EXPANSION IN ADULTS: A NOVEL PROTOCOL

A Thesis

by

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ABSTRACT

Purpose

To evaluate and compare the skeletal and dentoalveolar effects produced by two maxillary expansion protocols in skeletally mature, non-growing adults.

Materials and Methods

The study sample included 40 (15 female, 25 male) treated subjects with an average age of 32.4 ±12.2 years at initial records (T0). All subjects were treated by two practitioners in a private practice setting. Upon recruitment, subjects were placed into three different surgical expansion groups, initially based on sex and age. Preoperative CBCT scans acquired at the initial appointment were utilized to further classify treatment groups based on radiographic modifiers. The two protocols, Type II and Type III, used the same micro-implant skeletal expander type-2 design (MSE-2, Great Lakes Orthodontics). Type II protocol consisted of an expander with four bi-cortical micro-implant screws, midline corticopunctures approximately 2 mm apart, and a vertical midline osteotomy. Type III protocol consisted of Type II protocol in adjunct with horizontal anterior maxillary osteotomies. Following adequate expansion and prior to appliance removal, post-expansion CBCT scans were acquired for T1 records. The average time difference between pre- and post-expansion scans was 0.6 ± 0.5 years. The scans were evaluated to determine the skeletal and dentoalveolar changes.

Results

Type II and Type III protocols showed significant increase from pre- to post-expansion for all variables except IOW. Anteriorly, AABW, AABWI, and AAPW showed significantly greater changes in Type III compared to Type II. Posteriorly, there were no significant differences between the changes. Dentally, ICW showed significantly more changes in Type III than Type II; however, the difference in changes at IMW was not significant.

Conclusions

Type II and Type III protocols are equally effective and successful at achieving expansion in the posterior region. Type III protocol can produce more significant expansion in the anterior region than Type II protocol; however, significant anterior changes, especially at ICW, are not usually desired for orthodontic purposes. This suggests that the less invasive Type II protocol is sufficient in producing significant changes in the region of interest for maxillary deficient skeletally mature, non-growing individuals.

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NOMENCLATURE

RME	Rapid maxillary expansion
SME	Slow maxillary expansion
CBCT	Cone-beam computed tomography
MSE	Maxillary skeletal expander
MARPE	Micro-implant-assisted rapid palatal expansion
DOME	Distraction osteogenesis maxillary expansion
SARPE	Surgically-assisted rapid palatal expansion
ANW	Anterior nasal width
AABW	Anterior apical base width
AABWS	Anterior apical base width superior
AABWI	Anterior apical base width inferior
AAPW	Anterior alveolar process width
IOW	Interorbital width
PNW	Posterior nasal width
PABW	Posterior apical base width
PAPW	Posterior alveolar process width
IMW	Intermolar width
ICW	Intercanine width
IQR	Interquartile range

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CHAPTER I

LITERATURE REVIEW

Introduction to Expansion

Expansion of the midpalatal suture has been widely used as an adjunct in traditional comprehensive orthodontic treatment for over 150 years.[1] The procedure of maxillary expansion was first introduced in 1860 by Angell, who fabricated a jackscrew across the roof of a patient's mouth with its ends abutting the premolars.[1] As the jackscrew is turned, lateral movement of the dentition is observed. This technique was popular during the late 19th and early 20th centuries, but then lost favor for a period of time. The procedure then regained popularity and use in the mid 20th century and has continued to serve as an important adjunct to orthodontic therapy.[2,3] Throughout history, palatal expansion has been indicated for multiple reasons as documented in orthodontic literature. It is widely accepted as a safe and reliable procedure, and has been performed to correct transverse deficiencies, to alleviate mild to moderate crowding by expanding arch perimeter, and to improve airway and nasal volume.[4-8] Adkins et al demonstrated that for every millimeter of transverse width increase, 0.7 mm of arch perimeter is gained at the premolar region in adolescents.[5] This expansion device applies force both orthodontically and orthopedically, resulting in not only dentoalveolar effects but also skeletal effects in adolescents. The mechanical stresses induced by rapid maxillary expansion (RME) results in the transmission of forces on the facial bones and their adjacent structures.[9] These forces produce both tensile and compressive strains on the craniofacial complex thus altering the craniomaxillary sutures involved.[10]

It has been shown throughout literature that the opening of the midpalatal suture is nonparallel and pyramidal in shape with the anterior region exhibiting more separation than the posterior as well as the inferior more than the superior.[11,12] As the maxilla is being expanded, there is also a downward and forward displacement and a shallowing of the palatal vault.[3,13,14] If sutural separation occurs at the midpalate, then a midline diastema will present itself between the upper central incisors. Over time, with proper retention, the newly expanded position of the sutures will eventually reorganize and long-term results and stability can be achieved.[15]

Previous studies utilized dental casts, two-dimensional radiographs, animal models, dry skulls, or finite element models (FEM) to analyze the orthodontic and orthopedic effects of RME pre- and post-expansion. These techniques reported variable results due to their limitations in producing accurate measurements, landmark identification, and superimpositions. Studies involving dry skulls lack soft tissue that play a role in limiting expansion. Animal models often have varying anatomical features that can be significantly different from humans. FEM allows for stress levels to be quantified and identified but are often based on dry human skulls. Thus, the use of cone-beam computerized tomography (CBCT) for the purpose of quantifying maxillary expansion was introduced.[16-18] The recent use of CBCT imaging in orthodontics allows for more accurate visualization of the maxillary complex and its associated structures three-dimensionally with minimal distortion or overlapping structures. Measurements can be made using tridimensional reference planes to orient images for more accurate analyses of change.[19] Recently, it has been suggested that a combination of linear and angular measurements both skeletally and dentally should be performed for the most comprehensive and accurate analysis of the three-dimensional images.[20]

Sutures and Structures Involved

The applied expansive force in RME initially causes compression of the periodontal ligament, followed by bending of the alveolar processes, dental tipping, and opening of the midpalatal suture.[21,22] If the force exceeds the limits of tooth movement and sutural resistance, then the sutures will open resulting in true skeletal expansion with minimal dentoalveolar effects. These skeletal effects of RME are not limited to the maxillary alveolus and midpalatal suture but are also seen in many other maxillary sutures directly or indirectly. The maxilla articulates with varying skull bones through both cranial and circummaxillary sutures, thus RME is expected to affect those adjacent structures as well.[9] These sutures play a role in uniting bones and absorbing forces throughout the craniofacial complex, acting as joints permitting relative movement between bones. Mechanical forces applied through RME not only change the position of the dentition, but also modify the growth of the entire maxillary complex by influencing the sutures.[23]

Sutures share the mechanical loads and are less stiff than the bones they join. Their flexibility and viscoelasticity are important in their mechanical role in accommodating deformations of the skull that occur during birth, cyclical loading from muscle activity, distension from internal pressures, and traumatic impacts.[24] Over time, their mechanical properties, such as morphology and fusion, adapt by responding to varying pressures of functional demand.[25,26] In fetal and early postnatal skulls, the sutures are patent and poorly developed in complexity; however, with age, bony interdigitation begins to develop.[23,24] These bony interdigitations become more irregular due to their increase in length and number. This increase in complexity is associated with cyclic loading during function, such as mastication. Feeding, which includes ingestion, mastication, and swallowing, is one of the major sources of large-magnitude cyclic loading that increases the interdigitation of sutures.[24,27] Byron et al showed that increased masticatory muscle force is associated with increased interdigitation as well as decreased tensile stiffness in the sagittal suture of the mouse model.[27] Thus, it is thought that individuals with stronger masticatory muscles, such as those found in hypodivergent individuals, will present with more complex interdigitations and sutural growth than those with weaker muscles found in hyperdivergent individuals. An individual's facial growth pattern has been shown to affect masticatory force and function, which in turn influences the anatomy of various sutures and structures in the craniofacial complex.[28]

To start, understanding the variability in the maturation of the midpalatal suture is crucial for evaluating the most suitable method of expansion for each individual. The midpalatal suture is described to have an end-to-end (butt, flat, or plane) relationship that ossifies over time from the posterior to the anterior.[23,29] Interdigitation and fusion begin to occur over time, but the advancement of the sutural maturation varies with sex and age. Studies have reported that individuals over a wide age range may have no signs of fusion indicating that it is not directly related to chronological age.[30] Due to this variability, Angelieri et al established a classification method to assess the morphology of the midpalatal suture in 2013.[29] They evaluated CBCT images and defined five maturational stages of the midpalatal suture based on their radiographic appearance. The midpalatal suture was defined as: (stage A) a straight high-density sutural line with little to no interdigitation, (stage B) a scalloped appearance of the high-density line, (stage C) two parallel scalloped high-density lines close together separated by some small low-density spaces, (stage D) fusion completed in the palatine bone with no evidence of a suture, and (stage E) fusion anteriorly in the maxilla. Their results showed a great variability in the maturation stages regarding chronological age as shown in previous studies. They determined that age is an unreliable factor when considering the maturation status of the midpalatal suture, and thus radiographic evaluation is a useful resource to aid in decision-making of expansion technique for each individual. In 2021, Oliveira et al evaluated CBCT images of adults with varying facial growth patterns to determine sutural maturity using the classification established by Angelieri et al.[28,29] They concluded that there is a statistically significant association between facial growth pattern and maturation stage of the midpalatal suture. Individuals with vertical facial growth patterns had a higher prevalence of lower maturation stages, thus indicating they are more likely to undergo intentional sutural separation.

Previous literature supports the notion that maxillary expansion affects more than the midpalatal suture alone. Its effects are seen in adjacent cranial and facial structures. Generally, the average amount of sutural opening is greater in the sutures directly articulating with the maxilla than those indirectly articulating.[31] It has been shown that the directly articulating sutures, zygomaticomaxillary and frontomaxillary, have the highest amounts of disarticulation.[31,32] Other investigators also found that midsagittal, parietal, and lambdoid sutures and craniofacial bones that articulate with the maxilla (except sphenoid bone) were distorted or displaced.[33,34] Additionally, expansion studies on rhesus monkeys showed opening of the spheno-occipital synchondrosis, which can be correlated with the downward and forward movement of the maxilla that occurs during the expansion process.[3,13,33] The sphenoid bone lies posterior to the maxilla, and the pterygoid plates of the sphenoid bone are interlocked with the palatine bones.[12] The restricting effect of the pterygoid plates reduces the ability of the palatine bones to separate. Structures closer to the cranial base are more rigid causing a decrease in their ability to separate. The zygomatic processes serve as resistant structures as well, but their sutures allow them to adjust to the expansive pressures from RME. It is important to note that in addition to the possible complex sutural morphology of some individuals, one of the major factors affecting successful skeletal expansion is the resistance from surrounding structures. In 2009, Wang et al evaluated the opening of circummaxillary sutures by RME in cats.[35] They classified the sutures into four groups based on anatomical plane and articulation with the maxilla. The groups were direct sagittal sutures (intermaxillary and nasomaxillary), direct coronal sutures (frontomaxillary and zygomaticomaxillary), indirect sagittal sutures (internasal and zygomaticotemporal), and indirect coronal sutures (nasofrontal). The results of this animal study indicated that the sutures running sagittally were significantly affected more than the sutures running coronally regardless of their direct or indirect articulation with the maxilla. In 2011, Ghoneima et al indicated that in addition to the midpalatal suture, the cranial and circummaxillary sutures significantly increased in width. These sutures included the intermaxillary, frontomaxillary, frontonasal, nasomaxillary, and internasal sutures, which is in agreeance with previous studies.[9,33,36-38] The sutures that did not show statistically significant increases in width were the zygomaticofrontal, zygomaticotemporal, zygomaticomaxillary, and pterygomaxillary sutures. Their nonsignificant changes may be explained by their increased resistance to expansion, bony rigidity, and interdigitation. In 2013, Bazargani et al conducted a systematic review to evaluate the three-dimensional effects of RME.[32] Their overall conclusion was that structures articulating directly with the maxilla had larger changes than the structures further away. Ultimately, studies involving animal models,[33,39] dry skulls,[40] and FEM[22,41,42] have shown that of the circummaxillary and circumzygomatic sutures, the nasal, zygomaticotemporal, and zygomaticomaxillary are specifically affected in RME.[18]

Expansion in Growing Children

To achieve an adequate amount of expansion, there are two schools of thought: slow maxillary expansion (SME) and rapid maxillary expansion (RME). Slow expansion applies low continuous forces to achieve 0.5 to 1.0 mm of expansion per week.[43,44] It has been shown that the lighter forces do not have the strength to overcome the tensile strength of the sutures and thus produce less disruption.[44,45] However, it does allow for greater sutural physiologic adjustment and stability than rapid expansion. Rapid expansion occurs by applying heavy forces over a short period of time at a rate of 0.25 to 1.0 mm of expansion per day.[6,43] The high magnitude forces allow for immediate midpalatal suture separation before any physiological changes can occur within the suture. The thought is that it minimizes unwanted dental effects, such as tipping, while maximizing true skeletal effects.

It has been shown that expansion should occur prior to the pubertal peak during early maturation stages (SMI 1 to 4 or CVM stages 1 to 3) in skeletal growth to result in a more favorable and pronounced orthopedic response.[46,47] This is supported by histological data provided by Melsen, who showed a higher level of response in preadolescent individuals at the sutural level due to less interdigitation of the midpalatal suture.[48] Thus, conventional expansion appliances are more predictable and orthopedically effective in growing patients. Numerous studies have investigated the short- and long-term stability of RME. The use of RME and fixed orthodontic appliances in adolescents to alleviate mild-to-moderate crowding showed stable results over time.[49]

In 2011, Leonardi et al evaluated the bony displacement of circummaxillary sutures in children with the use of multislice computed tomography (CT) scans.[31] Their results showed significant changes in the zygomaticomaxillary, zygomaticotemporal, nasomaxillary, frontonasal, zygomaticofrontal, frontomaxillary, and internasal sutures with varying degrees of significance levels. The average amount of disarticulation was higher in those directly articulating to the maxilla, but those further from and indirectly articulating to the maxilla were still affected although to a lesser degree. Woller et al evaluated changes in the circummaxillary sutures following RME using three-dimensional CBCT images in growing children.[18] All of the treated patients had conventional tooth-borne RPE designs, and imaging was taken at two timepoints. The first represented the baseline prior to RPE delivery, and the second was taken at the following appointment after last screw activation. Various landmarks, reference planes, and measurements were taken to evaluate the changes pre- and post-expansion. The results exhibited significant displacement of the midpalatal suture, with the anterior having greater amounts than the posterior. Both the superior and inferior borders of the zygomaticomaxillary suture move transversely, slightly downward, and forward, which is consistent with the previous finding that the entire maxilla displaces downward and forward with RME. The frontonasal suture showed significant displacement in a down and forward direction as well. The intermaxillary suture measured at the anterior nasal spine (ANS) showed significant transverse changes, but the transpalatal suture did not have a significant change. This is consistent with a previous study that suggested nonsignificant separation between the palatine and maxillary bones was due to the sphenoid bone preventing sutural displacement.[40] Overall, significant forward and downward displacement of the maxilla and transverse width increases are seen with RME in growing children at the midpalatal, zygomaticomaxillary, intermaxillary, and frontonasal sutures.[18]

Expansion in Non-Growing Adults

Unfortunately, it is not always possible to treat patients at the ideal timing for maxillary skeletal expansion since many present to the clinician for treatment after their pubertal growth spurt, which is the ideal treatment time. Expansion after closure of the cranial base and midfacial sutures has been shown to cause more of a dentoalveolar effect rather than skeletal, and often times limited to only dentoalveolar.[50] RME in the skeletally mature adult is more unreliable with several potential adverse side effects, including relapse, instability, increased dental tipping, gingival recession, bone loss, and root resorption.[6,51,52] With advancing maturity, the more rigid skeletal structures and complex sutures present as a limitation to the amount of expansion that can be achieved. Since the results of RME may be unpredictable, various approaches have been introduced to overcome the increased mechanical resistance and limitations of the skeletally mature non-growing individuals. These surgical procedures are designed to resect the resistive areas: zygomatic buttresses (lateral support), piriform aperture pillars (anterior support), pterygoid junctions (posterior support), and midpalatal suture (median support).[53] Once these areas of interest are resected, then expansion can be facilitated with greater ease and success.

The introduction of either surgically undermining the maxilla to allow for more ease of expansion or surgically moving the maxilla entirely became popular for palatal expansion in adults.[12,54,55] These surgical options are known as surgically-assisted rapid palatal expansion (SARPE) and Le Fort osteotomy. Both of these procedures are often indicated to allow maxillary expansion to be attainable for these skeletally mature individuals. Segmental Le Fort osteotomy involves a three-dimensional repositioning of the maxilla whereas SARPE utilizes distraction osteogenesis to expand the maxilla. Both options facilitate expansion and provide a more predictable outcome than traditional tooth-borne RME appliances in adults; however, they are much more invasive and have the potential for various complications. In addition to the increased risks, surgical procedures are costly and require recovery time that may not be feasible for some individuals.[50] When considering a Le Fort osteotomy, the lateral movement of the maxillary segments is instantaneous. The amount of movement and expansion that can be performed and obtained is limited by the palatal mucoperiosteum overlying the bone.[12] This mucoperiosteum can also play a role in the relapse and stability of the newly expanded position. In addition to the physical limits of surgical expansion, there are numerous complications that can occur peri- and post-operatively. Some complications reported by previous studies include intra- and post-operative hemorrhage, post-operative infection, mucosal tearing, bad fractures, bone deficiency, dental complications, oral fistulas, delayed healing, periodontal and gingival complications, sinusitis, ischemia, and complications leading to removal of fixation screws and plates.[56] Segmental Le Fort osteotomy has also been associated with post-surgical relapse and instability. Due to this, it is considered one of the least stable orthognathic surgical procedures, and overexpansion is often recommended to allow for the expected relapse.[57] SARPE combines distraction osteogenesis with orthodontics and is another option for mature palates and sutures. It is thought to have greater stability compared to the Le Fort osteotomy, but literature also proposes that its stability is not significantly greater. The one thing that is known is the SARPE, like the Le Fort osteotomy, also has its risks. The complications reported include gingival recession, dehiscence, resorption of buccal bone, significant hemorrhage, root resorption, infection, pain, devitalization of teeth, alar base flaring, sinus infection, injury to the maxillary nerve branches, and fracture of interdental bone.[53] Chamberland and Proffit[58] assessed the stability of SARPE and found that one third of the transverse expansion achieved with SARPE is anticipated to be lost to relapse and does not produce more stable expansion than segmental Le Fort osteotomies. Due to the possible complications and general anesthesia needs with both SARPE and Le Fort osteotomy procedures, it is important to weigh the risks and benefits of these invasive surgical approaches for skeletally mature individuals. Various systematic reviews of the literature have assessed the stability and effectiveness of the two surgical approaches. The results from the reviews indicate that SARPE can result in significant expansion both dentally and skeletally and appears to be stable over time.[59,60] Moreover, both treatment modalities can be successful with SARPE showing more effectiveness when there are larger expansion requirements.[57] However, due to the variability of existing literature, the evidence may be inconclusive and meta-analysis is not possible.[57,59] Lastly, with these surgical options come possible undesirable facial side effects such as widening of the nose and increased inter alar distance. These side effects may not be acceptable to some individuals.

More recently, the micro-implant-assisted rapid palatal expansion (MARPE) appliance was introduced and has since become more popular.[61,62] The thought is that the appliance can localize the lateral forces to the midpalatal suture and its underlying basal bone to minimize undesired adverse effects on the dentition that often occur with conventional rapid palatal expanders (RPE).[61] The bone-supported expansion appliance incorporates micro-implants into the palatal jackscrew of the conventional RPE to induce expansion at the skeletal level.[62] This technique has been shown to decrease buccal tipping of the dentition and reduce risks of gingival recession. Since this technique is less invasive than surgical options, it may be more optimal for these non-growing patients who do not want to undergo surgery. Multiple studies have been conducted using FEM to evaluate expansion with the use of the MARPE.[62,63] They found that this method may be beneficial for more skeletally mature individuals to achieve the desired expansion, but increased stresses are seen in implant supported maxillary skeletal expander (MSE) compared to conventional RPE. The conventional RPE force application site is at the palatal surface of the maxillary posterior teeth, which is further away from the resisting structures than MSE. The implant supported MSE force application site is at the implants, which are embedded in the palatal bone. Due to this, more force is needed to overcome the stresses and achieve greater levels of expansion in the implant supported expansion technique.[63] Since the introduction of the MARPE, various studies have been performed to show the success of midpalatal suture separation in the post-pubertal growth spurt stage without the use of surgery [64-66]; however, there is a limited number of high-quality prospective clinical trials in literature. Throughout the introduction of the MARPE, there are also complications that have been discovered. Patients with severe maxillary transverse deficiency have increased palatal vault depths.[67] This poses the issue of insufficient width for placement of the screw body in the appliance and can cause tissue damage to the palatal tissue as the expander is being activated. Additionally, screw bending, screw breakage, dental tipping, periodontal side effects, nasal soft tissue complications, and asymmetry have all been reported as possible complications of MARPE. Elkenawy et al concluded that MSE achieves parallel expansion, in contrast to triangular expansion seen in conventional RME, but there is a high chance of asymmetrical expansion that may affect overall appearance and facial soft tissue as the sutural split takes the path of least resistance.[68] In 2017, Cantarella et al found that the split of the midpalatal suture was asymmetrical with an average of one-half of anterior nasal spine (ANS) moving 1.1 mm ± 1.0 mm more than the contralateral half in the transverse direction.[69] Kim et al found that 30.3% of subjects resulted in asymmetric nasomaxillary expansion (greater than 1 mm difference).[70] Almaqrami et al found that nearly half of the patients experienced significant asymmetry (greater than 1 mm). Additionally, they demonstrated that the presence of an initial asymmetric position of the midpalatal suture has a correlation with asymmetric expansion and may be a contributing factor for the incidence of transverse asymmetric split after MARPE expansion.[71] Some explanations that have been proposed for asymmetric expansion include mechanical bone densities, biological responses, unilateral posterior crossbites serving as restrictive forces, asymmetric anatomic position of the midpalatal suture, and unilateral split of the frontomaxillary suture.[61,70,71] Thus it is important to monitor expansion to prevent possible overlying soft tissue asymmetric changes. Although Elkenawy reported parallel expansion in the anteroposterior direction, other studies have found the opposite.[72] A recent systematic review and meta-analysis published in The Korean Journal of Orthodontics found that although many studies claim a more parallel expansion relationship between ANS and PNS,[68,69,73] the midpalatal suture separation is still v-shaped with more expansion in the anterior than the posterior[74] (73.25% ratio of PNS to ANS compared to the 90% and 89.6% reported in Baik et al[73] and Cantarella et al,[69] respectively).

Although the MARPE was initially introduced for non-growing individuals, the technique has been rationalized for use in early and late adolescents.[75-79] When comparing tooth-borne and bone-borne RME appliances, similar interdental widths were reported; however, bone-borne appliances showed significantly more skeletal changes with more minimal adverse buccal bone width changes.[75,78] Bone-borne expanders significantly increase maxillary and facial widths, whereas tooth-borne expanders significantly increase nasal width.[77] mcmullen et al secondarily analyzed CBCT scans of growing and non-growing patients who previously underwent expansion with MARPE.[80] Their results showed that both groups experienced sutural opening in a parallel fashion from ANS to PNS. It was successful in both growing and non-growing individuals, but greater skeletal and dentoalveolar changes were found in growing individuals due to their less mature interdigitations. Still, in addition to the promising results seen with MARPE, a recent systematic review and meta-analysis reported that MARPE can induce dental and periodontal side effects.[81]

Increased literature is now being presented regarding MARPE in skeletally mature individuals. In 2018, Cantarella et al looked at midfacial changes associated with MARPE.[82] Significant lateral displacement of the zygomaticomaxillary complex was found with outward rotation of the zygomatic bone resulting in midface expansion. Additionally, Colak et al reported their MARPE with bi-cortical engagement of the micro-implants allows for disarticulation of the pterygopalatine suture.[83] In 2020, Oliveira et al assessed and compared the stresses of MARPE and tooth-borne RME on circummaxillary sutures in pigs.[84] Their results showed greater displacement of the midpalatal suture in the MARPE group, as well as more constant tension in the midpalatal and zygomaticomaxillary sutures. There are many articles reporting the advantages of bone-borne or hybrid tooth-bone-borne RME such as increased sutural opening and minimized tooth tipping,[85,86] but the evidence is variable in how outcome measures are collected and analyzed. Additionally, many of the current studies are retrospective in nature and contain possible reported biases.[85,87] Therefore, definite conclusions are difficult to form via systematic reviews and meta-analyses.

In skeletally mature adults, MARPE has now furthermore been performed in conjunction with corticopunctures or micro-osteoperforations to improve results.[72,88-91] Due to the increased resistance from the surrounding structures in these individuals, the thought is that the corticopunctures will be advantageous in reducing bone resistance during maxillary expansion to allow for more significant skeletal results.[14,89] Recently, Meirelles et al evaluated patients who received MARPE with corticopuncture and compared them to patients who did not have corticopuncture procedures.[91] They found that the total success rate of the midpalatal suture opening was 70%, but those who received corticopunture showed an 80% success rate while those with no corticopuncture had a 53.8% success rate. In 2019, Silva-Coll et al published a case report utilizing corticotomy-assisted MARPE with ridge augmentation in a 46-year-old man.[92] The long-term results indicated the method is efficient and stable up to 7 years. Currently, there are limited studies looking at the effects of MARPE in conjunction with corticopunctures compared to MARPE alone. In 2021, Bud et al retrospectively evaluated 20 patients who received corticopuncture therapy in association with MARPE in a case series report.[90] It was concluded, based on the limitations present, that MARPE associated with corticopuncture therapy efficiently split the midpalatal suture in adults and that split was almost parallel in the anteroposterior direction. It is important to note that most of the current research is limited and are either case series or case reports. Thus, future randomized controlled clinical trials are needed to allow for more comprehensive evaluation and analysis of the results pertaining to MARPE in association with corticopunctures.

In addition to RME, SARPE, Le Fort osteotomy, and MARPE, distraction osteogenesis maxillary expansion (DOME) is another alternative. It was first described in 2017 as a more predictable method for expanding the maxilla in adults with obstructive sleep apea (OSA).[93] These individuals had narrow nasal floors and narrow maxillae with high arched palates and underwent DOME to help improve nasal breathing. DOME integrates osteotomies with a micro-implant anchored RME device to more reliably expand the nasal floor along the midpalatal region.[93] In 2017, Liu et al conducted a prospective cohort study that found successful separation of the midpalatal suture and expansion of the maxillary and nasal floors with DOME.

Yoon et al concluded that DOME reduced the severity of OSA and refractory nasal obstruction and increased REM sleep in adults that presented with narrow maxillas.[94] This procedure is less invasive than SARPE or Le Fort osteotomies, thus reducing post-operative risk and complications, but is more invasive than RME and MARPE. Currently, the majority of the literature on DOME is centered around variables such as apnea-hypopnea index (AHI), Epworth Sleepiness Scale (ESS), and oxygen desaturation index.[93,94] Thus, comparisons to expansion studies evaluating changes in intermolar width, alveolar process width, apical base width, etc. Are difficult. One study refers to the DOME procedure as minimally invasive surgical and miniscrew-assisted rapid palatal expansion (MISMARPE).[95] This study is the only one to perform measurements outside of nasal volume, AHI, and those listed previously. The results observed greater expansion in the anterior region than the posterior region due to an absence of pterygomaxillary disjunction.

Introduction to Present Study

In skeletally mature non-growing patients, expansion requires techniques different than those utilized in growing adolescents. It has been shown that conventional expansion methods are limited in their ability to produce true skeletal and orthopedic effects without undesired adverse dentoalveolar effects in these individuals. The expansion can be unpredictable and warrant invasive surgical protocols, such as SARPE and Le Fort osteotomies, to achieve true orthopedic transverse maxillary changes and successful outcomes. The invasive procedures, although provide more predictable results, have the possibility of severe and devastating post-operative complications. For individuals who need skeletal expansion and are past their pubertal peak, the conventional RPE does not provide enough force to overcome the resisting structures; however, these same individuals may not need surgical procedures as invasive as SARPE or Le Fort osteotomies. Thus, MARPE, MARPE with corticopunctures, and DOME are available options in the middle ground between conventional RPE and surgery. Previous literature has shown that some individuals who have undergone MARPE treatment have possible failures, side effects, and unsuccessful outcomes. On the other hand, individuals who need expansion may not require something as invasive as DOME. To date, there are limited studies evaluating corticopunctures and osteotomies of varying levels of invasiveness in conjunction with MARPE to achieve true skeletal expansion.

The present study will look at a proposed protocol that is slightly more invasive than MARPE with corticopunctures but less invasive than DOME. Expansion for orthodontic purposes is limited by the biological need of each patient. There is a limit to the amount of expansion that is desired and in order to achieve it in a predictable manner, various techniques have been introduced. The proposed protocol involves expansion utilizing MARPE with midline corticopunctures as well as a vertical midline osteotomy. Ultimately, it is important to establish the most minimally invasive surgery that can predictably provide successful expansion of the sutures in skeletally mature non-growing individuals. Choosing the most effective but least invasive protocol that will achieve successful expansion is different from person to person and specific to each individual’s skeletal maturity. The aim of the present study is to evaluate and compare the skeletal and dentoalveolar effects produced by different maxillary expansion protocols in skeletally mature adults.

CHAPTER II

MATERIALS AND METHODS

Study Design and Population

The records of 102 patients treated by two clinicians in an oral maxillofacial and surgery private practice setting in DFW between September 2017 and December 2021 were retrospectively analyzed. Sample selection was based on the following criteria:

Inclusion criteria:

i. Complete records with pre- and post-expansion cone-beam computed tomography (CBCT) radiographs
ii. Maxillary transverse discrepancy with a need for expansion
iii. Adult patient over the age of 18 years
iv. Healthy individuals

Exclusion criteria:

i. Thin palatal bone
ii. Physical limitations
iii. Micro-implant skeletal expander type-1 (MSE-1)
iv. Missing maxillary first molars
v. Cbcts with missing reference points (crista galli)
vi. Previous facial trauma with surgical intervention

A study sample of 40 individuals (15 female and 25 male) met the criteria and were identified by one investigator. The median patient age was 29.3 (18.2) years (average 32.4 ± 12.2 years) at the time of pre-expansion records. The time between pre- and post-expansion was a median of 0.5 (0.4) years (average of 0.6 ± 0.5 years). The Institutional Review Board of Texas A&M University School of Dentistry reviewed and approved this retrospective longitudinal study (IRB2021-1537).

Surgical Treatment

All subjects were treated by two practitioners in a private practice setting. Upon recruitment, subjects were placed into three different surgical expansion treatment groups, initially based on sex and age (Figure 1). Preoperative CBCT scans were acquired at the initial appointment to further classify treatment groups. The cbcts were evaluated to determine if radiographic modifiers would be applied to the subject’s initial treatment classification. Radiographic modifiers included zygomatic buttress width and maxillary palatal bone thickness. A zygomatic buttress width of ≥ 3 mm or a maxillary palatal bone thickness of ≥ 5 mm indicated the subject’s initial treatment classification would be elevated to the next treatment classification and protocol (Figure 2). All surgical types had the same micro-implant skeletal expander type-2 design (MSE-2, Great Lakes Orthodontics) attached to the maxillary first molars, cemented by the orthodontist. All patients were instructed to turn the expander twice a day until adequate expansion was achieved as determined by the orthodontist.

Type I: Micro-implant Assisted Rapid Palatal Expansion

Four bi-cortical micro-implant screws placed by the surgeons.

Type II: MARPE with Corticopunctures at the Midpalatal Suture and Vertical Midline Osteotomy

Type I protocol in adjunct with corticopunctures approximately 2 mm apart along the median palatine suture through both cortical plates using a 1.5 mm twist drill from the posterior nasal spine to the nasopalatine canal. In addition to the midline corticopunctures, a vertical midline osteotomy taken posteriorly to the nasopalatine foramen was performed with an osteotome through a vertical submarginal incision.[89]

Type III: Distraction Osteogenesis Maxillary Expansion (DOME)[93]

Type II protocol in adjunct with an anterior maxillary osteotomy made from the zygomaticomaxillary buttress to the piriform rim using a piezo surgery unit via two 10 mm horizontal vestibular incisions in the premolar region. Due to insufficient sample size discovered during records collection, only subjects who received treatment protocols Type II and Type III were included in the study.

Records and Data Collection

Imaging

CBCT scans were performed using an i-CAT flex and TX studio software (Kavo Dental, Brea, CA) unit with one of two settings – expanded or non-expanded.

Expanded settings:

- Modality – CT
- Volume Size – 23D x 17H cm
- Voxel Size – 0.3 mm
- Scan Time – 17.8 seconds
- Exposure Time – 7.4 seconds
- Kvp – 120
- Ma – 5
- Scan DAP – 877.6 mgy cm^2

Non-expanded settings:

- Modality – CT
- Volume Size – 16D x 13H cm
- Voxel Size – 0.3 mm
- Scan Time – 8.9 seconds
- Exposure Time – 3.7 seconds
- Kvp – 120
- Ma – 5
- Scan DAP – 623.9 mgy cm^2

All patients had CBCT scans taken pre-operatively at the initial appointment (T0) and at follow up after adequate expansion was achieved, prior to appliance removal (T1). All scans were saved and exported as digital imaging and communications in medicine (DICOM) files and imported into Dolphin Imaging (Patterson Technology, Chatsworth, CA) for evaluation. Non-expanded files were not downsized when imported, but expanded files were downsized by 10%

when imported into Dolphin for data collection. Cbcts obtained for all 40 subjects were traced by one principal investigator and 11 measurements were digitized. The measurements evaluated pre- and post-expansion included: anterior nasal width (ANW), anterior apical base width (AABW), anterior apical base width superior (AABWS), anterior apical base width inferior (AABWI), anterior alveolar process width (AAPW), interorbital width (IOW), posterior nasal width (PNW), posterior apical base width (PABW), posterior alveolar process width (PAPW), intercanine width (ICW), and intermolar width (IMW) (Table 1).

Orientation

Data measurements and evaluation were performed using parameters validated from Ribeiro et al.[19] A tridimensional reference plane orientation was achieved using three planes: sagittal, coronal, and axial planes (Figure 3). The right and left sagittal views were oriented so that the Frankfort horizontal [upper rim of external auditory meatus (i.e. Porion) and the inferior border of the orbital rim (i.e. Orbitale)] are parallel to the true horizontal. The coronal view was used to verify that the floors of the right and left orbits are in the same plane. The right and left posterior borders of the ramus and the gonial angles were checked to ensure that they are properly superimposed. Using the axial view, the images were oriented so that basion and the midpalatal suture are in the same plane.

To evaluate anteroposterior differences, separate sets of measures were taken in the anterior and posterior regions of the maxilla. The most superior point on crista galli was first located and verified in all three views (Figure 4). It served as the reference point for defining the anterior and posterior regions of interest, defined by two coronal planes passing through the maxilla 10 mm anterior and 10 mm posterior to the reference point (Figure 5). Five measures will be made on the anterior plane, and four measures will be made on the posterior plane.

Anterior Measurements

Using the sagittal view, the coronal plane was moved 10 mm anterior to the most superior point on crista galli. Then, five measurements were made on the coronal view (Figure 6). Anterior nasal width (ANW) is the maximum distance between the right and left nasal cavity on the anterior reference plane. Anterior apical base width (AABW) is the distance between the right and left buccal contours of the maxilla using the tangent to the lower border of the right nasal cavity. Anterior apical base superior (AABWS) and inferior (AABWI) are the distances between the right and left buccal contours of the maxilla using a plane parallel and 5 mm superior or inferior to AABW, respectively. Anterior alveolar process width (AAPW) is the maximum distance between the buccal aspects of the right and left dentoalveolar processes. Each measurement was made on the pre- and post-expansion CBCTS for each of the 40 subjects.

Posterior Measurements

Using the sagittal view, the coronal plane was moved 10 mm posterior to the most superior point on crista galli. Then, four measurements were made on the coronal view (Figure 7). Interorbital width (IOW) is the maximum distance between right and left lateral outer orbital walls. Posterior nasal width (PNW) is the maximum distance between the right and left nasal cavity on the posterior reference plane. Posterior apical base width (PABW) is the distance between the right and left buccal contours of the maxilla using the tangent to the lower border of the right nasal cavity. Posterior alveolar process width (PAPW) is the distance between the right and left alveolar crests, measured at their most inferior limits. Each measurement was made on the pre- and post-expansion cbcts for each of the 40 subjects.

Dental Measurements

Dental changes were evaluated separately. For intermolar width, the maxillary first molars were positioned so that (a) the three roots converge, as determined on the axial view, and (b) the entire palatal root can be seen in the sagittal view. Using the coronal view, the distance between the mesial palatal cusps was measured (Figure 8A). For intercanine width, the axial and sagittal views were oriented so that both planes showed the pulp chambers of the permanent canines, with the sagittal view showing the most coronal portion of the pulp chambers. Using the coronal view, the distance between the cusp tips of the permanent canines was measured (Figure 8B). Each measurement was made on the pre- and post-expansion CBCTS for each of the 40 subjects.

Blinding

The same blinded investigator was calibrated and performed all measurements.

Statistical Analysis

All measurements were carried out and collected by one principal investigator. The data was evaluated using SPSS Software (Version 28.0.0; IBM ® CORP, Armonk, NY). The skewness and kurtosis statistics showed that the data were not normally distributed. Central tendencies and dispersions were described with medians and interquartile ranges (IQR). Mann-Whitney U tests were used to compare the two groups (MARPE II and DOME); Wilcoxon Signed Rank tests were used to evaluate differences between T0 and T1. A probability level of 0.05 was used to determine statistical significance. Since there were no statistically significant between-group differences in pretreatment age ($p = 0.470$) and sex ($p = 0.110$), the males and females were analyzed together. To evaluate intra-examiner reliability, the cbcts of 8 randomly chosen patients were reoriented and measured a second time.

CHAPTER III

RESULTS

Sample Description

The records of 102 subjects were evaluated and resulted in a study sample of 40 subjects (15 females and 25 males) that met the criteria. Due to insufficient sample size, the data collection and evaluation included only subjects for treatment protocols Type II and Type III. The median age of the 40 subjects was 29.3 (18.2) years (average 32.38 ± 12.18 years) at the time of pre-expansion records (T0). The median time difference between pre- and post-expansion was 0.5 (0.4) years (average 0.6 ± 0.5 years). Both groups demonstrated similar baseline characteristics including sex, age, and follow-up time difference. There were no statistically significant between-group differences in age or follow-up time between males and females (Table 2). The sample size was 24 subjects in Type II (n = 24) and 16 subjects in Type III (n = 16).

Reliability

Observer reliability was tested using a random sample of 20% of the subjects (n = 8). The subjects were reoriented and measured again. Krombach's Alpha test and intra-class correlation coefficient (ICC) were used to test reliability. ICC with a 95% confidence interval ranged from 0.86 to 0.99.

Within-Group Comparisons for Type II and Type III (Wilcoxon Signed Rank Test)

Type II (n = 24)

The median for each variable increased from pre- to post-expansion for all variables except IOW. All measurements showed statistically significant within-group differences from pre- to post-expansion, except for IOW (Table 3, Figure 9).

Anterior Measurements:

Anteriorly, all measurements showed statistically significant within-group changes from pre- (T0) to post-expansion (T1), all of which were larger at T1. The smallest change of the anterior measurements was AABWI. AABWI had an outlier that greatly affected the iqrs, but still showed significant differences even when the subject was removed from statistical analysis. After Bonferroni correction, all anterior measurements showed statistical significance.

Posterior Measurements:

Posteriorly, all measurements showed statistically significant within-group changes from pre- to post-expansion, except for IOW. All posterior measurements were greater at T1 compared to T0, except for IOW. IOW showed a median, but the change was not statistically significant. The decrease can possibly be explained by the small sample size. Even after Bonferroni correction, PNW, PABW, and PAPW were still statistically significant.

Dental Measurements:

Dentally, both IMW and ICW showed statistically significant within-group changes from pre- to post-expansion, with both having larger median values at T1 than at T0. After Bonferroni correction, the difference for both IMW and ICW remained statistically significant.

Type III (n = 16)

The median for each variable increased from pre- to post-expansion for all variables except IOW. Similar to Type II, all measurements for Type III showed statistically significant within-group differences from pre- to post-expansion, except for IOW (Table 4, Figure 10).

Anterior Measurements:

Anteriorly, all measurements showed statistically significant within-group changes from pre- to post-expansion, with all having larger median values at T1 than at T0. ANW showed the least amount of median. After Bonferroni correction, all anterior measurements remained statistically significant.

Posterior Measurements:

Posteriorly, all measurements showed statistically significant within-group changes from pre- to post-expansion except for IOW. All posterior measurements were greater at T1 compared to T0, except for IOW. Similar to Type II within-group change, IOW decreased from pre- to post-expansion, but that change was not statistically significant. The decrease can be possibly explained by the small sample size. The remaining posterior variables, PNW, PABW, and PAPW, stayed statistically significant after Bonferroni corrections.

Dental Measurements:

Dentally, IMW and ICW showed statistically significant within-group changes from pre- to post-expansion, both of which were larger at T1. After Bonferroni correction, the difference for both variables remained statistically significant.

Comparison of Anterior and Posterior Changes

Changes were compared between anterior and posterior measurements at similar landmarks for each treatment group. The variables that were evaluated are nasal width (ANW-PNW), apical base width (AABW-PABW), and alveolar process width (AAPW-PAPW). Within the Type II surgical protocol group, there were no statistically significant differences between anterior and posterior changes at any of the variables (Table 5, Figure 11). Although there were no significant differences, within Type II, the greatest difference occurred at the alveolar process width between PAPW and AAPW and the least difference occurred at the nasal width between PNW and ANW. Unlike Type II, the Type III surgical protocol group showed statistically significant differences between anterior and posterior changes at all of the variables (Table 5, Figure 12). Similar to Type II though, the greatest difference occurred at the alveolar process width between PAPW and AAPW, and the least difference occurred at the nasal width between PNW and ANW.

Between-Group Comparisons at T0 and T1 (Mann-Whitney U Tests)

Pre-Expansion (T0)

There were no statistically significant between-group differences in the initial measurements for anterior, posterior, and dental (Figure 13-15). Overall, the median values were slightly greater for all variables in Type III than Type II, except for IOW, although not significant (Table 6). This indicates that at pre-expansion all the measurements for anterior, posterior, and dental variables were not significantly different.

Post-Expansion (T1)

There were statistically significant differences in the post-expansion measurements between the groups for all anterior measurements and ICW, with each having higher median values in Type III compared to Type II; however, the posterior measurements and IMW were not statistically significant (Table 7; Figure 16-18). After Bonferroni correction, only AAPW and ICW showed statistical significance.

Anterior Measurements:

All variables showed statistically significant differences, but after Bonferroni corrections, only AAPW showed significance (Table 7, Figure 16). ANW showed the least median difference of 1.8 mm between Type II and Type III at post-expansion. AAPW, AABW, and AABWS showed median between-group differences of 5.7 mm, 6.0 mm, and 6.6 mm, respectively, which were 3-3.5x greater than the difference at ANW. AABWI showed the greatest median difference of 7.3 mm.

Posterior Measurements:

There were no statistically significant differences at IOW, PNW, PABW or PAPW (Table 7, Figure 17). For the posterior variables, PNW, PABW, and PAPW were greater in Type III, but IOW was greater in Type II. PNW showed the least median difference of 0.8 mm between Type II and Type III. IOW and PABW showed the same median between-group difference of 1.6 mm. Lastly, PAPW showed a similar difference as IOW and PABW with a median of 1.9 mm, which was over 2x greater than the difference at PNW.

Dental Measurements:

There was a statistically significant difference at ICW but not at IMW (Table 7, Figure 18). The between-group difference at ICW was also statistically significant after Bonferroni correction. ICW showed a median difference of 3.0 mm between Type II and Type III. IMW showed a median between-group difference of 2.1 mm, although not statistically significant.

Changes

There were statistically significant between-group changes for AABW, AABWI, AAPW, and ICW. There were no statistically significant between-group changes for ANW, AABWS, IMW, or any of the posterior variables (Table 8, Figure 19-21). After Bonferroni corrections, only ICW showed statistical significance.

Anterior Measurements:

AABW, AABWI, and AAPW showed statistically significant between-group anterior changes; however, after Bonferroni corrections they no longer showed significance (Table 8, Figure 19). ANW and AABWS approached significance. The median anterior changes were all greater in Type III than in Type II. ANW increased the least for both Type II and Type III. It changed 1.5 mm (IQR = 2.7 mm) for Type II, and twice as much for Type III with a median of 3.0 mm (IQR = 2.7 mm). AABWS changed 1.8 mm (IQR = 5.2 mm) for Type II and 3.8 mm (IQR = 5.9 mm) for Type III, which was 2x greater than Type II. AABW and AABWI each changed a similar amount for both Type II and Type III. AABW and AABWI increased the same median of 3.0 mm for Type II with a IQR of 5.2 mm and 5.0 mm, respectively. For Type III, AABW and AABWI increased a similar median of 4.8 mm (IQR = 5.6 mm) and 4.9 mm (IQR = 5.4 mm), respectively. AAPW had the greatest amount of change for both Type II and Type III. Type II showed a median increase of 3.4 mm (IQR = 5.2 mm) whereas Type III showed a 5.5 mm (IQR = 5.3 mm) increase at AAPW. The change in AABW, AABWI, and AAPW was 1.6x greater in Type III than in Type II.

Posterior Measurements:

There were no statistically significant between-group posterior changes (Table 8, Figure 20). All posterior variables changed a similar amount for Type II and Type III. IOW changed the least amount of 0.1 mm for both Type II and Type III with a IQR of 2.0 mm and 1.4 mm, respectively. PNW changed 1.7 mm for both Type II (IQR = 1.4 mm) and Type III (IQR = 1.7 mm). PABW changed 2.0 mm (IQR = 2.1 mm) for Type II and 1.7 mm (IQR = 1.6 mm) for Type III, a similar amount but slightly less in Type III. And lastly, PAPW changed the most of the posterior variables with a median of 2.7 mm (IQR = 3.3 mm) for Type II and 3.3 mm (IQR = 3.0 mm) for Type III.

Dental Measurements:

There was a statistically significant between-group dental change for ICW but not for IMW. After Bonferroni correction, ICW remained statistically significant (Table 8, Figure 21). The change was greater for both IMW and ICW in Type III than Type II. But in Type II, the change at IMW was greater than ICW, whereas in Type III the change at ICW was greater than IMW. IMW increased 4.1 mm (IQR = 4.9 mm) for Type II and 5.7 mm (IQR = 4.8 mm) for Type III, which was 1.4x greater. ICW increased 2.9 mm (IQR = 4.4 mm) for Type II and 6.0 mm (IQR = 3.5 mm) for Type III, which was 2.1x greater.

CHAPTER IV

DISCUSSION

Anterior Changes

In skeletally mature non-growing adults, both surgical protocols produce significant within group pre-expansion to post-expansion changes in the anterior region. Additionally, the increase in width was significant after Bonferroni corrections at all variables (ANW, AABW, AABWS, AABWI, and AAPW). Successful expansion was achieved whether the patient received Type II or Type III surgical protocols from pre- to post-expansion. Dentally, ICW showed significant increase in both Type II and Type III protocols as well from T0 to T1.

When comparing expansion between groups, the increase in width for all anterior measurements was greater in Type III compared to Type II. The present study shows the changes at ANW and AABWS were 2x greater in Type III than in Type II, which is clinically significant although not statistically significant. In Type III, anterior nasal width increased a median of 3.0 mm. A previous study showed that the anterior nasal floor increased a mean of 4.7 mm.[93] In the study, nasal width was measured differently compared to this study, but furthermore it wasn't fully described and thus not reproducible by future studies. It was stated that they measured the anterior nasal floor width at the level of the nasopalatine nerve, which in comparison to this study, is positioned more inferior. As literature has shown, structures closer to the force of application and more inferior experience greater effects of expansion.[11,12] In addition to this comparison being between means and medians, this difference in measurement location may explain why the present study showed a smaller amount of anterior nasal width increase. A more recent study in 2022 showed a mean increase of 5.7 mm in nasal floor width.[97] Similarly, this comparison of means to medians is not a direct assessment that can be made with certainty. Moreover, this previous study did not describe where the nasal floor width was measured in the anteroposterior position or landmarks, and thus conclusive comparisons cannot be extrapolated between the results of the previous literature and this study. The changes at AABW, AABWI, and AAPW were significantly more with Type III protocol, about 1.6x larger, than with Type II protocol.

A recent study published in 2022 by Haas et al uses a minimally invasive surgical and miniscrew-assisted rapid palatal expansion (MISMARPE) technique, that described in the methods is almost identical to DOME.[95] From the measurement descriptions in the article, there are two anterior variables that are similar, although not identical, and can be compared to the present study: anterior maxillary distance and anterior alveolar process distance. However, keeping in mind the comparisons are made between the medians reported in this present study for Type III protocol and the means in the previous study, the associations may not be conclusive. Haas et al reported a mean change of 3.7 mm in anterior maxillary distance while the median change in AABW was 4.8 mm in this study for Type III. Anterior alveolar process distance and AABWI were at similar landmarks between the two studies and showed a mean and median change of 4.4 mm and 4.9 mm, respectively. The slight variations in the results can be explained by the comparison of means and medians as well as different methods for measuring the anterior variables. The present study utilized a reference plane 10 mm anterior to the most superior reference point of crista galli, while the previous study measured the largest width at the region of the upper canine, which was more anterior to the reference plane of this study. Furthermore, Haas et al did not specify exactly at what position on the coronal plane that the upper canine region was chosen. Another possible explanation for the differences is the previous study's limitation of a small sample size (n = 11). Overall, in this study, the anterior changes in Type II ranged from 1.5 mm to 3.4 mm whereas in Type III they ranged from 3.0 mm to 5.5 mm, which was statistically significant at AABW, AABWI, and AAPW. To date, there is only one randomized control trial comparing MARPE with and without corticopuncture, and there are no studies comparing MARPE with corticopunctures to DOME. Unfortunately, the randomized control trial was not conducted with clear descriptions regarding the measurements taken making it unfeasible to directly compare to the results found in the present study's Type II protocol.[96]

Dentally, the anterior change at ICW was statistically significant and 2x greater in Type III with a median increase of 6.0 mm while Type II had a median increase of 2.9 mm. Type III protocol is more successful at producing significant changes at ICW than Type II protocol. After Bonferroni correction to account for the multiple comparisons being made, only the change at ICW of all the anterior variables remained significant. This means the significant differences shown at the changes between the protocols at AABW, AABWI, and AAPW is not as strong as that at ICW.

The overall greater changes produced by Type III protocol indicate that it was more effective in producing anterior skeletal and dental changes than Type II protocol, which can be explained by the nature of the surgery. Type III protocol is more invasive than Type II protocol. The additional anterior maxillary osteotomy made from the zygomaticomaxillary buttress to the piriform rim allows for more significant change and increase in the width of the anterior region at varying landmarks compared to Type II protocol. With this information and the data presented in the present study, Type III protocol was significantly better at producing significant anterior changes than Type II protocol; however, expansion for orthodontic purposes is more frequently necessary in the posterior region. Type III protocol is more invasive than Type II protocol and the greater anterior expansion seen with Type III may not be clinically significant or relevant for orthodontic purposes.

Posterior Changes

In skeletally mature non-growing adults, both surgical protocols produce significant within group pre-expansion to post-expansion changes in the posterior region, except at IOW. Additionally, the increase in width was significant after Bonferroni corrections at PNW, PABW, and PAPW. There were no significant changes at IOW in either Type II or Type III from T0 to T1. Ultimately, successful posterior expansion was achieved whether the patient received Type II or Type III surgical protocols. Dentally, IMW also showed significant increase in both Type II and Type III protocols, and the increase was still significant after Bonferroni correction.

When comparing expansion between groups, the increase in width for all posterior measurements was not significantly different between Type II and Type III protocols. The posterior changes in Type II ranged from 0.1 mm to 2.7 mm, and in Type III they ranged from 0.1 mm to 3.3 mm. IOW changed a median of 0.1 mm for both Type II and Type III protocols. PNW also changed the same median amount of 1.7 mm for both protocols. A previous study showed that the posterior nasal floor increased a mean of 4.2 mm, which is vastly different from the results of this study.[93] In the previous study, the anterior nasal floor increased a similar amount to the posterior nasal floor whereas the present study showed significantly greater change in the anterior than the posterior. An explanation for this difference may be that the posterior nasal floor width was measured at the level of the maxillary first molar palatal root, which is more inferior than PNW measured in this study. Beyond this description, there were no further details defining the landmarks measured. Additionally, this is a comparison of means to medians and is not a reliable direct comparison. In the 2022 study by Haas et al, similar to the anterior variables, there are posterior variables that can also be compared to the present study: posterior maxillary distance, posterior alveolar process distance, and posterior dental crown distance.[95] However, keeping in mind the comparisons made are also between the medians reported in the present study and the means in the previous study. Posterior maxillary distance and PABW were similarly measured and resulted in a mean 3.4 mm and median 1.7 mm increase, respectively. Posterior alveolar process distance and PAPW showed similar mean and median changes of 3.2 mm and 3.3 mm, respectively. Similar to the anterior variables, the variations in the results can be explained by the comparison of means and medians as well as different methods for measuring the posterior variables. This present study utilized a reference plane 10 mm posterior to the most superior reference point of crista galli, while the previous study measured the largest width at the region of the upper first molar. However, it did not specify exactly at what position on the coronal plane that region was chosen. The variable with the largest difference was seen at PAPW and posterior maxillary distance. A possible explanation for this is the previous study’s limitation of a small sample size. In the present study, PABW changed 2.0 mm in Type II and 1.7 mm in Type

III, with a difference in change of 0.3 mm. In 2022, de Oliveira et al reported a change in nasal floor width of 2.8 mm; however, this was reported as a mean change as opposed to the present study's median.[72] Additionally, the slight difference can be explained by the small sample size of four, reported as a case series study. In a more recent retrospective study, Meirelles et al reported that the suture opening in the posterior region measured between the lateral margins of the greater palatine foramen showed a 2.1 mm increase, which is similar to the changes shown at PABW in the present study.[91] PAPW changed 2.7 mm in Type II and 3.3 mm in Type III, with a difference in change of 0.6 mm.

Dentally, the posterior change at IMW was greater in Type III with 5.7 mm of change whereas Type II showed 4.1 mm of change. Intermolar width in this present study also showed a larger change compared to the mean change of 4.3 mm reported in a previous study analyzing DOME.[95] Although there was greater increase with Type III protocol than Type II, that difference was not statistically significant.

The similar changes between the two surgical protocols indicate that the methods were comparably effective in their ability to expand skeletally and dentally in the posterior region. Thus, if posterior expansion is the main objective of the treatment, then either protocol will produce similar results. The more invasive Type III anterior maxillary osteotomy is not shown to have significant posterior effects like it has on the anterior region in comparison to Type II. Significant posterior expansion will be achieved regardless of the surgical protocol, and the conclusion that one is more effective in the posterior region than the other cannot be made from this present study. With this information, it can be suggested there is no need to perform the more invasive Type III protocol when both allow for significant posterior expansion, which is usually the region of interest for expansion in patients with maxillary transverse deficiencies.

Anterior to Posterior Changes

The relationship between anterior and posterior changes within surgical protocol type was evaluated. The skeletal variables measured at both the anterior region and posterior region were nasal width, apical base width, and alveolar process width. A comparison of these variables between anterior and posterior was performed for Type II and Type III protocols separately. This allows for a direct comparison of changes in the anterior and posterior in relation to each other for each protocol.

Within the Type II protocol, there were no significant differences between the anterior and posterior changes. For nasal width, the anterior (ANW) and posterior (PNW) changes were similar at 1.5 mm and 1.7 mm, respectively ($Z = -0.730$, $p = 0.465$). For apical base width, the anterior (AABW) change was 3.0 mm and the posterior (PABW) change was 2.0 mm ($Z = -0.957$, $p = 0.338$). For alveolar process width, the anterior (AAPW) change was 3.4 mm and the posterior (PAPW) was 2.7 mm ($Z = -1.386$, $p = 0.166$). The Z-scores showed that the magnitude of change was greater at the alveolar process width than at apical base width than at the nasal width. The similar changes at each variable for the anterior and posterior regions, more specifically at the alveolar process width (79.1%) may suggest that the expansion seen in Type II protocol is more parallel in the anteroposterior relationship as shown in the literature for patients who have received MARPE treatment alone or in conjunction with corticopunctures.[68,82,90,98] However, this is not seen at the level of the apical base width (67.8%) which is similar to other studies that refute the parallel expansion pattern in MARPE.[74] In the vertical direction, there is increasingly more expansion as the variables move from superior to inferior, possibly suggesting that the expansion in the vertical relationship is more pyramidal in shape as seen in conventional RME.[11,12,74] An explanation for this is seen in previous literature showing that structures further from the force application are less affected, while the ones closer in proximity to the expansive force see greater changes.[63]

Within the Type III protocol, there were significant differences between the anterior and posterior changes. The changes at the anterior level were significantly greater than those seen at the posterior level, which was also generally seen in the more recent literature evaluating a procedure similar to DOME.[95] For nasal width, the anterior (ANW) change was 3.0 mm, which is 1.8x more than the posterior (PNW) change of 1.7 mm ($Z = -2.386$, $p = 0.017$). For apical base width, the anterior (AABW) change was 4.8 mm, which is 2.8x greater than the posterior (PABW) change of 1.7 mm ($Z = -2.741$, $p = 0.006$). For alveolar process width, the anterior (AAPW) change was 5.5 mm, which is 1.7x more than the posterior (PAPW) change of 3.3 mm ($Z = -2.898$, $p = 0.004$). Like Type II, the Z-scores showed that the magnitude of change was greater at the alveolar process width than at apical base width than at the nasal width, but unlike Type II, greater anterior expansion is seen in Type III. This may suggest a more pyramidal in shape anteroposterior opening, similar results in previous literature.[95] However, in the vertical direction similar to Type II, there is increasingly more expansion in the inferior than the superior also possibly suggesting a more pyramidal in shape vertical opening. Although the more anterior landmarks are further from the force application, the increased expansion experienced in this region can be explained by the anterior osteotomies performed in Type III protocol that reduces the resistance to allow for more significant expansion to occur. The findings in expansion pattern are similar to some of the previous literature.[74,95] However, there is literature that suggests a more parallel anteroposterior expansion opposed to the v-shaped pyramidal pattern. Two recent systematic reviews have opposing results, parallel versus pyramidal, due to their inclusion of different studies.[74,99] Most of the current research have limitations ranging from selection bias to small sample sizes. The literature is not conclusive on the expansion pattern in the anteroposterior direction, but most agree that the expansion is more pyramidal in shape in the vertical direction.

Overall, the relationship between anterior and posterior changes within Type III surgical protocol had significant differences whereas with Type II did not. Thus, as stated previously, the present study indicates that if more significant anterior change relative to posterior change is desired, then Type III protocol will be more effective than Type II protocol.

Superior and Inferior Changes

Skeletal changes were greater in the inferior regions when compared to the superior regions for both Type II and Type III surgical protocol groups. In the present study, listed from superior to inferior, the anterior measurements were ANW, AABWS, AABW, AABWI, and AAPW, while the posterior measurements were IOW, PNW, PABW, and PAPW. In the Type II surgical protocol group, the anterior changes from superior to inferior increased from 1.5 mm (ANW) to 3.4 mm (AAPW). In the Type III surgical protocol group, the anterior changes from superior to inferior increased from 3.0 mm (ANW) to 5.5 mm (AAPW). Although the posterior changes were not significant, they also followed the superior to inferior increase in change that the anterior region showed. In the Type II surgical protocol group, the posterior changes from superior to inferior increased from 0.1 mm (IOW) to 2.7 mm (PAPW). In the Type III surgical protocol group, the posterior changes from superior to inferior increased from 0.1 mm (IOW) to 3.3 mm (PAPW). Since the more superior landmarks are further away from the expansive force of application, they saw the least amount of change compared to the more inferior landmarks. This suggests a more pyramidal in shape opening in the vertical relationship, similar to that seen in conventional RME and some previous literature on marpes.

Clinical Significance

The present study suggests that both surgical protocols are effective in expanding the maxilla independently; however, there is significantly more expansion in the anterior region with Type III protocol. There is no significant difference between the expansion achieved in the posterior region between the two protocols, so the use of the more invasive Type III protocol may not be necessary to achieve adequate and successful expansion if less anterior changes are desired. Ultimately, expansion for orthodontic purposes is more often required in the posterior region than in the anterior region. Furthermore, there is also a limit to the expansion that is biologically attainable and/or necessary. Thus, expansion utilizing the Type II protocol is significant and effective in the regions of interest without the use of the more invasive techniques and osteotomies required in Type III protocol.

Limitations and Future Studies

The results of the present study should be considered preliminary. A limitation of the study is the insufficient sample size. With more power, some of the results that approached significance would have been significant, but that cannot be directly concluded with the present study. Moreover, since the distribution of the data was skewed and kurtotic, non-parametric statistics were used to analyze the data. This resulted in the use of medians and interquartile ranges for data interpretation whereas majority of previous literature is reported in means and standard deviations. Once Bonferroni corrections were made, many of the significant differences seen were no longer significant due to the variability that is inherent in this study due to the small sample size. Thus, the differences reported in the results of the study cannot all be strongly concluded. The sample was not randomized and was sorted into surgical groups based on sex and age prior to radiographic analysis. The radiographic modifiers utilized to further establish the patient's treatment protocol affects the outcome of the study. Theoretically, patients with increased skeletal maturity and thicker bone are assigned the more invasive treatment protocol, which introduces selection bias into the present study. Since predetermined factors and possible predictors were utilized in the study to assign treatment protocols, an important future study may evaluate the success of the systematic approach to determining treatment modality for each patient.

Lastly, to date, there is only one study that evaluates distraction osteogenesis maxillary expansion (DOME) using similar outcome variables measured in this study. DOME was introduced as a treatment option for patients with obstructive sleep apnea, and thus most if not all of the literature is focused on variables such as nasal volume, Nasal Obstruction Symptom Evaluation (NOSE) scale, Epworth Sleepiness Scale (ESS), apnea-hypopnea index (AHI), body mass index (BMI), and Oxygen Desaturation Index (ODI). Two studies that did include nasal floor width were not comprehensive in their description regarding measurements and landmarks.[93,97] So ultimately one study was able to make more direct comparisons to the Type III protocol in this study. Similar to DOME studies, literature analyzing MARPE in conjunction with corticopuncture is limited. Most recent studies are case reports or case series. In order to fully compare the two protocols, more studies need to be conducted looking at each protocol independently that observe multiple outcome variables such as those presented in this article.

Future studies are important to conduct before conclusively recommending a protocol to skeletally mature non-growing patients. Without a control group (Type I protocol, MARPE only) to compare the individuals in the present study to, the conclusions are not as clinically significant and/or relevant. Utilization of three-dimensional analysis such as superimpositions would be beneficial in ensuring changes are evaluated in all three dimensions. And lastly, analyzing the side effects that have been discovered in MARPE only patients in Type II and Type III protocols would allow for more conclusive evidence on the basis of their introduction into treatment recommendations. As clinicians continue to increase their interest and education in expansion, it is important for clinical recommendations to be supported by evidence-based literature. This is especially important when the treatment proposed may involve varying levels of invasive procedures.

CHAPTER V

CONCLUSIONS

Within the limitations of this preliminary study comparing Type II surgical protocol to Type III surgical protocol as described previously, the following conclusions can be drawn:

1. Type II and Type III surgical protocols resulted in significant changes pre- to post-expansion.
2. Type III surgical protocol had significantly more anterior changes than Type II surgical protocol.
3. Posterior changes were not significantly different between Type II and Type III surgical protocols, thus Type II protocol is sufficient for successful expansion.
4. Dentally, ICW and IMW had greater change in Type III protocol than Type II protocol, but only ICW was statistically significant.
5. Similar differences in anterior to posterior changes in Type II protocol may suggest that the opening is more parallel in the anteroposterior direction compared to Type III protocol.
6. Increased changes in the inferior compared to the superior for both surgical protocols suggest that the opening is more pyramidal in shape in the vertical direction.

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APPENDIX A

FIGURES

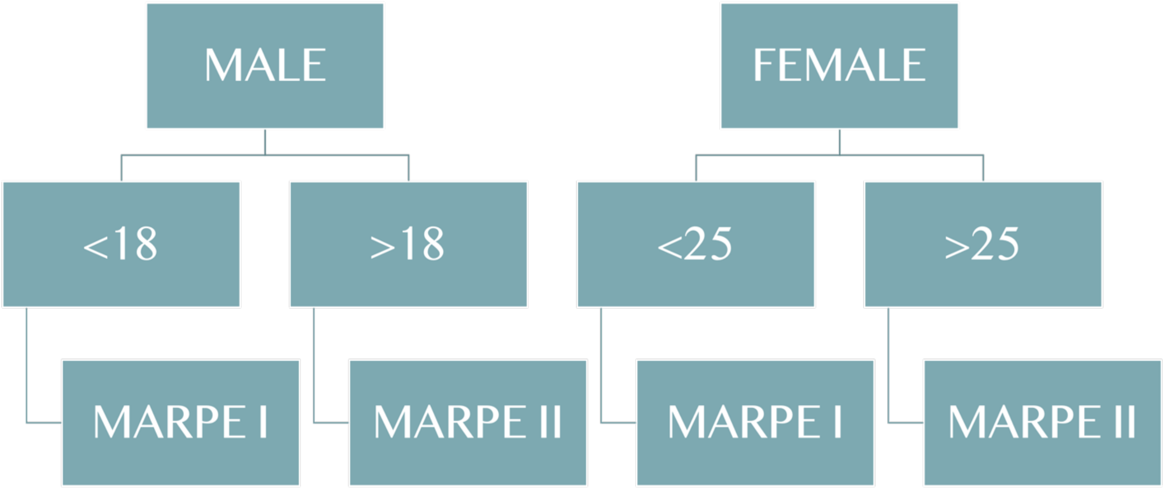


Figure 1. Initial treatment group classification based on sex and age.

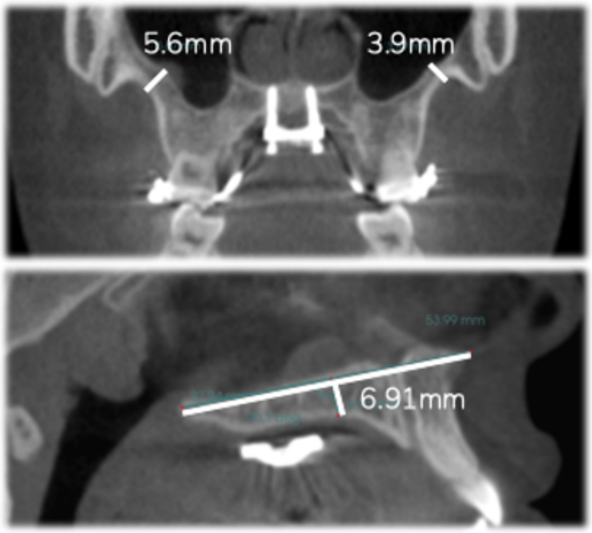


Figure 2. Radiographic Modifiers (zygomatic buttress width and palatal bone thickness) utilized for further treatment protocol classification.

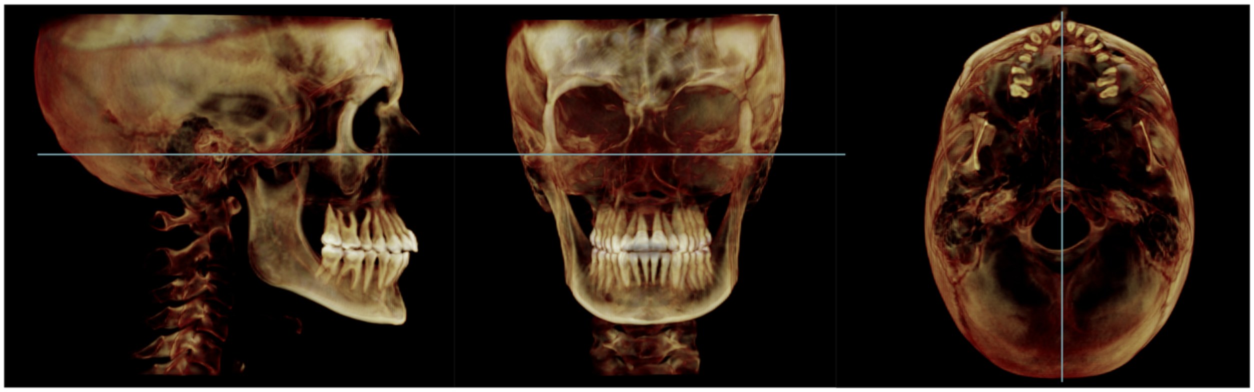


Figure 3. Hard tissue rendering from CBCT scans oriented using reference planes.

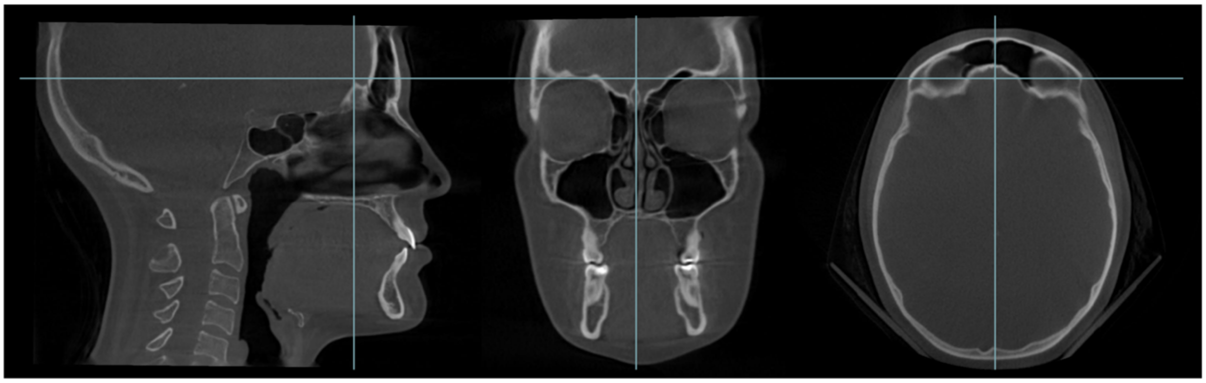


Figure 4. Most superior point on crista galli on all three planes (sagittal, coronal and axial).

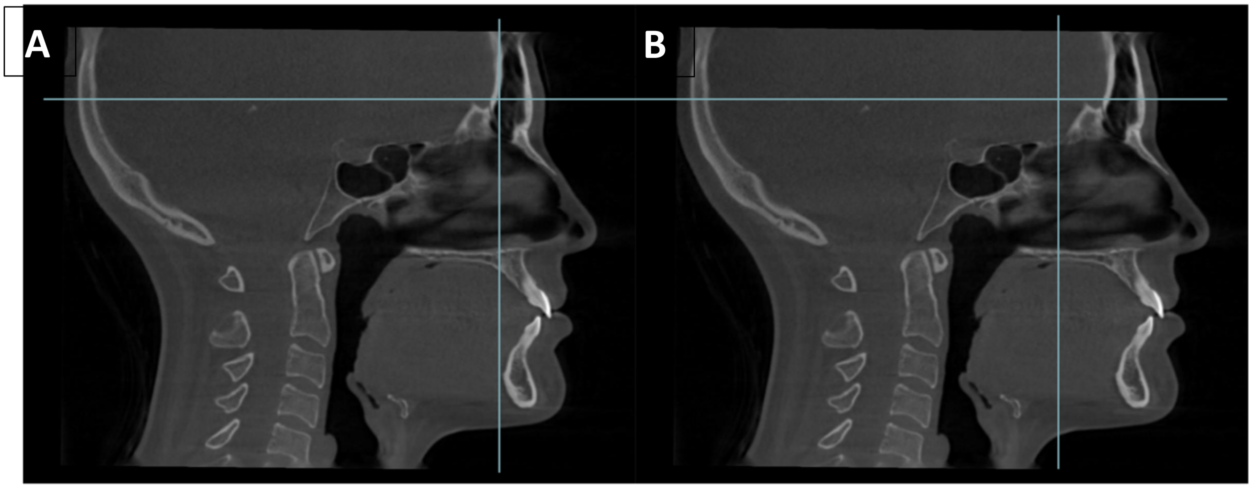


Figure 5. Reference planes: 10 mm anterior (A) and posterior (B) to crista galli superior reference point.

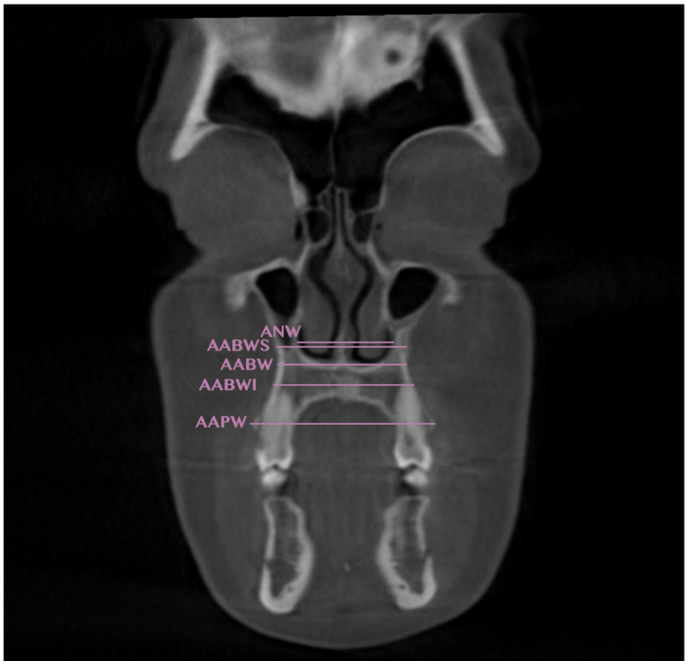


Figure 6. Anterior measurements acquired from anterior reference plane: Anterior nasal width (ANW), anterior apical base width (AABW), anterior apical base width superior (AABWS), anterior apical base width inferior (AABWI), and anterior alveolar process width (AAPW).

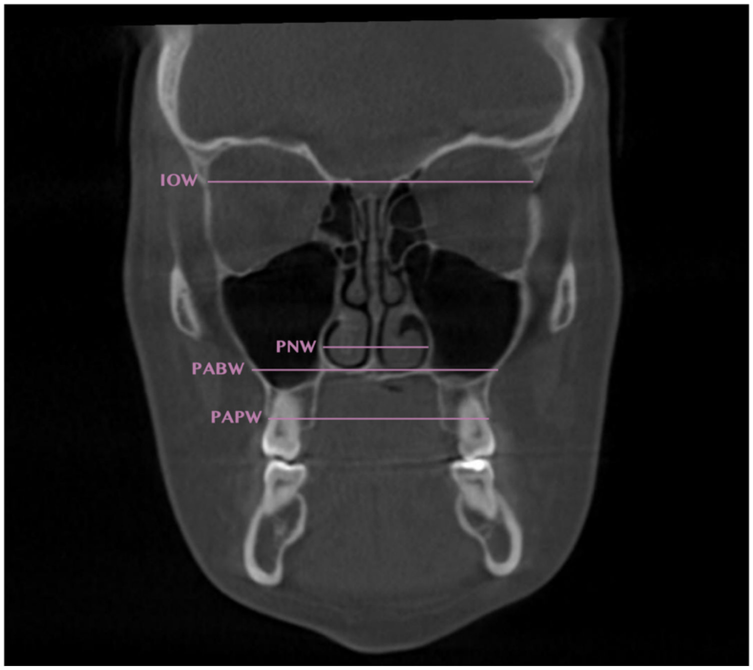


Figure 7. Posterior measurements acquired from posterior reference plane: Interorbital width (IOW), posterior nasal width (PNW), posterior apical base width (PABW), and posterior alveolar process width (PAPW).

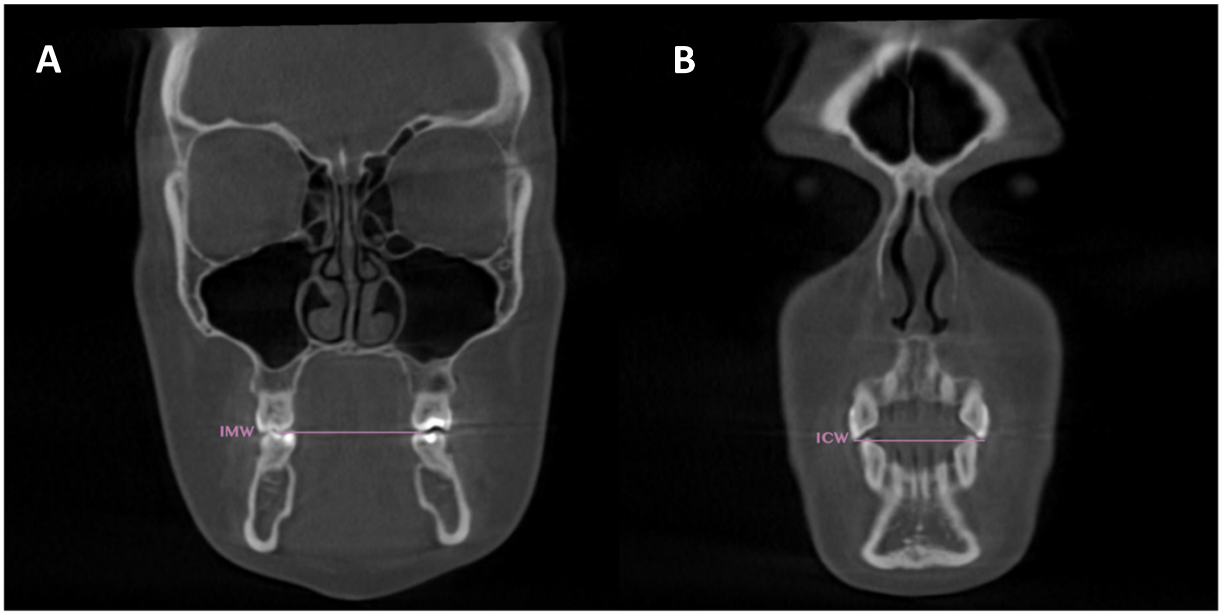
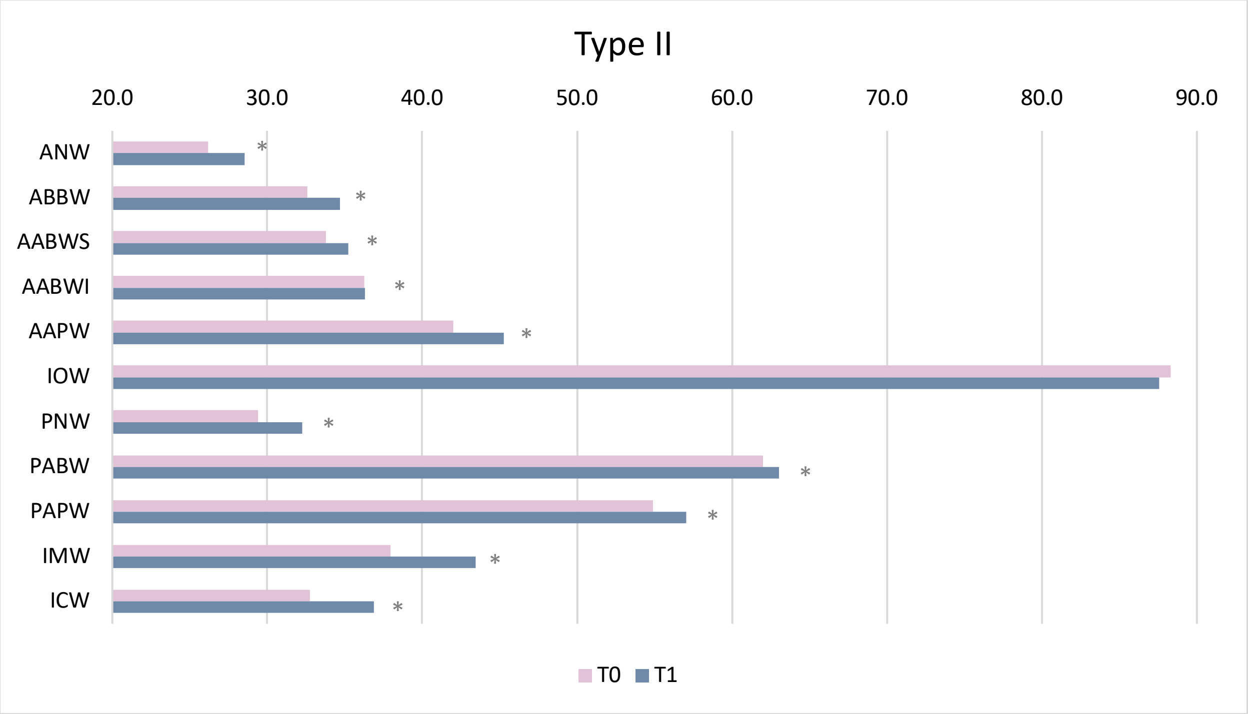
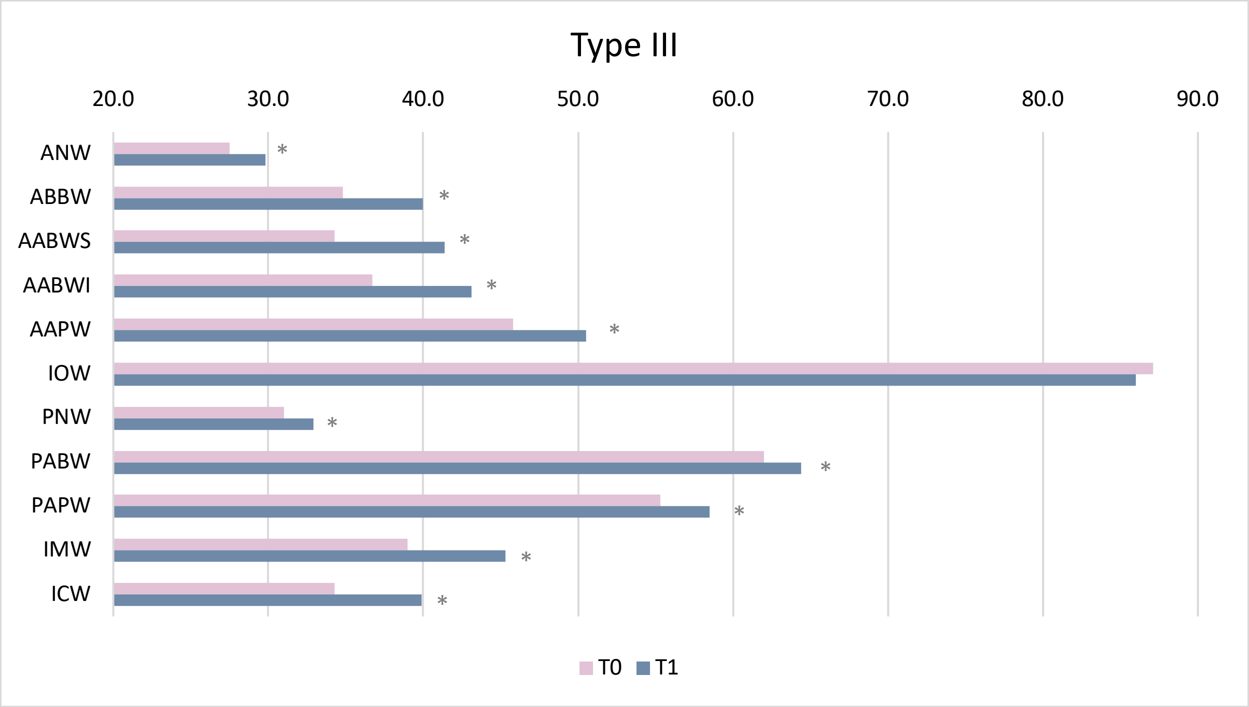


Figure 8. Dental measurements: A. Intermolar width (IMW) and B. Intercanine width (ICW).



* Indicates statistical significance

Figure 9. Comparison of anterior, posterior and dental measurements between pre- (T0) and post-expansion (T1) in the Type II surgical protocol group (n = 24).



* Indicates statistical significance

Figure 10. Comparison of anterior, posterior and dental measurements between pre- (T0) and post-expansion (T1) in the Type III surgical protocol group (n = 16).

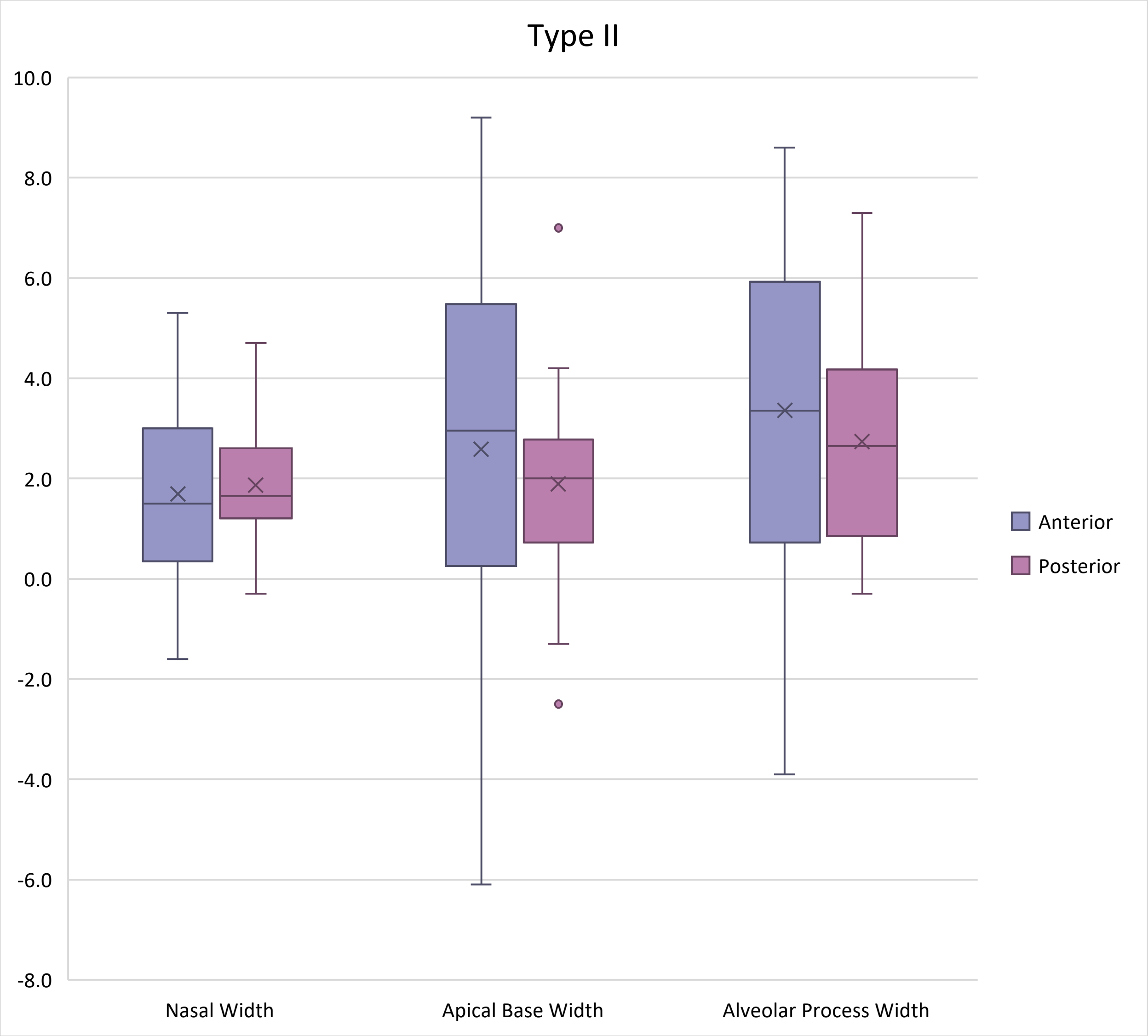
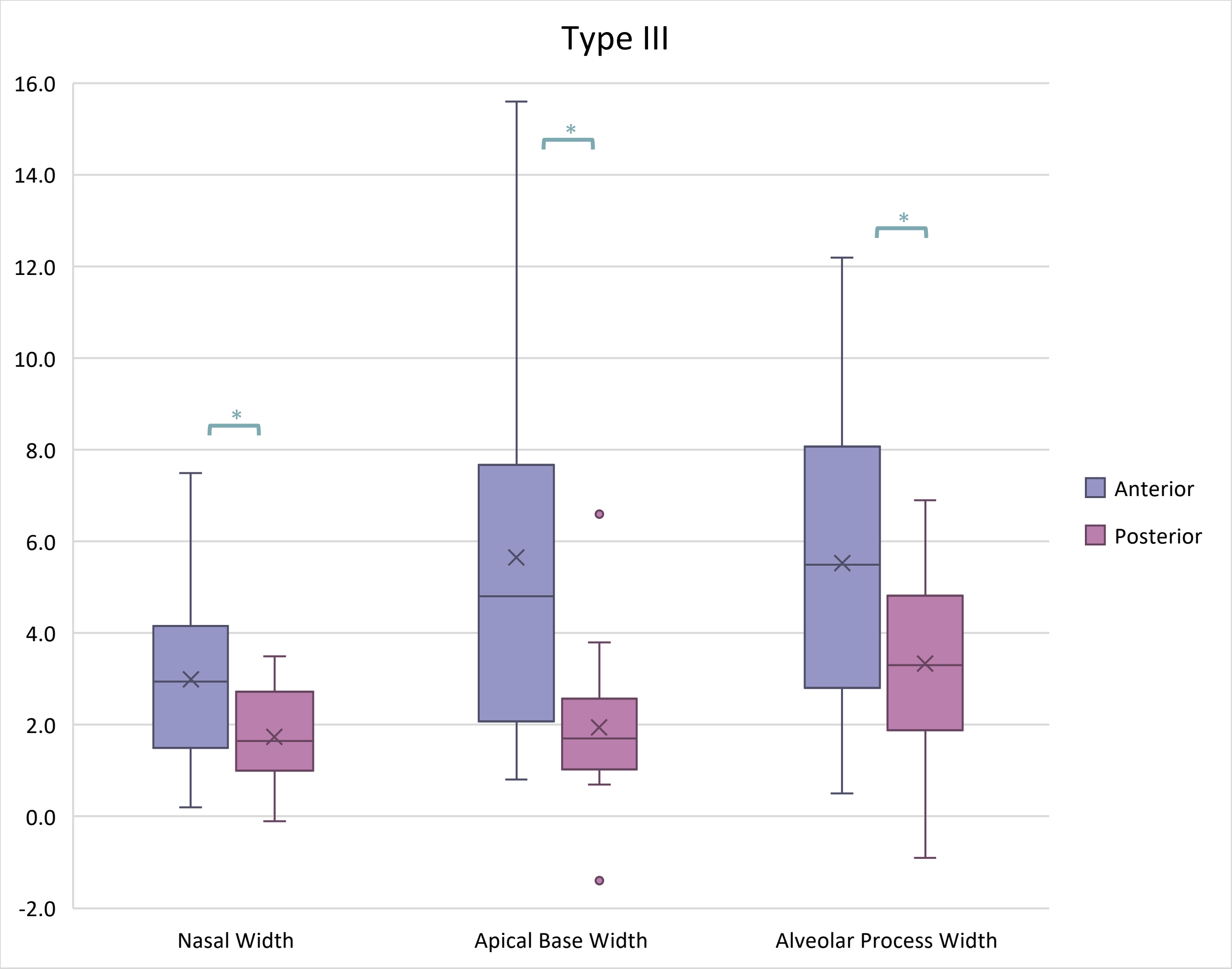


Figure 11. Comparison of anterior and posterior changes (Δ) within Type II surgical protocol group.



* Indicates statistical significance

Figure 12. Comparison of anterior and posterior changes (Δ) within Type III surgical protocol group.

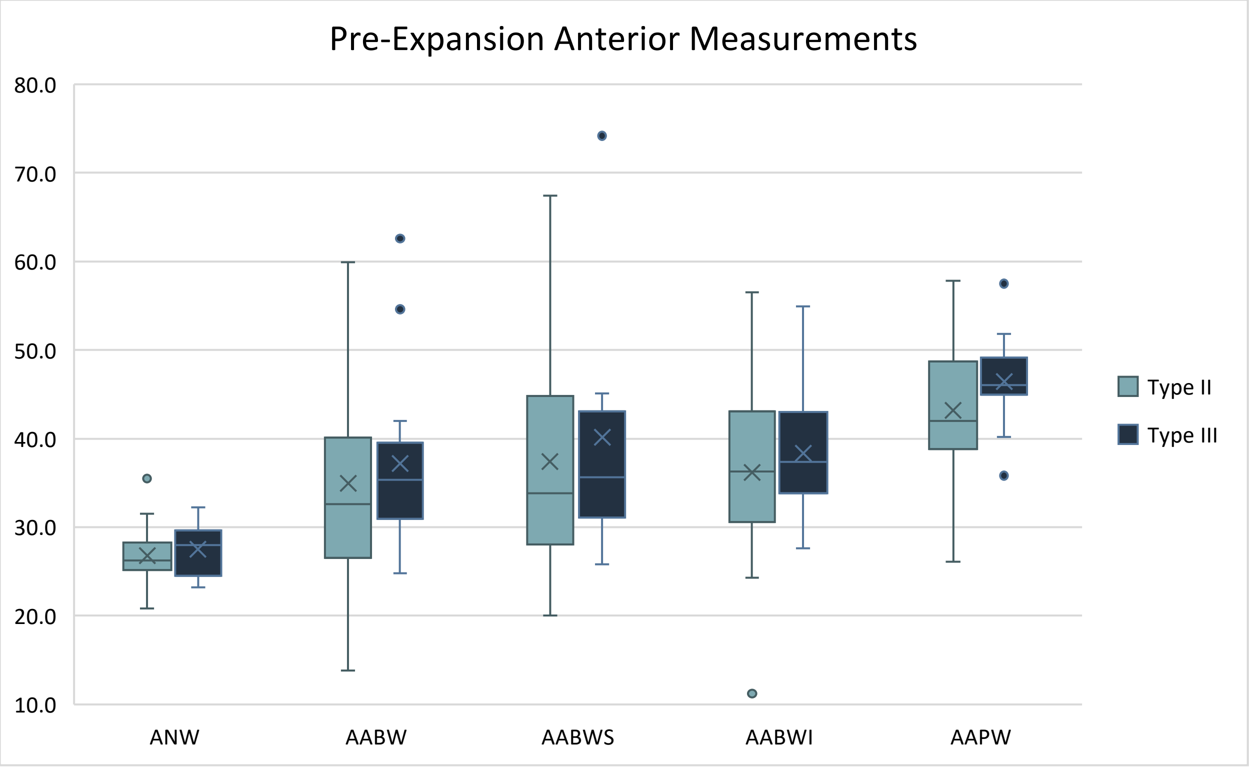


Figure 13. Comparison of anterior measurements between Type II and Type III surgical protocol groups at pre-expansion (T0).

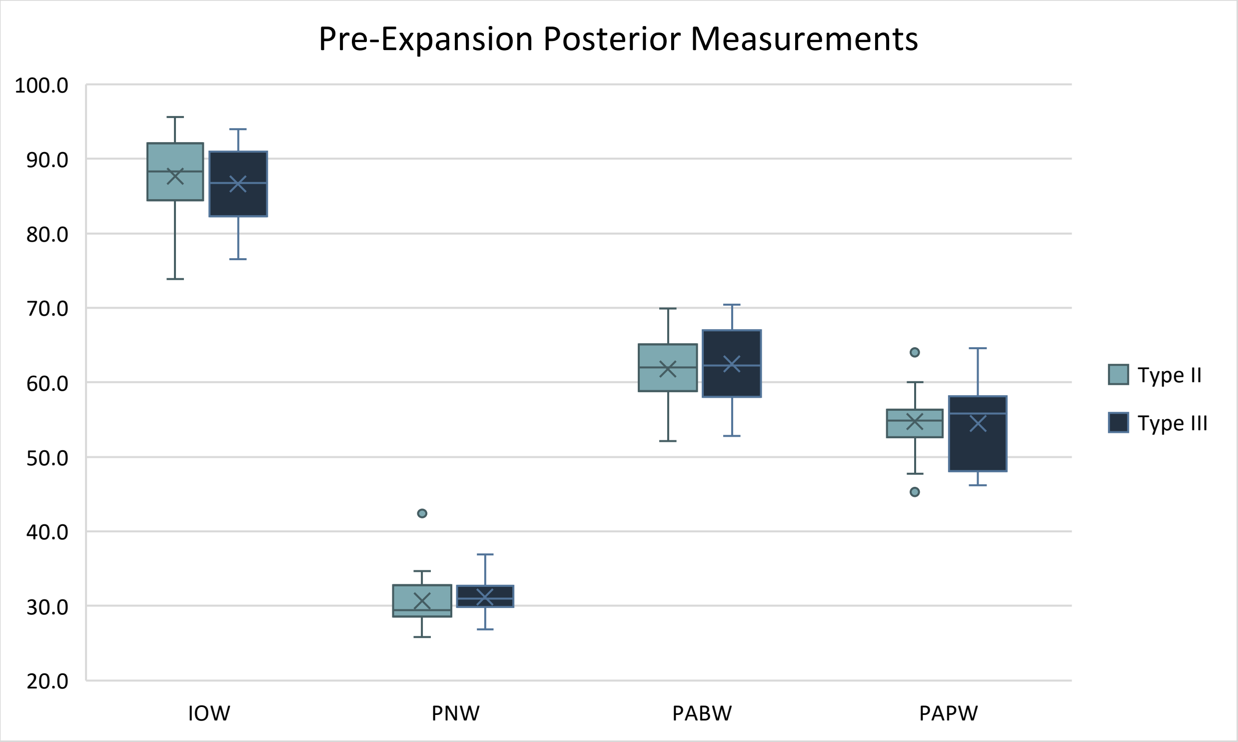


Figure 14. Comparison of posterior measurements between Type II and Type III surgical protocol groups at pre-expansion (T0).

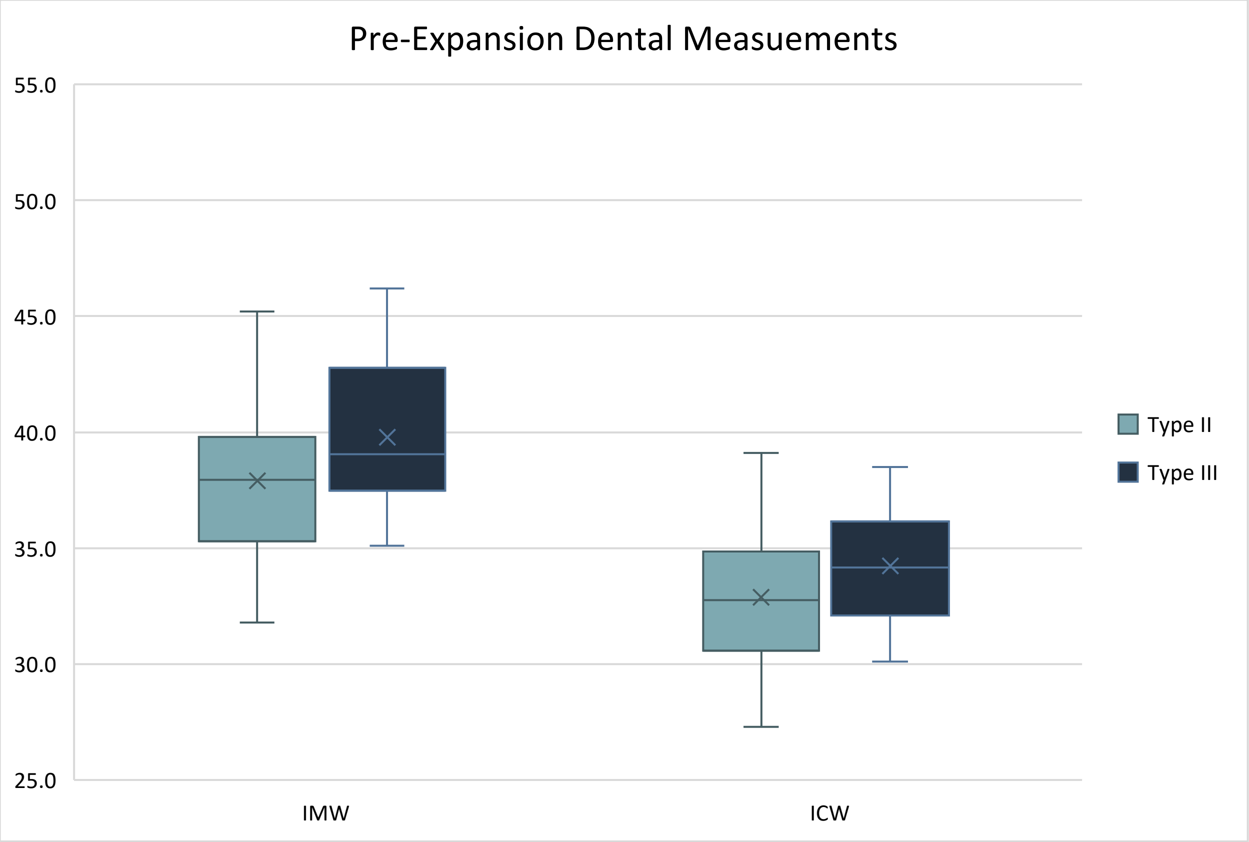
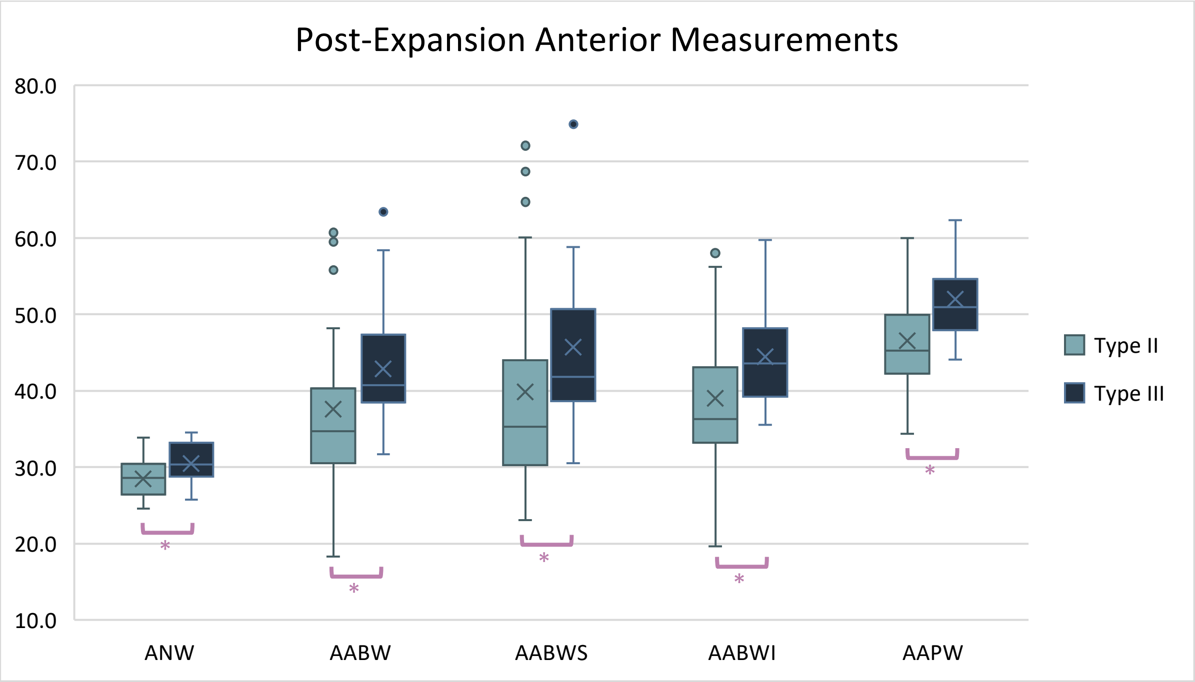


Figure 15. Comparison of dental measurements between Type II and Type III surgical protocol groups at pre-expansion (T0).



* Indicates statistical significance

Figure 16. Comparison of anterior measurements between Type II and Type III surgical protocol groups at post-expansion (T1).

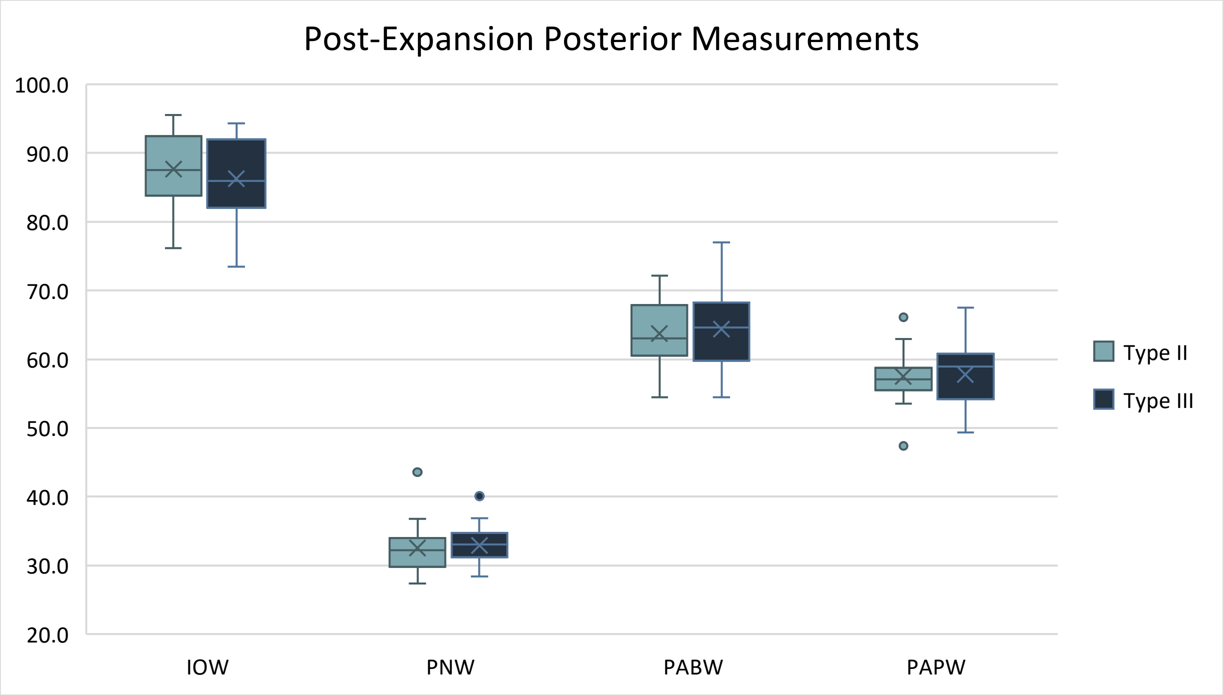
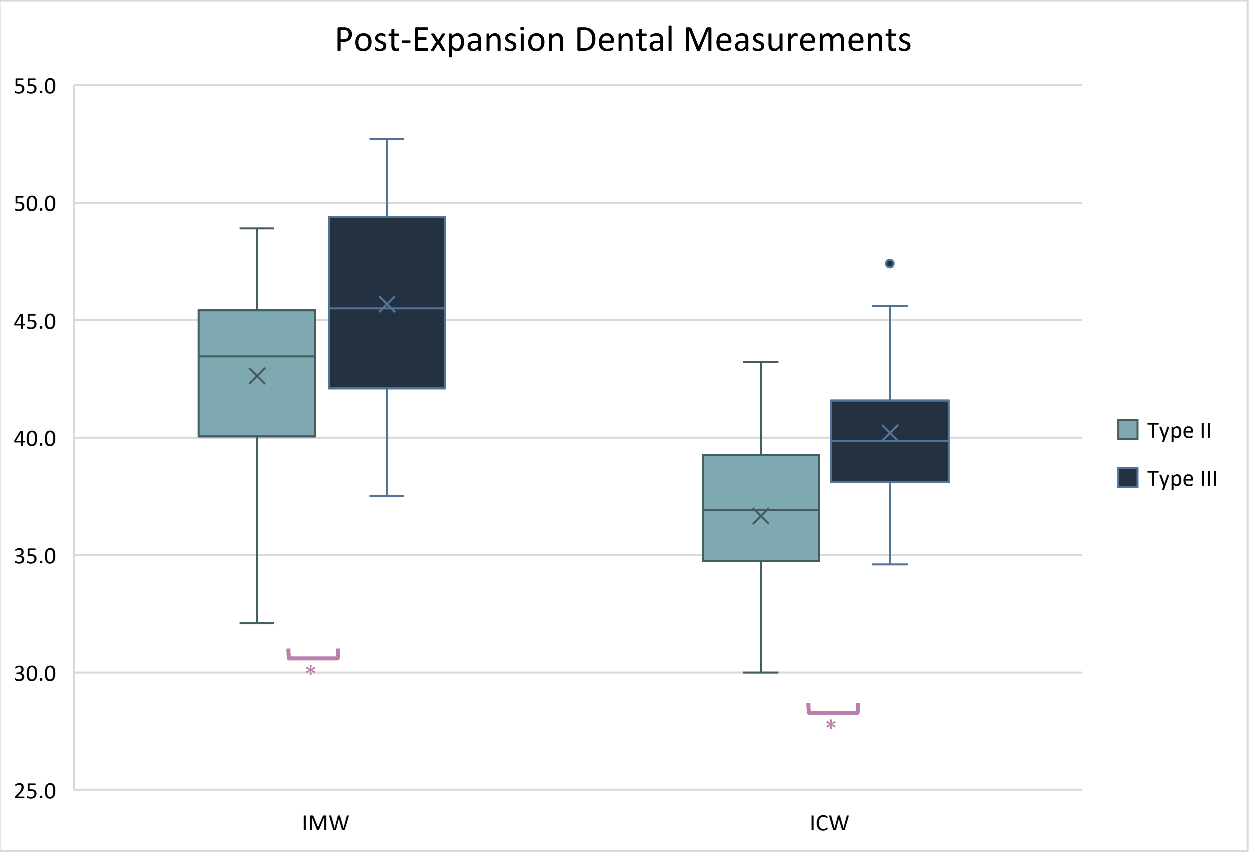
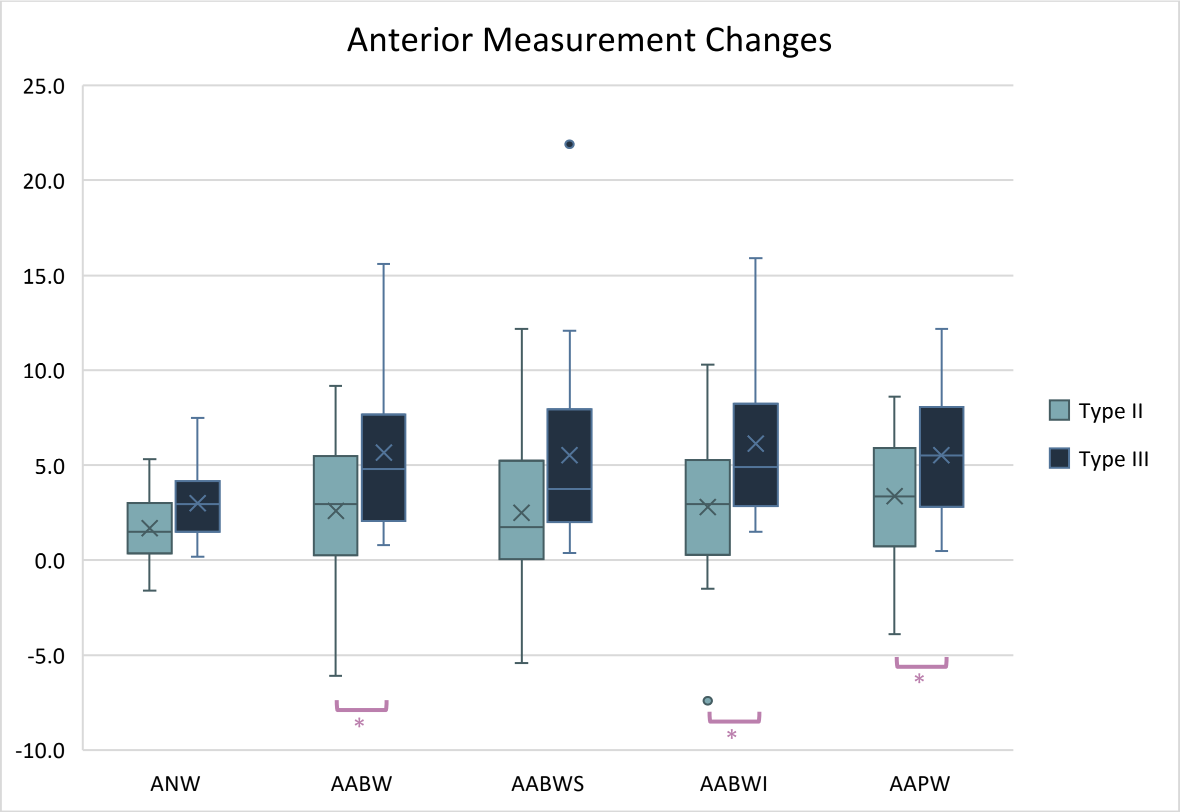


Figure 17. Comparison of posterior measurements between Type II and Type III surgical protocol groups at post-expansion (T1).



* Indicates statistical significance

Figure 18. Comparison of dental measurements between Type II and Type III surgical protocol groups at post-expansion (T1).



* Indicates statistical significance

Figure 19. Comparison of anterior changes (Δ) between Type II and Type III surgical protocol groups.

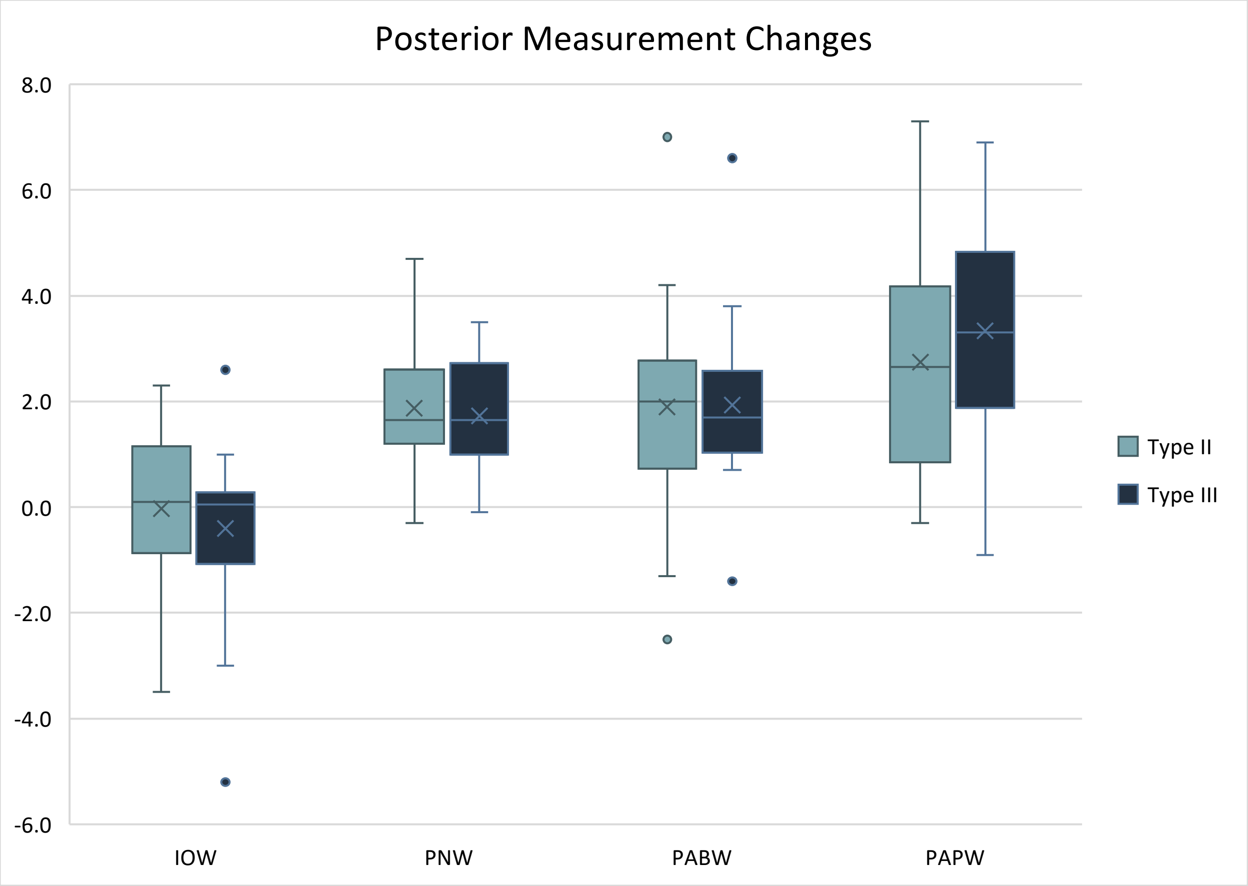
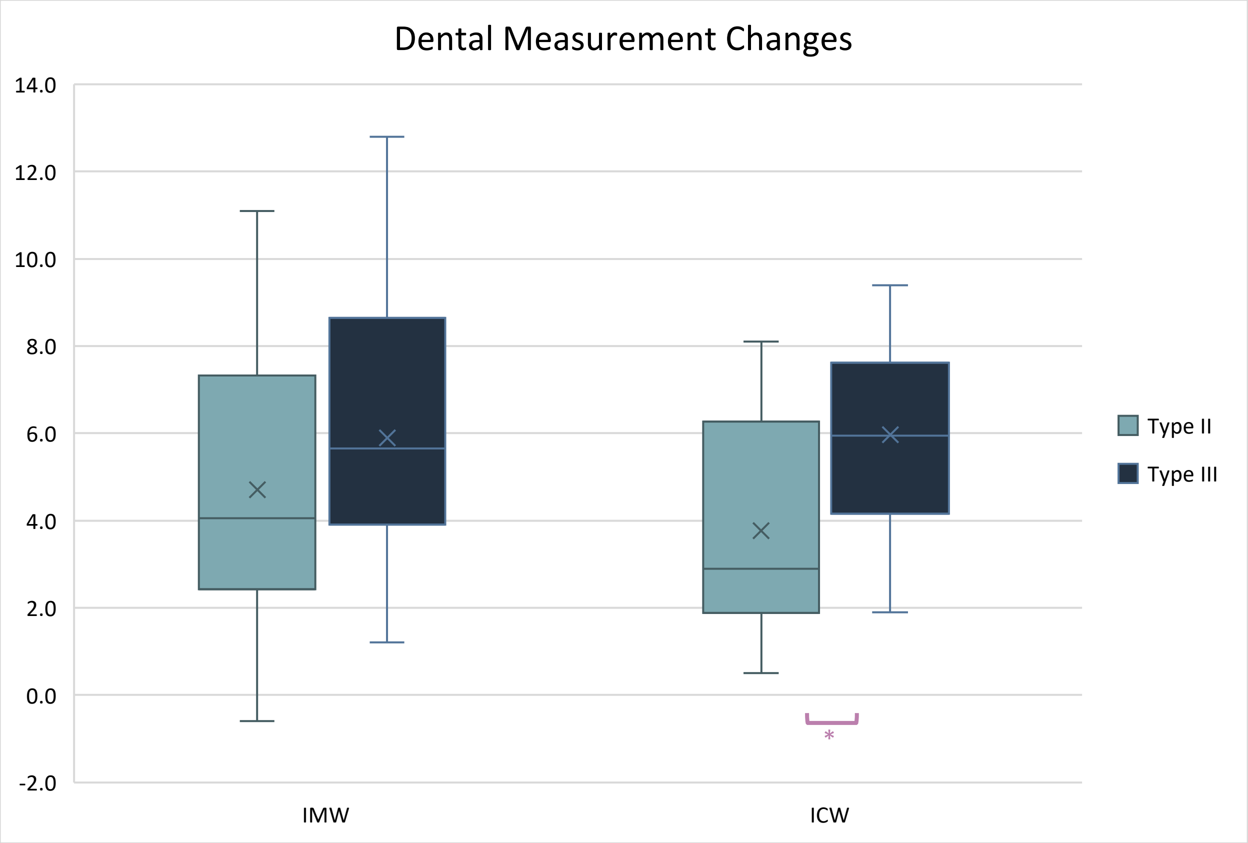


Figure 20. Comparison of posterior changes (Δ) between Type II and Type III surgical protocol groups.



* Indicates statistical significance

Figure 21. Comparison of dental changes (Δ) between Type II and Type III surgical protocol groups.

APPENDIX B

TABLES

Table 1. Outcome measurements with abbreviations and definitions.

Abbreviations	Measurement	Descriptions
Measurements using the anterior reference plane		
ANW	Anterior nasal width	Maximum distance between right and left nasal cavity
AABW	Anterior apical base width	Right and left buccal contours of maxilla using a plane parallel and 5 mm superior to AABW
AABWS	Anterior apical base width superior	Right and left buccal contours of maxilla using the tangent to the lower border of the nasal cavity
AABWI	Anterior apical base width inferior	Right and left buccal contours of maxilla using a plane parallel and 5 mm inferior to AABW
AAPW	Anterior alveolar process width	The maximum distance between the buccal aspects of the right and left dentoalveolar processes
Measurements using the posterior reference plane		
IOW	Interorbital width	The maximum distance between right and left lateral outer orbital walls
PNW	Posterior nasal width	Maximum distance between right and left nasal cavity
PABW	Posterior apical base width	Right and left buccal contours of maxilla using the tangent to the lower border of the nasal cavity
PAPW	Posterior alveolar process width	Distance between the right and left alveolar crests, measured at their most inferior limits
Dental measurements		
IMW	Intermolar width	Distance between the mesiopalatal cusp tips of the first permanent maxillary molars
ICW	Intercanine width	Distance between the cusp tips of maxillary permanent canines

Table 2. Sample distribution.

	Combined				
	N	Mean	Stdev	Median	IQR
Age	40	32.4	12.2	29.3	18.2
Time Diff	40	0.6	0.5	0.5	0.4
	Female				
	N	Mean	Stdev	Median	IQR
Age	15	34.9	12.0	32.4	15.6
Time Diff	15	1.0	0.7	0.8	0.9
	Male				
	N	Mean	Stdev	Median	IQR
Age	25	30.9	12.3	26.7	18.9
Time Diff	25	0.4	0.3	0.4	0.3

Table 3. Comparison of anterior, posterior and dental measurements between pre- (T0) and post-expansion (T1) in the Type II surgical protocol group (n = 24).

Variable	Units	T0		T1		Probability
		Median	IQR	Median	IQR	
ANTERIOR MEASUREMENTS						
ANW	Mm	26.2	3.1	28.6	4.0	<0.001
ABBW	Mm	32.6	13.6	34.7	9.8	0.004
AABWS	Mm	33.8	16.7	35.3	13.8	0.006
AABWI	Mm	36.3	12.5	36.3	9.8	0.002
AAPW	Mm	42.0	9.8	45.3	7.7	<0.001
POSTERIOR MEASUREMENTS						
IOW	Mm	88.3	7.7	87.6	8.6	0.797
PNW	Mm	29.4	4.2	32.3	4.2	<0.001
PABW	Mm	62.0	6.3	63.1	7.3	<0.001
PAPW	Mm	54.9	3.7	57.1	3.2	<0.001
DENTAL MEASUREMENTS						
IMW	Mm	38.0	4.5	43.5	5.4	<0.001
ICW	Mm	32.8	4.3	36.9	4.5	<0.001

Gray indicates significance ($p < 0.05$).

Bold indicates significance after Bonferroni correction.

Table 4. Comparison of anterior, posterior and dental measurements between pre- (T0) and post-expansion (T1) in the Type III surgical protocol group (n = 16).

Variable	Units	T0		T1		Probability
		Median	IQR	Median	IQR	
ANTERIOR MEASUREMENTS						
ANW	Mm	28.0	5.1	30.4	4.5	<0.001
ABBW	Mm	35.4	8.6	40.7	8.9	<0.001
AABWS	Mm	35.6	12.0	41.9	12.1	<0.001
AABWI	Mm	37.4	9.2	43.6	8.9	<0.001
AAPW	Mm	46.1	4.2	51.0	6.7	<0.001
POSTERIOR MEASUREMENTS						
IOW	Mm	86.8	8.8	85.9	10.0	0.683
PNW	Mm	31.0	2.9	33.1	3.5	<0.001
PABW	Mm	62.3	9.0	64.6	8.5	<0.001
PAPW	Mm	55.9	10.0	59.0	6.6	<0.001
DENTAL MEASUREMENTS						
IMW	Mm	39.1	5.3	45.5	7.3	<0.001
ICW	Mm	34.2	4.1	39.9	3.5	<0.001

Gray indicates significance ($p < 0.05$).

Bold indicates significance after Bonferroni correction.

Table 5. Comparison of anterior to posterior changes within Type II and Type III groups.

Variable	Type II		Type III	
	Z	Probability	Z	Probability
ANW-PNW	-0.730	0.465	-2.386	0.017
AABW-PABW	-0.957	0.338	-2.741	0.006
AAPW-PAPW	-1.386	0.166	-2.898	0.004

Gray indicates significance ($p < 0.05$)

Table 6. Comparison of anterior, posterior and dental measurements between Type II and Type III surgical protocol groups at pre-expansion (T0).

T0						
Variable	Units	Type II		Type III		Probability
		Median	IQR	Median	IQR	
ANTERIOR MEASUREMENTS						
ANW	Mm	26.2	3.1	28.0	5.1	0.331
AABW	Mm	32.6	13.6	35.4	8.6	0.469
AABWS	Mm	33.8	16.7	35.6	12.0	0.436
AABWI	Mm	36.3	12.5	37.4	9.2	0.469
AAPW	Mm	42.0	9.8	46.1	4.2	0.084
POSTERIOR MEASUREMENTS						
IOW	Mm	88.3	7.7	86.8	8.8	0.557
PNW	Mm	29.4	4.2	31.0	2.9	0.292
PABW	Mm	62.0	6.3	62.3	9.0	0.733
PAPW	Mm	54.9	3.7	55.9	10.0	0.713
DENTAL MEASUREMENTS						
IMW	Mm	38.0	4.5	39.1	5.3	0.095
ICW	Mm	32.8	4.3	34.2	4.1	0.157

Table 7. Comparison of anterior, posterior and dental measurements between Type II and Type III surgical protocol groups at post-expansion (T1).

T1						
Variable	Units	Type II		Type III		Probability
		Median	IQR	Median	IQR	
ANTERIOR MEASUREMENTS						
ANW	Mm	28.6	4.0	30.4	4.5	0.029
AABW	Mm	34.7	9.8	40.7	8.9	0.016
AABWS	Mm	35.3	13.8	41.9	12.1	0.036
AABWI	Mm	36.3	9.8	43.6	9.0	0.013
AAPW	Mm	45.3	7.7	51.0	6.7	0.002
POSTERIOR MEASUREMENTS						
IOW	Mm	87.6	8.6	85.9	10.0	0.452
PNW	Mm	32.3	4.2	33.1	3.5	0.486
PABW	Mm	63.1	7.3	64.6	8.5	0.859
PAPW	Mm	57.1	3.2	59.0	6.6	0.692
DENTAL MEASUREMENTS						
IMW	Mm	43.5	5.4	45.5	7.3	0.051
ICW	Mm	36.9	4.5	39.9	3.5	0.008

Gray indicates significance ($p < 0.05$).

Bold indicates significance after Bonferroni correction.

Table 8. Comparison of anterior, posterior and dental changes (∆) between Type II and Type III surgical protocol groups.

Change (∆)						
Variable	Units	Type II		Type III		Probability
		Median	IQR	Median	IQR	
ANTERIOR MEASUREMENTS						
ANW	Mm	1.5	2.7	3.0	2.7	0.070
AABW	Mm	3.0	5.2	4.8	5.6	0.027
AABWS	Mm	1.8	5.2	3.8	5.9	0.060
AABWI	Mm	3.0	5.0	4.9	5.4	0.018
AAPW	Mm	3.4	5.2	5.5	5.3	0.054
POSTERIOR MEASUREMENTS						
IOW	Mm	0.1	2.0	0.1	1.4	0.539
PNW	Mm	1.7	1.4	1.7	1.7	0.795
PABW	Mm	2.0	2.1	1.7	1.6	0.795
PAPW	Mm	2.7	3.3	3.3	3.0	0.345
DENTAL MEASUREMENTS						
IMW	Mm	4.1	4.9	5.7	4.8	0.304
ICW	Mm	2.9	4.4	6.0	3.5	0.011

Gray indicates significance ($p < 0.05$).

Bold indicates significance after Bonferroni correction.