Soft tissue facial changes in patients 18 years and older after bone-anchored maxillary expansion- a pilot study

by

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A thesis submitted in partial fulfillment of the requirements for the degree of

Master of Science

Medical Sciences - Orthodontics

University of Alberta

Abstract

Introduction: Maxillary expansion is a therapeutic modality utilized by orthodontists in order to increase the transverse dimension of the maxilla and correct transverse maxillary discrepancies that is commonly utilized in cases with posterior crossbite and maxillary crowding. This thesis will elaborate on how bone-anchored maxillary expansion can affect soft-tissue changes in adult patients. The importance of this thesis is that unlike similar articles we will be utilizing a 3D facial scanner, in conjunction with a CBCT to evaluate the soft tissue changes after maxillary expansion. Linear changes will be measured to determine the changes from pre-maxillary expansion compared to post-maxillary expansion.

Methods: The sample population includes 20 patients and were randomly assigned to the Dresden (Group A) and Moon expander (Group B) groups. The inclusion criteria were as follows: requirement of maxillary expansion treatment for the groups, need of post-expansion orthognathic surgery would be included, full permanent dentition erupted (except 3rd molars), treatment may involve post-expansion tooth extraction or not, no syndromic characteristics or systemic diseases clinically determined or based on previous records and male and female between ages 18-30 years.

Each patient in Group A and B will undergo CBCT and 3D facial photographs/scannings at pre-treatment (before maxillary expansion), and after the completion of expansion. These pre- and post-treatment soft tissue measurements will be compared to determine soft tissue changes due to maxillary expansion. To determine measurements from the 3D facial scans, the OrthoInsight

software will be used. To determine CBCT landmark measurements, 3D Slicer software will be used. The landmarks that will be included is: nasal width, mouth width, alar base width, upper philtrum width, nasal tip prominence, nasolabial angle, upper lip thickness, upper lip to E-line, lower lip to E-line, upper lip height, lower lip height, height of nose, and lower anterior facial height (LAFH).

Results: It can be inferred that there are no statistically significant changes from T0 to T1 for any measurements except for endocanthion. Measuring endocanthion on the two imaging modalities can lack reliability due to its lack of clear demarcation.

The study questioned whether there was an inconsistency in measuring the patients with either the CBCT or 3D facial scanner. The conclusion was that at T0, the following measurements had inconsistencies between the two imaging modalities: height of nose, lower lip to E-line, lower anterior facial height, height of lower lip, and nasal tip prominence. At T1, the following measurements had inconsistencies: height of vermillion border, lower anterior facial height, mouth width, height of lower lip, nasal tip prominence, and endocanthion.

In addition, there was no statistical significant difference between the Dresden and Moon expander on the changes in the facial soft tissue.

Conclusions: In research question 1, measuring endocanthion on the two imaging modalities can lack reliability due to its lack of clear demarcation. For research question 2, the inconsistencies of these measurements mainly stem from the CBCT field of view, not including the soft tissue menton. Specifically, the lower anterior facial height and height of lower lip. Furthermore, the absence of the nasion point in select patients, attributed to the CBCT's field of view limitations,

could potentially create a discrepancy in the height of nose measurement. Moreover, the complexity of visualizing the mouth region in the CBCT scans may impact the precision and reliability of lip-related measurements in the study.

Furthermore, this research study concluded that there is no difference between the Dresden and Moon expander on the soft tissue changes.

Preface

This thesis is an original work by Gursimrit Grewal. The research project was conducted at the Orthodontics Graduate Clinic at the University of Alberta with the ethics approval from the Research Ethics Board (Pro00084145) from the University of Alberta on August 06, 2020. No part of this thesis has been previously published.

Acknowledgements

I want to dedicate this research project to my loving husband, Manjot. Your love, support and patience over these past 3 years will never be overlooked, and I will be forever grateful. I never hesitated to take this big step to go back to school because I knew I had your unwavering encouragement to make this as seamless as can be. Thank you for making my dream possible, there is no-one else I would rather share this with. I love you more than you can ever imagine.

I also want to dedicate this research project to my parents. Dad and Mom, you instilled in me that the sky is the limit, and I was more than capable of doing anything I put my mind to. You gave me the confidence to chase my aspirations fearlessly. You never doubted me… which helped me never doubt myself. Thank you for always nurturing my dreams and being my guiding light every step of the way.

To my sister, Jas, I am lucky to have someone like you to look up-to. You unconditionally lent a hand and ear during my journey and I am forever grateful to have you in my corner. To my sister, Par, thank you for always believing in me and encouraging me to dream big. To my little nephew, who thinks I am too old to be in school, I love you beyond words and I promise I'm done… for now.

To my supervisor, instructor and mentor, Dr. Manuel Lagravere, thank you for always showing your endless support over the years. You are an inspiration to many, and I will continue to look up to you. Thank you to Dr. Oh and Dr. Giseon for playing a vital role in the completion of this project.

Lastly, thank you to my colleagues, Austin, Silvia and Harsimrat. The three of you are beyond intelligent, professional, and hard-working. Time for us to stun the real-world!

Table of Contents

List of Tables

Figures

Chapter 3-

Chapter 5-

Chapter 1– Introduction and Problem Statement

1.1 Introduction

Rapid maxillary expansion (RME) is a widely known orthodontic treatment protocol that is aimed to treat patients with a maxillary transverse discrepancy. The appliance has many different purposes such as posterior crossbite correction, relief of crowding, increase in airway dimensions and in conjunction with facemask therapy for class III patients.[1–3] It is known to widen and increase the transverse dimensions in the maxilla. Expansion appliances are designed to deliver orthopedic forces that split the mid-palatal suture of the maxillary and palatine bones to widen the arches. Once the amount of expansion has been achieved to correct the crossbite, over-correction is desired to take in account possible relapse. At this stage, the expansion appliance is inactive for three months. After this period, a retention (i.e. TPA, existing expander, removable Hawley or Essix) protocol depending on the clinicians discretion is installed and kept for six months.[4] It is important to understand that the gradual fusion of this mid-palatal suture presents with great variability according to age and gender of the patient.[5,6] The failure of maxillary expander appliances can be attributed to the fusion of the mid-palatal suture, and commonly this fusion occurs in late adolescents and young adults.

The most common design of maxillary expander appliances is a tooth-borne expander, which is typically anchored to the first molars. If used on an adult patient, this can result in consequences to the surrounding alveolar structures and dentition. The common consequences are more dental tipping rather than skeletal expansion, periodontal concerns such as recession and bone loss, and root resorption.[7,8] Conventionally, for non-growing patients, the most common maxillary expansion technique is known as a surgically assisted rapid palatal expander

(SARPE). A surgical procedure is indicated since there is increased interdigitation/fusion of the maxillary suture, and increased thickness and rigidity of the maxillary bone.[5,9,10] However, the inherent risks of a surgical operation, together with the cost, the hospitalization and attendant morbidity may pose a constraint for patients to undergo this procedure. [11]

More recently, a non-surgical bone-borne expansion method has been developed by Lee et al, and Moon et al,[19] known as the micro-implant assisted rapid maxillary expander (MARPE). MARPE is either a tooth-bone-borne expander or solely a bone-borne expander. This bone-anchored maxillary expander has gained attention as a viable option for correcting maxillary transverse discrepancies in adult patients without the need of surgery. It was designed to maximize the skeletal effects and to minimize the dentoalveolar effects of expansion. This is due to histological studies that propose that the mid-palatal suture does not fully ossify throughout our life, possibly due to the constant mechanical stress it undergoes.[12,13] Unlike traditional methods, this innovative approach involves the placement of mini-implants, also known as temporary anchorage devices (TADs), in the maxillary bone. These TADs serve as stable anchor points for the expansion device, allowing controlled and gradual separation of the maxillary bones.

However, maxillary expansion may not be limited to skeletal and dental changes, but may affect the overlying surrounding soft tissues. Berger et al.[14] initially associated soft tissue alterations with skeletal changes after RME through an analysis of soft tissue changes in patients who underwent orthopedically or surgically assisted RME. They analyzed posteroanterior cephalograms and confirmed that the soft tissue changes/skeletal changes ratio was 1:1. These

findings were supported by those in a recent study by Pangrazio-Kulbersh et al., who used cone beam computed tomography (CBCT)[14]. Although several studies have reported the skeletal and dental effects of RME, only a few studies and scarce data have addressed alterations in the overlying soft tissue. A systematic review and meta-analysis by Huang et al. aimed to test the hypothesis that no facial soft tissue changes occur after nonsurgical rapid maxillary expansion (RME), in order to provide a reference for orthodontists.[15] Their findings suggest that RME results in a significantly increased nasal width, mouth width, upper philtrum width, and distance from the lower lip to the E line after the retention phase.

Studies that show the effect that maxillary expansion has on the facial soft tissues have utilized two-dimensional techniques, ie. lateral cephalograms, frontal photographic views, or by direct physical measurements.[16,17] Lane and Harrell reported that the position of the head, distance between the camera and the subject, and the camera angle are all the factors that will result in unwanted discrepancies in the conventional method of photography.[16,17] These disparities provoke questions concerning the validity of quantitative information derived from this imaging system. On the other hand, landmark identification in the soft tissue is complicated due to the rounded and elastic nature of the tissue. Due to these tools having their own inherent limitations, more recent research has considered the use of CT, CBCT or stereophotogrammetry to conclude on the assumptions of soft tissue changes after maxillary expansion.[14,18,19] In a 2018 study conducted by Abedini et al, they analyzed soft tissue changes in 25 non-growing patients, ages 14-25 years of age, utilizing 3D facial scans for patients who underwent maxillary expansion with micro-implants. They analyzed the 3D facial images before expansion (T0), after expansion (T1), and 1 year retention (T2). The conclusion is that the maxillary skeletal expander

has a statistically significant impact on the soft tissue of the face, particularly in the region of the paranasal and cheeks area.[16]

The effects of maxillary expanders and soft tissue facial changes has yet to be deeply investigated, specifically in non-growing patients. The significance of this thesis is important because we will be utilizing a 3D facial scanner, in conjunction with a CBCT to evaluate the soft tissue changes after maxillary expansion. Linear measurements will determine the changes from pre-maxillary expansion (T0) compared to post-maxillary expansion (T1). In addition, many of the recent studies focus on this topic in adolescent patients; however, there has been a lack of studies that investigate the effects of bone-anchored maxillary expanders on the soft tissue morphology in adult patients. Since this topic is not fully understood yet, it provides important relevant information to the patient and it would be in the patients' best interest if this is understood and communicated by the orthodontist.

1.2 Research Questions

Research Questions:

1.Is there a consistency between the soft tissue measurements (*mm*) derived from the CBCT and 3D facial scan?

2. Is there a difference between the two different expanders (Dresden expander and Moon expander) in terms of effects on mean soft tissue measurements (*mm*)?

3. Is there a difference in the mean facial soft tissue measurements (*mm*) at pre-treatment (T0), and post-treatment (T1)?

1.3 Hypotheses

First research question:

H_o → There is no consistency between the soft tissue measurements (*mm*) derived from the CBCT and 3D facial scan

H_a → There is a consistency between the soft tissue measurements (*mm*) derived from the CBCT and 3D facial scan

Second research question:

H_o → There is no difference between the two different expanders (Dresden expander and Moon expander) in terms of effects on mean soft tissue measurements (*mm*)

H_a → There is a difference between the two different expanders (Dresden expander and Moon expander) in terms of effects on mean soft tissue measurements (*mm*)

Third research question:

H_o → There is no difference in the mean facial soft tissue measurements (*mm*) at pre-treatment (T0), and post-treatment (T1)

H_a → There is a difference in the mean facial soft tissue measurements (*mm*) at pre-treatment (T0), and post-treatment (T1)

Chapter 2 Literature Review

2.1 Morphology of maxilla

Firstly, to diagnose and treat patients utilizing maxillary expansion, it would be ideal to understand the biologic events that are implicated orthodontically and orthopedically. The knowledge of the structures affected by maxillary expansion should be understood in both the vertical and horizontal direction, and most importantly, the variations in different age groups.

The mid-palatal suture is arranged in an overlapping and sinuous pattern, with three to five layers of bone margins and thick connective tissue interposed between them. The mid-palatal suture represents the fusion of maxillary palatal processes, but also the fusion of alveolar palatal processes of the jaws and horizontal osseous laminae of the palatal bones. This in turn indicates that maxillary expansion affects the neighboring areas. Furthermore, the maxilla is separated into three segments: the anterior segment (before the incisive foramen, or intermaxillary segment), the middle segment (from the incisive foramen to the suture transversal to the palatal bone), the posterior segment (after the suture transversal to the palatal bone)

It is also important to understand the ossification process. Mann et al has identified that the sequence of ossification begins with the incisive suture, followed by the posterior segment of the mid-palatal suture, followed by the transverse palatine suture, and then the middle segment of the mid-palatal suture. [2]

2.2 Etiology of maxillary transverse deficiencies

Epidemiological studies show that transverse malocclusions are quite common in nearly all populations. Therefore, this topic should be widely researched and recognized to better treat

patients effectively and successfully. Transverse malocclusions do not exist as a separate entity and are usually combined with either sagittal or vertical malocclusions or both.[3] For example, a Class II relationship may disguise a transversal involvement of the maxilla due to a posterior positioning of the mandibular arch, whereas in skeletal Class III patients , the anterior positioning of the mandible may accentuate maxillary deficiency or even project a non-existent deficiency.[4]

When posterior crossbites are identified, it is important to acknowledge the etiology of the malocclusion to further treat the deficiency with intention. Transverse malocclusions can be the result of a combination of inherited or acquired changes. Crossbites can develop as the result of persistent digit sucking habit, inherited narrowed maxilla, a functional shift, abnormal tooth eruption or from mouth breathing and airway problems. [5]

2.3 Diagnosis of Maxillary Transverse Deficiencies

To effectively and successfully correct a transverse malocclusion, early and accurate diagnosis is imperative. More research has focused on the diagnosis of maxillary transverse deficiencies, which include clinical evaluation, model analysis, and radiographic measurements.

When evaluating a patient clinically, some of the main manifestations are severe crowding, rotations, buccal/palatal displacement of the teeth, crossbite (uni- or bilateral), high palatal vaults, and hourglass or V-shaped occlusions. Another indication is buccal corridor width, where there is an excessive negative space or a shadow that occurs in the corners of the mouth while

smiling. [6] Patients with a narrow or tapered maxilla can have an increased buccal corridor. Broadening the smile has become particularly more esthetically pleasing to some and the popularity of a broad smile has increased. With maxillary expansion, increasing the trans-palatal width will help achieve a broad smile and eliminate or reduce the dark spaces present in the buccal corridors. Some soft tissue manifestations include hollowing of the paranasal region, nasolabial fold deepening, or narrowing of the alar bases.[6,7] Another key point is to assess for a mandibular shift upon closure. This can present clinically as a lateral chin deviation, which can be noted from the frontal facial photograph/examination or a unilateral crossbite. Management of a mandibular shift would include a muscle deprogramming device, or disarticulation by a bite plate, to temporarily disarticulate the occlusion for a few weeks. This can determine if the unilateral crossbite was a true skeletal asymmetry or a functional shift from centric relation. [6,8,9]

Upon model analysis, arch symmetry and transverse tooth inclination variability must be analyzed via study cast. The study casts can determine if the transverse deficiency is absolute versus relative. The transverse discrepancy is claimed as relative when the posterior teeth occlude when placed in canine class I. Patients with a class III malocclusion, may involve a posterior crossbite, which is eliminated when casts are articulated into a class I relationship. On the contrary, if the model casts are articulated into class I and there is a posterior crossbite present, the transverse discrepancy is seen as absolute. The magnitude of the discrepancy can be investigated from the cast, whether it be skeletal or dental. [6,9] Dental compensations can be seen with permanent first upper and lower molar inclinations. It has been seen with molars that have excessive buccal or lingual torque. Ideally, a gauge can be placed across the buccal and lingual cusps, and if both the buccal and lingual cusps are touching the gauge, it would be indicated that

there is no discrepancy of the transverse axial inclination. The dental compensations for inclinations of upper maxillary molars that are buccally inclined and lower molars that are lingually inclined are said to have dental compensations. A 1 mm displacement from the transverse occlusal plane would indicate a 10 degree of buccolingual inclination.[6] To differentiate between a skeletal and dental transverse discrepancy, it is seen that two or more posterior teeth are in crossbite, the discrepancy is determined as skeletal. However, this is not true for all cases. If there are no posterior teeth in crossbite, there still may be a skeletal transverse discrepancy that is masked by posterior dental compensations. If these dental compensations are corrected, and an improvement of the posterior transverse inter-arch relationship results, then a dental origin is likely to be the cause of the discrepancy. However, if the posterior transverse relationship worsens then a skeletal origin is likely. [6,9]

For radiographic measurements, the available diagnostic tools are posteroanterior cephalograms (PAC), which are considered reliable. However, due to the 2D image of the skeletal structures, it is difficult to accurately identify the landmarks. Also, the bony landmarks used to measure maxillary and mandibular transverse deficiency have a large degree of separation from the apical and dentition bases.[6] Another radiographic method are CBCTs, which are widely used and show more invariability and reproducibility for transverse measurements. To name a few methods that utilize CBCTs, the University of Pennsylvania Cone-Beam CT analysis, the Yonsei transverse index, Rocky Mountain analysis and Case Western University's (CWRU) transverse analysis. [10,11]

2.4 Management of Transverse Deficiencies

Proper management of a maxillary transverse deficiency is knowing that there are several different approaches to widening the maxillary arch, and acknowledging that age may play a factor in the treatment modality. The techniques can be explained as the following: rapid expansion, slow expansion, alternating constriction and expansion, arch wire expansion, surgical expansion and temporary anchorage device supported expansion. [6,12]

Identifying and addressing a transverse deficiency at an early stage offers several advantages. The primary benefits include averting asymmetric growth in cases of bilateral or unilateral crossbite and minimizing or eliminating the need for surgical correction in the future. Secondary benefits encompass a broader arch perimeter for accommodating future teeth alignment, enhancement in sagittal malocclusion, and potential improvements in airway function. [13]

Management of transverse deficiencies are mainly dictated by age. Undertaking orthopedic expansion is most effective before the closure of midfacial sutures and cranial base, making it easier to achieve successful treatment goals. It is seen that the opportune period for RME is during the growth spurt or up to the age of 15 years. The transverse growth of the palate, driven by the osteogenic activity of the midpalatal suture, persists until approximately 16 years in girls and 18 years in boys. Nevertheless, the fusion of the midpalatal suture exhibits significant variability based on age and gender. To consider RME as a viable option in late adolescents or young adults, it is crucial to comprehend the individual variability in midpalatal suture fusion and predict its feasibility. [4] Furthermore, assessments of skeletal maturity have been proposed,

among them cervical vertebral maturation, hand- wrist radiographs, and more recently using CBCT to assess maxillary sutural maturity. [2,6]

One of the types of management that is widely researched and known involves the application of rapid maxillary expansion. This is a procedure that involves opening the midpalatal suture. This intervention is preferably carried out during the growth phase of patients, prior to the ossification of the suture. RME administered before reaching the peak of skeletal maturation yields more pronounced skeletal effects compared to post-peak application. If maxillary expansion is successful, there is likely a diastema opening between the maxillary central incisors, and crossbite overcorrection has been achieved.[14] The overcorrection is due to the possibility of relapse. The outcomes of maxillary expansion range from no correction to a horizontal gain of 4 mm. For the treatment modality to assume no correction, it is seen to be likely due to the skeletal maturity of the patient, or lack of retention.[1]

Rapid expansion becomes a less predictable treatment option for individuals reaching the end of adolescence or early adulthood. If the patient begins the treatment while the patient is skeletally mature, there is a likely chance that there is progressive calcification and interdigitation on the maxillary sutures, specifically the mid palatal suture. The rapid maxillary expansion would have resistances from these structures, which would deliver dentoalveolar effects than orthopedic expansion. Unwanted effects when used in a skeletally mature patient, including lateral tipping of posterior teeth, extrusion, periodontal membrane compression, buccal root resorption, alveolar bone bending, fenestration of the buccal cortex, palatal tissue necrosis, inability to open the midpalatal suture, pain, and instability of the expansion. [15–17]

Due to the complications associated with attempting to alter the transverse orthopedically at an older age, the proposed orthodontic treatment to achieve skeletal expansion is a surgically-assisted rapid palatal expansion (SARPE), segmental or midline osteotomy, or a mini-implant assisted rapid palatal expansion (MARPE). The SARPE technique consists of a LeFort I osteotomy, where the traditional method is a midpalatal osteotomy followed by a tooth- or bone-borne device. For skeletally mature patients with constricted maxillary arches, the indications for SARPE encompass several scenarios. These include addressing posterior crossbite, expanding the maxillary arch perimeter, or when there are no further surgical jaw movements in the treatment plan. SARPE is also utilized for widening the maxillary arch as a preliminary procedure for other orthognathic surgery, aiming to minimize the risks of inaccuracy and instability. Additionally, it is employed to create more space for maxillary dentition crowding when extraction is not considered. In cases of maxillary hypoplasia in palate cleft patients, SARPE is used for widening. Furthermore, it is employed to reduce wide black buccal corridors in the smile and overcome suture resistance in situations where orthopedic maxillary expansion has failed. [6,18] On the contrary, the segmental or midline osteotomies is beneficial since it allows for surgical repositioning of the maxilla, if there is a sagittal or vertical discrepancy in addition to correcting the transverse discrepancy. As for the SARPE, any further maxillary or mandibular repositioning must be done in another surgery.

2.5 MARPE

There has been an on-going pursuit of a non-surgical remedy for maxillary transverse deficiency in individuals for patients who may not want to undergo an invasive surgical treatment. A less

invasive approach was researched and had led to the development of Miniscrew-Assisted Rapid Palatal Expansion by Lee et al. in South Korea and Moon et al. in the USA. [19] MARPE, whether tooth-bone-borne or exclusively bone-borne, features a rigid component linking to miniscrews implanted in the palate. This arrangement allows the expansion force to be directly applied to the basal bone of the maxilla. In the appliance that is developed by Lee et al, the miniscrews are secured to the turn-key by extensions welder to the expansion screw, and joined with light-curing resin. The miniscrews are in the palatal region and parallel to the midpalatal suture. The miniscrews should be placed in a thicker bone area to increase the primary stability and provide more efficient forces to the nasomaxillary complex. [1]

The design of MARPE aims to enhance skeletal effects while minimizing dentoalveolar impacts, informed by previous histological studies suggesting that the midpalatal suture remains incompletely ossified in humans, potentially due to constant mechanical stress, even in advanced age.[19] A systematic review that was published by Kapentanovic et al had a summary of evidence that was beneficial to assess the efficacy of MARPE. In the studies presented, it was seen that the MARPE demonstrated to be a highly effective treatment modality, with a mean success rate of 92.5%. In five out of seven studies, skeletal maxillary transverse maxillary expansion was statistically significant. The mean amount of skeletal expansion was 2.33 mm with a range of 1.63 mm-3.03 mm. There were five studies that reported on dental transverse maxillary expansion, with the intermolar width increase being 6.55 mm with a range of 5.50 mm-7.59 mm. The dental side effects that were reported include buccal dental tipping, which proved to be statistically significant and ranged from 2.07 degrees to 8.01 degrees. One study suggested that

there were soft tissue changes of the nose, mainly suggesting that MARPE produces slight nasal widening.[19]

Nonetheless, MARPE has gained significant attention in recent years, and numerous researchers have investigated its effectiveness. This allows the clinician and patient to choose a non-surgical technique if needed.

2.6 Effects on the soft tissue after receiving expansion treatment

The aim of expansion treatment is to correct maxillary transverse deficiencies through skeletal and dental movements. However, expansion can elicit a secondary effect on soft tissues. This information is limited and requires more investigation. Clinicians should be aware of the effects of maxillary expansion on the facial appearance and be able to provide patients with information before the beginning of treatment in order to manage patient expectations.

The study by Ramieri et al completed a transverse palatal distraction technique on eighteen individuals with a range of 18-35 years of age. It was shown that the transverse palatal distraction technique was very effective in increasing the transverse diameter of the maxilla, which increased the support of the soft tissues of the cheeks and nasolabial folds. It was seen that the comparison of the averaged facial surfaces at T0 (before treatment) and T1 (six months post-treatment) revealed changes in the cheek and paranasal regions, labial commissure and chin, although all changes were minor. The noticeable change, which ranged from 1-3 mm, was the increased soft tissue projection of the paranasal and cheek areas. In fact, statistical significance was seen concerning the sagittal and transverse projection of the cheek point and enlargement of

the nasal base. Moreover, the observed enlargement of the nasal base, although small, could have functional consequences on the nasal airflow. The increase seen in the paranasal area noticed from T0 to T1 was not seen in the T1 to T2, and was slightly less. The possible explanation could be that there was recovery from the residential swelling, and lateralisation of the alar crests seemed to develop progressively. From T1 to T2 (one year post-treatment), for all other regions these measurements remained stable and no further changes in the measurements were observed.[20] The limitations of this study is that the skeletal expansion was measured with dental casts rather than a radiographic. The dental casts would consider both dental and skeletal movements. To overcome this limitation, a computed tomography radiograph would be ideal to measure the skeletal changes after expansion.

Lee et al evaluated that the nose tends to widen and move forward and downward.[21] Meanwhile, Nguyen et al also found that the cheeks and nose showed lateral and forward movements, where the nasal width increased by 2.05 mm. [22] Abedini et al, similarly found a displacement in both the paranasal area and cheeks that were stable after a year. Also, the alar width increase ranged from 0.93 to 2.05 mm. However, some limitations of these studies were that they were either retrospective, investigated only short-term effects or only nasal soft tissues, including younger patients, or used two-dimensional frontal photographs. [23]

In the study conducted by Kritj et al on twenty-nine patients with a mean age of 25.9 years of age, it was found that expansion with MARPE leads to an increased in soft tissue measurements in the regions of the nose, left and right of the philtrum, and upper lip tubercle demonstrated an statistically significant anterior movement. These changes persisted from T0-T2. However, the

alar width showed an initial increase from T0-T1, and then decreased after 1 year. This study suggested that the amount of nasal widening was not directly correlated with the amount of dental expansion. This leads us to conclude that the soft tissue changes can be possibly attributed to a multitude of factors such as weight gain/loss, tissue elasticity, and soft tissue thickness when evaluating the long-term effects of expansion. [24] The limitations of this study is that fixed appliances were placed 3 months after the end of expansion (T1). As a consequence, the results of T1–T2 and at T2 show both the change of the immediate soft tissue effects following MARPE and the effect of treatment with fixed appliances. However, this is inherent to any orthodontic expansion treatment. Furthermore, the superimposition of 3D facial images was accurate only if the face was captured with the same facial expression at every time point. However, Maal et al. found a mean variation of 0.25 mm between 3D facial images. In absolute terms, this is a very small variation, but given that most results in this study were under 1 mm, this could have impacted the outcomes. [24]

Similarly, Shetty et al, conducted a study on ten individuals in the age group of 18-30 years, who underwent treatment with a MARPE. This study proposed that the mean distance from the soft tissue subnasale to H-line before and after mini-implant rapid palatal expansion was 5.60 and 6.26 mm, respectively, which showed this comparison of this distance to be statistically significant. This could be attributed to the conclusion of studies that following maxillary expansion the maxilla moves downwards, associated with a downward and backward rotation of the mandible. However, a study completed by Kilic et al reported that the distance from the soft tissue subnasale to H-line did not show a significant increase. In addition, the mean value of the H-angle before and after the MARPE treatment was 14.85 and 17.11, respectively, proven to be

statistically significant. In another study completed by Aras et al, they suggested that there was a statistically significant increase in H-angle post-treatment, which indicated that the upper lip became more prominent relative to the overall soft tissue profile. [20,25] The limitations of the study completed by Shetty et al were that the changes were recorded immediately after the expansion, and were not taking into account the possibility of relapse. Ideally, there should be follow-up to assess for long-term effects.

A prospective study conducted by Lee et al on 30 patients who underwent MARPE treatment showed that there was a significant increase in the alar width, alar base width, inferior width of the nostrils and alar curvature width measured by Euclidean distances. It was also found that the relative amount of expansion achieved by MARPE, the nasal soft tissue widening was observed at a ratio of approximately 8.1% to 17.3%. In this study, it was seen that the alar base width had the largest increase, which could be attributed to the alar base being closer to the coronal plane than is the alar; therefore, more affected by the MARPE. Landmarks situated close to the midline, such as pronasale and subnasale, displayed greater displacement along the y and z axis compared to the x-axis. This indicated statistically significant downward and forward movement. This notion of the maxilla being displaced forward and downward due to its effects on the circum-maxillary suture has been investigated by Sarver and Johnston seen in patients with RME. Interestingly, all landmarks, except the alar right, exhibited a consistent trend of displacement toward the forward and downward directions. Therefore, it is crucial for clinicians to be aware that the nasal contours may undergo forward or downward shifts following MARPE. In specific cases, the forward displacement of pronasale could potentially positively influence facial aesthetics.[26] This study possesses certain limitations. One constraint of the current research

is that the observed changes were immediate responses rather than permanent ones. It remains unclear whether the outcomes represent a transient stretching of the soft tissue or a substantial and enduring displacement. Conducting a long-term follow-up study is imperative to address this uncertainty. Additionally, the exploration of 3D superimposition remains an ongoing area of investigation. For instance, potential deformations in overlapping regions, such as the soft tissue nasion due to further expansion of the frontonasal suture, need to be considered. While the study utilized what is currently deemed the optimal overlap method, the limited sample size introduces the possibility that even a slight error in the overlapping region could hold significance.[26]

In comparison, for adolescent patients, Huang et al conducted a systematic review and meta-analysis on the soft tissue effects of a rapid maxillary expander. This study showed that there is a statistically significant increase in the nasal width, alar base width and distance from the lower lips to Rickett's E-line after expansion occurred.[27] In a similar context, Truong et al. evaluated the effect of growth by treating patients with an RPE and using a control group who were not treated with an RPE. It was found that there was a significant increase in the nasal soft tissues immediately after expansion and regressed to normal growth after some time. This could also contribute to the idea that there is a temporary increase in the soft tissues rather than a permanent soft tissue displacement. [27] The study's constraints stem from relying on results and conclusions derived from patients in the growth phase, coupled with an observational period limited to 6 months. Consequently, it is crucial to exercise caution when interpreting the findings in the context of patients beyond the growth phase and when considering long-term outcomes.

2.7 Types of Facial Analysis

Analyzing soft tissue in orthodontics has been a challenging task; however, there has been progress in the technology to help capture the facial changes associated with certain treatment modalities. Previously, the traditional methods utilized two-dimensional (2D) imaging technology, which were seen as conventional photographic techniques and cephalometrics to investigate overall facial growth and evaluate clinical outcomes of facial surgery. Nonetheless, 2D imaging systems have their constraints, including notable radiographic projection errors, enlargement, distortion, radiation exposure, challenges in landmark identification, imprecise replication of measurements, considerable variability in the positioning of reference points like the sella turcica, and substantial limitations in evaluating soft tissue balance. [28] However, in the present, there are different 3D imaging techniques to overcome the limitations associated with photographic techniques.[20] Lane and Harrell reported that the position of the head, distance between the camera and the subject, and the camera angle are all factors that will yield unwanted discrepancies when analyzing changes in the soft tissue.[23]

Landmark identification is difficult due to the rounded and elastic nature of soft tissue. Therefore, in order to accurately evaluate the soft tissue, 3D imaging methods such as CBCTs and 3D facial scans are needed.[23] CBCT is a widely accepted method of analyzing the effects of orthodontic treatment on soft tissues. The progress in software development allows for manipulation of the CBCT images to evaluate soft tissue, which can be used to assess volumetric measurements and morphological evaluation with accuracy, reliability and precision.[25] The main disadvantages that CBCTs pose are they are expensive, may not be readily available, and high radiation dose. Another 3D imaging technique used is 3D laser scanning, which is a non-invasive

technique for capturing facial morphology and soft tissue. Kujipers et al[29] reported that laser scanning and stereophotogrammetry are reliable soft tissue imaging systems with a maximum measurement error of <1 mm. The capturing time is described as the main disadvantage. Stereophotogrammetry captures a 3D image by a pair of configured cameras and combines photos taken from two different directions. This technique is non-invasive, no radiation exposure, accurately captures facial structures, short acquisition time, and can be combined with CBCT imaging. However, the disadvantages can be seen with distortions caused by tissue reflections, hair, eyebrows, and curved surfaces. [29]

Chapter 3 – Methodology

3.1 Recruitment and Participant Flow

This is a prospective study on a randomized clinical trial done at the orthodontics graduate clinic at University of Alberta with the ethics approval from the Research Ethics Board (Pro00084145) from the University of Alberta.

There were twenty patients included in the study with 10 patients in the Dresden expander group and 10 patients in the Moon expander group. The patients were randomly allocated into each of these groups. However, in the Moon expander group, one patient was eliminated from the study since the CBCT was taken in a small FOV, and there was no progress scan available for the 3D facial scanner for the same patient. One patient from the Dresden expander group had no progress scans for the 3D facial scanner, and another patient did not have the progress scan for CBCT. Subsequently, a patient in the Moon expander group did not have the progress scan for the facial scanner; therefore, the facial scanner measurements were not calculated for this patient. The flow-chart of the study participants are shown in the figure below:

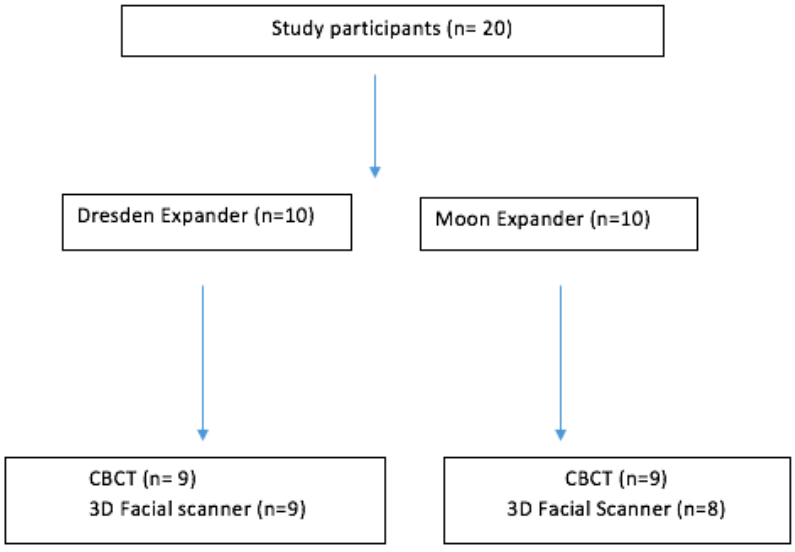


Figure 1: Flow chart for study participants

Sample size was not determined yet because patient recruitment is still underway. The variability and distribution of the outcome measures are not fully established, making it difficult to calculate an accurate sample size at this stage. As more data are collected, we can better estimate parameters such as effect size and variance, allowing us to adjust the sample size accordingly to ensure the study's validity and power.

3.2 Inclusion and Exclusion Criteria

The inclusion criteria is indicated as follows: the patients must have a requirement of maxillary expansion treatment with a maxillary transverse deficiency of more than 5 mm or bilateral posterior crossbite. Patients must be 17 years or older.

The exclusion criteria is indicated as follows: patients with syndromic characteristics or systemic diseases. Patients who present with narrow palates, large toris and/or asymmetric (canted) maxillary palatal planes that would not support the placement of the expander appliance.

In order to measure the amount of maxillary transverse deficiency for these patients, the measurements from the maxillary palatal cusps of the first molars and the central fossa of the mandibular first molar were obtained. The difference between the two suggested the amount of expansion necessary. A 20% relapse was accounted for in the amount of expansion needed.

The patients were randomly allocated to either the Dresden or Moon Expander group using a random number generator. If the patient was not suitable for a Dresden or Moon expander due to an anatomical limitation, the patient was then treated with the alternative expander. The following table describes the subjects demographics at the start of treatment:

Appliance	Mean age ± SD	Age range	# of female patients	# of male patients
Dresden (n=10) Group A	27.67 ± 8.73	17.1-47.9	3	7
Moon (n=10) Group B	25.73 ± 7.58	17.1-39.11	7	3

Table 1: Subject demographics including age, age range, number of female and male participants

3.3 Blinding

Although the patients were randomly allocated to the Dresden or Moon expander group using a number generator, complete blinding of this study was not possible. The clinician and patient during the treatment were not blinded. However, during the interpretation, the CBCTs and the 3D facial scanners were anonymized.

3.4 Experimental Design

Each patient had two sets of records completed. The first set of records taken were at pre-treatment (T0) and the second set was completed after maxillary expansion treatment (T1). The CBCT taken after the completion of maxillary expansion was to confirm a sutural split, otherwise it would be in the patient's best interest to undergo surgical expansion. The average timing between T0 to T1 was 2.8 months. The set of records that are obtained is a comprehensive orthodontic clinical charting and diagnostic exam, intra-oral and extra-oral photos, Cone Beam Computed Tomography (CBCT), and 3D facial scan, nasal obstruction symptom evaluation (NOSE) questionnaires, and peak nasal inspiratory flow (PNIF). The NOSE questionnaires, and PNIF are being used for other experimental purposes.

The CBCTs were taken in a large field of view at 16 x 13.3 cm, voxel size 0.30 mm, 120 KVP, 18.54 mAs and 8.9 seconds using I-CAT New Generation Machine. All CBCTs were taken by a radiology technician at the University of Alberta. The patients were stabilized using strips with their Frankfort horizontal plane positioned parallel to the floor. The patients are encouraged to maintain their dentition in maximum intercuspation, place their tongue behind their upper incisors, avoid any swallowing, and avoid movement during the scan. The files were stored in DICOM format, coded, and blinded. The CBCTs are assessed for their soft tissue measurements using the 3D Slicer software (version 4.11.20210226, Boston, MA, USA). The CBCTs can also be accessed through the 3D Dolphin Software (version 11.95, Chatsworth, CA, USA).

The 3D facial scans were obtained by the Insight 3D Scanner (Motion View LLC, Chattanooga, TN, USA). The scans were taken by a clinical assistant at the University of Alberta. Similar to the positioning of the patients for the CBCT, the scans were taken with the patients' Frankfort horizontal plane parallel to the floor. Patients were encouraged to maintain a neutral facial expression. The scans were coded and blinded for this study.

Prior to starting treatment, a set of records will be taken for each respective patient (T0). Group A treatment will involve maxillary expansion with the onplant-anchored expansion appliance called the Dresden expander. Model casts of the patient's dentition will be obtained and expansion appliance will be fabricated consisting of onplants located between the upper second premolar and first molar with an average of 9 mm away from the palatal suture. Local

anesthetic (2% lidocaine, 1:100,000 epinephrine, 1 carpule) is administered to numb the palatal region between the upper second premolar and the first molars. Once adequate anesthetic is delivered, the appliance is inserted and the two temporary anchorage devices (TADs) are placed bilaterally to support the appliance. The TADs size are 9-11 mm in length. Appliance will be activated 1 time, which equals 0.25 mm, each day since the day of insertion until there is a presence of a diastema between the upper central incisors (teeth #11 and 21). Once this space is present, activation will stay the same until 20% over-expansion to account for possible relapse. Patients were given proper instructions on how to activate the appliance. Throughout the expansion period, patients attended multiple appointments to establish whether the amount of expansion has been achieved, and instructed if more expansion is needed. Once the complete expansion is obtained, a new set of records will be obtained (T1). The patient will proceed with full upper and lower braces for completion of their orthodontic treatment. Complete records will be taken again at the end of all the orthodontic treatment and 2-years after removal of all appliances where the patient would be dismissed. After confirmation from the second CBCT, if the suture did not separate, the patient would need to be aware that the alternative treatment to achieve successful maxillary expansion would need to be a surgical option.

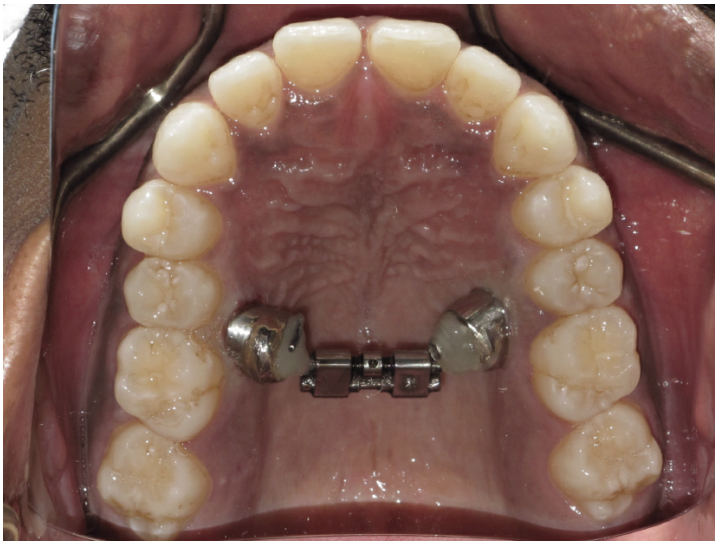


Figure 2: Dresden Expander

Group B treatment will consist of a maxillary skeletal expander appliance known as a Moon expander. Model casts of the patient's dentition will be obtained and expansion appliance will be fabricated consisting of bands located on the upper first molars and soldered to the Moon design screw. If the patient has a missing upper first molar, it is indicated to band the upper premolar. Local anesthetic (2% lidocaine, 1:100,000 epinephrine, 1 carpule) is administered to numb the palatal region adjacent to the mid-palatal suture. Appliance is cemented with "reliance ultra-band-lok®" on the upper first molars and then four temporary anchorage devices (TADs) of 11-13mm in length are inserted (two on each side of the mid-palatal suture). Appliance will be activated two times each day from the day of insertion until there is a presence of a diastema between the upper central incisors, which equals 0.3 mm of maxillary expansion per day. Patients were given proper instructions on how to activate the appliance at their own disposal. Throughout the expansion period, patients attended multiple appointments to establish whether the amount of expansion has been achieved. Once the complete expansion is obtained, a new set of records will be obtained (T1). The patient will proceed with full upper and lower braces or clear aligner therapy for completion of their orthodontic treatment. Complete records will be taken again at the end of all the orthodontic treatment and 2-years after removal of all appliances where the patient would be dismissed. After confirmation from the second CBCT, if the suture did not separate, the patient would need to be aware that the alternative treatment to achieve successful maxillary expansion would need to be a surgical option.

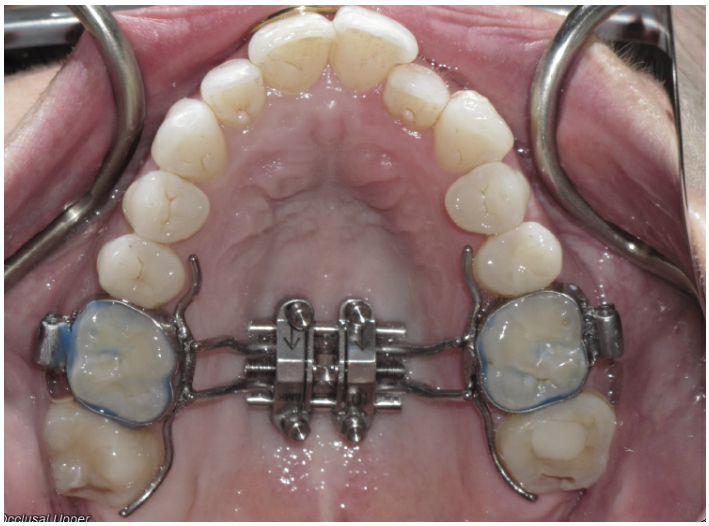


Figure 3: Moon Expander

All TADs for both the Dresden and Moon expanders were placed by one orthodontist. The minimum activation for both groups was a minimum of 5 mm total activation or until the maxillary transverse deficiency was fully corrected. The goal was to match the palatal cusps of the maxillary molars to the buccal cusps of the mandibular molars based on the McNamara protocol. The expanders were kept inactive in the patient's mouth for six months to prevent any relapse and to stabilize the expansion.

After expansion was completed, it was determined that the mean amount of expansion in mm for the patients is 1.86 ± 1.31. The mean amount of expansion was calculated by measuring the difference between maxillary width from left and right jugal at T0 and T1. The mean number of turns completed during their orthodontic treatment is 49.21 ± 19.77.

3.5 Head Orientation of the CBCT scans in Dolphin software

Orientation calibration was completed prior to identifying the landmarks. The scans were oriented in two planes as seen below (Figure 4). In the frontal view, the horizontal reference line was placed from right to left exocanthion. In the sagittal view, the vertical reference line was placed perpendicular to the horizontal reference and placed on the soft tissue nasion and the soft

tissue pogonion. Similar to orientating the CBCTs, the 3D facial scans were re-oriented using the same reference lines in the OrthoInsight 3D software (Version 7.7.5570; Motion View LLC, Chattanooga, TN, USA).

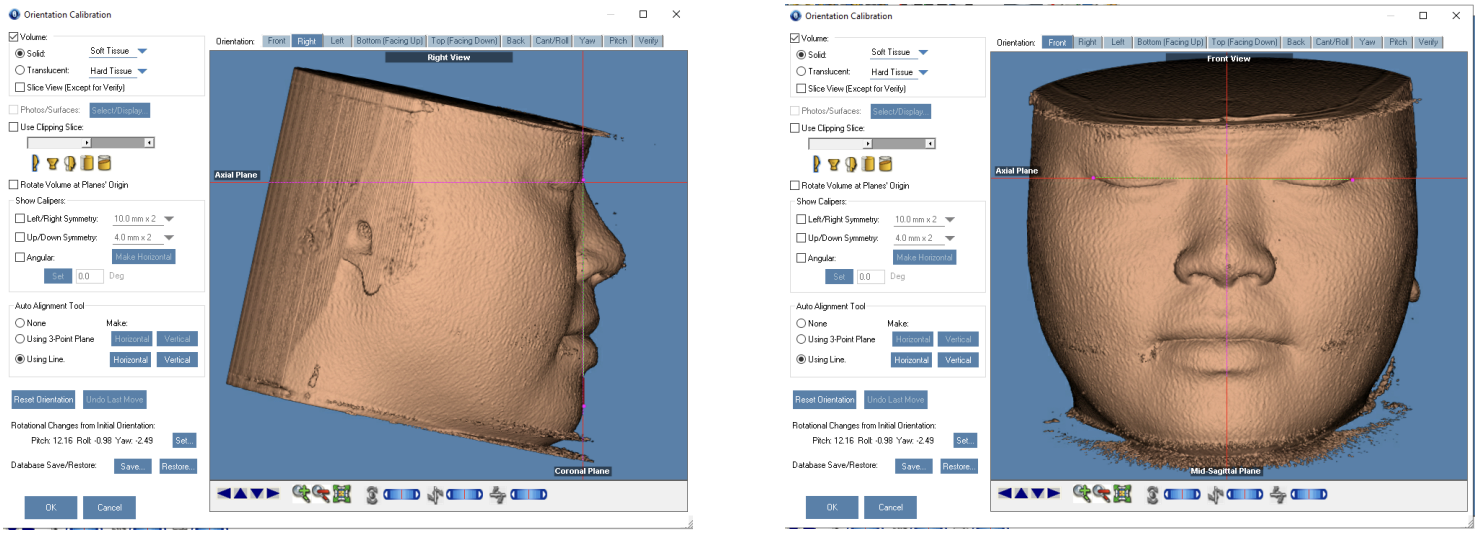


Figure 4: Orientation calibration of CBCTs in Dolphin software

3.6 Method used for analyzing facial soft tissue measurements utilizing the CBCT and 3D facial scans

Once the CBCTs were gathered, and the head orientation of the scans were manipulated in the Dolphin software, the scans were saved as anonymous DICOM files and coded for blinding purposes. The data was transferred to the 3D Slicer software (version 4.11.20210226, Boston, MA, USA) for further analyses. Under volume rendering, the MR default was chosen to display the soft tissue of the patient. This preset allows the soft tissues to be visible. A 2.0 mm red spherical marker was chosen to identify the landmarks. Once all landmarks were completed, the respective measurements were recorded.

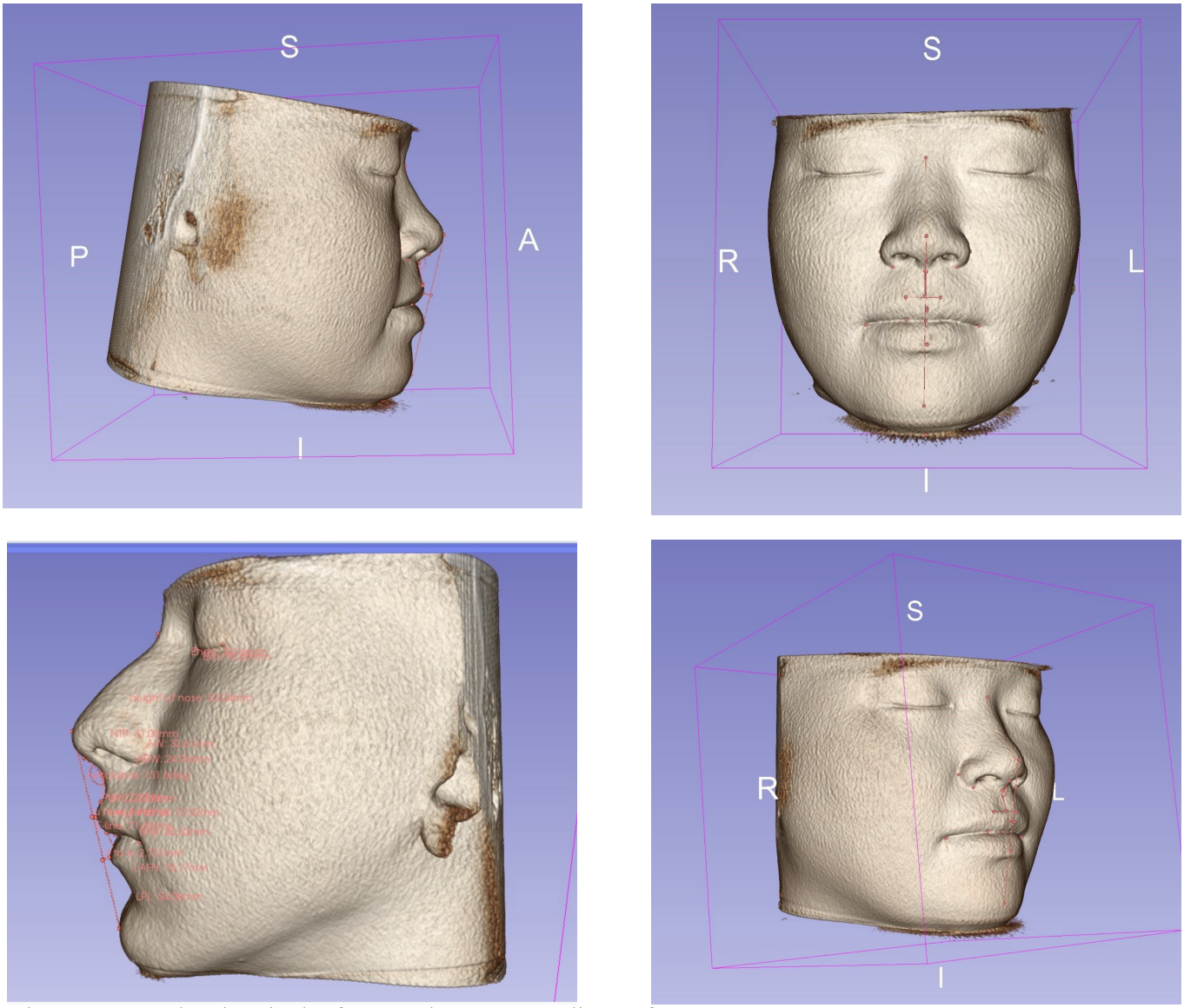


Figure 5: Frontal and sagittal reference planes on 3D Slicer software

As for the 3D facial scans, they were saved as OI3D files and coded for blinding purposes. OrthoInsight RD software (Version 7.7.5570; Motion View LLC, Chattanooga, TN, USA) was utilized to identify the soft tissue measurements. A spherical marker was used to

identify the soft tissue measurements with a diameter of 0.5 mm. Due to software and time limitations, only Euclidean distances were measured for this research study.

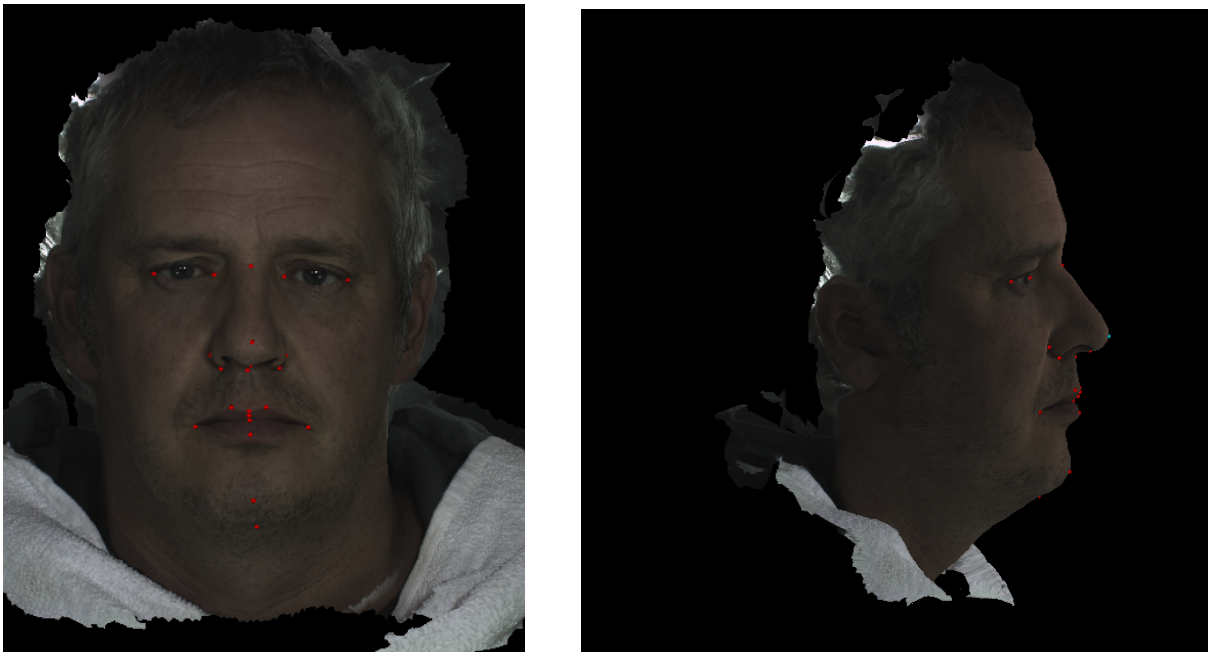
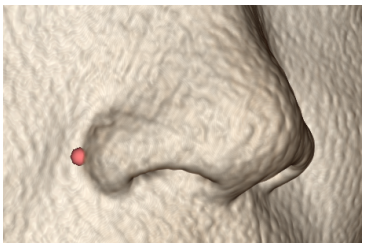
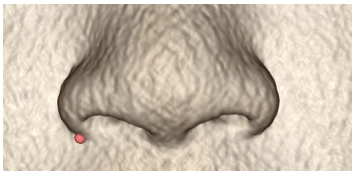
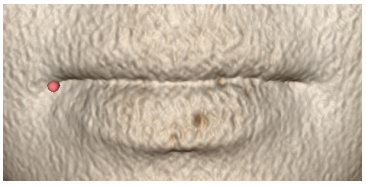
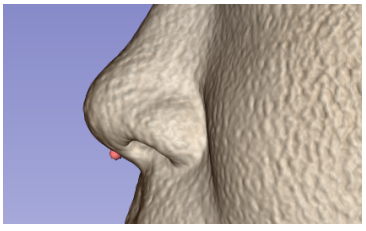
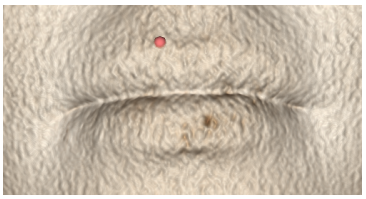
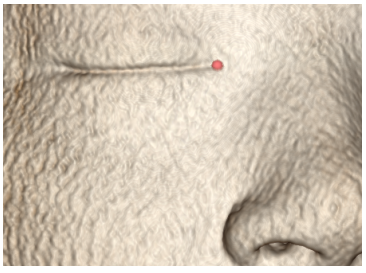
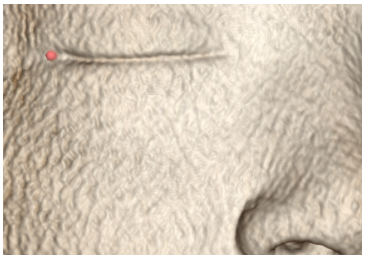
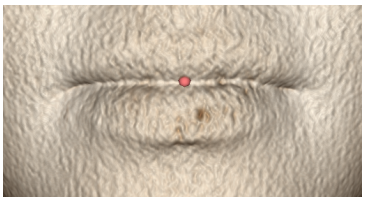
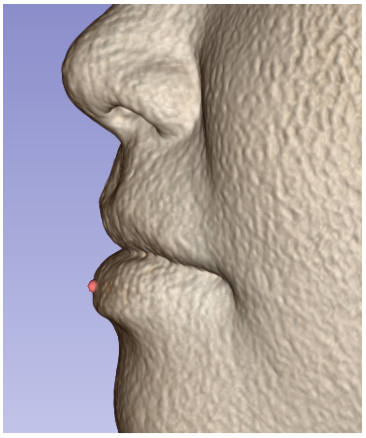
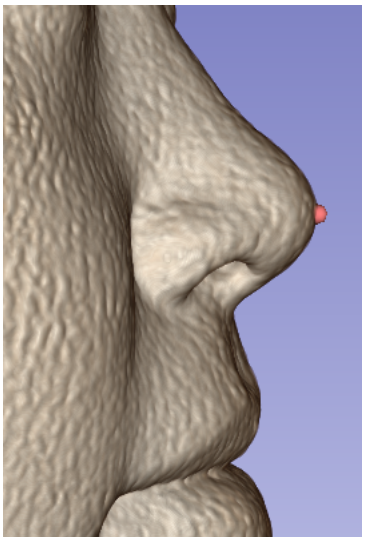


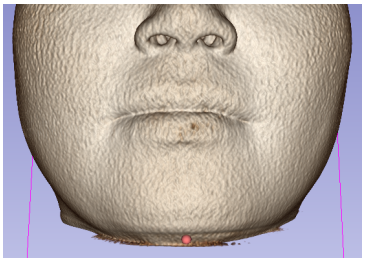
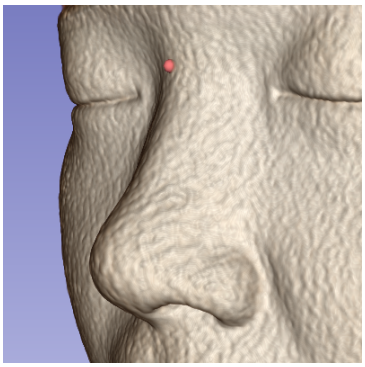
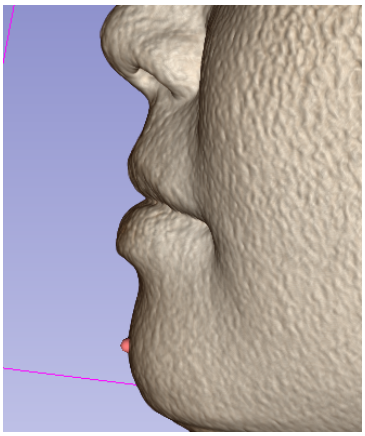
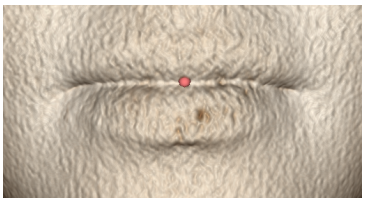
Figure 6: Frontal and lateral views on Orthoinsight software

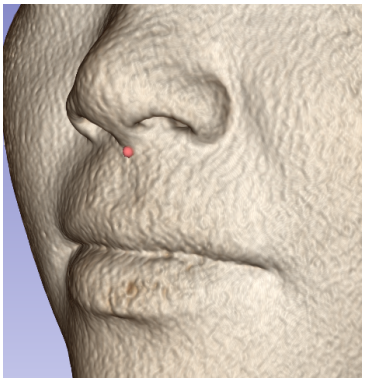
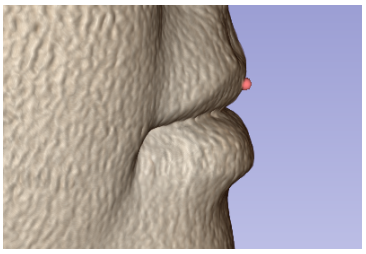
Twenty-two landmarks were identified in both the CBCT and 3D facial scanners. These twenty two landmarks resulted in fourteen soft tissue linear/angular measurements. The twenty two landmarks are described below in table 2 and the fourteen soft tissue measurements are shown in Table 3. The CBCT and 3D facial scans with the respective landmarks can be visualized in Figure 5 and 6 in different reference planes.

3.7 Landmarks and measurements of the soft tissue in CBCT scans and 3D facial scans

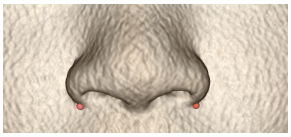
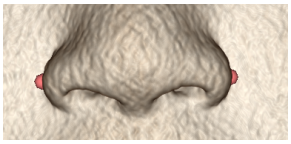
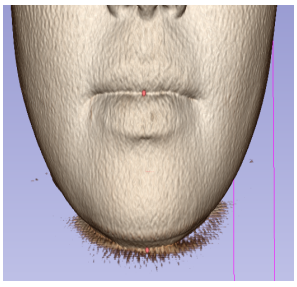
Soft Tissue Landmark	Abbreviation	Definition	Illustration
Alare	Al*	Most lateral point on each lateral contour	
Alare base	Ab*	Point where the nasal alar intersects the face on the interior margin of the nose	
Chelion	Ch*	Point at each labial commissure	
Columella	Col	Point of inferior margin of the nasal septum linking the nasal tip to the nasal base	
Crista philtri	Cph*	Point of crossing of the vermillion of the upper lip and elevated margin of the philtrum	
Endocanthion	En*	Point at the inner commissure of the fissure of the eye	

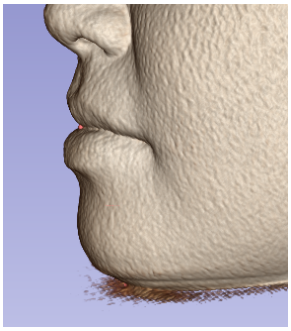
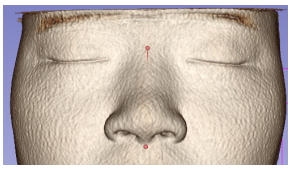
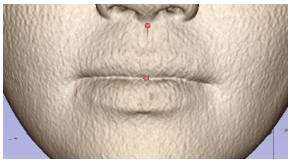
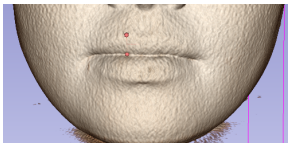
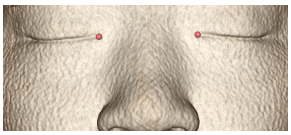
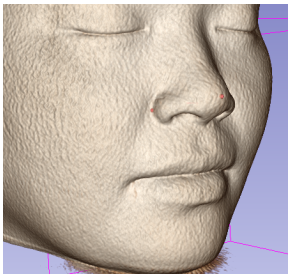
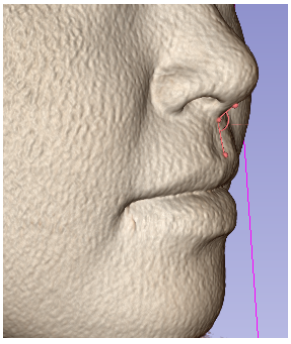
Exocanthion	Ex*	Point at the outer commissure of the fissure of the eye	
Labiale superius	Ls	Midpoint of the vermillion of the upper lip	
Lower lip anterior point	Llap	Point at the most anterior point of the upper lip	
Pronasale	Prn	Most anterior midpoint of the apex of the nose	

Soft tissue menton	Me	Most inferior midpoint on soft tissue contour of the chin	
Soft tissue nasion	Na	Intersecting point between the soft tissue profile and the sella-nasion line	
Soft tissue pogonion	Pg	Most anterior midpoint on soft tissue contour of the chin	
Stomion	Stm	Midpoint of the horizontal labial fissure	

Subnasale	Sn	Midpoint between columella nasi and philtrum of upper lip	
Upper lip anterior point	Ulap	Point at the most anterior point the upper lip	

* indicates bilateral landmarks (right and left)
Table 2: Twenty two landmarks with definitions

Soft Tissue Landmark	Abbreviation	Definition	Illustration
Alar Base Width	ABW	Most lateral point of the base of insertion of each nostril	
Alar Width	AW	Most lateral point to the contour of each nostril	
Height of Lower lip	HofLL	Stomion to soft tissue menton	

			
Height of Nose	HofN	Soft tissue nasion to subnasale	
Height of Upper Lip	HofUL	Subnasale to stomion	
Height of Vermillion of Upper Lip	HofVUL	Labiale superius to stomion	
Intercanthal Width	ICW	Right to left endocanthion	
Nasal tip prominence	NTP	Ala to pronasale	
Nasolabial angle	NL	Angle between soft tissue nasion, subnasale, labiale superioris	

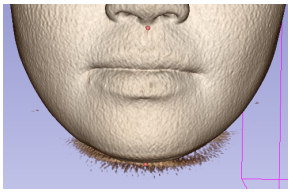
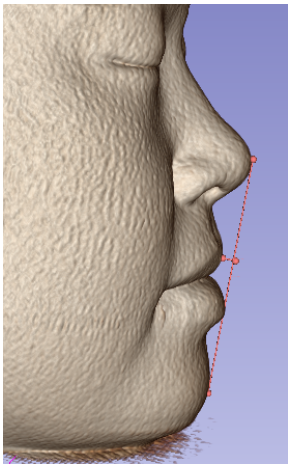
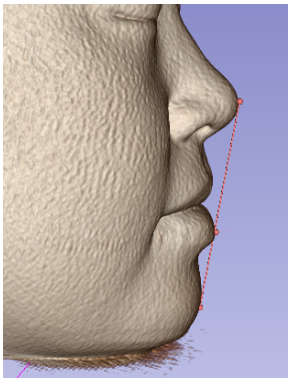
Mouth Width	MW	Right labial commisure to left labial commissure	
Lower Facial Height	LFH	Subnasale to soft tissue menton	
Philtrum width	PW	Right to left christa philtri at the vermillion border of the upper lip	
Upper lip to E-line	ULtoE	Upper lip to E-line (pronasale to soft tissue pogonion)	
Lower lip to E-line	LLtoE	Lower lip to E-line (pronasale to soft tissue pogonion)	

Table 3: Thirteen linear measurements and one angular measurement with measurements

3.1.8 Research Questions

First research question:

H_o → There is no consistency between the soft tissue measurements (*mm*) derived from the CBCT and 3D facial scan

H_a → There is a consistency between the soft tissue measurements (*mm*) derived from the CBCT and 3D facial scan

Second research question:

To answer this research question, we used the values of T1-T0 for each landmark.

H_o → There is no difference between the two different expanders (Dresden expander and Moon expander) in terms of effects on mean soft tissue measurements (*mm*)

H_a → There is a difference between the two different expanders (Dresden expander and Moon expander) in terms of effects on mean soft tissue measurements (*mm*)

Third research question:

To answer this research question, we had separated the imaging modalities.

H_o → There is no difference in the mean facial soft tissue measurements (*mm*) at pre-treatment (T0), and post-treatment (T1)

H_a → There is a difference in the mean facial soft tissue measurements (*mm*) at pre-treatment (T0), and post-treatment (T1)

For the first research question, the Wilcoxon rank signed test was performed. Under the two related samples test, the first variable was the landmarks for CBCT at T0 and T1 and the second variable was the landmarks for the facial scanner at T0 and T1, subsequently. Intraclass correlation coefficient describes how similar units in the same group resemble each other where a value of 1 would represent a complete agreement and a value approaching 0 would represent no agreement. Rangers for ICC from 0.81 to 1.00 indicate almost perfect agreement and between 0.7 and 0.9 are acceptable. Intra and inter-reliability were determined using the intraclass correlation co-efficient (ICC). For intra-rater reliability, this was conducted on nine CBCTs and nine 3D facial scans utilizing all 14 soft tissue measurements at three different time points. The different time points were conducted seven days apart from each other. The inter-reliability has been completed between the author and NMM (orthodontic resident with training using CBCTs and 3D facial scans).

For the second research question, the Mann-Whitney U-test was performed. The two independent samples test was performed and the grouping variable was the two types of expanders, Dresden and Moon. The test was also performed by separating the two imaging modalities. The table below shows the Wilcoxon p-values for both imaging modalities.

For the third research question, the Wilcoxon rank signed test was performed. Under the two related samples test, the first variable was each landmark at T0 and the second variable was the same landmark at T1. The test was performed by separating the two imaging modalities. The table below shows the Wilcoxon p-values for both imaging modalities.

Chapter 4– Results

4.1 Statistical Analysis

The statistical analysis was performed using the Statistical Package for Social Science (IBM SPSS, version 28.0, SPSS Inc., Chicago, IL, USA). The significance level was set at $\alpha = 0.05/14 = 0.0036$. In order to determine the statistical significance of the research questions, non-parametric tests were conducted. Non-parametric test was chosen for the statistical analysis due to the small sample size. The Wilcoxon signed rank test was performed for the first and third research question. The Mann Whitney U-test was performed for the second research question. To reiterate the research questions described in Chapter 3, the null hypothesis and alternative hypothesis is as followed:

First research question:

$H_o \rightarrow$ There is no consistency between the soft tissue measurements (*mm*) derived from the CBCT and 3D facial scan

$H_a \rightarrow$ There is a consistency between the soft tissue measurements (*mm*) derived from the CBCT and 3D facial scan

Second research question:

To answer this research question, we used the values of T1-T0 for each landmark.

$H_o \rightarrow$ There is no difference between the two different expanders (Dresden expander and Moon expander) in terms of effects on mean soft tissue measurements (*mm*)

$H_a \rightarrow$ There is a difference between the two different expanders (Dresden expander and Moon expander) in terms of effects on mean soft tissue measurements (*mm*)

Third research question:

To answer this research question, we had separated the imaging modalities.

H_0 → There is no difference in the mean facial soft tissue measurements (*mm*) at pre-treatment (T0), and post-treatment (T1)

H_a → There is a difference in the mean facial soft tissue measurements (*mm*) at pre-treatment (T0), and post-treatment (T1)

4.2 Intra-examiner and inter-examinar reliability and measurement error

The inter- and intra-reliability was calculated using the intraclass correlation coefficient (ICC). The inter-reliability was calculated with another orthodontic student, with training in measuring landmarks with the CBCT and 3D Facial scanner. The inter-reliability was completed by landmarking three measurements on ten CBCTs and ten 3D facial scanners at three different time points. The intra-reliability was completed by measuring all the landmarks for each patient with a CBCT and 3D facial scan at T0. These were measured at three different time points, all more than seven days apart.

The results of the reliability analysis were assessed as per the Portney and Watkin's ICC guidelines[21] as shown in Table 4. ICC ranging between 0.75 to 0.90 is considered "good", and above 0.90 is considered "excellent". Values below 0.5 are considered "inadequate" and necessitate better identification of landmarks and standardization.[21]

4.3 Reliability Results

The ICC results for inter-rater reliability as described in Table 4 showed excellent agreement for all the measurements. The lower bound for the 95% confidence interval showed good agreement for alar width and mouth width for the 3D facial scanner group, and alar width and nasal tip prominence for the CBCT group.

Measurement	**ICC for CBCT (*Single measures*)**	**95% Confidence Interval (lower bound, upper bound)**	**ICC for 3D Facial Scanner (*Single measures*)**	**95% Confidence Interval (lower bound, upper bound)**
Alar Width	0.94	(0.87, 0.97)	0.97	(0.83, 0.99)
Mouth Width	0.99	(0.97, 0.99)	0.97	(0.87, 0.99)
Nasal tip prominence	0.94	(0.85, 0.97)	0.97	(0.93, 0.97)

Table 4: Inter-reliability describing the ICC values and the 95% confidence interval for each landmark in the CBCT and 3D Facial Scanner groups

The ICC results are described below in Table 6, and for intra-rater reliability, all the ICC values showed excellent agreement for all measurements in the CBCT group. The 95% confidence intervals showed a good agreement (0.874) at the lower bound for height of nose, and poor agreement (0.187) at the lower bound for nasal tip prominence.

The ICC results for intra-rater reliability in the 3D facial scanner group showed excellent agreement for all measurements, except for alar base width, nasolabial angle, lower anterior facial height, philtrum width, height of lower lip and endocanthion. The ICC for the measurements which showed good agreement were the following: lower anterior facial height (0.840), philtrum width (0.896), and endocanthion (0.760). The ICC for the measurements which showed moderate agreement were: alar base width (0.643) and height of lower lip (0.740). The lower bound for the 95% confidence interval indicating less than excellent agreement were: poor agreement for alar base width (0.387), moderate agreement for nasolabial angle, poor agreement for lower anterior facial height (0.394), good agreement for philtrum width (0.750), poor agreement for height of lower lip (0.257), and moderate agreement for endocanthion (0.561).

Measurement error was calculated for each of the landmarks by subtracting the three different time-points used in reliability for the 3D facial scanner and CBCT group from one another. The difference between the subsequent time points were then averaged. The measurement error values for the subsequent measurements are described below in Table 5.

Measurements	**ICC for CBCT (*Single Measures*)**	**95% CI of ICC (lower bound, upper bound)**	**Measurement error (CBCT)**	**ICC for 3D Facial Scanner (*Single Measures*)**	**95% CI of ICC (lower bound, upper bound)**	**Measurement error (3D Facial Scanner)**
Alar Width (1)	0.998	(0.996, 0.999)	0.42 mm	0.989	(0.975, 0.995)	0.15 mm
Alar Base Width (2)	0.952	(0.999,1.000)	1.41 mm	0.643	(0.387, 0.883)	0.98 mm
Height of nose (3)	0.983	(0.874, 0.982)	0.73 mm	0.953	(0.901, 0.980)	0.56 mm
Height of upper lip (4)	0.985	(0.966, 0.994)	0.47 mm	0.962	(0.920, 0.984)	0.25 mm
Height of vermillion border (5)	0.996	(0.992, 0.999)	0.41 mm	0.950	(0.895, 0.979)	0.14 mm
Nasolabial angle (6)	0.954	(0.901, 0.982)	6.97 degrees	0.732	(0.518, 0.876)	1.60 degrees
Upper lip to E-line (7)	0.994	(0.988, 0.998)	0.29 mm	0.969	(0.934, 0.987)	0.18 mm
Lower lip to E-line (8)	0.992	(0.982, 0.997)	0.27 mm	0.983	(0.963, 0.993)	0.30 mm
Lower anterior facial height (9)	0.978	(0.940, 0.992)	1.78 mm	0.840	(0.394, 0.949)	1.05 mm
Mouth width (10)	0.984	(0.962, 0.994)	0.83 mm	0.947	(0.879, 0.979)	0.42 mm
Philtrum width (11)	0.935	(0.835, 0.976)	0.56 mm	0.896	(0.750, 0.959)	0.50 mm
Height of lower lip (12)	0.967	(0.920, 0.988)	2.13 mm	0.740	(0.257, 0.910)	1.16 mm
Nasal tip prominence (13)	0.991	(0.187, 0.741)	0.41 mm	0.961	(0.961, 0.993)	0.26 mm
Endocanthion (14)	0.980	(0.929, 0.993)	1.33 mm	0.760	(0.561, 0.892)	0.52 mm

Table 5: Intra-reliability describing the ICC values and the 95% confidence interval for each landmark in the CBCT and 3D Facial Scanner groups

4.4 Results for research question 1

The statistical analysis for the first research question was determined by a non-parametric statistical hypothesis test, specifically the Wilcoxon signed rank test. For this research question, it is being determined if there is a consistency between the two imaging modalities, CBCT and 3D facial scanner when measuring the soft tissue facial changes. The significance level was set at $\alpha = 0.05/14 = 0.0036$.

The p-values were proven to be significant ($p < 0.0036$) for five measurements at T0: height of nose ($p < 0.001$), lower lip to E-line ($p=0.003$), lower anterior facial height ($p < 0.001$), height of lower lip ($p < 0.001$), and nasal tip prominence ($p < 0.001$). Subsequently, this means that there is an inconsistency in measuring these particular measurements when using the CBCT or 3D facial scanner at T0. In other words, for these measurements, we reject the null hypothesis and accept the alternative hypothesis.

The p-values were proven to be significant ($p < 0.0036$) for six measurements at T1: height of vermillion border ($p < 0.001$), lower anterior facial height ($p < 0.001$), mouth width ($p=0.003$) height of lower lip ($p=0.001$), nasal tip prominence ($p < 0.001$) and endocanthion ($p=0.002$). For these measurements, there is an inconsistency when using either the CBCT or 3D facial scanner at T1. In other words, for these measurements, we reject the null hypothesis and accept the alternative hypothesis. This means that there is an inconsistency between the CBCT and 3D facial scanner measurements at T1 or these six measurements.

The intraclass correlation coefficient describes how similar units in the same group resemble each other where a value of 1 would represent a complete agreement and a value approaching 0 would represent no agreement. These measurements showed excellent agreement (0.89-1.00) between the CBCT and 3D facial scanner at T0: alar width (0.95), nasal tip prominence (0.95), and philtrum width (0.89). The measurements that displayed good agreement: height of nose (0.82), height of upper lip (0.79), height of vermillion border (0.75), endocanthion (0.88) and mouth width (0.73). The measurements that had a moderate agreement were: nasolabial angle (0.62), upper lip to E-line (0.56), and lower lip to E-line (0.66). The measurements which had a poor agreement were: alar base width (0.50), lower anterior facial height (0.3), and height of lower lip (0.06).

According to the descriptive statistics, as described below in Table 6, the mean soft tissue measurements (mm) between the CBCT and 3D facial scanner at T0 were all similar, except for a few measurements that were over 1.5 mm of a difference. This clinical significance level was determined by twice the mean standard deviation of the normative data completed by Metgzer et al.[50] A clinical significance of two standard deviations was chosen to encompass 95% of the data distribution, in which any numbers outside of that value would be considered abnormal. The following measurements that have over 1.5 mm difference between the imaging modalities were: alar base width (difference of 2.63 mm), height of upper lip (1.62 mm), height of vermillion border (1.82 mm), height of nose (difference of 2.12 mm), lower lip to E-line (1.55 mm), nasolabial angle (difference of 4.09 degrees), lower anterior facial height (difference of 8.8 mm), nasal tip prominence (1.78 mm), mouth width (difference of 3.37), and height of lower lip (difference of

7.71 mm). In addition, the mean soft tissue measurements (mm) between the CBCT and 3D facial scanner at T1 were all similar, except for the following that were over 1.5 mm of a difference: height of nose (difference of 2.7 mm), height of vermillion border (difference of 2.53 mm), lower anterior facial height (difference of 7 mm), mouth width (difference of 3.51 mm), height of lower lip (difference of 6.05 mm), nasal tip prominence (1.74 mm), and endocanthion (difference of 4.36 mm).

Measurements	Wilcoxon P-value (CBCT, Facial scanner at T0)	Mean(SD)/Median for CBCT at T0	Mean(SD)/Median for Facial Scanner at T0	95% CI of ICC (CI lower bound, CI upper bound) – T0	Wilcoxon P-value (CBCT, facial scanner at T1)	Mean(SD)/Median for CBCT at T1	Mean(SD)/Median for Facial Scanner at T1	95% CI of ICC (CI lower bound, CI upper bound) – T1
Alar width	0.207	35.58(3.79) / 35.35 (mm)	36.80(4.96) / 37.21 (mm)	0.95 (0.85, 0.98)	0.860	36.36 (3.84) / 36.62 (mm)	36.77(5.87)/35.86 (mm)	0.80 (0.42, 0.93)
Alar base width	0.127	26.31(2.53) / 26.51 (mm)	28.94(5.35) / 27.96 (mm)	0.50(-0.24, 0.82)	0.382	27.49 (3.22) / 27.37 (mm)	28.51(4.95)/29.01 (mm)	0.35 (-0.92, 0.78)
Height of Nose	<0.001	50.94(3.66) / 50.91 (mm)	48.82(4.37) / 48.47 (mm)	0.82 (-0.02, 0.95)	0.006	51.29 (3.86) / 50.94 (mm)	48.59(3.90)/48.62 (mm)	0.68 (-0.08, 0.90)
Height of upper lip	0.004	20.22(2.90) / 21.06 (mm)	21.84(2.40) / 22.11 (mm)	0.79 (0.17, 0.93)	0.011	20.30 (3.29) / 20.55 (mm)	21.52(2.25)/21.53 (mm)	0.79 (0.27, 0.93)
Height of Vermillion border	0.013	10.76(2.22) / 10.38 (mm)	8.94 (2.75) / 8.39 (mm)	0.75 (0.14, 0.92)	<0.001	11.17 (2.53) / 11.15 (mm)	8.64 (2.11) / 8.63 (mm)	0.72 (-0.22, 0.93)
Nasolabial angle	0.495	73.52(18.98)/69.50 (degrees)	69.43(10.74)/69.73 (degrees)	0.62 (-0.05, 0.86)	0.782	71.72(17.14)/ 73.20 (degrees)	70.25(11.59)/70.39 (degrees)	0.72 (0.20, 0.90)
Upper lip to E-line	0.706	3.88 (1.73) / 3.84 (mm)	4.74 (3.28) / 4.35 (mm)	0.56 (-0.25, 0.84)	0.860	3.81 (2.16) / 3.53 (mm)	4.18 (2.51) / 3.18 (mm)	0.81 (0.45, 0.93)
Lower lip to E-line	0.003	3.25 (2.12) / 3.09 (mm)	4.80 (3.98) / 4.32 (mm)	0.66 (0.08, 0.88)	0.117	3.73 (2.59) / 2.87 (mm)	4.17 (2.85) / 3.51 (mm)	0.74 (0.27, 0.91)
LAFH	<0.001	67.71(4.43) / 67.99 (mm)	76.51(8.28) / 73.20 (mm)	0.30 (-0.28, 0.70)	<0.001	68.57 (4.51) / 69.26 (mm)	75.54(6.96)/74.40 (mm)	0.37 (-0.28, 0.75)
Mouth width	0.008	48.95(4.20) / 49.70 (mm)	52.32(4.37) / 52.79 (mm)	0.73 (0.13, 0.91)	0.003	49.64 (4.18) / 48.73 (mm)	53.15(4.91)/54.24 (mm)	0.79 (0.17, 0.93)
Philtrum width	0.316	13.59(2.14) / 12.68 (mm)	14.47(3.06) / 14.30 (mm)	0.89 (0.70, 0.96)	0.689	13.83 (2.45) / 13.75 (mm)	14.39(3.05)/14.30 (mm)	0.84 (0.53, 0.95)
Height of lower lip	<0.001	46.95(4.00) / 47.93 (mm)	54.66(6.66) / 51.14 (mm)	0.06 (-0.58, 0.46)	0.001	47.97 (3.92) / 48.36 (mm)	54.02(5.81)/54.56 (mm)	0.14 (-0.806, 0.448)
Nasal tip prominence	<0.001	32.84(3.23) / 32.82 (mm)	34.62(3.41) / 33.63 (mm)	0.95 (0.02, 0.99)	<0.001	32.82 (2.91) / 32.34 (mm)	34.56(3.06)/34.12 (mm)	0.90 (0.34, 0.97)
Endocanthion	0.018	34.16(3.11) / 33.78 (mm)	32.81(4.28) / 31.84 (mm)	0.88 (0.60, 0.96)	0.002	34.65 (3.38) / 34.35 (mm)	30.29(3.88) /30.76 (mm)	0.25 (-0.31, 0.67)

Table 6: Summary of the Wilcoxon P-value, descriptive statistics and ICC for research question 1

4.5 Results for research question 2

The statistical analysis for the second research question was determined by a non-parametric statistical hypothesis test, specifically the Mann-Whitney U-Test. For this research question, we are determining if there is a difference between the two different expanders, Dresden and Moon, when measuring the soft tissue facial changes. The significance level was set at $\alpha = 0.05/14 = 0.0036$.

For the second research question, the p-values for the 13 linear measurements and 1 angular measurement were all above the significance level of $p>0.0036$; therefore, we can accept the null hypothesis and reject the alternative hypothesis. This means that there is no difference in the soft tissue measurements between the two expanders (Dresden and Moon).

According to the descriptive statistics, as described in Table 7, the soft tissue measurements in the CBCT group exhibits a difference of less than 0.675 mm between the Dresden and Moon expanders from T0 to T1, with the exception of the following measurements: the mean alar width from T1-T0 has a 1.255 mm discrepancy with the Moon expander showing a larger difference, the mean alar base width from T1-T0 has a 0.985 mm discrepancy with the Moon expander showing a larger difference, the mean nasolabial angle from T1-T0 has a 1.334 degree discrepancy with the Moon expander showing a larger difference, the mean lower anterior facial height from T1-T0 has a 0.884 mm discrepancy with the Dresden expander showing a larger difference, the mean mouth width from T1-T0 has a 0.874 mm discrepancy with the Dresden expander showing a larger difference and the mean endocanthion from T1-T0 showing a 1.817 mm difference with Moon

expander showing a larger difference. The clinical significance value for this research question was 0.675 mm. The clinical significance value was determined by twice the mean standard deviation of the normative data completed by Venezia et al.[51] The measurements that showed more than a 0.675 mm/degree mean difference were considered to be an abnormal.

The soft tissue measurements in the 3D facial scanner group exhibited a difference of less than 0.675 mm between the Dresden and Moon expanders from T0 to T1, with the exception of the following measurements: the mean alar base width from T1-T0 has a 1.243 mm discrepancy with the Dresden expander showing a larger difference the mean nasolabial angle from T1-T0 has a 1.159 degree discrepancy with the Dresden expander showing a larger difference, the mean upper lip to E-line from T1-T0 has a 0.725 mm discrepancy with the Dresden expander showing a larger difference, the mean lower lip to E-line from T1-T0 has a 1.413 mm discrepancy with the Dresden expander showing a larger difference, the mean lower anterior facial height from T1-T0 showing a 4.109 mm difference with the Dresden expander showing a larger difference, the mean mouth width from T1-T0 has a 0.931 mm discrepancy with the Dresden expander showing a larger difference, and mean height of lower lip from T1-T0 showing a 3.101 mm difference with the Dresden expander showing a larger difference.

Measurements	P-value (CBCT)	Mean (SD) / Median for Moon expander for CBCT (T1-T0)	Mean (SD) / Median for Dresden expander for CBCT (T1-T0)	P-value (Facial scanner)	Mean (SD) / Median for Moon Expander for Facial Scanner	Mean (SD) / Median for Dresden Expander for Facial Scanner
Alar width	0.094	1.413 (1.728) / 0.460 (mm)	0.158 (1.237) / 0.120 (mm)	0.815	-0.066 (4.364) / 0.960 (mm)	0.003 (3.090) / 0.960 (mm)
Alar base width	0.161	-1.676 (1.329)/ -1.750 (mm)	-0.691 (1.908) / -0.090 (mm)	0.321	-0.225 (1.286) / -0.190 (mm)	1.018 (2.238) / 1.960 (mm)
Height of Nose	0.863	-0.251 (0.947) / -0.222 (mm)	-0.462 (1.923) / -0.370 (mm)	0.743	-0.185 (3.103) / -0.310 (mm)	0.586 (4.003) / 1.600 (mm)
Height of upper lip	0.730	0.163 (1.175) / -0.110 (mm)	-0.002 (0.818) / -0.260 (mm)	0.606	0.210 (1.387) / -0.175 (mm)	-0.798 (2.710) / -0.570 (mm)
Height of Vermillion border	0.863	0.266 (0.852) / 0.230 (mm)	0.144 (0.965) / 0.380 (mm)	0.370	0.005 (1.498) / -0.200 (mm)	-0.571 (1.745) / -0.710 (mm)
Nasolabial angle	0.605	1.767 (7.289) / 0.300 (degrees)	0.433 (4.796) / 1.500 (degrees)	0.888	0.213 (7.269) / -0.770 (degrees)	1.372 (7.549) / -0.770 (degrees)
Upper lip to E-line	0.666	-0.356 (0.724) / -0.373 (mm)	0.214 (1.429) / -0.337 (mm)	0.167	-0.175 (1.063) / 0.360 (mm)	-0.900 (1.571) / -0.220 (mm)
Lower lip to E-line	0.666	0.634 (1.469) / 0.260 (mm)	0.335 (1.734) / -0.033 (mm)	0.114	0.115 (1.545) / 0.260 (mm)	-1.298 (1.841) / -0.160 (mm)
LAFH	0.387	0.419 (2.230) / 0.780 (mm)	1.293 (2.813) / 1.420 (mm)	0.059	1.205 (3.381) / 1.130 (mm)	-2.904 (4.371) / -4.170 (mm)
Mouth width	0.436	0.227 (2.982) / -0.390 (mm)	1.147 (2.344) / 1.690 (mm)	0.481	0.338 (2.119) / 0.225 (mm)	1.269 (3.493) / 0.760 (mm)
Philtrum width	0.258	-0.688 (0.845) / -0.360 (mm)	0.186 (1.658) / 0.770 (mm)	0.370	0.353 (1.235) / 0.250 (mm)	-0.149 (1.120) / -0.090 (mm)
Height of lower lip	0.863	-0.837 (2.272) / -0.510 (mm)	-1.196 (2.660) / -1.390 (mm)	0.059	-0.994 (3.206) / -1.040 (mm)	2.107 (3.493) / 1.830 (mm)
Nasal tip prominence	0.297	-0.248 (0.776) / 0.010 (mm)	0.217 (1.349) / 0.480 (mm)	0.815	0.086 (0.949) / 0.020 (mm)	-0.166 (1.146) / -0.230 (mm)
Endocanthion	0.666	0.442 (2.948) / -0.380 (mm)	2.259 (3.099) / 2.600 (mm)	0.006	-4.489 (3.754) / -4.540 (mm)	-4.489 (3.755) / -4.540 (mm)

Table 7: Summary of the p-values, and descriptive statistics for research question 2

4.6 Results for research question 3

For the third research question, the statistical analysis proved that soft tissue facial changes from T0 to T1 after bone-anchored maxillary expansion were not statistically significant in any of the measurements, except for endocanthion in the CBCT group.

From the descriptive statistics described in Table 8, the changes between T0 to T1 were minimal. The clinical significance value for this research question was 0.675 mm. Similarly to the other two research questions, the clinical significance value was determined by twice the mean standard deviation of the normative data completed by Venezia et al.[51] The measurements that showed more than a 0.675 mm/degree mean difference were considered to be abnormal. These values that were above 0.675 mm/degrees in the CBCT group were: alar width (0.786 mm), alar base width (1.183 mm), nasolabial angle (1.100 degrees), LAFH (0.856 mm), mouth width (0.687 mm), height of lower lip (1.016 mm), and endocanthion (1.863 mm). The values that were above 0.675 mm/degrees for the 3D facial scanner group were: nasolabial angle (0.826 degrees), LAFH (0.971 mm), mouth width (0.831 mm), and endocanthion (2.526 mm). The measurements that showed a mean increase from T0 to T1 in the CBCT group were the following: alar width (0.786 mm), height of upper lip (0.081 mm), height of vermillion border (0.205 mm), nasolabial angle (1.10 degrees), lower lip to E-line (0.485 mm), lower anterior facial height (0.856 mm), mouth width (0.687 mm), and endocanthion (1.863 mm). The measurements that showed a mean decrease were the following: alar base width (-1.183 mm), height of nose (-0.356 mm), upper lip to E-line (-0.071), philtrum width (-0.251), height of lower lip (-1.016 mm), and nasal tip prominence (-0.156).

The measurements that showed a mean increase from T0 to T1 in the 3D Facial scanner group were the following: alar base width (0.432 mm), height of nose (0.223 mm), nasolabial angle (0.826 mm), mouth width (0.831 mm), philtrum width (0.087 mm), and height of lower lip (0.648 mm). The measurements that showed a mean decrease were the following: alar width (-0.029 mm), height of upper lip (-0.324 mm), height of vermillion border (-0.300 mm), upper lip to E-line (-0.559 mm), lower lip to E-line (-0.663 mm), lower anterior facial height (-0.971 mm), nasal tip prominence (-0.047 mm), and endocanthion (-2.526 mm).

Measurements	Wilcoxon p-value (CBCT)	Mean (SD) / Median of T1-T0 for CBCT	Wilcoxon p-value (Facial scanner)	Mean (SD) / Median of T1-T0 for Facial Scanner
Alar width	0.072	0.786 (1.594) / 0.285 (mm)	0.927	-0.029 (3.621) / 0.960 (mm)
Alar base width	0.011	-1.183 (1.674) / -1.165 (mm)	0.510	0.432 (1.907) / -0.150 (mm)
Height of Nose	0.139	-0.356 (1.475) / -0.335 (mm)	0.890	0.223 (3.519) / -0.210 (mm)
Height of upper lip	0.823	0.081 (0.986) / -0.160 (mm)	0.678	-0.324 (2.187) / -0.190 (mm)
Height of Vermillion border	0.207	0.205 (0.885) / 0.364 (mm)	0.248	-0.300 (1.610) / -0.630 (mm)
Nasolabial angle	0.530	1.100 (6.025) / 0.900 (degrees)	1.000	0.826 (7.208) / -0.770 (degrees)
Upper lip to E-line	0.325	-0.071 (1.137) / -0.355 (mm)	0.268	-0.559 (1.366) / -0.180 (mm)
Lower lip to E-line	0.284	0.485 (1.567) / 0.245 (mm)	0.203	-0.633 (1.808) / -0.140 (mm)
LAFH	0.229	0.856 (2.503) / 1.090 (mm)	0.459	-0.971 (4.362) / -0.630 (mm)
Mouth width	0.325	0.687 (2.644) / 0.705 (mm)	0.190	0.831 (2.315) / 0.380 (mm)
Philtrum width	0.404	-0.251 (1.353) / -0.285 (mm)	0.620	0.087 (1.167) / 0.020 (mm)
Height of lower lip	0.096	-1.016 (2.407) / -1.230 (mm)	0.353	0.648 (3.625) / 0.930 (mm)
Nasal tip prominence	0.991	-0.156 (1.094) / 0.075 (mm)	0.917	-0.047 (1.033) / -0.150 (mm)
Endocanthion	0.001	1.863 (2.639) / 1.365 (mm)	0.040	-2.526 (4.353) / -3.100 (mm)

Table 8: P-value and descriptive statistics for research question 3

Chapter 5 – Discussion, Conclusion and Limitations

5.1-Discussion

The primary objective of this study was to investigate potential soft tissue facial changes following bone-anchored maxillary expansion in adult patients. Bone-anchored maxillary expansion has become a newer concept in orthodontics and is able to address maxillary transverse deficiencies in non-growing patients. Therefore, understanding its impact on facial soft tissues is essential for comprehensive treatment planning and to communicate these potential changes to patients. While the skeletal changes associated with maxillary expansion have been well-documented, the influence on facial soft tissues is an area that warrants thorough exploration. The findings from this research not only have the potential to enhance our understanding of the physiological responses to bone-anchored maxillary expansion but also to inform and optimize treatment strategies for individuals undergoing such interventions. There is scarce data regarding the impact of maxillary expansion on soft tissue facial changes, especially concerning the growing application of MARPE. It is crucial to highlight that the present study uniquely examines soft tissue changes using both CBCT and 3D facial scans concurrently, a methodology not employed in prior studies. This is important since it has been proven that CBCT has been an adequate tool for analyzing soft tissue, but the addition of 3D facial scans to further analyze the results strengthens the study.

The first research question was to determine if there is an inconsistency between the two imaging modalities. In assessing soft tissues in orthodontics, previously it was noted that most authors used 2D images like lateral cephalometric radiographs and photographs to determine any

soft tissue effects on patients.[14,20,21] However, this does not provide accurate and precise information due to the 3D nature of facial structures. In recent years, the development of 3D imaging has made it possible to accurately measure soft tissue in the third dimension. These imaging techniques are CBCT, laser scanning, stereophotogrammetry and structured light techniques.[22] This has facilitated precise diagnosis, analysis, treatment planning and evaluation of outcomes for orthodontists. While CBCTs have found extensive applications in orthodontics, the role and reliability of 3D facial scans have been a subject of active research. Due to the lack of true color and surface texture on CBCTs, the integration and possible interchangeability between the two modalities would be beneficial. The current study successfully evaluated facial soft tissues by utilizing CBCTs and a 3D facial scanner. This is beneficial because there are currently no studies that have successfully employed both techniques simultaneously.

We conducted a descriptive statistics analysis of all measurements, categorizing them into CBCT and 3D facial scanner groups. The creation of this analysis was to validate any similarities and identify any potential variations among measurements obtained through the two imaging modalities. The mean difference between the measurements at either T0 or T1 between the two imaging modalities should be minimal. Described in table 7, between the CBCT and 3D facial scanner groups, certain measurements exhibited inconsistencies across various statistical levels, indicating a discernible pattern. These measurements were the lower anterior facial height and lower lip. The lower anterior facial height and height of the lower lip exhibited a p-value <0.036, poor agreement in their intraclass correlation coefficient (ICC), and two measurements which displayed the largest mean differences between the T0 and T1 groups. The biggest limitation of achieving accuracy with these measurements were identifying the “soft-tissue menton” landmark.

In many of the CBCT scans, the image was cut off at that area which made estimating the landmark difficult. In Figure 7 below, it shows a patient where the soft tissue menton is cut off.

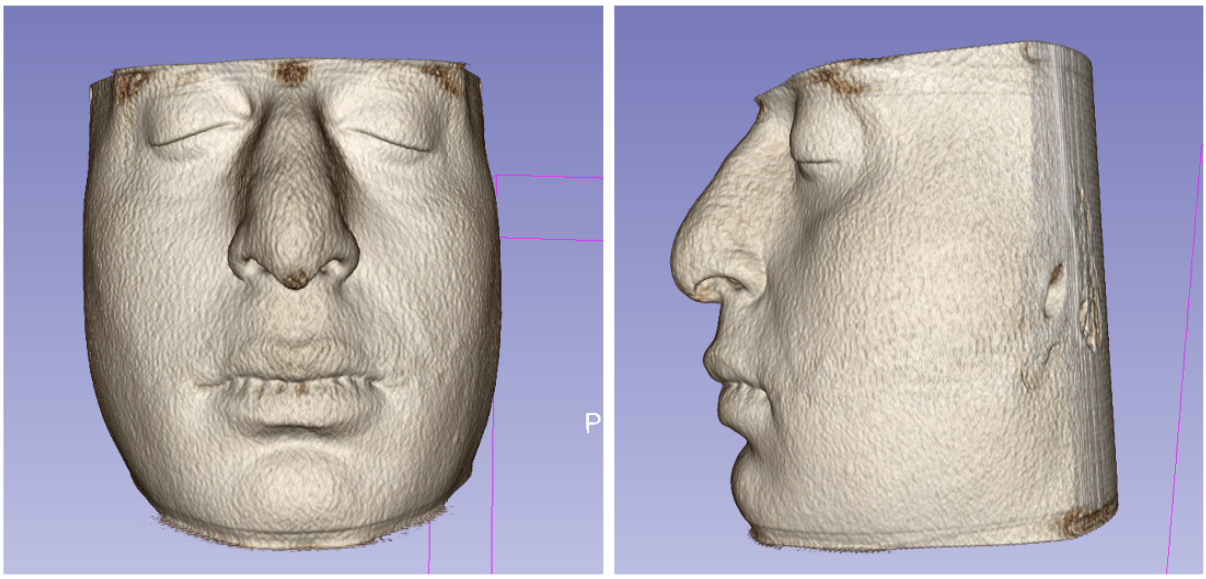


Figure 7: CBCT scan of patient with no inclusion of the soft tissue menton in the field of view

In addition, for the lower lip height, not only did we have to identify the soft tissue menton, but the lip margins were difficult to read in the CBCT scans. Not only was identifying the landmark difficult on the CBCT and 3D facial scanners, the landmark can be quite arbitrary and there can be a discrepancy when identifying the exact location for the soft tissue menton.

It is also notable that when the patient is obtaining the CBCT, the patient is encouraged to place their dentition into maximum intercuspation. During the process of capturing the 3D facial scan, patients may effortlessly assume a more relaxed lip position, potentially exerting significant influence on these particular measurements. In Figure 8 below, the variation in facial expressions can cause a discrepancy between the measurements and inconsistency between the two imaging modalities. In the CBCT scan for this patient, there is noticeable separation of the lips, which could impact the measurements of soft tissue. Moreover, since determining the precise measurement

locations is challenging, it is hard to determine if there is a genuine discrepancy between the two imaging modalities.

Figure 8: On the left is the CBCT of the patient and on the right is the 3D facial scan of the patient at the same time point

In the Kyung-Yen Nahm et al[23] study, focusing on the accurate registration of CBCT scans and 3D facial scans, the authors found that on average the soft tissue surface discrepancy between the two modalities should be approximately 0.60 mm. In addition, Aljawad et al, concluded that the average surface differences between facial scans and CBCT images were less than 1.0 mm.[24] However, the surfaces that were compared were the forehead, nasal bridge and malar areas.[24] It is common to use the forehead and parts of the glabella or nasal structures as reference areas to superimpose images of non-growing patients and/or within a short examination period of 6 months or less.[25] These regions demonstrate morphological stability, sufficient reproducibility, and results comparable to the golden standard technique. Positioned near the facial center but situated in the upper third of the face, this area enables accurate evaluation of the middle and lower facial regions, which are predominantly influenced by treatment and growth[26] and exhibit the highest variability

in the human face.[27] This superimposition reference aligns with the recommendation of the 3dMD camera manufacturer, involving a corresponding forehead area and the nasal bridge.[25] In this study, numerous measurements are incorporated that may be susceptible to various influences and do not exhibit morphological stability.

The conclusion was that at T0, the following measurements had statistically significant inconsistencies between the two imaging modalities: height of nose, lower lip to E-line, lower anterior facial height, height of lower lip, and nasal tip prominence. At T1, the following measurements had inconsistencies: height of vermillion border, lower anterior facial height, mouth width, height of lower lip, nasal tip prominence, and endocanthion. The discrepancies can be altered by changes in the patients' facial expressions, data inaccuracy, and positioning error. It is crucial to highlight that the discrepancies observed in the imaging modalities primarily stemmed from measurements that were challenging to identify, with alterations in facial expression potentially affecting these measurements. In addition, it is important to note that the soft tissue surrounding the lip region is difficult to identify in the CBCT scans. Also, in a select few patients, the soft tissue nasion was not in the field of view in the CBCT. This could have significant discrepancies on the above-mentioned measurements.

The second research question addressed whether there is a difference between the Moon and Dresden expander on the amount of soft tissue changes. It was significant to examine whether the appliance's design would have varying effects on the soft tissues. The statistical analysis concluded that there is no discrepancy between the Dresden and Moon expander when analyzing

the soft tissue measurements. The statistical analysis proved that the p-value for all measurements were above the significance level; therefore, there is no difference in soft tissue measurements between the Dresden and Moon expander. The descriptive statistics described in Table 8 showed that all the measurements showed a minimal difference between the two expanders in the CBCT group. The notable larger mean differences concluded that Moon expander in the CBCT group showed a range of a difference of 1.26-1.82 mm/degree from T0 to T1 for three measurements: alar width, nasolabial angle, and endocanthion. On the contrary, between the two expanders in the 3D facial scanner group was the Dresden expander showing a difference of 1.16-3.10 mm/degree for four measurements: nasolabial angle, lower lip to E-line, lower anterior facial height and height of lower lip. Ultimately, the descriptive statistics showing the mean difference between the two expanders from T0 to T1 for the soft tissue measurements were minimal. The main take-away from this research question is that there are no statistically significant changes between the Moon and Dresden expander when comparing the soft tissue changes.

The decision to use either the Moon expander or Dresden expander can ultimately be the decision of the clinician depending on the patients' best interest. The Dresden expander may be preferable for patients who have craniofacial abnormalities with missing teeth, missing upper molars, or heavily restored molars. Also, since the Moon expander has bands on the upper first molars, this would be indicated for patients' whose orthodontic treatment plan includes molar or premolar expansion. According to Lagravere et al, tooth-borne expansion resulted in significantly more long-term expansion at the maxillary premolar crown and root than the bone-borne expansion.[28]

It is important to understand the potential effects that the design of either tooth-bone-borne or bone-borne expander. Canan and Senişik observed significant expansion between the maxillary molars in both tooth-borne-borne and bone-borne expanders.[29] It was also noted that there was more expansion detected solely on the right side. In addition, Canan and Senişik did not observe statistically significant differences in dental tipping between the two expander appliances. However, there was notable post-expansion buccal tipping of maxillary molars reported with hybrid expanders, in contrast to the bone-borne expanders. [29] This side effect can be predicted as the hybrid expanders include bands on the molars, unlike the bone-borne expanders which are not attached to any teeth. Similarly, Oh et al. reported a similar result in their retrospective CBCT study, noting slightly less buccal tipping of molars with bone-borne expanders compared to hybrid expanders immediately after expansion.[30] Moon et al. conducted a retrospective CBCT study, revealing a significantly greater dental expansion in hybrid expanders compared to bone-borne expanders, though no notable difference in the amount of skeletal expansion between the two groups was found. [31] It was seen that significant buccal movement of premolars occurred in both groups, even without attachment to any appliances. [29] This phenomenon is attributed to the movement of premolars along with their skeletal base during the expansion process. The increased inter-premolar width aligns with findings from prior research employing CBCT.[32,33] This could potentially be attributed to alveolar bone bending or rotation of the maxillary halves during expansion.[34] In summary, it can be inferred that the two appliances exhibit minimal differences in regards to the amount of skeletal expansion, which subsequently would impact the overlying soft tissue. The slight differences primarily pertain to dental expansion, particularly in terms of buccal tipping, with limited implications for the overlying soft tissue.

The third research question answers whether there are any facial soft tissue changes after MARPE treatment. The aesthetic expectations of patients have shown a consistent rise in recent years. Considering this, various clinical and radiographic studies have investigated the skeletal and dental impacts of MARPE; however, there are limited studies showing the possible effects that it has on the facial soft tissues. Only a few studies have investigated this subject, and although there is consensus that facial soft tissues undergo positional changes following MARPE, discrepancies exist concerning the area and extent of these effects.[16,35–37] The statistical analysis proved that there are no soft tissue facial changes from T0 to T1 after bone-anchored maxillary expansion, except for the endocanthion in the CBCT group.

Kritj et al,[38] evaluated twenty-nine patients, who underwent MARPE treatment and concluded that there were statistically significant changes in the soft tissue regions of the nose, left and right philtrum and upper lip tubercle. These measurements were anterior movement of 0.30 mm, 0.93 mm, 0.74 mm, and 0.81 mm, respectively, immediately after expansion (T0–T1). These changes persisted as an overall effect (T0–T2). The alar width initially increased by 1.59 mm, and then decreased by 0.08 mm after 1 year, but this effect was not significant. The inter-premolar width (IPW) increased by 4.58 mm and remained stable 1 year later. There was no significant correlation between the increase in IPW and alar width ($r = 0.35$, $p = 0.06$).[38] In our study, the nasal tip prominence in the 3D facial scanner group decreased by 0.05 mm. However, we did not measure the anterior movement of the left and right philtrum. In addition, the alar width decreased by 0.03 mm. Ultimately, these changes were minimal.

The nasal area has been specifically researched for patients who underwent SARPE. Given the numerous publications highlighting soft tissue alterations in the nasal region following SARPE, it would be beneficial to explore and address these changes in the context of this study. The most common side effects of SARPE treatment were widening of the nose, evident in both short-term and long-term scenarios, showcasing an increase in alar width ranging from 1.10 to 3.09 mm. [39–42] Nevertheless, the influence on nasal shape remains ambiguous utilizing MARPE. While Ngan et al.[43] and Filho et al.[44] have examined these effects, their use of conventional two-dimensional (2D) lateral cephalograms presents significant drawbacks, particularly in assessing soft tissue changes from a frontal viewpoint. In a recent 2020 study by Lee et al[35], this study analyzed 30 patients who underwent MARPE and used the method of stereophotogrammetry to assess nasal soft tissue changes. They evaluated changes by assessing the linear distances and volumetric changes in the nasal region. A statistically significant increase (with a mean of 1.214 mm) in the alar base width following MARPE was observed. [35] In a previous study for patients who underwent SARPE, expansion of over 5 mm resulted in an alar width increase of 1.66 mm and alar base width increase of 3.09 mm.[40] Hence, the observed width increases were comparatively smaller than those documented following SARPE, likely due to the MARPE procedure resulting in a lower percentage of skeletal expansion. In our study, although there was no statistically significant change seen for the alar base width, there was still an increase of 0.43 mm seen in the 3D facial scanner group. Similarly, the alar width increased by 0.73 mm in the CBCT group. In addition, the soft tissues of the nose are thought to widen and shift forward and downward.[35] While this could be advantageous for individuals with a narrow nasal width prior to treatment, it may pose a challenge for adult patients with an already wide nose, even with a minimal increase of 1 mm. There exists no clear threshold for how a layperson perceives changes in nasal width.

Consequently, aesthetic evaluation becomes intricate, necessitating clinicians to provide ample information to patients about expected changes before initiating treatment. Additionally, a thorough diagnosis is crucial. This does not align with our current study since this would have had significant changes on the height of nose, nasolabial angle, alar width, alar base width, and nasal tip prominence.

Comparatively, a study completed by Johnson et al[18], analyzed changes in soft tissue nasal width in pre-pubertal and post-pubertal patients who underwent RME. While this study did not encompass MARPE or non-growing patients, it provides insights into the effects of expansion within a different age group and with an alternative expansion appliance. The study indicated that the general increases in greater alar cartilages (GAC) were typically less than 1.5 mm, suggesting that the treatment impact of RME on the greater alar cartilages' width is not clinically substantial. Across all groups, a minor rise in nasal width is observable during the active expansion phase (within 1 mm for both alar base widths and GAC), succeeded by a slight reduction or nearly no change during the retention period. The cumulative outcome resulted in a width increase smaller than 1.5 mm for both measurements. [18] However, the patients treated with RPE were growing, which is inherent to this therapy, thereby complicating comparison with the results for MARPE. Similarly, Truong et al. assessed the impact of growth by examining the nasal soft tissues of growing individuals who underwent RPE treatment. These results were compared to a control group of individuals around the same age who did not undergo RPE treatment. The study revealed that, despite a significant initial increase in nasal soft tissue immediately after expansion, it returned to the average level expected in normal growth and development over time. This suggests a transient stretching of the soft tissues rather than a permanent alteration. [45] In a study conducted

by Molla et al, that utilized the same landmarks and similar methodology as the current study, it was noted that children aged 7-11 years who have undergone rapid maxillary expansion experience facial soft tissue changes comparable to patients who have not undergone any expansion. In regards to both CBCTs and 3D facial scans, there were no statistically significant differences found between the two groups over the one-year observation period. [52]

It has been observed that MARPE has a tendency to separate the mid-palatal suture in a more parallel movement than RPE.[46] This separation of the mid-palatal suture in a parallel fashion allows for separation of the posterior portion of maxilla. [47] As a result, the circum- maxillary suture, located near the posterior aspect of the maxilla, is more directly influenced, resulting in an increase in both downward and forward displacement of the maxilla. This has also been concluded by Sarver and Johnston[48], who reported that the maxilla is displaced forward and downward during RPE because of the influence of the treatment on the circum-maxillary suture. Kilic et al.[49] reported an expected increase in the skeletal profile convexity owing to an anterior maxillary movement along with a clockwise mandibular rotation. This downward movement of the maxilla, and clockwise rotation of the mandible ultimately would affect the lower anterior facial height, lower lip to E-line, and height of lower lip. There were no statistically significant changes to these measurements from T0 to T1 in our study. Since the soft tissue menton was more predictable in the facial scanner group, the descriptive statistics show an increase in the height of lower lip by 0.65 mm, and a decrease in the lower lip to E-line by 0.66 mm, which could be related to the counter-clockwise rotation of the mandible. On the contrary, the lower anterior facial height had a slight decrease of 0.97 mm. The potential anterior movement of the maxilla after expansion would affect the upper lip to E-line and nasolabial angle; however, this was not in agreement with our study. These measurements did not have a statistically significant change from T0 to T1 in either

CBCT or 3D facial scanner groups. In fact, the nasolabial angle did have a slight increase in both CBCT and 3D facial scanner group of 1.10 and 0.83 degrees, respectively. Also, the upper lip to E-line decreased by 0.07 and 0.56 mm, respectively.

Overall, it should be considered that soft tissue changes could be multifactorial and the magnitude of change could be influenced by other factors, such as the soft tissue thickness, tissue elasticity, or change in weight, particularly when evaluating longer-term effects. Moreover, some of the patients have facial hair, complicating the process of landmarking and potentially introducing alterations to the results, as illustrated in Figure 9 below.

Figure 9: Patients 3D facial scanner taken at two different time points, depicting the change in facial hair

5.2 Limitations

This study possesses several limitations, which will be elaborated further. Firstly, since the population group is adult patients, there could be many variations that could affect the results of the study. The adult patients could have changes in weight, receive cosmetic enhancements, changes in soft tissue elasticity due to aging, and have changes in the amount of facial hair, which could alter measurements or make facial structures less visible. It would be difficult to control these factors in future studies.

Moreover, the patients may change their facial expressions between the imaging modalities. The patients were instructed to maintain maximum intercuspation in the CBCT group, and in the 3D facial scanner group, they were encouraged to maintain a relaxed facial expression. This could alter the measurements. Also, the slightest frown or smile could impact the measurements.

In future studies, it would be highly advantageous to investigate the degree of change in millimeters that correlates with noticeable perceptions. Understanding these aspects not only enhances our comprehension of the aesthetic impacts of maxillary expansion but also informs clinical practice by pinpointing critical stages in patient awareness and satisfaction. By quantifying the minimum extent of change that registers perceptibly, future research can contribute significantly to refining treatment protocols and improving patient outcomes.

In addition, some patients received full lower braces during expansion, in which they could have received bite ramps on the posterior teeth to disocclude. Once the records on T1 were completed, the bite ramps could prevent the patient from biting into maximum intercuspation and could create a discrepancy from T0 to T1.

An additional potential limitation of the study lies in the limited number of time points assessed. The time-points assessed in this study was pre-expansion (T0) and post-expansion (T1). Ideally, a future investigation could enhance its methodology by examining measurements at multiple timepoints, encompassing pre-expansion, immediate post-expansion, post-expansion at 6 months retention, and subsequent post-retention evaluations. This would allow us to further investigate the long-term effects of maxillary expansion, since transient soft-tissue stretching could occur post-expansion. Moreover, this approach would allow for a more comprehensive and detailed analysis of soft tissue changes following expansion. However, given the considerations of radiation exposure and adherence to the ALARA (as low as reasonably achievable) principle as outlined by the Centers for Disease Control and Prevention, this might pose a challenge. Alternatively, the utilization of 3D facial scans could be considered to minimize radiation risks. Furthermore, as mentioned earlier, CBCT imaging may introduce a higher potential for patient positioning errors and field of view considerations.

Another limitation in our study was the assessment of soft tissue changes. It would be notable that super-impositions or surface registrations may produce more accurate results due to the complex morphology and rounded nature of the face. However, due to time constraints and software limitations, the superimpositions and surface registrations were not able to be completed. Additionally, for facial soft tissues with high dimensionality, it may be prudent to assess Manhattan distances rather than Euclidean distances. While Euclidean distance represents the shortest distance between two points, Manhattan distance is measured along axes at right angles.

Another limitation is the small population size present in this research study. This poses a challenge for generalizability, reliability and reduces the statistical power. Additionally, the study may not adequately represent the population's diversity, leading to potentially biased results.

Findings from a small sample may lack external validity, cautioning against broad generalizations. To further strengthen future studies, we should be mindful of these limitations and consider the need for larger, more diverse samples for robust and applicable study outcomes.

5.3 Conclusions

It can be inferred that there are no statistically significant changes from T0 to T1 for any measurements except for endocanthion. Measuring endocanthion on the two imaging modalities can lack reliability due to its lack of clear demarcation.

In addition, the study questioned whether there is an inconsistency in measuring the patients with either the CBCT or 3D facial scanner. The interchangeability of these imaging modalities would be beneficial since the 3D facial scanner has no radiation, cost friendly, and visualization of facial soft tissue is impressive. The conclusion was that at T0, the following measurements had inconsistencies between the two imaging modalities: height of nose, lower lip to E-line, lower anterior facial height, height of lower lip, and nasal tip prominence. At T1, the following measurements had inconsistencies: height of vermillion border, lower anterior facial height, mouth width, height of lower lip, nasal tip prominence, and endocanthion. The inconsistencies of these measurements mainly stem from the CBCT field of view not including the soft tissue menton. Specifically, the lower anterior facial height, and height of lower lip. Furthermore, the absence of the nasion point in select patients, attributed to the CBCT's field of view limitations, could potentially create a discrepancy in the height of nose measurement. Moreover, the complexity in visualizing the mouth region in the CBCT scans may impact the precision and reliability of lip-related measurements in the study.

Furthermore, this research study concluded that there is no difference between the Dresden and Moon expander on the soft tissue changes.

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Appendix

Intraclass Correlation Coefficient

Landmarks		Intraclass Correlation[b]	95% Confidence Interval		F Test with True Value 0			
			Lower Bound	Upper Bound	Value	df1	df2	Sig
1	Single Measures	.998[a]	.996	.999	1803.826	16	32	<.001
	Average Measures	.999[c]	.999	1.000	1803.826	16	32	<.001
2	Single Measures	.952[a]	.874	.982	82.931	16	32	<.001
	Average Measures	.983[c]	.954	.994	82.931	16	32	<.001
3	Single Measures	.983[a]	.962	.993	167.941	16	32	<.001
	Average Measures	.994[c]	.987	.998	167.941	16	32	<.001
4	Single Measures	.985[a]	.966	.994	193.049	16	32	<.001
	Average Measures	.995[c]	.989	.998	193.049	16	32	<.001
5	Single Measures	.996[a]	.992	.999	758.583	16	32	<.001
	Average Measures	.999[c]	.997	1.000	758.583	16	32	<.001
6	Single Measures	.954[a]	.901	.982	59.931	16	32	<.001
	Average Measures	.984[c]	.965	.994	59.931	16	32	<.001
7	Single Measures	.994[a]	.988	.998	536.650	16	32	<.001
	Average Measures	.998[c]	.996	.999	536.650	16	32	<.001
8	Single Measures	.992[a]	.982	.997	414.131	16	32	<.001
	Average Measures	.997[c]	.994	.999	414.131	16	32	<.001
9	Single Measures	.978[a]	.940	.992	188.807	16	32	<.001
	Average Measures	.993[c]	.979	.997	188.807	16	32	<.001
10	Single Measures	.984[a]	.962	.994	209.322	16	32	<.001
	Average Measures	.994[c]	.987	.998	209.322	16	32	<.001
11	Single Measures	.935[a]	.835	.976	60.189	16	32	<.001
	Average Measures	.977[c]	.938	.992	60.189	16	32	<.001
12	Single Measures	.967[a]	.920	.988	113.642	16	32	<.001
	Average Measures	.989[c]	.972	.996	113.642	16	32	<.001
13	Single Measures	.480[a]	.187	.741	3.747	16	32	<.001
	Average Measures	.734[c]	.408	.896	3.747	16	32	<.001
14	Single Measures	.980[a]	.929	.993	247.432	16	32	<.001
	Average Measures	.993[c]	.975	.998	247.432	16	32	<.001

Table A1: ICC results for intra-rater reliability for the CBCT measurements. Single measures were recorded.

Intraclass Correlation Coefficient

Landmarks		Intraclass Correlation[b]	95% Confidence Interval		F Test with True Value 0			
			Lower Bound	Upper Bound	Value	df1	df2	Sig
1	Single Measures	.989[a]	.975	.995	250.636	17	34	<.001
	Average Measures	.996[c]	.992	.998	250.636	17	34	<.001
2	Single Measures	.643[a]	.387	.833	6.125	17	34	<.001
	Average Measures	.844[c]	.654	.937	6.125	17	34	<.001
3	Single Measures	.953[a]	.901	.980	59.893	17	34	<.001
	Average Measures	.984[c]	.964	.993	59.893	17	34	<.001
4	Single Measures	.962[a]	.920	.984	78.133	17	34	<.001
	Average Measures	.987[c]	.972	.995	78.133	17	34	<.001
5	Single Measures	.950[a]	.895	.979	58.294	17	34	<.001
	Average Measures	.983[c]	.962	.993	58.294	17	34	<.001
6	Single Measures	.732[a]	.518	.876	10.406	18	36	<.001
	Average Measures	.891[c]	.764	.955	10.406	18	36	<.001
7	Single Measures	.969[a]	.934	.987	93.116	17	34	<.001
	Average Measures	.989[c]	.977	.996	93.116	17	34	<.001
8	Single Measures	.983[a]	.963	.993	165.529	17	34	<.001
	Average Measures	.994[c]	.987	.998	165.529	17	34	<.001
9	Single Measures	.840[a]	.394	.949	45.400	17	34	<.001
	Average Measures	.940[c]	.661	.982	45.400	17	34	<.001
10	Single Measures	.947[a]	.879	.979	65.991	17	34	<.001
	Average Measures	.982[c]	.956	.993	65.991	17	34	<.001
11	Single Measures	.896[a]	.750	.959	36.871	17	34	<.001
	Average Measures	.963[c]	.900	.986	36.871	17	34	<.001
12	Single Measures	.740[a]	.257	.910	24.043	17	34	<.001
	Average Measures	.895[c]	.510	.968	24.043	17	34	<.001
13	Single Measures	.982[a]	.961	.993	153.799	17	34	<.001
	Average Measures	.994[c]	.986	.998	153.799	17	34	<.001
14	Single Measures	.760[a]	.561	.892	10.499	17	34	<.001
	Average Measures	.905[c]	.793	.961	10.499	17	34	<.001

Table A2: ICC results for intra-reliability for the 3D facial scanner measurements. Single measures were recorded.

Descriptive Statistics

	N	Mean	Std. Deviation	Minimum	Maximum	Percentiles 25th	50th (Median)	75th
AWT0CBCT	18.00	35.58	3.79	29.63	41.67	32.10	35.35	39.35
ABWT0CBCT	18.00	26.31	2.53	20.97	30.37	24.57	26.51	28.27
HofNT0CBCT	18.00	50.94	3.66	44.54	60.32	48.29	50.91	53.71
HofULT0CBCT	18.00	20.22	2.90	14.86	25.83	19.01	21.06	22.05
HofVBT0CBCT	18.00	10.76	2.22	7.56	15.10	8.70	10.38	12.90
NAT0CBCT	18.00	73.52	18.98	40.20	116.10	61.98	69.50	83.45
UltoElineT0CBCT	18.00	3.88	1.73	.68	6.81	2.58	3.84	5.37
LltoElineT0CBCT	18.00	3.25	2.12	.26	7.07	1.35	3.09	5.51
LAFHT0CBCT	18.00	67.71	4.43	59.69	75.88	63.92	67.99	71.45
MWT0CBCT	18.00	48.95	4.20	41.37	57.56	46.59	49.70	51.15
PhWT0CBCT	18.00	13.59	2.14	10.98	18.61	11.95	12.68	15.19
HofLLT0CBCT	18.00	46.95	4.00	39.67	53.10	43.74	47.93	50.05
NTPT0CBCT	18.00	32.84	3.23	26.93	38.88	30.32	32.82	35.25
EnT0CBCT	18.00	34.16	3.11	29.14	40.03	32.08	33.78	36.70
AWT0FS	17.00	36.80	4.96	28.17	43.85	32.71	37.21	40.99
ABWT0FS	17.00	28.94	5.34	22.37	37.64	23.91	27.96	34.08
HofNT0FS	17.00	48.82	4.36	40.82	59.67	46.28	48.47	50.75
HofULT0FS	17.00	21.84	2.40	17.83	27.44	19.52	22.11	23.07
HofVBT0FS	17.00	8.94	2.75	5.00	13.95	6.67	8.39	10.71
NAT0FS	17.00	69.43	10.74	42.79	95.18	63.95	69.73	72.60
UltoElineT0FS	17.00	4.74	3.28	.46	13.92	2.05	4.35	6.73
LltoElineT0FS	17.00	4.80	3.97	.10	16.04	1.60	4.32	6.92
LAFHT0FS	17.00	76.51	8.29	62.81	91.04	70.77	73.20	84.08
MWT0FS	17.00	52.32	4.37	44.13	59.76	50.14	52.79	55.26
PhWT0FS	17.00	14.47	3.06	10.26	19.79	11.78	14.30	16.91
HofLLT0FS	17.00	54.66	6.67	44.99	68.10	50.11	51.14	59.98
NTPT0FS	17.00	34.63	3.41	29.30	40.53	32.50	33.63	38.39
EnT0FS	17.00	32.81	4.29	25.29	41.04	30.05	31.84	36.57

Table A3: Descriptive statistics for the measurements in research question 1. Listed are the values for the measurements in T0 for CBCT and 3D facial scanner

Descriptive Statistics

	N	Mean	Std. Deviation	Minimum	Maximum	Percentiles 25th	50th (Median)	75th
AWT1CBCT	18	36.36	3.84	31.27	42.76	32.21	36.62	39.69
ABWT1CBCT	18	27.50	3.22	20.02	33.36	25.34	27.37	30.01
HofNT1CBCT	18	51.29	3.86	45.31	60.43	48.57	50.94	53.14
HofULT1CBCT	18	20.30	3.29	14.75	26.83	17.94	20.55	22.45
HofVBT1CBCT	17	11.17	2.53	7.22	15.17	8.89	11.15	13.75
NAT1CBCT	18	71.72	17.14	29.10	102.40	63.00	73.20	81.65
UltoElineT1CBCT	18	3.81	2.16	.30	8.53	2.31	3.53	4.92
LltoElineT1CBCT	18	3.73	2.59	.50	8.44	1.43	2.87	6.25
LAFHT1CBCT	18	68.57	4.51	60.74	77.30	65.81	69.26	72.19
MWT1CBCT	18	49.64	4.17	43.64	58.61	46.05	48.73	52.99
PhWT1CBCT	17	13.83	2.45	9.85	18.67	11.92	13.75	15.66
HofLLT1CBCT	18	47.97	3.92	40.17	55.09	45.44	48.36	50.74
NTPT1CBCT	18	32.82	2.91	27.41	38.58	30.67	32.34	35.42
EnT1CBCT	17	35.72	3.96	30.34	43.98	31.72	34.82	38.73
AWT1FS	17	36.77	5.87	25.56	44.23	33.44	35.86	43.18
ABWT1FS	17	28.51	4.95	21.06	36.81	24.58	29.01	32.62
HofNT1FS	17	48.59	3.90	40.53	55.12	45.84	48.62	51.84
HofULT1FS	17	21.52	2.25	16.82	25.22	20.38	21.53	23.34
HofVBT1FS	17	8.64	2.11	4.81	13.17	7.15	8.63	10.04
NAT1FS	17	70.25	11.59	42.29	87.60	63.72	70.39	78.62
UltoElineT1FS	17	4.18	2.51	1.41	9.33	2.15	3.18	6.23
LltoElineT1FS	17	4.17	2.85	.15	10.93	2.29	3.51	6.87
LAFHT1FS	17	75.54	6.96	64.22	90.54	70.59	74.48	81.68
MWT1FS	17	53.15	4.90	43.08	61.60	49.87	54.24	56.91
PhWT1FS	17	14.38	3.05	9.33	20.71	11.81	14.30	17.15
HofLLT1FS	17	54.02	5.81	46.29	67.17	49.29	54.56	58.70
NTPT1FS	17	34.58	3.06	29.93	40.30	32.41	34.12	36.93
EnT1FS	17	30.29	3.88	21.49	36.22	28.44	30.76	33.87

Table A4: Descriptive statistics for the measurements in research question 1. Listed are the values for the measurements in T1 for CBCT and 3D facial scanner

Test Statistics[a]

	AWT0FS – AWT0CBCT	ABWT0FS – ABWT0CBCT	HofNT0FS – HofNT0CBCT	HofULT0FS – HofULT0CBCT	HofVBT0FS – HofVBT0CBCT	NAT0FS – NAT0CBCT	UltoElineT0FS – UltoElineT0CBCT
Z	-1.293[b]	-1.552[b]	-3.206[c]	-2.741[b]	-2.430[c]	-.724[c]	-.414[b]
Asymp. Sig. (2-tailed)	.196	.121	.001	.006	.015	.469	.679
Exact Sig. (2-tailed)	.207	.127	<.001	.004	.013	.495	.706
Exact Sig. (1-tailed)	.103	.063	<.001	.002	.007	.248	.353
Point Probability	.005	.004	.000	.000	.001	.016	.019

Test Statistics[a]

	LltoElineT0FS – LltoElineT0CBCT	LAFHT0FS – LAFHT0CBCT	MWT0FS – MWT0CBCT	PhWT0FS – PhWT0CBCT	HofLLT0FS – HofLLT0CBCT	NTPT0FS – NTPT0CBCT	EnT0FS – EnT0CBCT
Z	-2.792[b]	-3.516[b]	-2.585[b]	-1.034[b]	-3.361[b]	-3.465[b]	-2.327[c]
Asymp. Sig. (2-tailed)	.005	<.001	.010	.301	<.001	<.001	.020
Exact Sig. (2-tailed)	.003	<.001	.008	.316	<.001	<.001	.018
Exact Sig. (1-tailed)	.002	<.001	.004	.158	<.001	<.001	.009
Point Probability	.000	.000	.001	.006	.000	.000	.001

a. Wilcoxon Signed Ranks Test

Table A5: Wilcoxon P-value for research question 1 at T0

Test Statistics[a]

	AWT1FS – AWT1CBCT	ABWT1FS – ABWT1CBCT	HofNT1FS – HofNT1CBCT	HofULT1FS – HofULT1CBCT	HofVBT1FS – HofVBT1CBCT	NAT1FS – NAT1CBCT	UltoElineT1FS – UltoElineT1CBCT
Z	-.207[b]	-.905[b]	-2.896[c]	-2.482[b]	-3.351[c]	-.310[c]	-.207[c]
Asymp. Sig. (2-tailed)	.836	.365	.004	.013	<.001	.756	.836
Exact Sig. (2-tailed)	.860	.382	.002	.011	<.001	.782	.860
Exact Sig. (1-tailed)	.430	.191	.001	.005	<.001	.391	.430
Point Probability	.020	.007	.000	.000	.000	.019	.020

Test Statistics[a]

	LltoElineT1FS – LltoElineT1CBCT	LAFHT1FS – LAFHT1CBCT	MWT1FS – MWT1CBCT	PhWT1FS – PhWT1CBCT	HofLLT1FS – HofLLT1CBCT	NTPT1FS – NTPT1CBCT	EnT1FS – EnT1CBCT
Z	-1.603[b]	-3.309[b]	-2.792[b]	-.426[b]	-2.999[b]	-3.051[b]	-2.897[c]
Asymp. Sig. (2-tailed)	.109	<.001	.005	.670	.003	.002	.004
Exact Sig. (2-tailed)	.117	<.001	.003	.689	.001	<.001	.002
Exact Sig. (1-tailed)	.058	<.001	.002	.344	<.001	<.001	.001
Point Probability	.006	.000	.000	.010	.000	.000	.000

a. Wilcoxon Signed Ranks Test

Table A6: Wilcoxon P-value for research question 1 at T1

Intraclass Correlation Coefficient

	Intraclass Correlation[b]	95% Confidence Interval		F Test with True Value 0			
		Lower Bound	Upper Bound	Value	df1	df2	Sig
Single Measures	.899[a]	.741	.963	19.880	15	15	<.001
Average Measures	.947[c]	.851	.981	19.880	15	15	<.001

Table A7: ICC for alar width for research question 1 at T0

Intraclass Correlation Coefficient

	Intraclass Correlation[b]	95% Confidence Interval		F Test with True Value 0			
		Lower Bound	Upper Bound	Value	df1	df2	Sig
Single Measures	.332[a]	-.109	.687	2.177	15	15	.072
Average Measures	.498[c]	-.244	.815	2.177	15	15	.072

Table A8: ICC for alar base width for research question 1 at T0

Intraclass Correlation Coefficient

	Intraclass Correlation[b]	95% Confidence Interval		F Test with True Value 0			
		Lower Bound	Upper Bound	Value	df1	df2	Sig
Single Measures	.689[a]	-.009	.905	10.993	15	15	<.001
Average Measures	.816[c]	-.019	.950	10.993	15	15	<.001

Table A9: ICC for height of nose for research question 1 at T0

Intraclass Correlation Coefficient

	Intraclass Correlation[b]	95% Confidence Interval		F Test with True Value 0			
		Lower Bound	Upper Bound	Value	df1	df2	Sig
Single Measures	.650[a]	.094	.876	7.206	15	15	<.001
Average Measures	.788[c]	.172	.934	7.206	15	15	<.001

Table A10: ICC for height of upper lip for research question 1 at T0

Intraclass Correlation Coefficient

	Intraclass Correlation[b]	95% Confidence Interval		F Test with True Value 0			
		Lower Bound	Upper Bound	Value	df1	df2	Sig
Single Measures	.599[a]	.073	.849	5.730	15	15	<.001
Average Measures	.749[c]	.137	.919	5.730	15	15	<.001

Table A11: ICC for height of vermillion border for research question 1 at T0

Intraclass Correlation Coefficient

	Intraclass Correlation[b]	95% Confidence Interval		F Test with True Value 0			
		Lower Bound	Upper Bound	Value	df1	df2	Sig
Single Measures	.446[a]	-.025	.761	2.649	15	15	.034
Average Measures	.617[c]	-.052	.864	2.649	15	15	.034

Table A12: ICC for nasolabial angle for research question 1 at T0

Intraclass Correlation Coefficient

	Intraclass Correlation[b]	95% Confidence Interval		F Test with True Value 0			
		Lower Bound	Upper Bound	Value	df1	df2	Sig
Single Measures	.386[a]	-.112	.731	2.246	15	15	.064
Average Measures	.557[c]	-.252	.844	2.246	15	15	.064

Table A13: ICC for upper lip to E-line for research question 1 at T0

Intraclass Correlation Coefficient

	Intraclass Correlation[b]	95% Confidence Interval		F Test with True Value 0			
		Lower Bound	Upper Bound	Value	df1	df2	Sig
Single Measures	.493[a]	.044	.784	3.519	15	15	.010
Average Measures	.661[c]	.084	.879	3.519	15	15	.010

Table A14: ICC for lower lip to E-line for research question 1 at T0

Intraclass Correlation Coefficient

	Intraclass Correlation[b]	95% Confidence Interval		F Test with True Value 0			
		Lower Bound	Upper Bound	Value	df1	df2	Sig
Single Measures	.176[a]	-.122	.534	1.981	15	15	.099
Average Measures	.299[c]	-.278	.696	1.981	15	15	.099

Table A15: ICC for lower anterior facial height for research question 1 at T0

Intraclass Correlation Coefficient

	Intraclass Correlation[b]	95% Confidence Interval		F Test with True Value 0			
		Lower Bound	Upper Bound	Value	df1	df2	Sig
Single Measures	.573[a]	.072	.834	5.054	15	15	.002
Average Measures	.729[c]	.134	.909	5.054	15	15	.002

Table A16: ICC for mouth width for research question 1 at T0

Intraclass Correlation Coefficient

	Intraclass Correlation[b]	95% Confidence Interval		F Test with True Value 0			
		Lower Bound	Upper Bound	Value	df1	df2	Sig
Single Measures	.806[a]	.540	.927	9.478	15	15	<.001
Average Measures	.892[c]	.701	.962	9.478	15	15	<.001

Table A17: ICC for philtrum width for research question 1 at T0

Intraclass Correlation Coefficient

	Intraclass Correlation[b]	95% Confidence Interval		F Test with True Value 0			
		Lower Bound	Upper Bound	Value	df1	df2	Sig
Single Measures	.028[a]	.225	.296	.894	15	15	.584
Average Measures	.058[c]	.580	.456	.894	15	15	.584

Table A18: ICC for height of lower lip for research question 1 at T0

Intraclass Correlation Coefficient

	Intraclass Correlation[b]	95% Confidence Interval		F Test with True Value 0			
		Lower Bound	Upper Bound	Value	df1	df2	Sig
Single Measures	.912[a]	.009	.982	99.570	15	15	<.001
Average Measures	.954[c]	.018	.991	99.570	15	15	<.001

Table A19: ICC for nasal tip prominence for research question 1 at T0

Intraclass Correlation Coefficient

	Intraclass Correlation[b]	95% Confidence Interval		F Test with True Value 0			
		Lower Bound	Upper Bound	Value	df1	df2	Sig
Single Measures	.785[a]	.430	.923	10.466	15	15	<.001
Average Measures	.879[c]	.601	.960	10.466	15	15	<.001

Table A20: ICC for endocanthion for research question 1 at T0

Intraclass Correlation Coefficient

	Intraclass Correlation[b]	95% Confidence Interval		F Test with True Value 0			
		Lower Bound	Upper Bound	Value	df1	df2	Sig
Single Measures	.669[a]	.265	.871	4.792	15	15	.002
Average Measures	.801[c]	.419	.931	4.792	15	15	.002

Table A21: ICC for alar width for research question 1 at T1

Intraclass Correlation Coefficient

	Intraclass Correlation[b]	95% Confidence Interval		F Test with True Value 0			
		Lower Bound	Upper Bound	Value	df1	df2	Sig
Single Measures	.212[a]	-.315	.633	1.521	15	15	.213
Average Measures	.349[c]	-.918	.775	1.521	15	15	.213

Table A22: ICC for alar base width for research question 1 at T1

Intraclass Correlation Coefficient

	Intraclass Correlation[b]	95% Confidence Interval		F Test with True Value 0			
		Lower Bound	Upper Bound	Value	df1	df2	Sig
Single Measures	.516[a]	-.038	.814	4.959	15	15	.002
Average Measures	.681[c]	-.079	.898	4.959	15	15	.002

Table A23: ICC for height of nose for research question 1 at T1

Intraclass Correlation Coefficient

	Intraclass Correlation[b]	95% Confidence Interval		F Test with True Value 0			
		Lower Bound	Upper Bound	Value	df1	df2	Sig
Single Measures	.655[a]	.159	.873	6.661	15	15	<.001
Average Measures	.791[c]	.274	.932	6.661	15	15	<.001

Table A24: ICC for height of upper lip for research question 1 at T1

Intraclass Correlation Coefficient

	Intraclass Correlation[b]	95% Confidence Interval		F Test with True Value 0			
		Lower Bound	Upper Bound	Value	df1	df2	Sig
Single Measures	.565[a]	-.099	.863	8.701	14	14	<.001
Average Measures	.722[c]	-.221	.927	8.701	14	14	<.001

Table A25: ICC for height of vermillion border for research question 1 at T1

Intraclass Correlation Coefficient

	Intraclass Correlation[b]	95% Confidence Interval		F Test with True Value 0			
		Lower Bound	Upper Bound	Value	df1	df2	Sig
Single Measures	.564[a]	.109	.823	3.492	15	15	.010
Average Measures	.722[c]	.197	.903	3.492	15	15	.010

Table A26: ICC for nasolabial angle for research question 1 at T1

Intraclass Correlation Coefficient

	Intraclass Correlation[b]	95% Confidence Interval		F Test with True Value 0			
		Lower Bound	Upper Bound	Value	df1	df2	Sig
Single Measures	.678[a]	.293	.874	5.069	15	15	.002
Average Measures	.808[c]	.453	.933	5.069	15	15	.002

Table A27: ICC for upper lip to E-line for research question 1 at T1

Intraclass Correlation Coefficient

	Intraclass Correlation[b]	95% Confidence Interval		F Test with True Value 0			
		Lower Bound	Upper Bound	Value	df1	df2	Sig
Single Measures	.581[a]	.157	.829	3.856	15	15	.007
Average Measures	.735[c]	.272	.906	3.856	15	15	.007

Table A28: ICC for lower lip to E-line for research question 1 at T1

Intraclass Correlation Coefficient

	Intraclass Correlation[b]	95% Confidence Interval		F Test with True Value 0			
		Lower Bound	Upper Bound	Value	df1	df2	Sig
Single Measures	.228[a]	-.121	.596	2.299	15	15	.059
Average Measures	.371[c]	-.275	.747	2.299	15	15	.059

Table A29: ICC for lower anterior facial height for research question 1 at T1

Intraclass Correlation Coefficient

	Intraclass Correlation[b]	95% Confidence Interval		F Test with True Value 0			
		Lower Bound	Upper Bound	Value	df1	df2	Sig
Single Measures	.649[a]	.094	.876	7.187	15	15	<.001
Average Measures	.787[c]	.172	.934	7.187	15	15	<.001

Table A30: ICC for mouth width for research question 1 at T1

Intraclass Correlation Coefficient

	Intraclass Correlation[b]	95% Confidence Interval		F Test with True Value 0			
		Lower Bound	Upper Bound	Value	df1	df2	Sig
Single Measures	.728[a]	.361	.900	6.102	14	14	<.001
Average Measures	.843[c]	.530	.947	6.102	14	14	<.001

Table A31: ICC for philtrum width for research question 1 at T1

Intraclass Correlation Coefficient

	Intraclass Correlation[b]	95% Confidence Interval		F Test with True Value 0			
		Lower Bound	Upper Bound	Value	df1	df2	Sig
Single Measures	.065[a]	-.287	.288	.788	15	15	.675
Average Measures	.139[c]	-.806	.448	.788	15	15	.675

Table A32: ICC for height of lower lip for research question 1 at T1

Intraclass Correlation Coefficient

	Intraclass Correlation[b]	95% Confidence Interval		F Test with True Value 0			
		Lower Bound	Upper Bound	Value	df1	df2	Sig
Single Measures	.065[a]	-.287	.288	.788	15	15	.675
Average Measures	.139[c]	-.806	.448	.788	15	15	.675

Table A33: ICC for nasal tip prominence for research question 1 at T1

Intraclass Correlation Coefficient

	Intraclass Correlation[b]	95% Confidence Interval		F Test with True Value 0			
		Lower Bound	Upper Bound	Value	df1	df2	Sig
Single Measures	.817[a]	.202	.947	18.599	15	15	<.001
Average Measures	.899[c]	.337	.973	18.599	15	15	<.001

Table A34: ICC for endocanthion for research question 1 at T1

Statistics

Imaging	Type of Expander			AWdiff	ABWdiff	HofNdiff	HofULdiff	HofVBdiff	NAdiff	UltoElinediff	LltoElinediff	LAFHdiff	Mwdiff	PhWdiff	HofLLdiff	NTPdiff	Endiff
CBCT	Moon	N	Valid	9	9	9	9	9	9	9	9	9	9	9	9	9	9
			Missing	1	1	1	1	1	1	1	1	1	1	1	1	1	1
		Mean		1.4133	-1.6756	-.2511	.1633	.2663	1.7667	-.3557	.6341	.4189	.2267	-.6878	-.8367	-.2478	.4422
		Median		.4600	-1.7500	-.2200	-.1100	.2300	.3000	-.3730	.2600	.7800	-.3900	-.3600	-.5100	.0100	-.3800
		Std. Deviation		1.72824	1.32939	.94687	1.17516	.85225	7.28852	.72410	1.46983	2.23043	2.98199	.84482	2.27186	.77611	2.94842
	Dresden	N	Valid	9	9	9	9	9	9	9	9	9	9	9	9	9	9
			Missing	1	1	1	1	1	1	1	1	1	1	1	1	1	1
		Mean		.1578	-.6911	-.4622	-.0022	.1436	.4333	.2140	.3351	1.2933	1.1467	.1856	-1.1956	.2167	.5478
		Median		.1200	-.0900	-.3700	-.2600	.3800	1.5000	-.3370	-.0330	1.4200	1.6900	.7700	-1.3900	.4800	-1.9900
		Std. Deviation		1.23653	1.90825	1.92331	.81839	.96493	4.79635	1.42888	1.73445	2.81367	2.34424	1.65828	2.66001	1.34977	5.56593
3D facial scanner	Moon	N	Valid	8	8	8	8	8	8	8	8	8	8	8	8	8	8
			Missing	2	2	2	2	2	2	2	2	2	2	2	2	2	2
		Mean		-.0662	-.2250	-.1850	.2100	.0050	.2125	-.1750	.1150	1.2050	.3375	.3525	-.9938	.0863	-.3175
		Median		.9600	-.1900	-.3100	-.1750	-.2000	-.7700	.3600	.2600	1.1300	.2250	.2500	-1.0400	.0200	.2350
		Std. Deviation		4.36456	1.28561	3.10345	1.38661	1.49784	7.26873	1.06320	1.54544	3.38145	2.11884	1.23467	3.20590	.94913	4.08310
	Dresden	N	Valid	9	9	9	9	9	9	9	9	9	9	9	9	9	9
			Missing	1	1	1	1	1	1	1	1	1	1	1	1	1	1
		Mean		.0033	1.0178	.5856	-.7978	-.5711	1.3722	-.9000	-1.2978	-2.9044	1.2689	-.1489	2.1067	-.1656	-4.4889
		Median		.9600	1.9600	1.6000	-.5700	-.7100	-.7700	-.2200	-1.6000	-4.1700	.7600	-.0900	1.8300	-.2300	-4.5400
		Std. Deviation		3.09051	2.23844	4.00370	2.70993	1.74553	7.54921	1.57134	1.84134	4.37056	2.51650	1.12007	3.49342	1.14641	3.75475

Table A35: Descriptive statistics for research question 2

Test Statistics[a]

Imaging		AWdiff	ABWdiff	HofNdiff	HofULdiff	HofVBdiff	NAdiff	UltoElinediff	LltoElinediff	LAFHdiff	Mwdiff	PhWdiff	HofLLdiff	NTPdiff	Endiff
CBCT	Mann-Whitney U	21.000	24.500	38.000	36.000	38.000	34.000	35.000	35.000	30.000	31.000	27.000	38.000	28.000	35.000
	Wilcoxon W	66.000	69.500	83.000	81.000	83.000	79.000	80.000	80.000	75.000	76.000	72.000	83.000	73.000	80.000
	Z	-1.723	-1.414	-.221	-.398	-.221	-.574	-.486	-.486	-.927	-.839	-1.193	-.221	-1.104	-.486
	Asymp. Sig. (2-tailed)	.085	.157	.825	.691	.825	.566	.627	.627	.354	.402	.233	.825	.269	.627
	Exact Sig. [2*(1-tailed Sig.)]	.094[b]	.161[b]	.863[b]	.730[b]	.863[b]	.605[b]	.666[b]	.666[b]	.387[b]	.436[b]	.258[b]	.863[b]	.297[b]	.666[b]
	Exact Sig. (2-tailed)	.090	.168	.845	.730	.863	.605	.666	.666	.387	.436	.248	.814	.297	.666
	Exact Sig. (1-tailed)	.045	.084	.422	.365	.432	.302	.333	.333	.193	.218	.124	.407	.149	.333
	Point Probability	.004	.006	.015	.032	.034	.030	.031	.031	.023	.025	.008	.018	.020	.031
3D facial scanner	Mann-Whitney U	33.000	25.000	32.000	30.000	26.000	34.000	21.000	19.500	16.000	28.000	26.000	16.000	33.500	16.000
	Wilcoxon W	69.000	61.000	68.000	75.000	71.000	70.000	66.000	64.500	61.000	64.000	71.000	52.000	78.500	61.000
	Z	-.289	-1.059	-.385	-.577	-.962	-.192	-1.443	-1.589	-1.925	-.770	-.962	-1.925	-.241	-1.925
	Asymp. Sig. (2-tailed)	.773	.290	.700	.564	.336	.847	.149	.112	.054	.441	.336	.054	.810	.054
	Exact Sig. [2*(1-tailed Sig.)]	.815[b]	.321[b]	.743[b]	.606[b]	.370[b]	.888[b]	.167[b]	.114[b]	.059[b]	.481[b]	.370[b]	.059[b]	.815[b]	.059[b]
	Exact Sig. (2-tailed)	.815	.321	.743	.606	.370	.888	.167	.120	.059	.481	.370	.059	.888	.059
	Exact Sig. (1-tailed)	.407	.161	.371	.303	.185	.444	.084	.060	.030	.240	.185	.030	.444	.030
	Point Probability	.036	.022	.035	.032	.025	.037	.014	.006	.006	.029	.025	.006	.037	.006

Table A36: P-values for research question 2. Exact significant [2*(1-tailed) Sig.)] was recorded.

Statistics

Imaging			AWdiff	ABWdiff	HofNdiff	HofULdiff	HofVBdiff	NAdiff	UltoElinediff	LltoElinediff	LAFHdiff	Mwdiff	PhWdiff	HofLLdiff	NTPdiff	Endiff
CBCT	N	Valid	18	18	18	18	18	18	18	18	18	18	18	18	18	18
		Missing	2	2	2	2	2	2	2	2	2	2	2	2	2	2
	Mean		.7856	-1.1833	-.3567	.0806	.2049	1.1000	-.0709	.4846	.8561	.6867	-.2511	-1.0161	-.0156	.4950
	Median		.2850	-1.1650	-.3350	-.1600	.3635	.9000	-.3550	.2447	1.0900	.7050	-.2850	-1.2300	.0750	-.5500
	Std. Deviation		1.59448	1.67386	1.47461	.98606	.88541	6.02456	1.13731	1.56716	2.50380	2.64476	1.35345	2.40680	1.09449	4.32116
3D facial scanner	N	Valid	17	17	17	17	17	17	17	17	17	17	17	17	17	17
		Missing	3	3	3	3	3	3	3	3	3	3	3	3	3	3
	Mean		-.0294	.4329	.2229	-.3235	-.3000	.8265	-.5588	-.6329	-.9706	.8306	.0871	.6476	-.0471	-2.5259
	Median		.9600	-.1500	-.2100	-.1900	-.6300	-.7700	-.1800	-.1400	-.6300	.3800	.0200	.9300	-.1500	-3.1000
	Std. Deviation		3.62091	1.90715	3.51933	2.18675	1.61023	7.20877	1.36683	1.80790	4.36160	2.31520	1.16652	3.62533	1.03346	4.35304

Table A37: Descriptive statistics for research question 3

Test Statistics[a]

	AWT1CBCT – AWT0CBCT	ABWT1CBCT – ABWT0CBCT	HofNT1CBCT – HofNT0CBCT	HofULT1CBCT – HofULT0CBCT	HofVBT1CBCT – HofVBT0CBCT	NAT1CBCT – NAT0CBCT	UltoElineT1CBCT – UltoElineT0CBCT
Z	-1.808[b]	-2.483[b]	-1.503[b]	-.240[c]	-1.302[b]	-.653[b]	-1.023[c]
Asymp. Sig. (2-tailed)	.071	.013	.133	.811	.193	.514	.306
Exact Sig. (2-tailed)	.072	.011	.139	.823	.207	.530	.325
Exact Sig. (1-tailed)	.036	.005	.069	.412	.103	.265	.162
Point Probability	.002	.000	.003	.008	.008	.007	.010

Test Statistics[a]

	LltoElineT1CBCT – LltoElineT0CBCT	LAFHT1CBCT – LAFHT0CBCT	MWT1CBCT – MWT0CBCT	PhWT1CBCT – PhWT0CBCT	HofLLT1CBCT – HofLLT0CBCT	NTPT1CBCT – NTPT0CBCT	EnT1CBCT – EnT0CBCT
Z	-1.111[b]	-1.241[b]	-1.023[b]	-.879[b]	-1.677[b]	-.022[b]	-3.053[b]
Asymp. Sig. (2-tailed)	.267	.215	.306	.379	.094	.983	.002
Exact Sig. (2-tailed)	.284	.229	.325	.404	.096	.991	.001
Exact Sig. (1-tailed)	.142	.114	.162	.202	.048	.496	<.001
Point Probability	.010	.008	.010	.014	.002	.008	.000

Table A38: Wilcoxon P-value for CBCT for research question 3. Exact significance (2 tailed) was recorded.

Test Statistics[a]

	AWT1FS – AWT0FS	ABWT1FS – ABWT0FS	HofNT1FS – HofNT0FS	HofULT1FS – HofULT0FS	HofVBT1FS – HofVBT0FS	NAT1FS – NAT0FS	UltoElineT1FS – UltoElineT0FS
Z	-.118[b]	-.686[c]	-.166[c]	-.450[c]	-1.184[c]	-.024[c]	-1.136[c]
Asymp. Sig. (2-tailed)	.906	.492	.868	.653	.237	.981	.256
Exact Sig. (2-tailed)	.927	.510	.890	.678	.248	1.000	.268
Exact Sig. (1-tailed)	.463	.255	.445	.339	.124	.500	.134
Point Probability	.018	.007	.018	.017	.005	.018	.005

Test Statistics[a]

	LltoElineT1FS – LltoElineT0FS	LAFHT1FS – LAFHT0FS	MWT1FS – MWT0FS	PhWT1FS – PhWT0FS	HofLLT1FS – HofLLT0FS	NTPT1FS – NTPT0FS	EnT1FS – EnT0FS
Z	-1.302[c]	-.781[c]	-1.349[b]	-.521[c]	-.970[c]	-.118[c]	-2.059[c]
Asymp. Sig. (2-tailed)	.193	.435	.177	.603	.332	.906	.039
Exact Sig. (2-tailed)	.203	.459	.190	.620	.353	.917	.040
Exact Sig. (1-tailed)	.101	.229	.095	.310	.176	.459	.020
Point Probability	.004	.014	.008	.008	.012	.009	.002

a. Wilcoxon Signed Ranks Test
b. Based on negative ranks.
c. Based on positive ranks.

Table A39: Wilcoxon P-value for 3D facial scanner for research question 3. Exact significance (2 tailed) was recorded.