest, most anterior point on the alveolar portion of the premaxilla, in the median plane, between the upper central incisors.
17. Upper Incisor Tip (U1T), the tip of the crown of the upper central incisor.
18. Upper Incisor Apex (U1A), the root apex of the upper central incisor.

19. Inferior Upper Dento-alveolar Process (IUD), a landmark located midway between labial and palatal dento-alveolar rims.
20. Superior Upper Dento-alveolar Process (SUD), a landmark along the long axis of dento-alveolar process, just underneath the Palatal Plane.
21. Upper Molar Crown (U6), the tip of the mesial cusp of the upper fist molar.
22. Upper Molar Apex (U6MA), the apex of the mesial buccal root of the upper first molar.
23. Upper Molar Distal (U6D), a landmark located at the most distal point of the upper first molar crown.
24. Lower Molar Crown (L6), the tip of the mesial cusp of the lower first molar.
25. Lower Molar Apex (L6MA), the apex of the mesial root of the lower first molar.
26. Lower Molar Distal (L6D), a landmark located at the most distal point of the lower first molar crown.
27. Lower Incisor Tip (L1T), the tip of the crown of the lower central incisor.
28. Lower Incisor Apex (L1A), the root apex of the lower central incisor.
29. Infradentale (Id), the highest, most anterior point on the alveolar process, in the median plane, between the mandibular central incisors.
30. Point B (Supramentale), the deepest point in the concavity of the anterior mandible between the alveolar crest and Pogonion.
31. Anterior Genioplasty Point (AGen), a point on the chin contour between B Point and Pogonion, which represents the anterior limit of a genioplasty osteotomy.
32. Pogonion (Pog *or* Pg), the most anterior point on the body chin.
33. Gnathion (Gn), the most antero-inferior point on the bony chin, located by bisecting mandibular and facial planes.
34. Menton (Me), the most inferior point on the bony chin.
35. Posterior Genioplasty Point (PGen), a mid-planed point on the lower border of the mandible representing the postero-inferior limit of a genioplasty osteotomy.
36. Antegonion, a mid-planed point on the inferior border of the mandible at the depth of concavity of the antegonial notch.
37. Inferior Gonion (IGo), a mid-planed point at a tangent to the inferior border of the mandible near Gonion.
38. Gonion (Go), a mid-planed point at the gonial angle of the mandible located by bisecting the posterior and inferior borders of the mandible.
39. Posterior Gonion (PGo), a mid-planed point at a tangent to the posterior border of the ramus Gonion.
40. Posterior Ramus, a mid-planed point on the posterior border of the ramus, approximately halfway between Gonion and Articulare.
41. Articulare (Ar), a mid-planed point located at the intersection of the posterior border of the ramus with the inferior surface of the cranial base.
42. Condylion (Cd), the most postero-superior point of the mid-planed contour of the mandibular condyle.
43. Sigmoid, a landmark at the deepest concavity of the mandibular sigmoid notch.
44. Anterior Ramus (Point J), a landmark at the deepest point of the curvature formed at the junction of the anterior portion of the ramus and the body of the mandible.
45. Center of Condyle, a landmark representing the center of rotation of the mandible, arguably the center of the head of the condyle.

46. Glabella (G), the most anterior point on the forehead, in the region of the supra-orbital ridges.
47. Superior Soft Tissue Nasion, a landmark located halfway between Glabella and Soft Tissue Nasion.
48. Soft Tissue Nasion (Ns *or* N’), the point of deepest concavity of the soft tissue contour of the root of the nose, which overlaid the naso-frontal suture.
49. Inferior Soft Tissue Nasion, a landmark located at the junction of the inferior limit of the concavity of soft tissue Nasion and the dorsum of the nose.
50. Nasal Dorsum, a landmark located approximately halfway from Nasion to Pronasale.
51. Inferior Nasal Dorsum, a landmark located at the junction of the dorsum and tip of the nose.
52. Superior Pronasale (SPn), a superior point on the tip of the nose.
53. Pronasale (Pn), the most prominent point on the tip of the nose.
54. Inferior Pronasale (IPn), an inferior point on the tip of the nose, as the top becomes confluent with the Columella.
55. Columella (Cm), the most anterior point on the columella of the nose, representing the anterior delimiter of the naso-labial angle.
56. Subnasale (Sn), a point at which the nasal septum merges with the upper cutaneous lip in the midsagittal plane.
57. Superior Labial Sulcus (SLs), the deepest point the concavity of the upper lip, midway between Subnasale and Labrale Superius.
58. Labrale Superius (Ls), a point indicating the muco-cutaneous junction of the upper lip and philtrum.
59. Inferior Labrale Superius (ILs), a landmark on the upper lip located midway between Labrale Superius and Stomion Superius.
60. Stomion Superius (Stms), the most inferior point on the vermilion of the upper lip.
61. Stomion Inferius (Stmi), the most superior point of the vermilion of the lower lip.
62. Superior Labrale Inferius (SLi), a landmark on the lower lip located midway between Stomion Inferius and Labrale Inferius.
63. Labrale Inferius (Li), the muco-cutaneous border of the lower lip.
64. Inferior Labrale Inferius (ILi), a landmark located midway between Labrale Inferius and Labiomental Fold.
65. Labiomental Fold (Lf), the deepest point in the concavity between Labrale Inferius and the soft tissue chin.
66. Inferior Labiomental Fold (ILf), a landmark located midway between Labiomental Fold and soft tissue Pogonion.
67. Soft Tissue Pogonion (Pog’ *or* Pg’), the most anterior point on the soft tissue chin.
68. Soft Tissue Gnathion (Gn’), the most antero-inferior point on the soft tissue chin.
69. Soft Tissue Menton (Me’), the most inferior point on the soft tissue chin, in the region inferior to Menton.
70. Mid Cervical Point, a landmark located midway between Soft tissue Menton and Cervical Point.
71. Cervical Point (Point C), the junction of the submental region and the neck.

The landmarks (as numbered above) are plotted in the sequence shown in the figure below:



8.2 Appendix 2

28 pre-defined landmarks are identified on the lateral profile photograph utilised by CASSOS.

Reproduced from CASSOS Manual, Part IV Appendix, Chapter 2 'Built-In Lateral Portrait Landmark Library' (CASSOS 2000-2004, SoftEnable Technology Ltd., Hong Kong).

1. Machine Porion (MaPo), the superior point of the external auditory meatus.
2. Glabella (G), the most anterior point on the forehead, in the region of the supra-orbital ridges.
3. Superior Soft Tissue Nasion (SNs), a landmark located halfway between Glabella and Soft Tissue Nasion.
4. Soft Tissue Nasion (Ns *or* N'), the point of deepest concavity of the soft tissue contour of the root of the nose, which overlaid the naso-frontal suture.
5. Inferior Soft Tissue Nasion (INs), a landmark located at the junction of the inferior limit of the concavity of soft tissue Nasion and the dorsum of the nose.
6. Nasal Dorsum, a landmark located approximately halfway from Nasion to Pronasale.
7. Inferior Nasal Dorsum, a landmark located at the junction of the dorsum and tip of the nose.
8. Superior Pronasale (SPn), a superior point on the tip of the nose.
9. Pronasale (Pn), the most prominent point on the tip of the nose.
10. Inferior Pronasale (IPn), an inferior point on the tip of the nose, as the top becomes confluent with the Columella.
11. Columella (Cm), the most anterior point on the columella of the nose, representing the anterior delimiter of the naso-labial angle.
12. Subnasale (Sn), a point at which the nasal septum merges with the upper cutaneous lip in the midsagittal plane.
13. Superior Labial Sulcus (SLs), the deepest point the concavity of the upper lip, midway between Subnasale and Labrale Superius.
14. Labrale Superius (Ls), a point indicating the muco-cutaneous junction of the upper lip and philtrum.
15. Inferior Labrale Superius (ILs), a landmark on the upper lip located midway between Labrale Superius and Stomion Superius.
16. Stomion Superius (Stms), the most inferior point on the vermilion of the upper lip.
17. Cheilion (Ch): the right commissure of the labial fissure.
18. Stomion Inferius (Stmi), the most superior point of the vermilion of the lower lip.
19. Superior Labrale Inferius (SLi), a landmark on the lower lip located midway between Stomion Inferius and Labrale Inferius.
20. Labrale Inferius (Li), the muco-cutaneous border of the lower lip.
21. Inferior Labrale Inferius (ILi), a landmark located midway between Labrale Inferius and Labiomental Fold.
22. Labiomental Fold (Lf), the deepest point in the concavity between Labrale Inferius and the soft tissue chin.
23. Inferior Labiomental Fold (ILf), a landmark located midway between Labiomental Fold and soft tissue Pogonion.
24. Soft Tissue Pogonion (Pog' *or* Pg'), the most anterior point on the soft tissue chin.

25. Soft Tissue Gnathion (Gn’), the most antero-inferior point on the soft tissue chin.
26. Soft Tissue Menton (Me’), the most inferior point on the soft tissue chin, in the region inferior to Menton.
27. Mid Cervical Point, a landmark located midway between Soft tissue Menton and Cervical Point.
28. Cervical Point (Point C), the junction of the submental region and the neck.

The landmarks (as numbered above) are plotted in the sequence shown in the figure below:

8.3 Appendix 3

UNIVERSITY OF BIRMINGHAM | SCHOOL OF DENTISTRY

Birmingham Community Healthcare NHS
NHS Foundation Trust

Participant Questionnaire

1. Would you find it more helpful to see a 3D image of your face or a 2D profile image during the surgical planning stage?

   Yes ☐ No ☐ Don't know ☐

   To use 3D images to their full extent you would need a special 3D x-ray to see the bones of your face, called a cone beam CT scan (CBCT). The CBCT scan involves exposure to radiation. Don't worry the 3D photo you had taken previously used normal cameras and NO radiation. We are all exposed to background radiation in our everyday lives. According to Government documents you will be exposed to about 0.0027 Sieverts of background radiation in one year. To put this into perspective the radiation you were exposed to during each side on (profile) x-ray was equivalent to between 1 to 2 days background radiation and for the CBCT scan of your facial bones you would be exposed 9 to 31 days background radiation. Any exposure to ionising radiation carries a risk of developing cancer, usually many years after exposure; the additional lifetime risk of cancer induction from the either type of x-ray is very low (0.001%).

2. Do you think the extra radiation exposure during the 3D scan (CBCT) would be "worth it" if it allowed you to see yourself in 3D before surgery?

   Yes ☐ No ☐ Don't know ☐

3. Do you think that seeing the profile prediction image of your face before surgery raises your expectations?

   Yes ☐ No ☐ Don't know ☐

4. Was the profile prediction facial image better, worse or as expected compared to your final soft tissue profile following surgery?

   The profile prediction was better than my facial profile ☐

   The profile prediction was worse than my facial profile ☐

   The profile prediction was and my facial profile look the same ☐

Consent Form
Severity of dentofacial deformity in profile: A patient's perspective.

<u>Research team: Balvinder Khambay, Sheena Kotecha, John Turner, Lorraine Barreto & Rhodri Williams, Jinesh Shah</u>

Please read and <u>initial</u> each statement below if you are happy to take part.

1. I confirm that I have read and understood the information sheet version 1.2 dated 12.December.2017 provided to me for the above study. ☐

2. I have had the opportunity to consider the information, ask questions and have had these answered satisfactorily. ☐

3. I understand that participation is voluntary and that I am free to withdraw at any time without giving any reason and without my treatment or legal rights being affected. ☐

4. I understand my data will be held securely on both an NHS and University of Birmingham IT systems ☐

5. I consent to taking part in the study. ☐

6. I understand that relevant sections of my medical notes and data collected during the study may be looked at by individuals from the Sponsor, from regulatory authorities or from the NHS Trust, where it is relevant to me taking part in this research. I give permission for these individuals to have access to these records. ☐

When completed, provide a copy for the parent, one to be kept in a file in a locked office at Birmingham Dental Hospital.

If you are happy to take part in the study, please sign below:

Print name: ______________________

Sign: ______________________ Date: ______________________

Name of person taking consent:

Print Name: ______________________ Job title: ______________________

Sign: ______________________ Date: ______________________

IRAS No: 231259

UNIVERSITY OF BIRMINGHAM

Information Sheet v1.2 (12/December/2017)

Severity of dentofacial deformity in profile: A patient's perspective.

We would like to invite you to take part in a research study.

- Before you decide whether to take part, it is important for you to understand why the research is being done and what it will involve.
- Please take time to read the following information carefully. Discuss it with others if you wish.
- You are free to decide whether or not to take part in this trial. If you choose not to take part, this will not affect the care you get from your orthodontist.
- Ask us if there is anything that is not clear or if you would like more information.

Important things that you need to know

- We want to find out if the current method of showing you what you are going to look like after surgery is the correct one?
- This study fits into the normal treatment, so there are no extra clinic visits or x-rays.
- You can stop taking part in the study at any time.

Contents

Why are we doing this study?

At the moment we try and show you what your face will look like after surgery based on a side view (profile) photograph of your face. We are not sure whether patients are used too looking at themselves in profile and if it is useful or are other methods of showing your face more helpful.

This project is part of an educational degree. The student/s involved are qualified senior dentists undertaking a research degree in their field of expertise. The student/s will be involved in all aspects of the project under the supervision of Prof. Balvinder Khambay, who is the principal investigator of the study.

Why have I been chosen?

We are looking for 40 volunteers between the ages of 18 and 55 who are ready for surgery and having their surgical plan confirmed by the surgical team.

Are there any risks associated with this treatment?

The x-ray examinations of your jaw are part of your routine care. If you take part in this study you will not undergo any additional x-rays. These procedures use ionising radiation to form images of your body and provide your doctor with other clinical information. Ionising radiation can cause cell damage that may, after many years or decades, turn cancerous. The chances of this happening to you are the same whether you take part in this study or not.

There are no risks associated with taking part in this study. Participation is entirely voluntary and your treatment will not be affected if you decide not to participate.

What is involved in this study?

You will be shown a profile picture of your face which has been changed so the upper and lower parts of your face are in the wrong position. You will be shown how to move the upper and lower parts of your face using a computer program and you be asked to move them into the positions you think they are now i.e. before your surgery and where you think they should be after surgery.

This step would be repeated 6-8 weeks at your next routine appointment.

In addition, during your first research visit appointment, to help us understand the data better we may ask you to answer some questions about you and where you had your surgery, whilst you are waiting for or during your appointment

Thank you for reading so far – if you are still interested, please continue reading the rest of this leaflet.

More information about taking part

What happens following completion of the study?

The study team will not need to contact you again however you would be able to speak to us at any time regarding the study if you wish.

What if there is a problem or something goes wrong?

If you have any problems these will be seen to immediately. If you are worried about the treatment received or the way you have been treated then you may contact the study team.

In the event that something does go wrong and you are harmed during the research and this is due to someone's negligence, then you may have grounds for a legal action for compensation against Birmingham Community Healthcare Trust but you may have to pay for legal costs. The normal National Health Service complaints mechanisms will still be available to you (if appropriate). In addition, the University will cover non-negligent harm/payment of compensation in the event of harm.

Confidentiality

All of the information that is collected regarding the participants, during the course of the research, will be kept strictly confidential. You will not be asked to provide any personal details. Information that has been provided will be anonymised.

With your consent, your dentist will be informed that they are partaking in this trial.

Who has reviewed the study?

All research conducted within the NHS is looked at by independent group of people, called a Research Ethics Committee to protect your safety, rights, wellbeing and dignity. Approval for this study has been granted by the Health Research Authority (IRAS No: 231259)

Organisation and funding

This study is being sponsored and funded by the University of Birmingham.

How to contact us

If you have any questions you can ask the study team:

Balvinder Khambay Sheena Kotecha	John Turner Lorraine Barreto	Rhodri Williams

Email: bchnt.bbtrial@nhs.net (We will aim to answer your queries within 24 hours)

Department Tel: 0121 466 5038 (Monday to Friday, 9am – 4.30pm)

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Holt Street
Aston
Birmingham B7 4BN

Thank you for reading this – please ask if you have any questions.

8.4 Appendix 4

The document below is the accepted author manuscript (also called the post-print) of this output. This is the version after any edits required by peer review but before any copyediting or typesetting by the publisher.

Author Contribution form

BRITISH JOURNAL OF ORAL & MAXILLOFACIAL SURGERY
Author contribution

Manuscript Title
The validity of using profile predictions for class III patients planned for bimaxillary orthognathic surgery

Please provide details in the table below of each author(s) contribution to the submitted manuscript

AUTHORS	Conception and design of study/review/case series	Acquisition of data: laboratory or clinical/literature search	Analysis and interpretation of data collected	Drafting of article and/or critical revision	Final approval and guarantor of manuscript
Sarah Franks		✓		✓	✓
Balvinder Khambay	✓		✓	✓	✓
Anant Bakshi	✓			✓	✓

The validity of using profile predictions for class III patients planned for bimaxillary orthognathic surgery

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Key words: self-perception; facial profile; photocephalometeric planning; prediction planning; 3D planning

Short title: Self-perception of facial profile

The validity of using profile predictions for class III patients planned for bimaxillary orthognathic surgery

ABSTRACT

This study assessed whether pre-operative class III patients could recreate their facial difference based on a profile photograph. Twenty class III pre-surgery bimaxillary orthognathic patients used CASSOS (SoftEnable Technology Ltd.) to manipulate a distorted soft tissue image of them until they felt it resembled their current soft tissue profile. Patients were able to move their upper lip and lower chin backward and forwards, as well as the lower chin up and down. Differences in the mean absolute distance between the patient-perceived position of the upper lip (Labrale superious) and chin (Pogonion) and the actual position of their upper lip and chin were measured on two occasions. Intra-patient reproducibility was found to be excellent (ICC 0.93 to 0.98). All differences were statistically significantly greater than 3mm, and would be clinically significant. Patients were better at re-creating their AP chin position rather than their AP upper lip and vertical chin positions. Approximately half of patients undergoing surgical correction of their class III skeletal pattern were unable to correctly identify their pre-surgical facial profile. Given the lack of awareness of their profile, this questions the validity of using profile planning for informed consent.

Keywords: self-perception; facial profile; photocephalometeric planning; prediction planning; 3D planning

INTRODUCTION

Facial attractiveness has many well-reported social advantages.[1] Attractive individuals are known to have several positive personality traits.[2,3] The importance of facial appearance in this ever-increasing world of social media is arguably more important than ever, especially among the younger age group.[4] There has been a paralleled increase in the number of cosmetic procedures undertaken by individuals. For instance, there has been a 60% increase in Botox injections from 2012 to 2019 with over 2.3 million injections performed in 2019.[5]

Individuals with a facial difference will often require orthognathic surgery to address their functional and aesthetic concerns. Part of the treatment planning process involves predicting the soft tissue outcomes following surgery. Sharing this with the patient is essential for gaining informed consent but also for increasing their understanding and acceptance of the recommended treatment.[6] Patients are more likely to be satisfied when they are involved in the decision-making process.[7,8] At present several methods to predict the outcome of surgery are available. These include model surgery[9], two-dimensional (2D) photocephalometric planning[10,11] and three-dimensional (3D) planning.[12,13] Two-dimensional cephalometeric planning is a well-established method of predicting soft tissue outcome following surgery. However, in the United Kingdom, not all NHS hospital Orthodontic / Maxillofacial Departments have access or routinely use 2D photocephalometeric planning software. Anecdotally, in the Departments that do, some maxillofacial surgeons are anxious showing any soft tissue profile predictions to the patients. They feel that the predictions may increase patient expectations, and lead to a dissatisfied outcome. The premise for this assumption must be that patients know what they look like in profile prior to and after surgery. Given that, as individuals, we frequently see frontal or portrait views of ourselves i.e. with selfies and traditional camera views, and more often mirror views of ourselves, is this a valid assumption?

Therefore the aim of this study was to assess whether pre-operative class III patients can recreate the severity of their facial difference based on a profile photograph. The null hypothesis was that the mean absolute difference in the patient-perceived position of the upper lip (Labrale superious, Ls) and chin (Pogonion, Pog) and the actual position of their upper lip and chin was not statistically significantly ($p<0.05$) greater than the 3.0mm clinical threshold.[14]

METHOD AND MATERIALS

This prospective study included 13 males and 7 females (mean age 22.0 years ± 6.0 months) who attended the joint orthognathic clinic, between July 2018 and November 2019 and were planned for bimaxillary surgery to correct their class III skeletal pattern (mean Wits -9.7 ± 3.2mm). Patients were non-syndromic and had no significant facial asymmetries.

MATERIALS AND METHODS

Computer-Assisted Simulation System for Orthognathic Surgery (CASSOS) (SoftEnable Technology Ltd., Hong Kong) software installed on a Dell Latitude 3340 Intel Core i3 13.3' screen Laptop was used to produce a morphable profile image.

For each patient a digital lateral cephalograms was taken in a standardised manner with Frankfort Plane parallel to the floor, lips in repose, and teeth in intercuspal position (ICP). The radiographs were uploaded into CASSOS and seventy-one pre-determined hard and soft tissue landmarks were identified generating a ‘tracing’. The visual information below Subnasale backwards, on the lateral cephalogram, was redacted, leaving on the soft tissue profile. A ‘matched image’ was generated by superimposing the redacted lateral cephalogram and the right profile photograph, Figure 1.

For each patient the starting point of each soft tissue profile outline was altered by advancing the chin anteriorly horizontally (x-axis) and vertically / inferiorly (y-axis) by 10mm and the maxillary horizontality posteriorly by 10mm. The first image the patients saw of themselves was the altered image.

Patients were shown a demonstration of the process using a mock profile. They were asked to manipulate their profile outline visible on screen, using the arrow keys, until they felt it resembled their current soft tissue profile, Figure 2. The soft tissue profile was saved (T_1) and following a 15-minute break each patient was asked to repeat the procedure and the second profile saved (T_2).

Finally each patient was asked to anonymously answer the following questions (1). Would you find it more helpful to see a 3D image of your face or a 2D profile image during the surgical planning stage? (2). Do you think the extra radiation exposure during the 3D scan (CBCT) would be “worth it” if it allowed you to see yourself in 3D before surgery?

Bland Altman plot was produced to show the bias and levels of agreement (LoA) between the mean differences in actual upper lip and chin position and patient- perceived position in the anterior-posterior (AP) direction and vertical directions. A negative value indicated the patient perceived landmark was more posterior or more superior in the x and y direction respectively, than the actual soft tissue landmark.

STATISTICAL ANALYSIS

Differences in Labrale superious (Ls) and Pogonion (Pog), in the x and y directions, between the actual patient profile and their perceived profile were extracted relative to Nasion (0, 0). The data was found to be normally distributed based on the Anderson-Darling test. The intraclass correlation coefficient (ICC) was used to determine intra-patient reproducibility. To prevent averaging of positive and negative values, as the signs refer to the direction, absolute mean values were used. A one-sample *t*-test was used to determine whether the mean absolute differences in the actual and perceived lip and chin position, in both the AP direction and vertical directions were significantly different to 3.0mm ($p<0.05$).

RESULTS

Sample size calculation

Following a sample size calculation (Minitab 19, State College, PA) 20 participants were necessary to determine whether the mean absolute difference in actual and perceived lip and chin position, were greater than 3.0 mm[14] , based on a significance level of 0.05, power of 80%, and standard deviation (SD) of 4.5mm.

Intra-patient reproducibility

The intra-patient reproducibility was found to be excellent (ICC score range 0.93 to 0.98). The mean absolute differences in AP upper lip and AP and vertical chin position between the T_1 and T_2 were 1.8 ± 2.1mm, 2.2 ± 2.2mm and 1.8 ± 1.4mm respectively.

Upper lip position relative to Nasion

The mean absolute difference in the actual and perceived lip was not statistically significantly different to 3.0mm (p=0.860), Table 1. There was a bias towards under advancing the upper lip and producing a more retrusive upper lip, accompanied with a large variation in response, Figure 3.

Chin position relative to Nasion

The mean absolute difference in the AP actual and perceived chin position was not statistically significantly different to 3.0mm (p=0.811). The Bland-Altman plot shows the bias towards producing a more protrusive chin position, Figure 4. For the vertical direction the mean absolute difference was statistically significantly greater than 3.0mm (p=0.017). The Bland-Altman plot shows the bias towards placing Pogonion more inferiorly, Figure 5. The wide limit of agreement from 12.8mm to -3.5mm suggests the large variation in perceived vertical chin position, Table 1.

Inter lip-chin relationship

The horizontal and vertical distances of the upper lip (Ls) to the chin point (Pog) were used to measure the relative position of the chin to the upper lip. Both the mean absolute differences between the actual and perceived Ls-Pog horizontal distance were statistically significantly greater than 3.0mm.

Responses of patients to 3D planning

Four out of the twenty patients reported they were concerned with the additional radiation exposure of a CBCT scan needed to produce a 3D prediction and would not find a 3D predication of any additional value.

DISCUSSION

This novel study determined whether patients with a class III facial disharmony were able to recreate their pre-surgical soft tissue facial profile. For two-dimensional photocephalometric prediction planning to be a valid form of media for patient communication, managing expectations and informed consent, the assumption must be that patients have a perception of their pre-surgical soft tissue facial profile, before presenting them with the profile prediction. Some surgeons are uncomfortable showing patients' their predictions, as they feel it may lead to unrealistic patient expectations. This creates a dilemma, the patient is undergoing an elective procedure to address their facial difference, but the surgeons are unwilling to show them the outcome. This could be seen as a paternalistic approach to treatment where the patient has no option but assume the surgeon "knows best". From a legal perspective this approach is no longer acceptable and is by no means informed consent.[15]

The results of the present study showed that out of the 20 class III patients, 9 patients correctly identified the AP position of their upper lip and 11 patients their AP chin position to within the 3mm clinical threshold.[14] Of these, only 5 patients correctly identify both their AP upper lip and chin positions. Based on the mean differences, there was a tendency for patients to under advance their upper lip i.e. positioning it more retrusive than it was in reality (-2.3 ±

3.0mm) and position their chin in approximately the correct AP position (0.8 ± 3.7mm). Twelve patients correctly identified their anterior-posterior upper lip / chin relationship. In the vertical direction, only 6 patients were able to position their chin correctly to within the 3mm clinical threshold. There was tendency for patients to position their chin more inferiorly than in reality. For this cohort of patients the mean absolute difference between the actual and perceived lip and chin positions for all measurements were 3mm or greater. One possible explanation for better AP chin point position may be that the chin is well defined and is an isolated feature, whist the perception of upper lip position may be influenced by the surrounding soft tissue i.e. nasal tip position, columella inclination or malar projection. There may be several reasons why patients produce a soft tissue profile that exaggerates their AP class III skeletal pattern and increased vertical dimension. It could be that patients do not know what they look like in profile, or patients have a distorted view of themselves, or patients are trying to guide the surgical plan. Reassuring the patients their identified images would not be used in the surgical decision-making process would have hopefully negated the effect of the later.

Previous studies have used silhouettes to assess facial attractiveness.[16-18] The present study used the patient's actual soft tissue profile, which could be "morphed", in real-time, in CASSOS. This allowed the individual to move their soft tissue and produce a smooth photorealistic image of their profile. Using conventional photo-editing software would have produced an image, that would have had gaps, and steps that could distract from the final image, similar to the 1:1 profile predications.[9] Previous studies have reported that only 42% of lay people were able to choose the correct silhouette, which best represented their facial profile.[17,18] This means over 50% of lay people are unable to recognise themselves in profile.

The authors acknowledge that the direction and amount the pre-surgical image was manipulated may affect the patient's ability to accurately recreate the various soft tissue positions. A future study could involve manipulating the pre-surgical images to both extremes, making a class III patient look class II versus an exaggerated class III and investigating the effects of orthodontic decompensation. This was beyond the scope of this study, but would be interesting.

As individuals, we rarely see ourselves in profile and are accustomed to viewing our faces from the frontal view, as a reflected frontal view in the mirror. de Runz et al (2016) reported a significant preference for mirror-reversed photographs over standard photographs among female patients who are undergoing facial aesthetic surgery.[19] This could also be of significance in orthognathic patients who were seeking correction of a mandibular asymmetry. We acknowledge that there may be a difference in facial perception between males and females and possibly between racial groups but was beyond the scope of this study, but does warrant further investigation.

If around half of class III patients do not know what they look like in profile, then the use of soft tissue profile predictions as a visualisation tool becomes questionable. The information provided by the computerised predication may not be in a format that the patients can not relate too and therefore may not be the ideal media for them to make an informed decision. The profile predictions maybe of some limited benefit in explaining the “general surgical plan” to the patient, but their use as an absolute indicator of outcome is probably of little benefit.

Even though three-dimensional orthognathic planning is routinely available in many centres outside of the UK, many NHS orthognathic teams do not have access to this method of planning, either due to cost, lack of specialised equipment or lack of expertise. In addition to this, there are concerns regarding the additional radiation exposure during the CBCT scan and the perceived advantages of using 3D orthognathic planning techniques. The majority of the patients in this study were millennials and were accustomed to viewing three-dimensional (3D) media in the form of video games and movies. It was therefore not surprising that 16 out of the 20 patients would have found it more helpful to see a 3D image of themselves following 3D surgical planning. Given the 3D nature of the face, it is not surprising that patients want to see themselves in 3D. This would be of greater significance in patients with a mandibular asymmetry. Whether the patients could correctly identify the severity of their class III skeletal pattern and whether they prefer the mirror-reversed view remains unknown and requires further work.

CONCLUSIONS

This study has shown approximately half of patients planned for surgical correction of their class III skeletal pattern could not correctly identify their pre-surgical facial profile. Patients were better at determining their anterior-posterior chin position than their upper lip position. The use of two-dimensional photocephalometric planning, as a tool for informed consent, may therefore be questionable, given that patients may not know what they look like prior to surgery, let alone after surgery. Generating a 3D facial soft tissue prediction maybe more useful as a patient information tool, but this requires further investigation.

ACKNOWLEDGEMENTS

The authors would like to thank [redacted] and the patients and orthognathic surgical team at the [redacted].

CONFLICT OF INTEREST

None

ETHICS STATEMENT/CONFIRMATION OF PATIENT PERMISSION

Ethical approval was been granted by the Health Research Authority ([redacted]). Consent for publication of images has been given.

REFERENCES

1. Riggio RE, Woll SB. The Role of Nonverbal Cues and Physical Attractiveness in the Selection of Dating Partners. *J Soc Pers Relat* 1984;**1**:347-57.
2. Cash TF and Kilcullen RN. The Aye of the Beholder: Susceptibility to Sexism and Beautyism in the Evaluation of Managerial Applicants 1*. J Appl Soc Psychol* 1985;**15**:591-605.
3. Sigall H and Ostrove N. Beautiful but dangerous: Effects of offender attractiveness and nature of the crime on juridic judgment*. J Pers Soc Psychol* 1975;**31**:410–14.
4. Fardouly, J and Vartanian LR. Social media and body image concerns: Current research and future directions. *Curr Opin Psychol* 2016;**9**:1–5.
5. American Society for Dermatologic Surgery. Survey on dermatologic procedures: report of 2019 procedures. https://www.asds.net/portals/0/PDF/procedures-survey-results-presentation-2019.pdf. Accessed 8th March 2021.
6. Kolokitha OE, Topouzelis N. Cephalometric methods of prediction in orthognathic surgery. *J Maxillofac Oral Surg* 2011;**10**:236-45.
7. AlKharafi L, AlHajery D, Andersson L. Orthognathic surgery: pretreatment information and patient satisfaction. *Med Princ Pract* 2014;**23**:218-24.

8. Kiyak HA, Hohl T, West RA, et al. Psychologic changes in orthognathic surgery patients: a 24-month follow up. *J Oral Maxillofac Surg* 1984;**42**:506-12.
9. Henderson D. The assessment, management of bony deformities of the middle, lower face. *Br J Plast Surg* 1974;**66**:378–96.
10. McNeill RW, Proffit WR, White RP. Cephalometric prediction for orthodontic surgery. *Angle Orthod* 1972;**42**:154-64.
11. Carter AC, Larson BE, Guenthner TA. Accuracy of video imaging in mandibular surgery. *Int J Adult Orthodon Orthognath Surg* 1996;**11**:289-300.
12. Xia J, Ip HH, Samman N, et al. Computer-assisted three-dimensional surgical planning and simulation: 3D virtual osteotomy. *Int J Oral Maxillofac Surg* 2000:**29**;11-7.
13. Xia J, Samman N, Yeung RW, et al. Computer-assisted three-dimensional surgical planing and simulation. 3D soft tissue planning and prediction. *Int J Oral Maxillofac Surg* 2000;**29**:250-58.
14. Jones RM, Khambay BS, McHugh S, et al. The validity of a computer-assisted simulation system for orthognathic surgery (CASSOS) for planning the surgical correction of class III skeletal deformities: single-jaw versus bimaxillary surgery. *Int J Oral Maxillofac Surg* 2007;**36**:900-08.
15. McKinnon C, Loughran D, Finn R, et al. Surgical consent practice in the UK following the Montgomery ruling: A national cross-sectional questionnaire study. *Int J Surg* 2018;**55**:66-72.
16. Naini FB, Donaldson AN, Cobourne MT, et al. Assessing the influence of mandibular prominence on perceived attractiveness in the orthognathic patient, clinician, and layperson. *Eur J Orthod* 2012;**34**:738-46.

17. Tufekci E, Jahangiri A, Lindauer SJ. Perception of profile among laypeople, dental students and orthodontic patients. *Angle Orthod* 2008;**78**:983-87.
18. Trehan M, Naqvi ZA, Sharma S. Perception of Facial Profile: How You Feel About Yourself. *Int J Clin Pediatr Dent* 2011;**4**:109-11.
19. de Runz A, Boccara D, Chaouat M, et al. Female plastic surgery patients prefer mirror-reversed photographs of themselves: A prospective study. *J Plast Reconstr Aesthet Surg* 2016;**69**:122-127.

CAPTIONS FOR ILLUSTRATIONS

Figure 1 Matched lateral cephalogram with lower half redacted (white box) and soft tissue profile (red line) with right profile photograph superimposed.

Figure 2 Simulation of profile based on patient-perceived appearance of a non-class III individual used in demonstration.

Figure 3 Bland and Altman plots for patient-perceived and actual anterior- posterior upper lip (Ls) position.

Figure 4 Bland and Altman plots for patient-perceived and actual anterior- posterior chin (Pog) position.

Figure 5 Bland and Altman plots for patient-perceived and actual vertical chin (Pog) position.

TABLE LEGEND

Table 1 Descriptive statistics for the mean and absolute mean differences between Labrale superious (Ls) and Pogonion (Pog), in the anterior-posterior (AP) and vertical (Vert) directions, between the actual patient profile and perceived profiles.

TABLE 1

	Actual position		Patient-perceived position		(Patient-perceived position) – (Actual position)								p-value
	Mean (mm)	SD (mm)	Mean (mm)	SD (mm)	Mean difference (mm)	SD (mm)	95% CI for the differences (mm)		Absolute Mean difference (mm)	SD (mm)	95% CI for the differences (mm)		
							Lower limit	Upper limit			Lower limit	Upper limit	
Ls (AP)	13.4	3.2	11.1	4.0	-2.3	3.0	-3.7	-0.9	3.1	2.2	2.1	4.1	0.860
Pog (AP)	13.1	5.6	13.9	6.0	0.8	3.7	-0.9	2.5	3.1	2.0	2.2	4.0	0.811
Pog (Vert)	102.4	8.5	107.0	9.5	4.7	4.2	2.7	6.6	5.1	3.6	3.4	6.8	0.017*
Ls – Pog (AP)	0.3	4.4	-2.7	5.4	3.1	3.9	-0.1	6.3	3.2	2.5	2.1	4.4	0.749
Ls – Pog (Vert)	-39.4	4.5	-43.8	6.3	4.4	3.9	0.9	7.9	4.4	3.9	0.9	7.9	0.015*

*Following a one sample *t*-test with a hypothesised mean of 3.0mm ($p<0.05$)

Figure 1

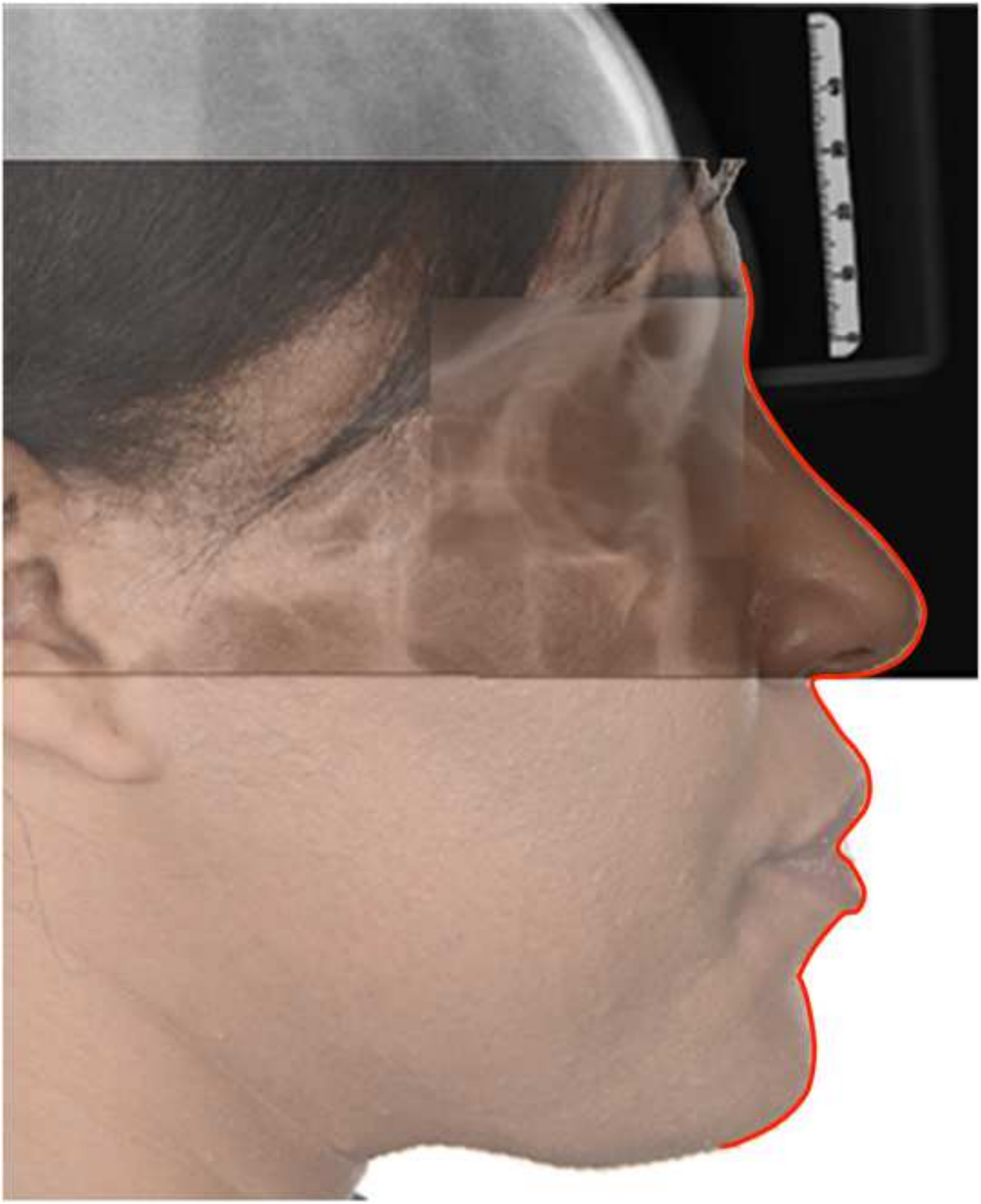
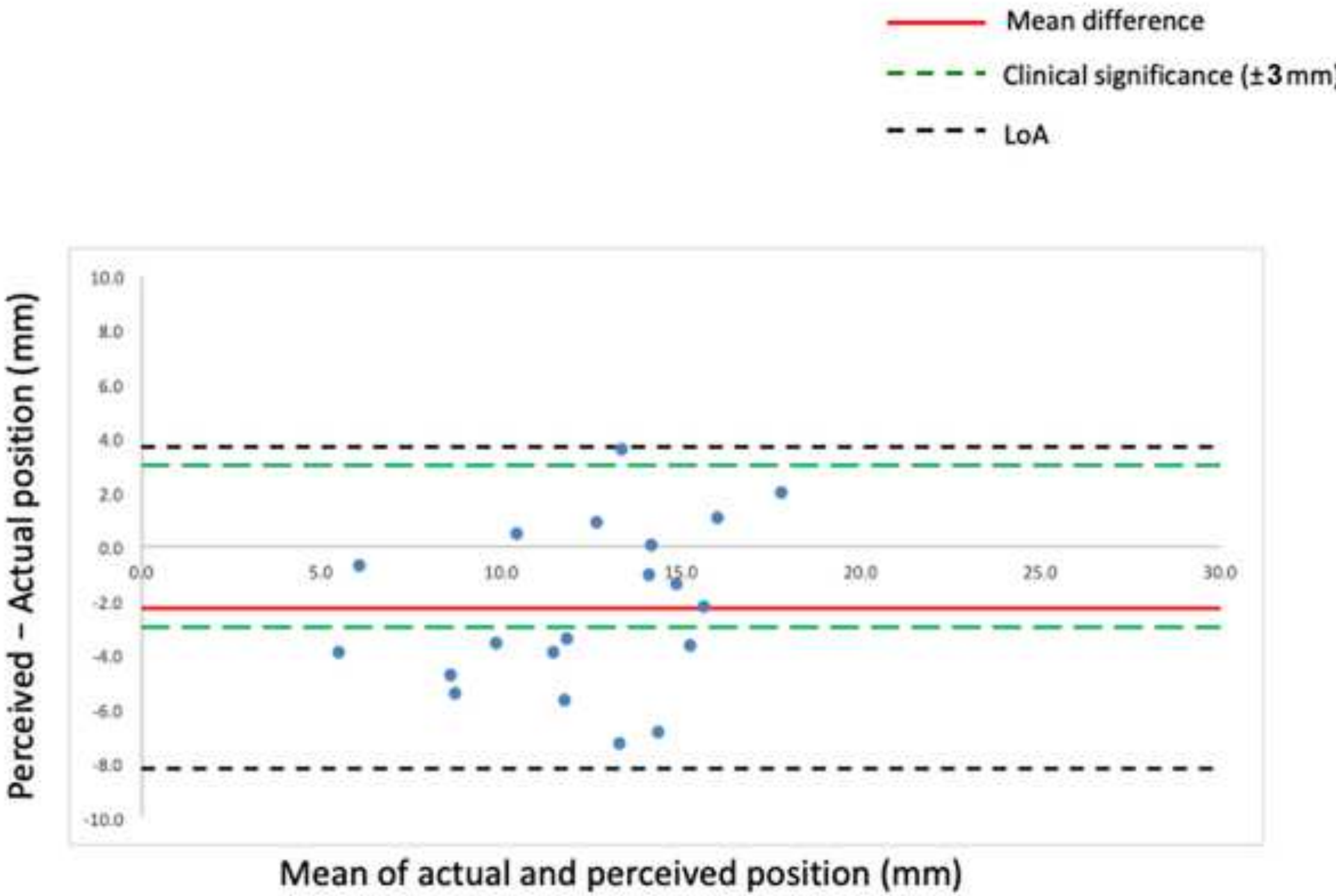


Figure 2

Figure 3


Mean difference
Clinical significance (±3 mm)
LoA
10.0
8.0
6.0
4.0
2.0
0.0
-2.0
-4.0
-6.0
-8.0
-10.0
0.0
5.0
10.0
15.0
20.0
25.0
30.0
Perceived – Actual position (mm)
Mean of actual and perceived position (mm)

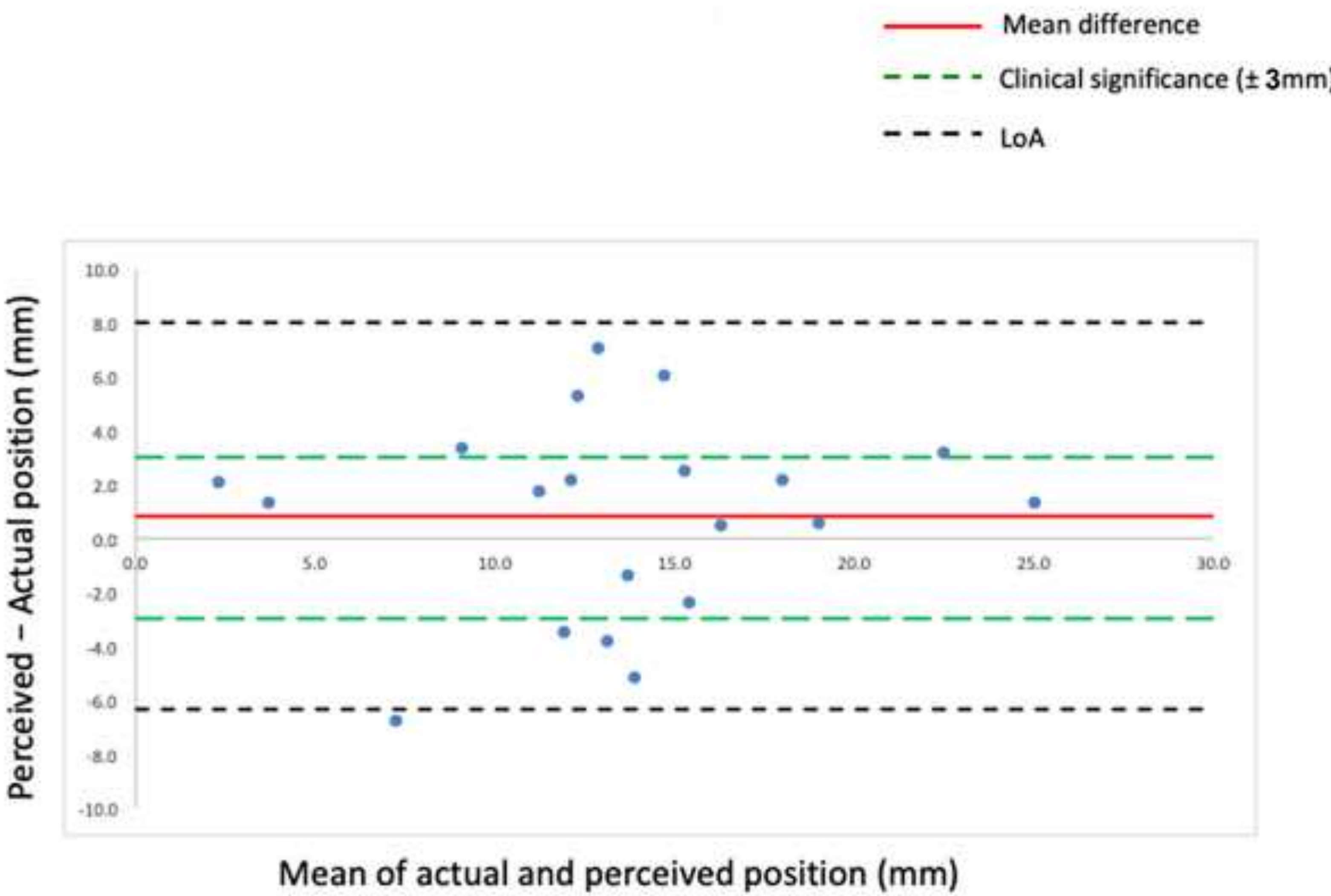
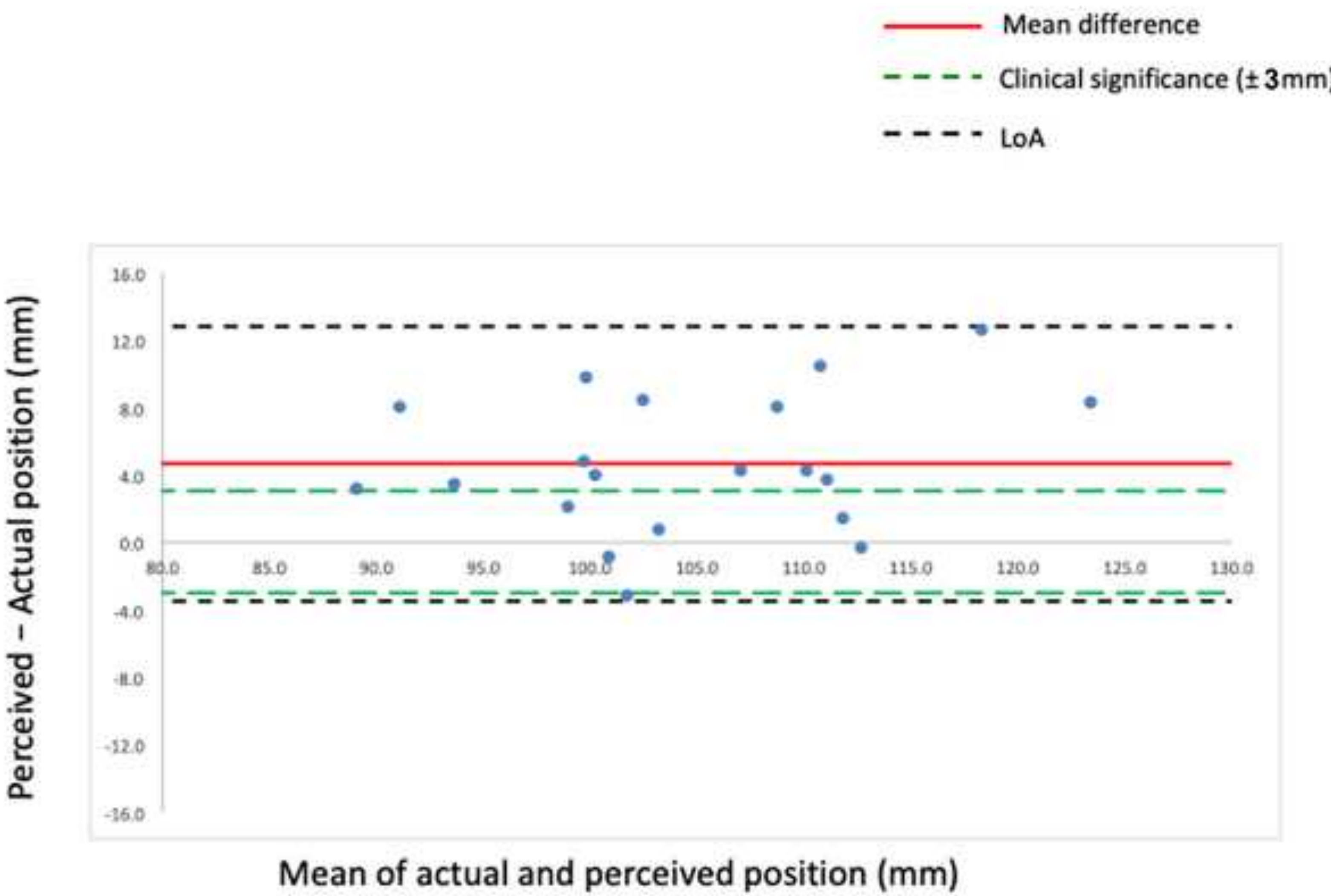

Mean difference
Clinical significance (± 3mm)
LoA
10.0
8.0
6.0
4.0
2.0
0.0
-2.0
-4.0
-6.0
-8.0
-10.0
0.0
5.0
10.0
15.0
20.0
25.0
30.0
Perceived – Actual position (mm)
Mean of actual and perceived position (mm)

Figure 5


Mean difference
Clinical significance (± 3mm)
LoA
16.0
12.0
8.0
4.0
0.0
-4.0
-8.0
-12.0
-16.0
80.0
85.0
90.0
95.0
100.0
105.0
110.0
115.0
120.0
125.0
130.0
Perceived – Actual position (mm)
Mean of actual and perceived position (mm)