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Mini-screw assisted RME vs. traditional RME to more successfully achieve mid-palatal sutural separation

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MINI-SCREW ASSISTED RME VS. TRADITIONAL RME TO MORE SUCCESSFULLY ACHIEVE MIDPALATAL SUTURAL SEPARATION

by

Clint Wire

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CERTIFICATE OF APPROVAL

MASTER'S THESIS

This is to certify that the Master's thesis of

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has been approved by the Examining Committee for the thesis requirement for the Master of Science degree in Orthodontics at the May 2019 graduation.

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ABSTRACT

Introduction

Treating adolescent maxillary constriction often includes a traditional RME appliance, with the aim of creating a separation of the midpalatal sutural (MPS). However, maxillary skeletal expansion becomes more difficult with age due to increased facial and mid-palatal, skeletal resistance. An emerging treatment option with the hopes of overcoming this skeletal resistance is a mini-screw assisted RME appliance. The purpose of this study is to evaluate the age and maturation at which successful separation of the maxillary MPS can be achieved, and whether or not this can be improved with the utilization of a mini-screw assisted RME appliance.

Materials and Methods

In this prospective clinical trial, N=96 (n=43 M, n=53 F) consecutively treated subjects exhibiting maxillary skeletal constriction underwent traditional RME treatment and N=13 (n=7 M, n=6 F) underwent MARME treatment utilizing mini-screws. Subjects were also classified into either pre-pubertal or post-pubertal groups based on maturation. Evidence of MPS separation was confirmed by the development of a diastema between upper central incisors and using a maxillary occlusal radiograph.

Results

Average age of the 96 subjects with traditional RME treatment was 13.8 years with 71.9% achieving successful separation of the maxillary MPS. Sutural separation occurred with traditional RME for 96% of the pre-pubertal group compared with 62% of the post-pubertal group. There was also a significantly strong negative correlation between age and percent ability

to get MPS separation with traditional RME. In contrast, average age of mini-screw RME subjects was 17.1 years (n=13), all were classified as post-puberty, and MPS separation occurred 100% of the time.

Conclusions

Utilization of mini-screw assisted RME is a good option for clinicians when treating post-pubertal adolescents and early adult patients. However, MPS separation is highly likely to occur in pre-pubertal patients treated with traditional RME. As a result, patient age and maturation should be taken into account when deciding between traditional or mini-screw assisted RME treatment.

PUBLIC ABSTRACT

A narrow upper arch can sometimes lead to shifting of the lower jaw, asymmetrical facial growth, and crowded teeth. The most common treatment for a narrow upper arch is for the patient to wear an appliance called a rapid maxillary expander, which pushes on the teeth to widen the upper jaw.

The primary aim of the expander appliance is to have a separation of the suture running down the center of the upper jaw, but as patients mature and grow older this becomes more difficult. The purpose of this study is to see at what age and maturation level separation of the suture will occur, and whether or not adding screws to the expander appliance will increase the likelihood of sutural separation.

Our study demonstrates that a traditional expander appliance is effective for patients who have not reached puberty, but that using screws in the expander appliance is helpful for patients who are post-puberty. These results will help dentists choose between different treatment options for patients with a narrow upper jaw.

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INTRODUCTION

As this study was conducted as a follow-up and extension of Dr. Samuel Christensen's thesis, Adolescent Skeletal and Dental Changes with Rapid Maxillary Expansion, it will follow a similar format and literature review (Christensen, 2018). The principal addition of this thesis includes a review, new data, and analysis of mini-screw assisted RME (MARME) treatment.

Transverse maxillary skeletal deficiency remains one of the problems orthodontists commonly face. A constricted maxilla can be associated with unilateral or bilateral posterior crossbite, maxillary and mandibular growth asymmetry, a CR-CO shift, and dental crowding. This is concerning as the prevalence of maxillary constriction is estimated to be 9.4% (Brunelle, Bhat, & Lipton, 1996). Treatment of maxillary constriction usually includes the use of a rapid maxillary expander (RME), with the aim of separating the midpalatal suture (MPS) and widening the maxilla. However, achieving successful separation of the MPS becomes more difficult as patients age and mature through adolescence, making it important to properly time the utilization of the RME appliance.

Maxillary growth in the transverse dimension occurs mainly through deposition of bone at the MPS, with remodeling occurring at the lateral aspects of the maxilla. More bone is deposited in the posterior of the suture than the anterior, and this differential growth causes the two halves of the maxilla to rotate in the transverse plane (Bjork & Skieller, 1974; Keith & Campion, 1922). Deposition and growth occur at the suture through adolescence with transverse maxillary growth usually completing for males at age 17 and for females at age 15 (Snodell, Nanda, & Currier, 1993).

RME treatment becomes more difficult as patients age and mature due to increased skeletal resistance. One turn of the RME appliance expansion screw produces, on average, between 2 to 10 pounds of force. However, this force level increases as patients age and mature due to increased skeletal resistance to the expansion. The skeleton is less likely to yield to the force of the RME and residual loads can be seen up to 20 pounds in older patients. Interestingly, there is no decrease in force levels during separation of the MPS, meaning that most of the skeletal resistance is from other maxillary articulations and not the suture itself (Isaacson & Ingram, 1964). In addition, studies in animals have found that the bone cells in older animals are less responsive to tensile forces than in younger animals, meaning that the body is less responsive to the forces of RME treatment as it ages and matures (Brin, Hirshfeld, Shanfeld, & Davidovitch, 1981).

The benefit of RME treatment is remarkably increased if MPS separation is achieved during expansion, signifying a more pronounced orthopedic skeletal response. Prior studies have shown that the amount of skeletal change is higher in children vs adults and that MPS separation is more likely to occur if expansion force is applied during the deciduous or mixed dentition period (Bell, 1982). Further studies have demonstrated that expansion in adults will only generate a skeletal contribution of 18%, compared to a skeletal contribution of 56% in children. Additionally, there significantly more dental tipping of the molars in adult patients, which is thought to be caused by the lack of orthopedic skeletal response (Handelman, Wang, BeGole, & Haas, 2000).

In order to achieve a more pronounced orthopedic skeletal effect during expansion on late adolescents, clinicians have begun to utilize mini-screw assisted RME appliances, otherwise known as non-surgical mini-screw assisted rapid maxillary expansion (MARME). Early studies have been very promising, concluding that bone-borne expanders produce greater transverse skeletal expansion in late-adolescent patients when compared to tooth-borne hyrax expanders. Mini-screw supported RME appliances have also been shown to cause less alveolar bending, less dental tipping, and less vertical alveolar bone loss at the first premolar than traditional RME appliances (Lin et al., 2015). Initial studies also indicate that when using MARME, MPS separation was 87% in patients over 18 years old (Choi, Shi, Cha, Park, & Lee, 2016).

The use of MARME to treat maxillary transverse discrepancies in late adolescent patients is an innovative treatment option. However, due to the potential risks that can be associated with placing mini-screws in adolescent patients, a less invasive treatment option such as traditional RME should be pursued if available. The purpose of this study is to evaluate the age and maturation level at which a successful separation of the MPS can be achieved by traditional RME. An additional aim is to assess the success rate of MARME in late adolescent patients and to determine if there is a certain age range and maturation level when MARME should be considered as a preferential treatment option over traditional RME.

LITERATURE REVIEW

Maxillary Growth and Development

The sagittal and vertical growth of the maxilla is has been very well documented, with generalized growth being directed downward and forward from the cranial base. Early on, forward movement of the maxilla in the sagittal plane occurs through cranial base growth, which continues until the age of six (Proffit, Fields, & Sarver, 2007). After this, sutural growth towards the palatine bone and depositional growth at the tuberosity further displaces the maxilla forward in the sagittal plane. Growth in the vertical plane continues through sutural growth at the zygomatic and frontal sutures as well as depositional growth in the alveolus as the eruption of teeth occurs (Bjork & Skieller, 1977).

In the transverse plane, the majority of maxillary growth occurs through deposition of bone at the midpalatal suture and through surface remodeling of the lateral aspects of the maxilla. In the past, metallic implants were used to determine the percentage of contribution of growth between these two methods of growth, finding that sutural growth accounted for 6.7mm of the total 9.5mm of maxillary transverse growth (Bjork & Skieller, 1977). Transverse growth at the posterior of the suture is also greater than at the anterior, and this growth differential pattern causes the two maxillary halves to rotate in the transverse plane (Bjork & Skieller, 1974). Consequently, the posterior aspect of the dental arch is widened more than the anterior as surface remodeling occurs at the lateral periosteal surface of the maxillary tuberosity (Enlow, Moyers, & Merow, 1975).

Maxillary growth in the transverse plane closely parallels the growth velocity curve of other cranial-facial structures. In addition, statural growth velocity curves can be used to generally predict the times of rapid acceleration and deceleration of transverse sutural growth, though MPS growth will reach completion before statural growth (Bjork, 1966). Maxillary transverse growth is most rapid between the ages of 7 and 11 in both males and females, with growth being complete at the age of 15 for females and 17 for males (Snodell et al., 1993). After completion of growth, the suture becomes more sinuous and interdigitated as the adolescent ages into adulthood. Complete obliteration of the suture generally does not occur until the 3rd decade of life, with closure progressing from oral to nasal and posterior to anterior. Interestingly, although sutural closure of the palate begins at the same time as the other facial sutures, it does not progress as rapidly and complete closure is generally later (Persson & Thilander, 1977).

Although the growth and development of the maxilla are well understood, the exact etiology of maxillary skeletal constriction is not. Some hypotheses that have been proposed include altered tongue position during mouth breathing and the effects of oral habits. Studies on rhesus monkeys demonstrated that obligate mouth breathing can lead to an increase in lower facial height, lowered mandibular position, and a narrow maxillary arch. The theory is that as the tongue is lowered away from the palate during mouth breathing, the inward pressure of the musculature and soft tissue overpower the dentition, leading to a constricted maxillary arch (Harvold, Chierici, & Vargervik, 1972). However, the studies exploring a greater incidence of crossbites in the mixed dentition with patients who engage in long-term digit or pacifier habits are mixed and inconclusive (Bowden, 1966; Warren et al., 2005). Due to the fact that a true cause and effect relationship for maxillary constriction has not yet been established, the etiology is generally associated with a combination of genetic and epigenetic factors.

Rapid Maxillary Expansion

Treatment for a maxillary constriction generally involves a rapid maxillary expansion appliance. One recent study estimated that 9.4% of the population has a maxillary transverse deficiency related to posterior crossbite (Brunelle et al., 1996). RME treatment is most often indicated for patients with posterior crossbites, but other indications include patients with maxillary deficiency in the anterior-posterior dimension, maxillary crowding, preparation for alveolar bone grafting in cleft-lip-palate patients, and functional shifts.

One of the first known cases of RME treatment was performed by E.H. Angell in 1860. He used a jack-screw appliance on a 14-year-old female with maxillary constriction, being bonded to the maxillary premolars and being turned twice a day for two weeks. After successful expansion, the patient developed a space between the upper central incisors and Angell concluded that the appliance had caused the maxillary bones to separate (Haas, 1961). Despite Angell's discovery, the popularity of RME appliances in the early 20th century fluctuated as many clinicians believed that gentle expansion of the dentition over a long period of time would also cause expansion of the skeleton. During this time, RME appliances were mainly utilized by rhinologists in order to expand the nasal cavity through separation of the midpalatal suture. Brown postulated that expansion of the dentition and lateral nasal walls would widen the nasal cavity and lead to increased nasal airflow (Brown, 1903). Although rhinologists were experiencing continued success with RME treatment, it was not until later that orthodontists would begin utilizing this treatment in the United States.

In 1961, Haas would reintroduce RME treatment and bring its popularity back among the orthodontic community. When running a clinical trial on pigs with an acrylic supported jackscrew, Haas found that he could gain up to 15mm of transverse expansion when MPS separation was achieved. After performing the same acrylic jack-screw treatment on 10 adolescent human patients, he found that he could separate the two halves of the maxilla by 8mm during separation of the MPS. His findings demonstrated how easily the MPS could be separated and the extent of the skeletal change that can occur when utilizing RME treatment (Haas, 1961).

Subsequently, RME would go on to gain widespread acceptance in treating transverse maxillary constriction. Over the years many adaptions and iterations of the maxillary expansion appliance have been proposed and studied. In 2005, Davidovitch compared the effects of 2-band and-4 band tooth-borne Hyrax expanders. He found that the 4-band expander created an increase in sutural width 4 times greater than that of the 2-band expander group. In addition, the 4-band group achieved MPS separation on patients up to 17 years of age, while the 2-band group was not able to create suture separation on any patient over the age of 12 (Davidovitch, Efstathiou, Sarne, & Vardimon, 2005). Another popular expansion appliance is the tooth-tissue-borne Haas expander which utilizes acrylic pads in the palate of the maxilla in hopes of obtaining additional skeletal anchorage. However, after a clinical trial done by Weissheimer in 2011, it was concluded that there was no skeletal benefit of the Haas type expander over the traditional Hyrax expander. In fact, the Hyrax type expander produced slightly greater orthopedic effects in 3 of the 5 skeletal points measured, though it was not thought to be clinically relevant (Weissheimer et al., 2011). In addition, Garib utilized computed tomography to further evaluate the periodontal effects of Haas and Hyrax expanders. He found that Haas expanders produced significantly less buccal bone dehiscence at the first premolar, which can be attributed to the fact that these teeth are not banded with a Haas type appliance (Garib, Henriques, Janson, de Freitas, & Fernandes, 2006).

Resistance to Expansion

During expansion with an RME, when the jackscrew is turned forces are first transmitted to the teeth anchoring the appliance. When the forces on the teeth exceed the load capacity and width of the periodontal ligament, the force is then applied to the alveolus and skeleton. This heavy force is too rapid and intense to cause tooth movement and are instead transmitted to the skeletal sutures (Zimring & Isaacson, 1965). These intense lateral forces on the skeleton then cause the MPS to open. Prior studies have shown that anywhere from 2-10 pounds of orthopedic force is required to cause MPS separation (Isaacson & Ingram, 1964).

The force from an RME appliance builds until movement of the dentition or skeleton occurs. After activation of the RME, the initial load is stored in the appliance until there is movement of the skeleton and the force is able to dissipate. One study demonstrated that the initial load from the appliance dissipates 30-50% in the first 15 minutes and then slowly declines over the next 24 hours. This dissipation of force is due to eventual movements of the maxilla and dentition. However, if the corresponding skeleton and dentition do not yield to the force, residual loads of up to 20 pounds can be observed with multiple daily activations (Isaacson & Ingram, 1964). In addition, higher residual loads, slower dissipation of force, and higher total loads with fewer activations are often seen in older patients due to increased skeletal resistance to expansion (Zimring & Isaacson, 1965).

As the MPS becomes more sinuous and interdigitated with age, it would seem logical that this would likely be the primary area of resistance to expansion. However, several studies have shown that this is not the case. Isaacson demonstrated that the expansion force after appliance activation remained constant, even after MPS separation was achieved. He concluded that this resistance to the force of expansion must be coming from other articulations in the maxilla (Isaacson & Ingram, 1964). Shetty would go on to demonstrate that the only predictable way to expand the maxilla in adults would be to perform midpalatal and pterygomaxillary osteotomies, signifying that maxilla needed to be disarticulated from the rest of the skeleton in order to be readily expanded (Shetty, Caridad, Caputo, & Chaconas, 1994). In addition, Haas also believed that the zygomatic buttress was the primary reason that the MPS suture opens more in the anterior than in the posterior during expansion (Haas, 1961).

As age increases, there is also a decrease in the cellular response to expansion forces. One study demonstrated this by evaluating the osteoblastic cyclic nucleotide levels expressed at the MPS in cats. They reported an increase in the osteoblastic activity with applied tensile forces in younger cats but showed a significant reduction in osteoblastic activity in older subjects (Brin et al., 1981). This suggests that the reduction in osteoblastic activity in older animals makes them less responsive to the forces of maxillary expansion.

Skeletal Effects of Expansion

As the forces of expansion are applied to the anchor teeth of the appliance, lateral bending of the alveolus begins to occur. As the alveolus bends outwardly, the teeth housed in the alveolar process are tipped buccally (R. A. Wertz, 1970). In addition, the teeth are compressed in the periodontal ligament due to the lateral forces applied by the appliance, which leads to additional facial tipping of the teeth. After this first phase of alveolar bending and dental tipping, if the force is sufficient and the restrictive forces of the skeleton yield to the load of the appliance, then separation of the MPS occurs.

The midpalatal suture opens in a pyramidal manner in both the transverse and frontal planes. In the transverse plane, the widest opening of the suture occurs at the anterior nasal spine and gradually narrows going posteriorly. As mentioned previously, posterior resistance from the zygomatic buttress is thought to be the reason for this wedge-shaped opening in the transverse plane (Haas, 1961). Similarly, in the frontal plane, the maxilla also separates in a pyramidal, wedge-shaped manner. The fulcrum is located in the superior maxilla near to the maxillofrontal suture and progressively widens from that point inferiorly. The two halves of the maxilla tip out laterally as much as 8 degrees, while the molars tip buccally as much as 14 degrees (Hicks, 1978).

Movement of the maxilla in the sagittal plane can also be observed during RME treatment. Downward and forward displacement of the maxilla has been reported, although the actual skeletal movement is very small and not clinically significant (Chung & Font, 2004). In addition, several studies have demonstrated that over the long term, any changes of the maxilla in the sagittal or vertical dimension associated with RME treatment are extremely minor and are often retrieved during retention (Chang, McNamara, & Herberger, 1997; R. A. Wertz, 1970).

Finally, changes in the maxilla during RME treatment can also lead to short term vertical changes in the position of the mandible. As the occlusion is disrupted from the lateral movement of the maxillary teeth, cusp-to-cusp interferences can occur which can open the bite. The mandible subsequently rotates down and back leading to a longer lower anterior facial height and steeper mandibular plane angle. However, studies have shown that these changes are transitory and that any mandibular displacement from RME treatment is recovered in the long term (Chang et al., 1997; R. A. Wertz, 1970).

Dental Effects of Expansion

If a successful separation of the MPS occurs during maxillary expansion, then a diastema will form between the two central incisors. As the teeth separate due to an opening of the suture, the roots of these teeth diverge and the crowns converge as they are pulled together through cervically located transeptal fibers. After completion of the expansion, the roots continue to diverge as the crowns are further brought together and ultimately closure of the diastema occurs around 4 months post-expansion (Haas, 1961).

Dental arch changes during expansion include increased arch width and increased arch perimeter with a decrease in arch length. One study reported that RME treatment of individuals in the mixed dentition averaged an increase in arch width of 2.9mm at the canines and 6.5mm at the molars. The average arch length decreased by 0.4mm while arch perimeter increased by 4.7mm. The authors went on to conclude that during RME treatment, every 1mm of arch expansion would yield an increase of 0.7mm in arch perimeter. In addition, the study also found that buccal inclination of maxillary molars increased by 7.3 degrees on average during expansion (Adkins, Nanda, & Currier, 1990).

All of the maxillary arch changes produced from RME treatment result from a combination of skeletal and dental movements. In general, skeletal changes account for a greater percentage of arch width increase in the anterior maxilla, while alveolar bending and buccal tipping account for most of the arch width change in the posterior maxilla (Garrett et al., 2008). This finding is supported by the idea that the zygomatic buttress restricts skeletal opening of the posterior suture and leads to an increase in the dentoalveolar effects of expansion in the molar region of the arch.

Periodontal Effects of Expansion

There can be untoward effects on the periodontium and supporting bone during expansion, especially if MPS separation is not achieved. These negative effects include gingival recession, attachment loss, and osseous defects on the buccal of the maxillary teeth. Teeth that are more often adversely affected by expansion are buccally positioned prior to treatment, have thin keratinized mucosa, and have the presence of plaque-induced inflammation (Garib et al., 2006; Wennstrom, Lindhe, Sinclair, & Thilander, 1987). In children, one study found that long-term gingival recession can be seen in 20% of patients treated with RME compared to only 6% of children in the control groups (Vanarsdall, 1995). Northway compared the amount of gingival recession in adults treated with surgically assisted rapid maxillary expansion to adults treated with conventional rapid maxillary expansion. The adult group treated with non-surgical expansion had twice the amount of recession at the molar and premolar. For example, the premolar crown length increased 1.2mm in the non-surgical group but only 0.5mm in the surgical group (Northway & Meade, 1997). These findings demonstrate the importance of achieving separation of the MPS in order to decrease the adverse effects that expansion can have on the periodontium.

Effects of Expansion with Increasing Age and Maturation

Several studies have demonstrated that as patients increase in age, opening of the MPS becomes more difficult and the amount of skeletal orthopedic change is reduced. For example, Handelman studied the amount of orthodontic change vs skeletal change after expansion when comparing children to adults. His results demonstrated that skeletal expansion accounted for 56%

of the total expansion in children yet only accounted for 18% of the total expansion in adults. He also found that there was a statistically significant increase in the amount of alveolar tipping and buccal inclination in the adult group compared to the child group (Handelman et al., 2000). These findings suggest that more dentoalveolar bending and dental tipping occur as patients grow into adulthood. A study performed by Hicks also found that skeletal expansion accounted for up to 30% of total arch width changes in patients 10-11 years of age, whereas older subjects of 14-15 years of age only experienced skeletal changes of 16% (Hicks, 1978). In addition, Krebs studied the amount of arch width increase due solely to an orthopedic change in patients treated with expansion. He found that skeletal change accounted for one-half of arch width increase in subjects 8-12 years of age but only one-third of the increase in patients 13-18 years of age (Krebs, 1964). Finally, a study done by Wertz found that even though expansion was clinically effective at all ages, older patients underwent minimal skeletal change and that their orthopedic results were not as stable long-term (R. Wertz & Dreskin, 1977).

Research has also found that patient maturation and pubertal status has an effect on the amount of expected dental vs skeletal change during expansion. For example, in 1982 Bell concluded that opening of the MPS was more difficult if the patient had already completed their pubertal growth spurt and that the most opportune time for a patient to undergo expansion was either before or during their pubertal growth period (Bell, 1982). Bacetti would go on to study the effects of maturation and puberty on expansion by using the cervical vertebral maturation method to place subjects into various groups based on their pubertal status. Patients were classified into either an early treatment group if they were pre-pubertal or placed in a late treatment group if they were post-pubertal. His results demonstrated that rapid maxillary expansion will produce a significant increase in intermolar width compared to controls, no matter if the patient is pre or post-puberty. However, subjects in the prepubertal group exhibited more significant and effective long-term skeletal changes in the maxillary and circomaxillary structures. For example, patients treated in the prepubertal group exhibited a transverse skeletal increase of growth of 3mm over controls, while the post-pubertal group only showed an increase of 0.9mm. The authors concluded that when RME therapy is performed after the pubertal growth spurt, the adaptions of the maxilla shift from skeletal level to more pronounced changes of the dentoalveolus (Baccetti, Franchi, Cameron, & McNamara, 2001). One limitation of this study is that the authors relied upon the cervical vertebral maturation method to assess the timing of the pubertal growth spurt. Research has shown that CVM is inferior to statural height, hand-wrist staging, and even chronological age at indicating peak growth velocity of the facial skeleton (Mellion, Behrents, & Johnston, 2013).

Mini-screw Supported Maxillary Expansion

When late adolescent and adult patients present with a severe transverse skeletal discrepancy due to a constricted maxilla, the treatment options are usually either surgically assisted rapid maxillary expansion or a maxillary segmental osteotomy with bilateral expansion of the maxillary segments. However, due to the inherent trauma, surgical risk, and high cost of these invasive procedures, many clinicians have been searching for alternative treatment options. One emerging and innovative treatment that clinicians have begun to utilize is mini-screw supported Hyrax appliances, otherwise known as non-surgical mini-screw assisted rapid maxillary expansion (MARME).

In 2010, a case study was performed on a 20-year-old man with a severely constricted maxilla as well as a skeletal anteroposterior class III discrepancy. Traditional treatment would include two surgeries: Surgically assisted rapid maxillary expansion followed by orthognathic surgery. Instead of pursuing surgical expansion, the researchers fabricated a 4-banded Hyrax appliance with four rigid connectors of stainless steel wire with helical hooks soldered onto the body of the appliance. Two of the hooks were placed in the anterior rugae region and the other two were placed posteriorly in the parasagittal area of the hard palate. Four 7-mm length mini-screws were placed in the center of the helical hooks under local infiltration anesthesia, and nonsteroidal anti-inflammatory drugs were prescribed for pain control. The expansion screw was turned once a day at a rate of 0.25mm per day for 6 weeks. Separation of the MPS was achieved and confirmed by intraoral radiographs as well as a PA cephalogram. Intermolar width showed an increase of 8.3mm and maxillary basal bone width and nasal width increased by 2.4mm and 2.5mm, respectively. The expansion was held for 3 months before further dental alignment and eventual orthognathic surgery. Following debond and at 18 months post-treatment, there was no gingival recession, bony dehiscence or attachment loss and an axial computed tomogram showed sound periodontal supported of all the maxillary roots (K. J. Lee, Park, Park, & Hwang, 2010).

Recently, researchers have sought to determine the validity and merit of mini-screw assisted RME appliances in treating transverse maxillary skeletal deficiency in young adults. Slight variations in appliance design have been introduced, though the general concept of a tooth-bone-borne Hyrax expander with titanium mini-screws inserted into the hard-palate remain similar. Common names include non-surgical mini-screw assisted rapid maxillary expansion (MARME), mini-implant-assisted rapid palatal expansion (MARPE), and maxillary skeletal expansion (MSE). The current literature remains promising and the popularity of this treatment has grown more popular among practicing clinicians.

In 2016, Choi performed a comprehensive study that evaluated the effects and stability of MARME treatment in 69 adult patients (mean age 20.9 years, range 18-28 years). His appliance included a 4-banded Hyrax appliance connected to 4 mini-screws near the midline of the palate. He found that MARME produced successful separation of the MPS in 87% of the patients (60/69). The study further noted that significant increases in the nasal cavity (0.9mm), maxillary width (1.9mm), and middle alveolus width (2.0mm) accounted for 19%, 43%, and 45%, respectively, of the total expansion in regard to intermolar width (4.4mm). All of the dental and skeletal changes remained stable during retention and subjects did not experience any significant gingival recession and/or bony dehiscences (Choi et al., 2016).

Cantarella produced similar results when he treated 15 subjects (mean age 17.2 years, range 13.9-26.2 years) with maxillary skeletal expansion and took CBCT images pre- and post-treatment to analyze the skeletal changes. She utilized a 2-banded Hyrax appliance placed on the 1st molars connected to 4 mini-screws placed near the midline of the palate. All subjects achieved separation of the MPS and imaging found that the amount of opening of the posterior suture was 90% of that found in the anterior suture. This near parallel anteroposterior opening of the suture is in contrast to the pyramidal shaped opening achieved with traditional RME appliances. In addition, expansion of the MPS was 71% and 63% at ANS (4.8mm) and PNS (4.3mm), respectively, of the amount of jackscrew activation (6.8mm). This ratio of sutural opening is dramatically higher than previous literature has reported for traditional RME appliances (Cantarella et al., 2017).

Lin performed a retrospective study that utilized CBCT to compare the expansion effects of late adolescent patients treated with either a traditional tooth-borne RME appliance (n = 13, age 17.4 ± 3.4 years) or a bone-borne MARPE appliance with no bands on the teeth (n = 15, age 18.1

± 4.4 years). The MARPE appliance used in this study utilized a tissue-borne acyclic base connected to 4 mini-screws placed in the lateral aspect of the palate. Their results showed that bone-borne MARPE appliances produced almost twice the amount of expansion at the skeletal level than the tooth-borne appliances. As in previous studies, traditional RME appliances produced a triangular opening of the suture while the MARPE appliance produced a nearly parallel MPS opening. The ratio of skeletal to dental expansion in the MARPE group (54.7-77.0%) was also greater than that of the traditional RME appliance group (25.6-42.9%). In addition, they also found that the bone-borne expander group had less alveolar bending, less dental tipping, and less alveolar bone loss. The authors concluded that bone-borne expansion can be an effective treatment modality for maxillary skeletal deficiency in late adolescent patients (Lin et al., 2015).

In contrast, Lagravere performed a study in 2010 that produced different results when using CBCT to compare bone-anchored RME appliances to traditional RME appliances. His findings showed that both appliances produced similar results both at the dental and skeletal level and that there was no advantage of mini-screw assisted expansion (Lagravere, Carey, Heo, Toogood, & Major, 2010). However, some researchers have questioned the findings of this study. Both subject groups were treated in early adolescence (average age 14.24 and 14.05 years) which could, in theory, have reduced the benefit of the additional skeletal anchorage provided by MARME. In addition, the appliance utilized by the researches in this study only included 2 mini-screws in the lateral posterior palate, different than the 4 mini-screws commonly placed in the anterior and posterior palate as seen with other MARME appliances (Lin et al., 2015).

In summary, the current literature on mini-screw assisted rapid maxillary expansion is very promising. Common findings include an increased transverse maxillary skeletal response, parallel opening of the midpalatal suture, and reduced side effects to expansion such as buccal tipping of the dentition, gingival recession, and bony dehiscence.

Mini-screw Supported RME Design

The amount of literature on mini-screw assisted RME design implications is very limited. Lee studied the effects of bicortical vs monocortical placed mini-implants on bone-borne expansion using skull models. He found that bicortical mini-screws provided more pronounced transverse displacement at all 3 of the reference points measured. In addition, the authors noted that bicortical mini-implants resulted in improved implant stability, decreased mini-implant deformation and fracture, and more parallel expansion in the coronal plane (R. J. Lee, Moon, & Hong, 2017). Another study analyzed the effects that various osteotomies of the maxilla and its articulations can have on bone-borne expansion. The authors concluded that simple surgical separation of the midpalatal suture prior to MARPE treatment in adults would lead to increased transverse skeletal expansion, increased expansion in the anterior dentition and decreased stress on the maxillary skeleton (S. C. Lee et al., 2014).

In 2014, researchers studied the skeletal and dental effects of 4 different types of mini-screw assisted expansion appliances on skull models. The appliances used were as follows: (A) 4 mini-screws inserted along the midline with no dental support, (B) 4 mini-screws placed into acrylic pads along the lateral aspect of the palate, (C) 4 mini-screws inserted along the midline with 4-banded dental support, and (D) surgically assisted appliance with 4-banded dental support. They found that type C expanders produced the greatest amount of transverse displacement of the dentoalveolar unit followed by type A, with type B producing the least. However, type B appliances produced alveolar expansion without any buccal tipping of the dentition, whereas type C produced the most inclination of the dentition during treatment. Type D produced the most parallel opening of the suture compared to the other appliances. The authors advised that mini-screws be placed on the lateral aspects of the palate to avoid any negative dental effects caused by expansion (H. K. Lee et al., 2014).

MATERIALS AND METHODS

Study Design and Participants

The study sample consisted of records from patients treated with rapid maxillary expansion (N=109; 59 females, 50 males, age range: 7-29) at the University of Iowa College of Dentistry Orthodontic Department (Table 1). Subjects were treated consecutively from July 2016 to December 2018. Inclusion criteria included a diagnosis of unilateral or bilateral crossbite, transverse dental compensations, minimal buccal overjet, and a treatment plan of rapid maxillary expansion. Any subjects with craniofacial anomalies including cleft lip and palate were excluded from the study. The study was reviewed and received approval from the University of Iowa institutional review board.

All of the subjects were treated by residents and faculty in the Orthodontic Clinic at the University of Iowa College of Dentistry. Subjects were given the option to be treated with a tooth-borne Hyrax expander or a bone-borne MARME appliance. Subjects in mid-to-late adolescence were presented with information on MARME appliances and with the possibility of achieving more skeletal expansion at their increased age and maturation with this treatment option. Out of the study sample, 13 subjects (average age: 17.1 years, age range: 14-22 years) elected to undergo MARME treatment. The MARME appliance consisted of Dentaurum Palex® Maxi 12mm screws with .036” wire soldered to the support arms to hold the mini-screws. All of the MARME appliances utilized four bands placed on the maxillary 1st premolars and 1st molars. Depending on the Clinician’s preference and availability, the mini-screws placed included Thomas Dentaurum SD® 1.6x8mm/1.6x10mm, Ortho Technology K1® 1.5x8mm/1.5x10mm, and 3M Unitek

1.8x8mm/1.8x10mm. The remaining 96 subjects were treated with a traditional RME Hyrax appliance (average age: 13.8 years, age range 7-29). Depending on the preference of the clinician and the width of the palate, a Dentaurum Palex® Maxi 12mm or 7mm screw was used. Clinicians chose to either utilize a 4-banded appliance or a 2-banded appliance with mesial extension arms that extended from the maxillary 1^{st} molars to the lingual of the maxillary 1^{st} premolars. Examples of both types of expander appliances can be seen in figure 1.

The appliances were activated 1 to 2 turns per day until the palatal cusps of the maxillary 1^{st} molars were almost in buccal crossbite with the buccal cusps of the mandibular 1^{st} molars, or until the clinician determined that adequate expansion had been achieved. Once activation of the appliance was completed, maxillary photographs, occlusal radiographs, and maxillary scans or models were created for record purposes. Separation of the MPS was confirmed by the development of a diastema between the maxillary central incisors or by interpretation of the maxillary occlusal radiograph. A Non-MPS Separation was determined by the clinician if there was an absence of a diastema between the maxillary central incisors and by interpretation of the maxillary radiograph. Example occlusal photographs and radiographs featuring subjects with MPS Separation and No Separation can be seen in figure 2.

In addition, the maturation status of available subjects was recorded at the time of expansion. Out of the 109 subjects included in the study, 10 subjects did not have information on maturation and were therefore not included in this section of the study. The subjects with maturation data (n=99, 55 females, 44 males) were divided into pre-pubertal and post-pubertal groups. Maturation was determined by asking the subject's parents the age of menarche in females, and the age of secondary sexual characteristics (voice change, cessation of pubertal growth spurt, facial or pubic hair) in males. If the subject was post-puberty, then the number of months that they were past puberty was also recorded.

Examination of Variables

The variables recorded in this study include age, gender, separation status, RME type, pre- or post-puberty, and months past puberty for every patient who was post-puberty. The association between the outcome variable of separation status (MPS Separation vs. No Separation) was tested for significance regarding gender, age, months past puberty, and pubertal status. Next, associations between the variable of separation status (MPS Separation vs. No Separation) and the type of RME appliance (MARME vs. traditional RME) were tested for significance with post-pubertal subjects at ages ≥13, 14, 15, and 16 years old. In addition, the relationship between age and the percent ability to get MPS separation at each year of age was evaluated. Finally, the relationship between the months past puberty and the percent ability to get MPS separation at 6-month intervals was also determined. Note that the MPS separation percentages for age and months past puberty were calculated by combining subjects into groups based each year of age and 6-month intervals, respectively, to obtain the percent of subjects who successfully achieved MPS separation.

Statistical Analysis

Descriptive statistics were conducted to provide a summary of the characteristics of the participants in the study. The chi-square test, Fisher's exact test, and the Wilcoxon rank-sum test as appropriate were used to detect the associations of successful separation of the maxillary MPS with gender, age, pubertal status, and the type of RME appliance. A Pearson correlation test was used to determine whether there was a significant relationship between months past puberty and percent of subjects to get MPS separation as well as between the age of the child and percent of subjects to get MPS separation. In addition, a simple linear regression analysis was conducted to generate an equation to describe the statistical relationship between these variables. All tests utilized a statistical significance level of 0.05, and SAS for Windows (v.9.4, SAS Institute Inc., Cary, NC, USA) was used for the statistical analysis.

Table 1 – Subject Demographic Information

Subject	Age (decimal)	Gender (M, F)	Pubertal Status (Pre=1, Post= 2)	Months Past Puberty	MPS Separation (1= Yes, 2= No)	RME =1 TAD RME = 2
1	15.17	F	2	33	1	1
2	12.08	F	2	10	1	1
3	13.25	M	2	5	1	1
4	13.33	M	2	8	1	1
5	13.58	F			1	1
6	14.33	M	2	36	1	1
7	18	M	2	30	2	1
8	10.58	M	1		1	1
9	16	M	2	15	1	1
10	18.42	M	2	60	2	1
11	16.25	M			2	1
12	12.33	F	1		1	1
13	13.67	F	2	25	1	1
14	12.08	M			1	1
15	13.67	M	1		1	1
16	13.42	F	2	13	1	1
17	12.75	F	2	4	2	1
18	12.58	F	1		1	1
19	14.75	M	2	11	2	1
20	12.25	F	1		1	1
21	11.08	F	1		1	1
22	12.42	M	1		1	1
23	11.67	M	1		1	1
24	14.42	F	2	4	1	1
25	16.58	F	2	36	2	1
26	11.25	F	1		1	1
27	12.75	F	2	14	1	1
28	14.58	F	2	47	2	1
29	15.17	M	2	31	1	1
30	12.58	M	2	18	1	1
31	10.75	M	1		1	1
32	14.08	F	2	13	1	1
33	14.92	F	2	15	2	1
34	14.33	F	2	35	2	1
35	10	F	1		1	1
36	15.67	M	2	55	2	1
37	15.75	M	2	16	1	1
38	13	F	1		1	1
39	11.42	M	1		1	1
40	14.75	F	2	22	2	1

Table 1 – Continued

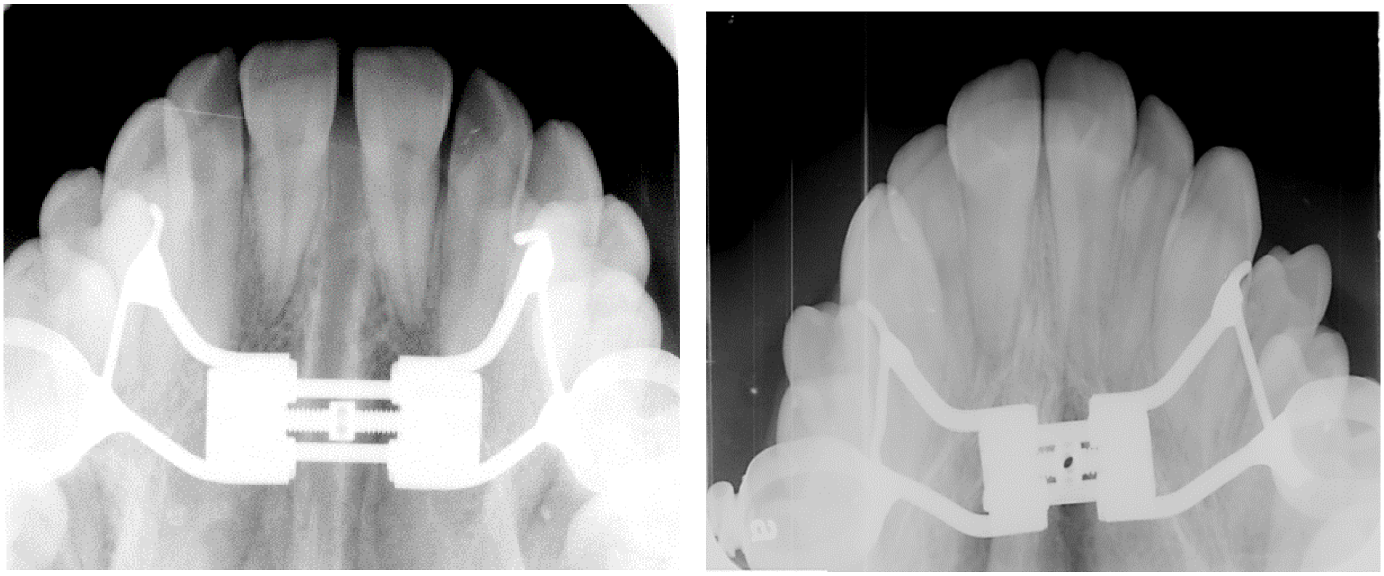
41	29.17	M	2		2	1
42	15.75	F	2	38	1	1
43	13.58	F	2		1	1
44	16.25	M	2	30	2	1
45	12.33	F	2	2	1	1
46	13	M	2	3	1	1
47	12.33	F			1	1
48	14.33	F	2	10	1	1
49	14.5	F	2	24	2	1
50	14.42	F	2	30	1	1
51	13	M	1		1	1
52	11.42	F	1		1	1
53	13.67	M	1		2	1
54	16.67	F	2	44	2	1
55	7.58	F	1		1	1
56	9.33	M	1		1	1
57	13	F			2	1
58	10.25	M	1		1	1
59	15	F	2	33	1	1
60	7.92	F	1		1	1
61	15	M	2	24	1	1
62	14	M	2	7	1	1
63	11.17	F	1		1	1
64	11.67	F	1		1	1
65	12.5	F	2	5	1	1
66	13.83	F	2	7	1	1
67	15.25	F	2	34	2	1
68	13.5	M			1	1
69	15.58	F	2	44	1	1
70	17.33	F	2	41	2	1
71	13.75	M	2	1	1	1
72	13.58	M	2	12	2	1
73	13.17	F	1		1	1
74	13.58	F	2	9	1	1
75	13.58	M	2	9	1	1
76	13.08	M	2	12	2	1
77	13.67	M	2	21	2	1
78	15.67	F	2	10	1	1
79	19.75	F	2	54	1	1
80	13.5	M			1	1
81	18.08	M	2	48	2	1
82	13.75	M	2	17	2	1
83	13.58	F	1		1	1
84	14	F	2	7	2	1

Table 1 – Continued

85	14.5	M	2	7	1	1
86	11.75	M	1		1	1
87	11.5	M	1		1	1
88	12.08	F	2	10	1	1
89	13.58	F			1	1
90	16.08	M			2	1
91	14.67	M			2	1
92	14.92	F	2	15	1	1
93	12.92	F	2	1	1	1
94	10.08	M	1		1	1
95	15.17	F	2	37	1	1
96	12	F	1		1	1
97	18	M	2	60	1	2
98	18	F	2	60	1	2
99	22.58	M	2	60	1	2
100	15.67	F	2	60	1	2
101	14.25	F	2	18	1	2
102	14.42	M	2	13	1	2
103	17.17	M	2	38	1	2
104	17.83	F	2	58	1	2
105	17.33	F	2	52	1	2
106	16.42	F	2	41	1	2
107	15.42	M	2	29	1	2
108	17.75	M	2	43	1	2
109	16.75	M	2	44	1	2

Figure 1 – Examples of a Traditional RME (left) and Mini-screw Assisted RME Appliance (right).

Figure 2 – Examples of MPS Separation (left) and No Separation (right).



RESULTS

A total of 109 subjects (54.1% females and 71.7% post-pubertal status) who fulfilled all the inclusion criteria were included in the study. Of the 96 subjects with traditional RME treatment (mean age=13.8±2.6 years, range=7.6-29.2 years), 71.9% achieved successful separation of the maxillary MPS and 67.4% were post-puberty. Among the 13 subjects with mini-screw assisted RME treatment (mean age=17.1±2.1 years, range=14.3-22.6 years), 100% had successful separation of the maxillary MPS and 100% were post-puberty. Table 2 displays a summary of descriptive results on the characteristics of the study subjects.

Traditional RME Treatment

A total of 96 subjects treated with a traditional RME, including 69 subjects who had successful MPS separation and 27 subjects who didn't, were included in the analysis. Of the 53 female subjects, 41 (77.4%) subjects had successful MPS separation. Among the 43 male subjects, 28 (65.1%) subjects had successful MPS separation.

Age, months past puberty and pubertal status were significantly associated with MPS separation status (Table 3). The data showed that age and months past puberty for subjects with successful MPS separation were statistically significantly lower than that observed among subjects without successful MPS separation ($p<0.001$ and $p=0.007$, respectively). Moreover, subjects that were pre-puberty were more likely to have successful MPS separation than that observed among the subjects who were post-puberty (96.4% vs. 62.1%; $p=0.001$). However, gender was not associated with MPS separation status ($p=0.185$).

Traditional RME: Age vs MPS Separation

For all subjects treated with a traditional RME, a Pearson correlation test provided strong evidence that a statistically significant correlation existed between age and percent ability to achieve MPS separation (p=0.0005). A strong correlation also was seen for females (p=0.0034) and for males (p=0.0002). Moreover, the Pearson coefficient of -0.92 indicated a strong negative correlation between the two variables. That is, as age increases, the percent chance to get MPS separation decreases, and vice versa. The Pearson coefficient -0.89 for females and the Pearson coefficient of -0.93 for males also indicated a strong negative correlation.

With simple linear regression, the MPS separation percentage was regressed on the age in years of the subject. Therefore, the percent of subjects who had successful MPS separation could be predicted from age of the child by the following equation: MPS Separation % = -14.1*Age + 255.3, with an overall model fit of R-square=0.845. This analysis revealed that the predictor of age was statistically significant (coefficient=-14.1, p=0.0005). That is, the equation shows that the coefficient for age (in years) is -14.1 which indicates that for every additional year in the age of the child you can expect the percentage of subjects who will have successful MPS separation to decrease by an average of 14.1%. R-square is equal to 0.845 which means that 84.5% of the variance in percent of subjects who had successful MPS separation was explained by age of the child. The fitted line plot in Figure 3 shows the same regression analysis results graphically.

For female subjects, the analysis revealed that the predictor of age was also significant (coefficient = -16.6, p=0.0034). The MPS separation percentage for females could be predicted from age by the following equation: MPS Separation % for Females = -16.6*Age + 291.8, with an overall model fit of R-square=0.784. The equation shows that the coefficient for age is -16.6%

and R-square is equal to 0.784. The fitted line plot in Figure 4 shows the same regression analysis results graphically.

In males, the analysis revealed that the predictor of age was significant as well (coefficient = -14, p=0.0002). The MPS separation percentage for males could be predicted from age by the following equation: MPS Separation % for Males = -14*Age + 254.1, with an overall model fit of R-square=0.874. The equation shows that the coefficient for age is -14% and R-square is equal to 0.874. The fitted line plot in Figure 5 shows the same regression analysis results graphically.

Traditional RME: Months Past Puberty vs MPS Separation

Of the 96 subjects treated with a traditional RME, 56 subjects who had records of months past puberty were included for the analysis. Among the 56 subjects (33 females and 23 males), 35 subjects had successful MPS separation. Of the 33 female subjects, 22 (66.7%) subjects had successful MPS separation. Among the 23 male subjects, 13 (56.5%) subjects had successful MPS separation.

For all subjects treated with a traditional RME, a Pearson correlation test of the data provided evidence that a marginally statistically significant correlation existed between months past puberty and percent ability to achieve MPS separation (p=0.0959). While a strong correlation was seen for females (p=0.0193), there was no statistically significant correlation for males (p=0.1147). Moreover, the Pearson coefficient of -0.90 indicated a strong negative correlation between the two variables. That is, as months past puberty increases, the percent chance to get MPS separation decreases, and vice versa. The Pearson coefficient of -0.98 for females also indicated a strong negative correlation.

With simple linear regression, the MPS separation percentage was regressed on months past puberty of the subject. Therefore, the percent of subjects who had successful MPS separation could be predicted from months past puberty of the child by the following equation: MPS Separation % = -12.9*Months Past Puberty +91.1, with an overall model fit of R-square=0.817. This analysis revealed that the predictor of months past puberty was statistically significant (coefficient= -12.9, p=0.0959). That is, the equation shows that the coefficient for months past puberty is -12.9, which indicates that for every additional 12 months past puberty of the child you can expect the percentage of subjects who will have successful MPS separation to decrease by an average of 12.9%. R-square is equal to 0.817 which means that 81.7% of the variance in percent of subjects who had successful MPS separation was explained by months past puberty. The fitted line plot in Figure 6 shows the same regression analysis results graphically.

For female subjects, the analysis revealed that the predictor of months past puberty was also significant (coefficient = -11, p=0.0193). The MPS separation percentage for females could be predicted from months past puberty by the following equation: MPS Separation % for Females -11*Months Past Puberty +91.7, with an overall model fit of R-square=0.962. The equation shows that the coefficient for age is -11% and R-square is equal to 0.962. The fitted line plot in Figure 7 shows the same regression analysis results graphically.

In males, however, the Pearson correlation analysis revealed that there was NO statistically significant correlation between months past puberty and the percent of males who had successful MPS separation (p=.1147). Therefore, the MPS separation percentage could not be predicted from months past puberty in male subjects.

Mini-screw Assisted RME Treatment

The data revealed that mini-screw assisted RME treatment was associated with a statistically significant higher chance of achieving MPS separation when compared to traditional RME for subjects in post-puberty at age ≥13, 14, 15, or 16 years old ($p<0.05$ in each instance).

Compared to subjects with mini-screw RME treatment, the subjects with traditional RME treatment were less likely to have successful MPS separation, especially as the age increased. At 13 years of age, the traditional RME achieved MPS separation in 58% of subjects compared to 100% of subjects treated with the Mini-screw assisted RME (p=0.003). This disparity is even larger at 16 years of age when traditional RME achieved MPS separation in only 20% of subjects compared to 100% of subjects treated with mini-screw assisted RME (p=0.001). Table 4 provides the detailed results from the analysis.

Table 2 – Summary of Characteristics of the Study Participants

Variables	Study Subjects (N=109)	
	Traditional RME Appliance (N=96)	Mini-Screw RME Appliance (N=13)
Gender (n, %)		
Female	53 (55.2)	6 (46.2)
Male	43 (44.8)	7 (53.8)
Age		
year, mean (SD) (range)	13.8 (2.6) (7.6-29.2)	17.1 (2.1) (14.3-22.6)
Months Past Puberty		
month, mean (SD) (range)	21.5 (15.7) (1.0-60.0)	44.3 (16.3) (13.0-60.0)
Pubertal Status (n, %)		
Pre-puberty	28 (32.6)	0 (0.0)
Post-puberty	58 (67.4)	13 (100.0)
Separation of the Maxillary MPS (n, %)		
Yes	69 (71.9)	13 (100.0)
No	27 (28.1)	0 (0.0)

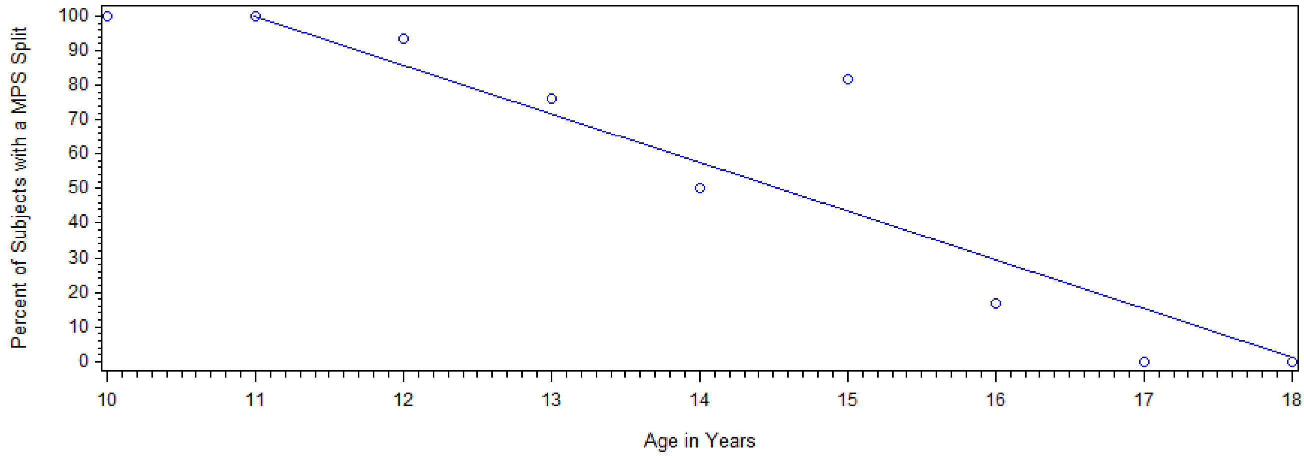
Table 3 – Factors Associated with MPS Separation Status among Subjects Treated with Traditional RME Appliances

Variables	Subjects with Traditional RME (N=96)		p-value
	MPS Separation (N=69) n (%)	**No Separation (N=27) n (%)**	
Gender			0.185
Female	41 (77.4)	12 (22.6)	
Male	28 (65.1)	15 (34.9)	
Age			**<0.001***
mean\median year	13.0\13.2	15.7\14.8	
Months Past Puberty			**0.007***
mean\median year	17.1\13.0	28.8\30.0	
Pubertal Status (n, %)			**0.001****
Pre-puberty	27 (96.4)	1 (3.6)	
Post-puberty	36 (62.1)	22 (37.9)	

*Statistically significantly ($p<0.05$) using the Wilcoxon rank-sum test

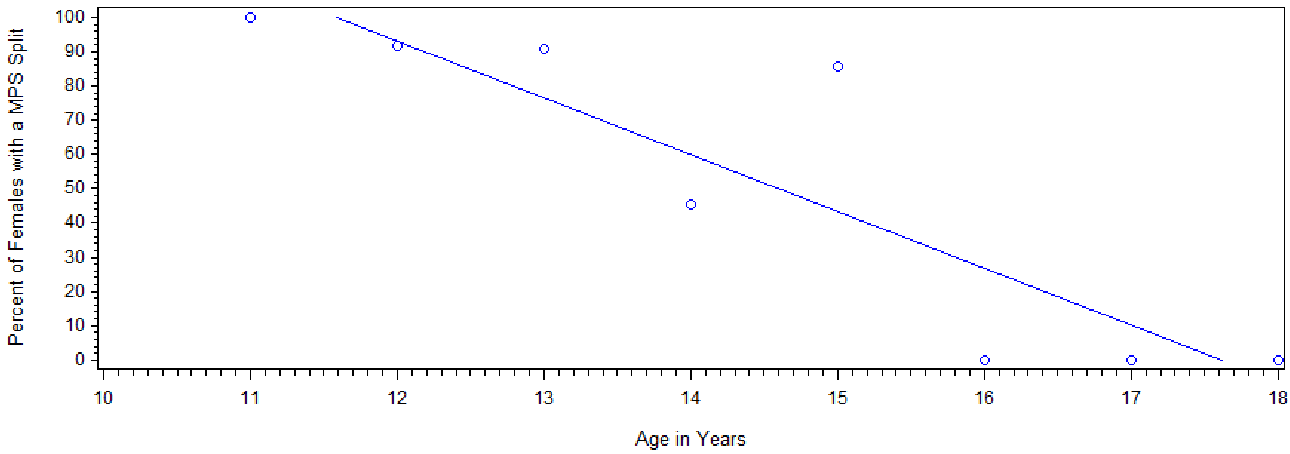
**Statistically significantly ($p<0.05$) using Fisher's exact test

Figure 3 – Relationship between Age and Percent of Subjects with MPS Separation



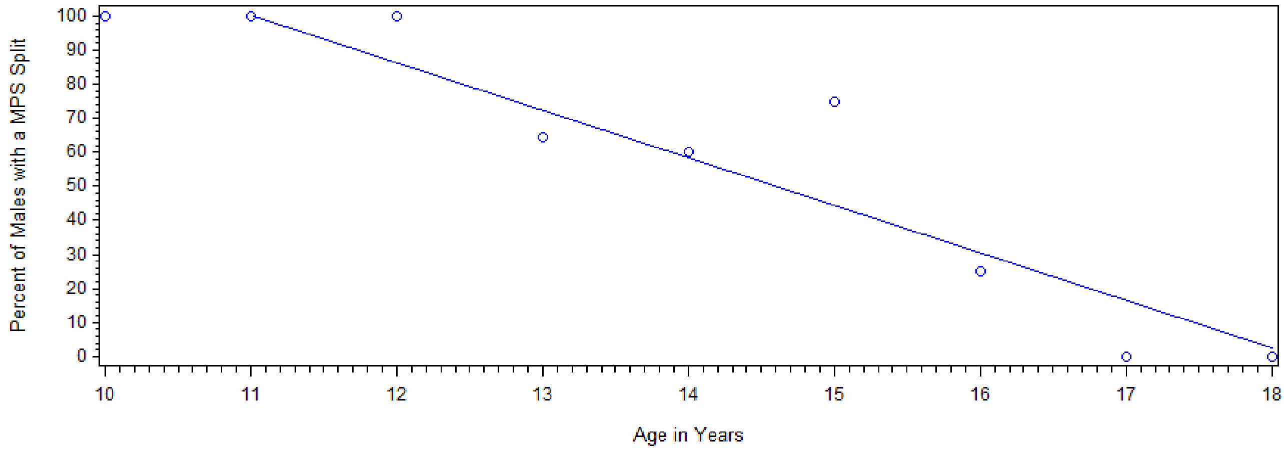
Regression Euqation:
Percent of Subjects Who Had a MPS Split = -14.1*Age + 255.3
(p=0.0005, R-SQ=84.5%)

Figure 4 - Relationship between Age and Percent of Females with MPS Separation



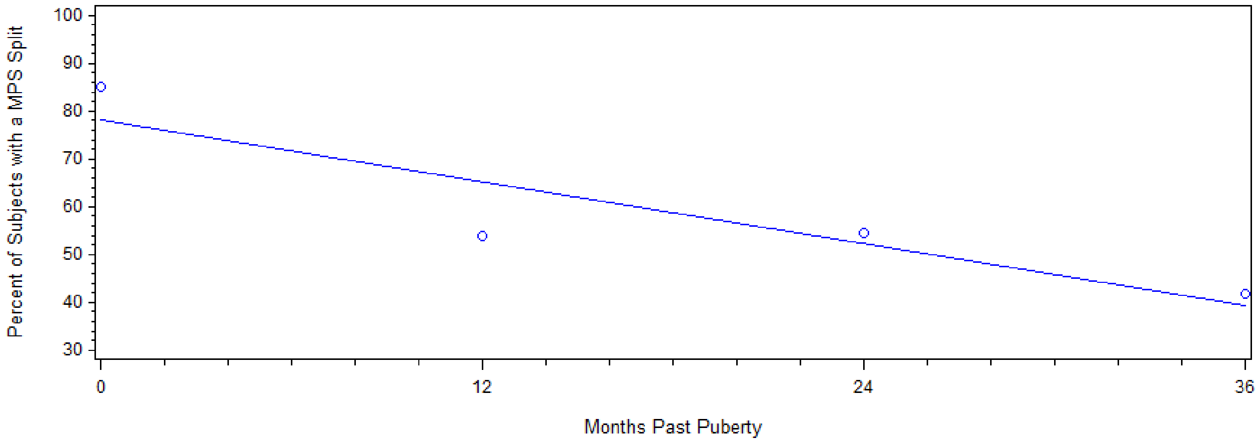
Regression Euqation:
Percent of Females Who Had a MPS Split = -16.6*Age + 291.8
(p=0.0034, R-SQ=78.4%)

Figure 5 - Relationship between Age and Percent of Males with MPS Separation



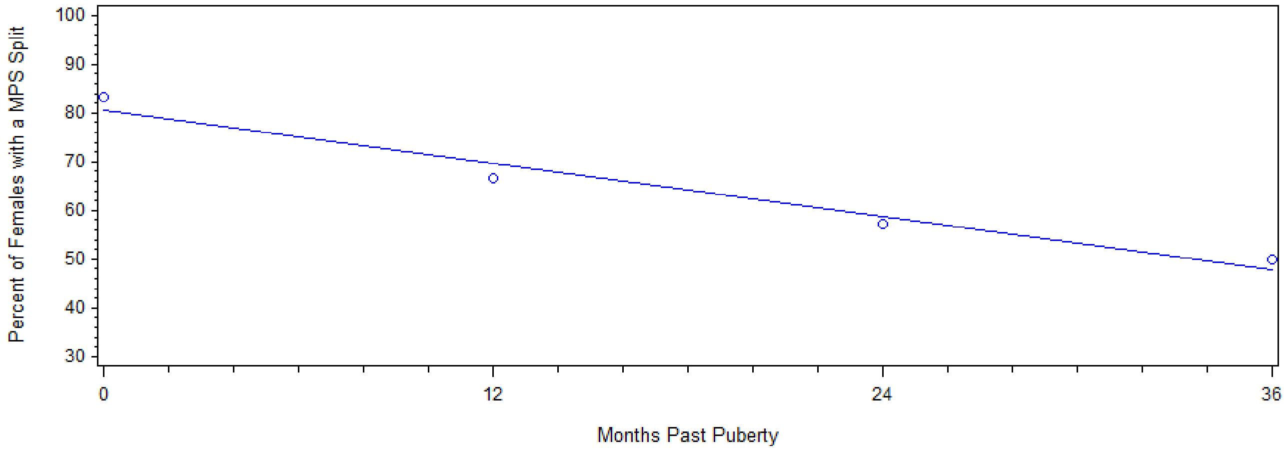
Regression Euqation:
Percent of Males Who Had a MPS Split = -14*Age + 254.1
(p=0.0002, R-SQ=87.4%)

Figure 6 - Relationship between Months Past Puberty and Percent of Subjects with MPS Separation



Regression Euqation:
Percent of Subjects Who Had a MPS Split = -12.9*Months Past Puberty + 91.1
(p=0.0959, R-SQ=81.7%)

Figure 7 - Relationship between Months Past Puberty and Percent of Females with MPS Separation



Regression Euqation:
Percent of Females Who Had a MPS Split = -11*Months Past Puberty + 91.7
(p=0.0193, R-SQ=96.2%)

Table 4 – Associations between MPS Separation Status and Types of RME Appliances for Post-Puberty Subjects at Age ≥13, 14, 15 and 16 Years Old

Type of RME Appliance	Subjects in Post-Puberty		p-value
	MPS Separation n (%)	No Separation n (%)	
Subjects aged ≥13 years (N=63):			
Traditional RME Mini-Screw RME	29 (58.0) 13 (100.0)	21 (42.0) 0 (0.0)	**0.003***
Subjects aged ≥14 years (N=49):			
Traditional RME Mini-Screw RME	19 (52.8) 13 (100.0)	17 (47.2) 0 (0.0)	**0.002***
Subjects aged ≥15 years (N=32):			
Traditional RME Mini-Screw RME	11 (52.4) 11(100.0)	10 (47.6) 0 (0.0)	**0.006***
Subjects aged ≥16 years (N=19):			
Traditional RME Mini-Screw RME	2 (20.0) 9 (100.0)	8 (80.0) 0 (0.0)	**0.001***

*Statistically significantly ($p<0.05$) using Fisher's exact test

Figure 8 – Age vs Percent Ability to get MPS Separation in All Subjects

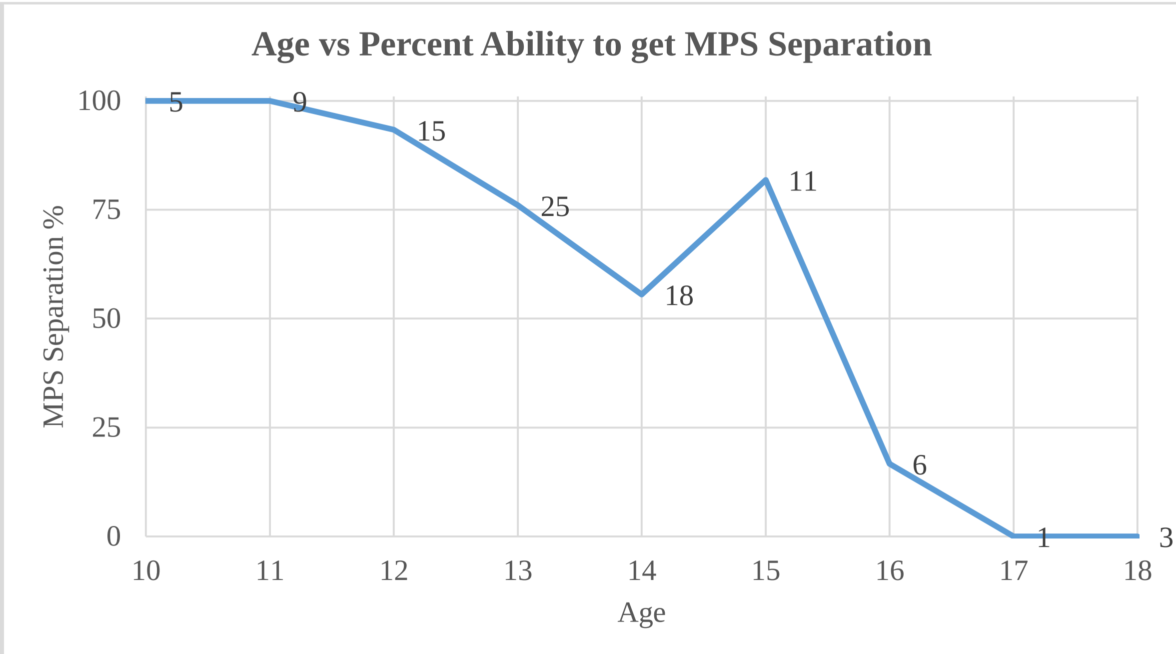


Figure 9 –Age vs Percent Ability to get MPS Separation in Males and Females

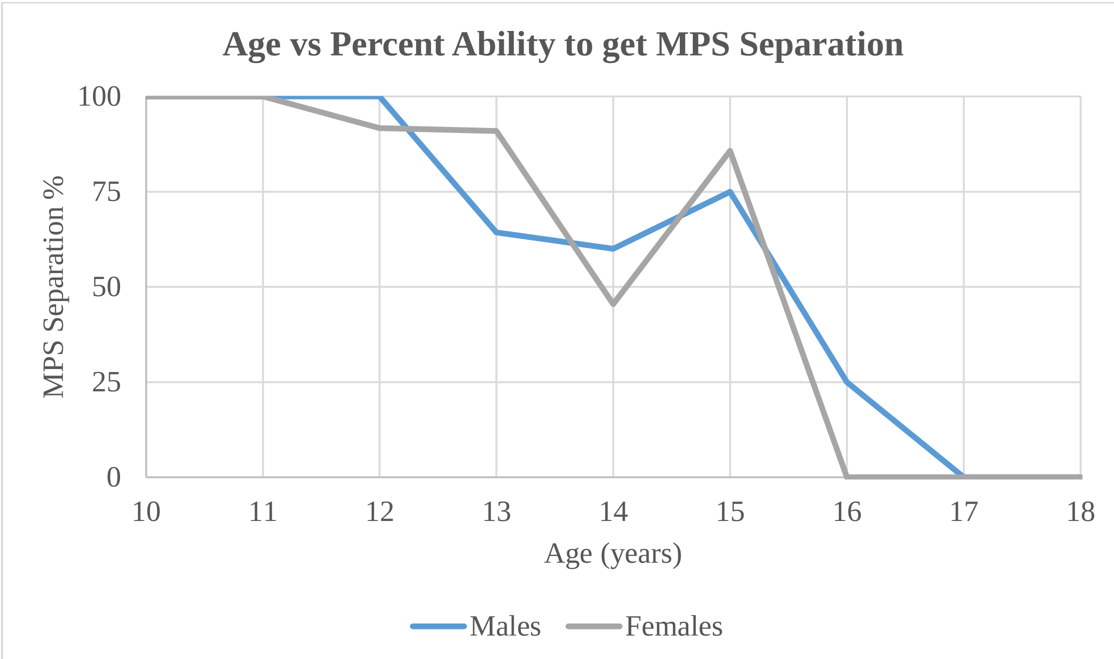


Figure 10 – Age vs Percent Ability to get MPS Separation in Males

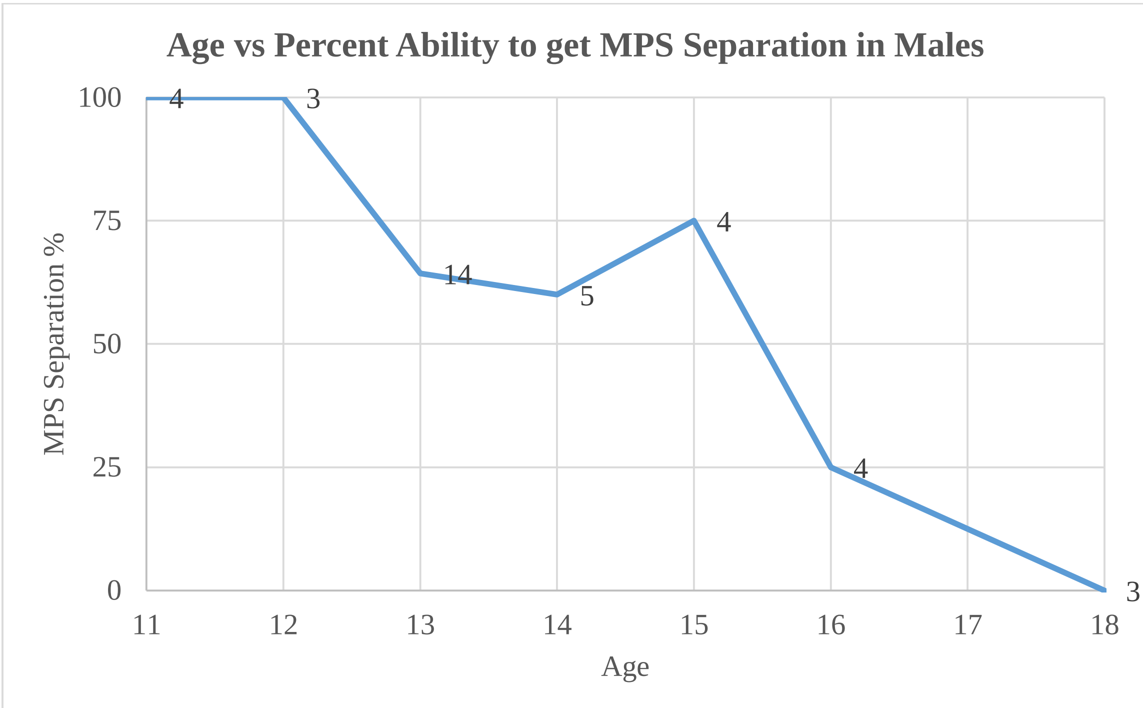


Figure 11 – Age vs Percent Ability to get MPS Separation in Females

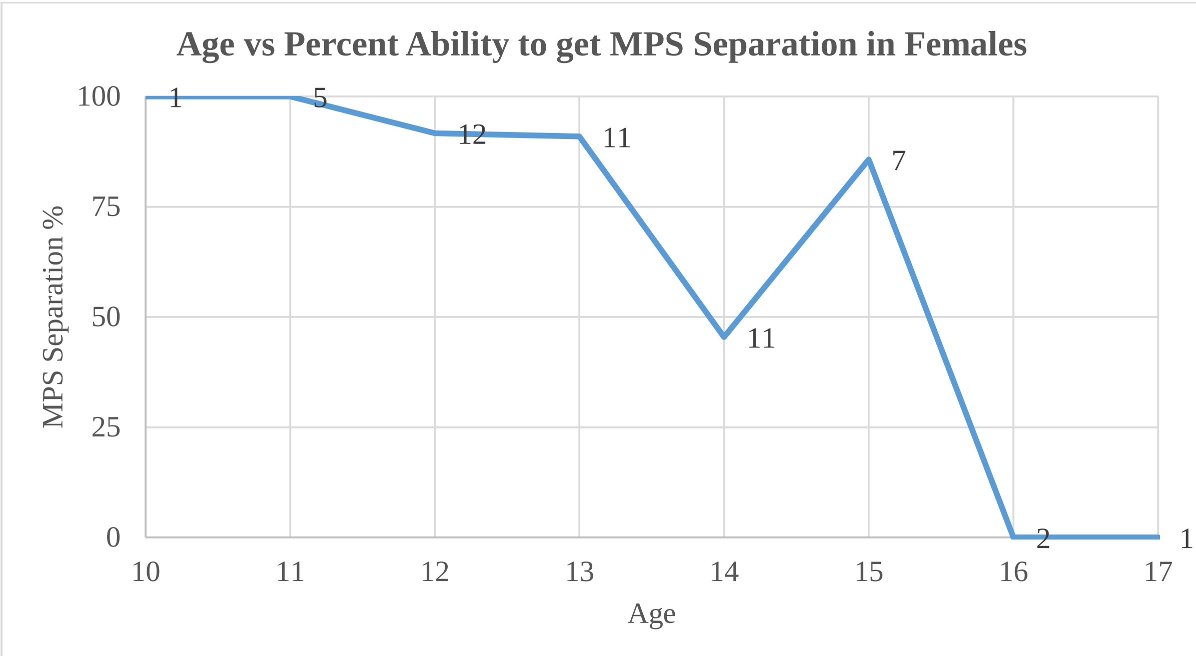


Figure 12 – Pubertal Status vs MPS Separation in All Subjects

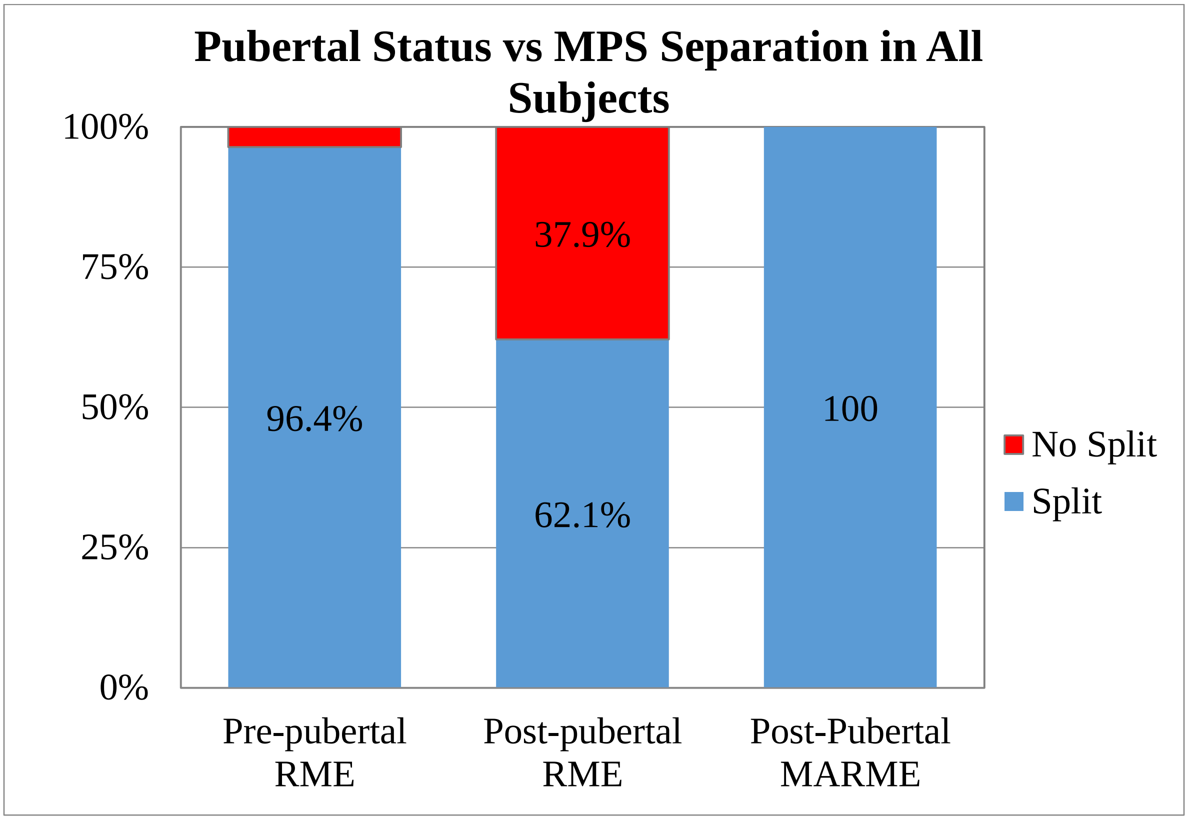


Figure 13 - Pubertal Status vs MPS Separation in Males

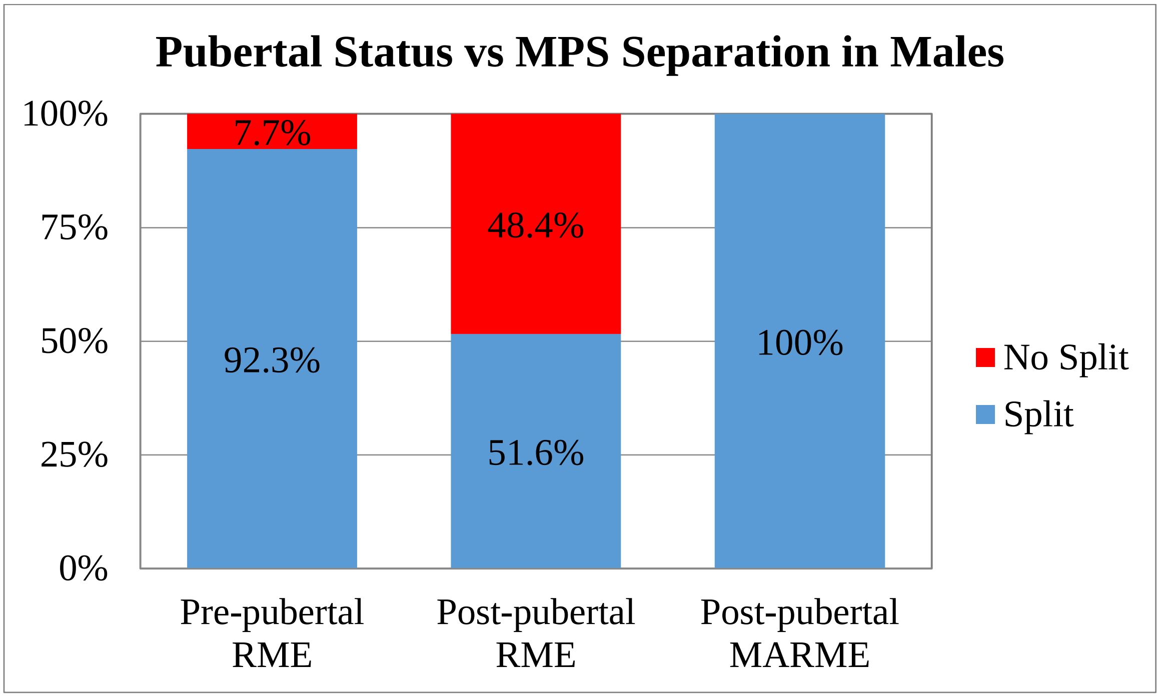


Figure 14 - Pubertal Status vs MPS Separation in Females

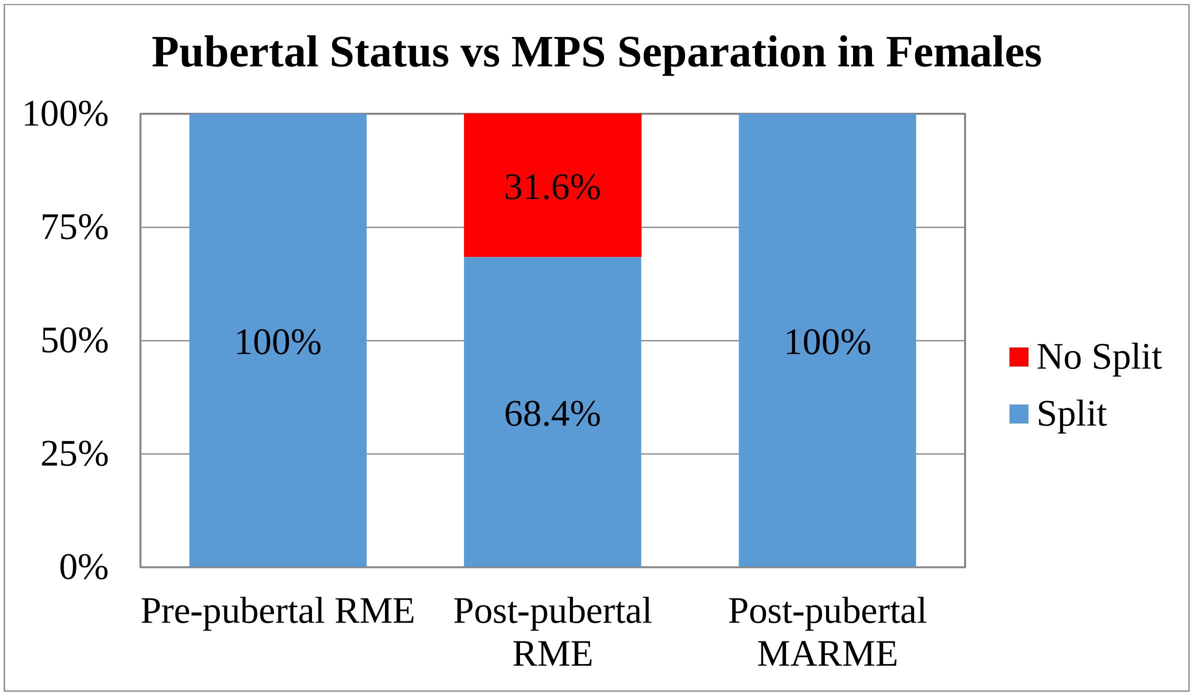


Figure 15 – Months Past Puberty vs Percent Ability to get MPS Separation in All subjects

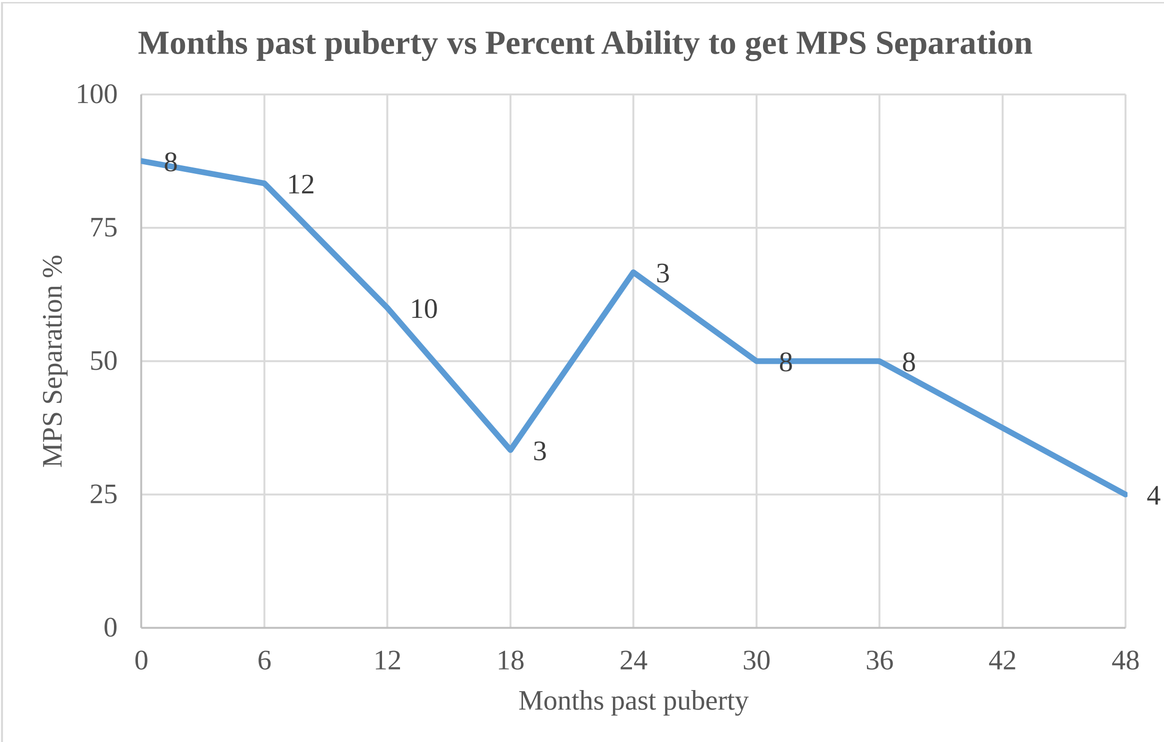


Figure 16 - Months Past Puberty vs Percent Ability to get MPS Separation in Males

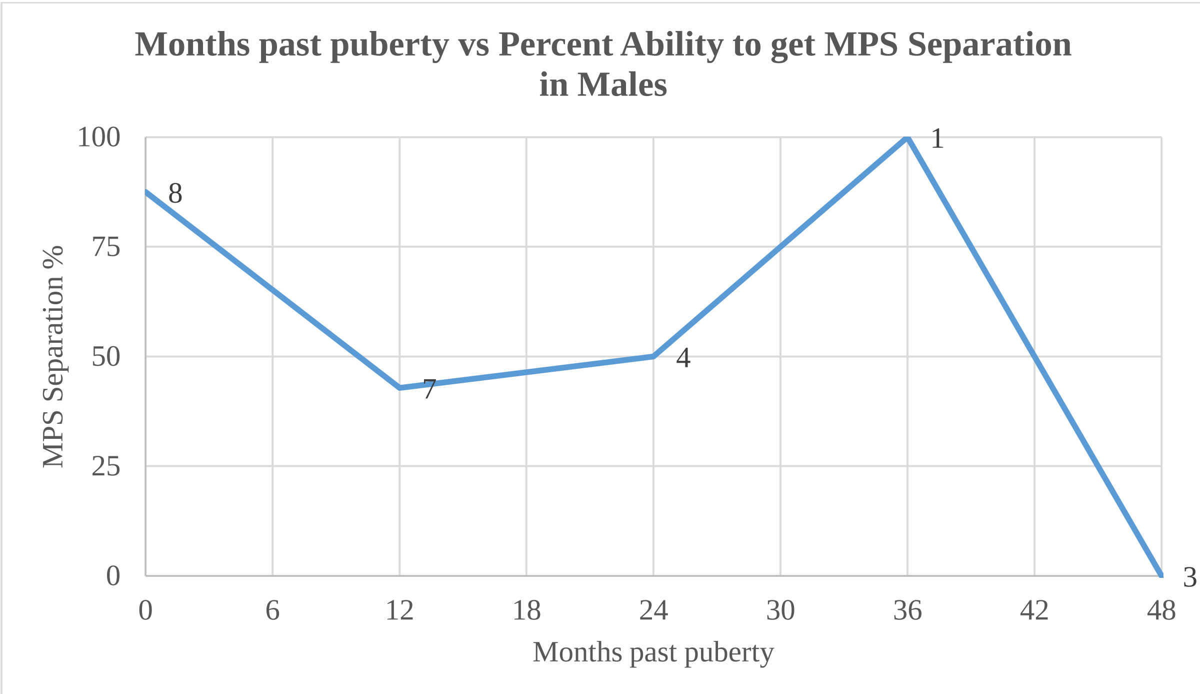
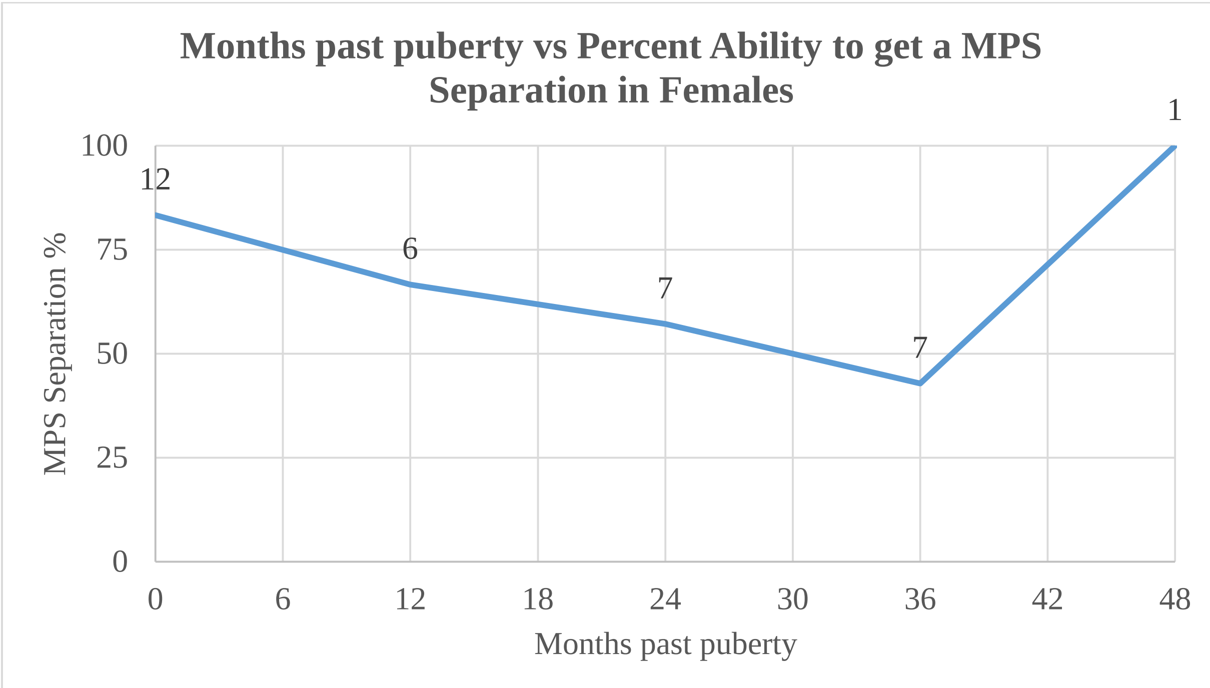


Figure 17 - Months Past Puberty vs Percent Ability to get MPS Separation in Females



DISCUSSION

The results of this study demonstrate that achieving separation of the MPS with a traditional RME appliance is highly successful in patients who are pre-puberty (96.4%), but becomes significantly less predictable in patients who are post-puberty (62.1%). These results are in agreement with prior studies that recommend RME treatment be performed either before or during the pubertal growth spurt (Baccetti et al., 2001; Bell, 1982). Our results also show that as a child increases in months past puberty, the likelihood of obtaining MPS separation significantly decreases. This is demonstrated by our findings that mean months past puberty was significantly higher in patients who did not achieve palatal separation ($p=0.007$). In addition, linear regression analysis demonstrated a significantly strong negative relationship between months past puberty and the ability to achieve MPS separation (-0.90). For every additional year post-puberty, the percent ability to obtain MPS separation decreased by 12.9%. This is illustrated by Figure 6 which shows a downward trend and declines to 50% around 24 months post-puberty. However, it is worth noting that 41.7% of subjects who were 36 months or more past puberty were still able to achieve MPS separation. Therefore, based on the results of this study, traditional RME appliance treatment should not be limited only to subjects who have not yet completed their pubertal growth spurt. Patients who have reached puberty within the last 2 years still have around a 50% chance to achieve significant maxillary skeletal expansion with a traditional RME appliance and possibly avoid more invasive expansion procedures.

The results of our study also demonstrate that older subjects who are in late adolescence are significantly less likely to achieve palatal separation compared to their younger peers, which is to be expected. The mean age of subjects who were able to obtain MPS separation with a traditional RME was 13.0 years old compared to 15.7 years old for those who did not achieve MPS separation ($p<0.001$). These results are in agreement with prior studies performed. For example, Handelman reported that skeletal expansion in children accounted for 56% of their increase in palatal width during RME treatment compared to only 18% in adults (Handelman et al., 2000). In addition, Wertz showed that older patients had little orthopedic change when compared to younger patients and that expansion in older patients was not as stable long term (R. Wertz & Dreskin, 1977). The results of these previous studies are likely to be explained by the older subject groups not achieving MPS separation and mainly experiencing pronounced dentoalveolar changes.

One novel aim of our study was to find out if chronological age can be used as a metric to determine the likelihood of achieving MPS separation with traditional RME appliances. The results from our correlation test and linear regression model demonstrate a significantly strong negative correlation between chronological age and the ability to obtain MPS separation ($r=-0.92$). For every additional year of age in the patient, the likelihood of achieving sutural separation decreased by 14.1%. These findings are illustrated in figure 3 which demonstrates a downward trend which reaches 50% around 14.5 years of age. Interestingly, 52.4% of subjects who were ≥15 years old achieved MPS separation but only 20% of subjects who were ≥16 years old obtained MPS separation. Based on our results, patients under the age of 13 years old can readily achieve skeletal expansion, yet patients over the age of 16 years old will rarely benefit orthopedically from traditional RME treatment.

In terms of mini-screw assisted rapid maxillary expansion, our study demonstrated that this new treatment approach is highly successful at achieving MPS separation in late adolescent patients. All of the subjects treated with mini-screw assisted RME appliances achieved sutural separation even though all of them were post-puberty by at least 12 months with an average age of 17.1 years old. Consequently, MARME treatment was determined to be significantly better than traditional RME treatment at achieving MPS separation in patients of all age groups ($p \leq 0.006$). Our results are in agreement with previous studies that found mini-screw assisted RME treatment to be superior at achieving skeletal expansion in late adolescent patients. For example, Choi found that 60 out of 69 patients over the age of 18 achieved sutural separation with a mini-screw assisted expansion appliance. Their MARME success rate of 87% was also far superior to the results of our traditional RME treatment which only achieved a 20% MPS separation rate in patients 16 years or older (Choi et al., 2016). In addition, Cantarella achieved a 100% MPS separation rate in 15 late adolescent patients using a mini-screw assisted RME appliance and determined that the amount of skeletal expansion was more profound than in previous studies with traditional RME appliances (Cantarella et al., 2017). Lin found similar results when he compared bone-borne (MARME) vs tooth-borne (RME) appliances with CBCT. His results showed that in late adolescence, bone-borne expanders produce twice the amount of skeletal expansion than traditional RME appliances and have less negative side effects on the dentition and surrounding periodontium (Lin et al., 2015). In summary, the results of our study further support the current research which has overwhelmingly demonstrated that mini-screw assisted RME treatment is significantly superior to traditional RME treatment at achieving skeletal expansion in late adolescent patients.

An additional aim of our study was to identify if there is a certain age range and maturation level when MARME should be considered as a preferential treatment option over traditional RME. Mini-screw assisted RME treatment is an invasive treatment option, as it includes giving local anesthesia and placing mini-screws in the palate of young, adolescent patients. In addition, the cost to the clinician is also much higher as a MARME appliance is more expensive to fabricate and requires 4 titanium mini-screws. When taking into account both the invasiveness and the cost of MARME treatment, we recommend that it should only be utilized when there is a significant benefit over traditional RME treatment. Based on the results of our study, any child that is less than 18 months post-puberty or under the age of 13 is highly likely to achieve adequate skeletal expansion with a traditional RME appliance. We also found that patients over the age of 16 are rarely able to achieve MPS separation with traditional RME treatment.

There was a substantial amount of variance on the ability to obtain MPS separation in patients between the ages of 13 to 16 years old with a traditional RME. According to Mellion, females reach the peak of their pubertal growth spurt at 11.5 years of age, with males reaching it at 14 years of age (Mellion et al., 2013). Several prior studies have suggested that RME treatment is most effective when performed either before or during the pubertal growth spurt (Baccetti et al., 2001; Bell, 1982). However, the results of our study demonstrate that patients who are even several years post-puberty can still achieve significant skeletal expansion. For example, 7 out of the 11 female subjects over the age of 15 years old achieved MPS separation even though they would be presumed to be at least 3 years past the peak of their pubertal growth spurt. In addition, it would seem likely that females would see a downward trend in the ability to achieve MPS separation around 2 years earlier than male subjects. However, based our results demonstrated in figure 9, this was not the case with our study sample as male and female MPS separation rate percentages were relatively similar in all age groups. This is likely due to our small sample size, and different trends in male and female MPS separation rates based on age would be expected with a larger sample of the population. There was also a small increase in the percent ability to achieve MPS separation from the age of 14 to 15 years of age in both males and females as demonstrated by figure 10 and 11. This could possibly be explained by late onset pubertal growth acceleration, which could lead to an increased ability for skeletal change in the circomaxillary structures.

There are several limitations to this study. Only a limited number of subjects were treated with mini-screw assisted rapid maxillary expansion and a larger sample size of patients would improve the significance of our findings. Second, it was difficult to assign male maturation status simply on secondary sexual characteristics. Recording the change in statural growth would have been more accurate at assessing pubertal growth status and should be used in the future. In addition, clinicians were not calibrated on assigning MPS separation status. There was not a standardized expansion protocol amongst the clinicians and there were slight variations in the expansion appliances. Finally, cone beam computed tomography could have been utilized to help more accurately determine the amount of skeletal expansion achieved by the subjects.

CONCLUSION

The purpose of this study was to evaluate the age and maturation level at which a successful separation of the MPS can be achieved by traditional RME treatment. An additional aim was to assess the success rate of MARME treatment in late adolescent patients and to determine if there is a certain age range and maturation level when MARME should be considered as a preferential treatment option over traditional RME treatment. In this prospective clinical trial, the records of 96 patients treated with traditional RME and 13 patients treated with MARME were evaluated. The results of this study suggest that:

- Pubertal status was significantly associated with the ability to achieve MPS separation.
- Chronologic age and months past puberty also proved to be useful metrics in determining the ability to achieve MPS separation.
- Mini-screw assisted RME treatment was significantly better at achieving MPS separation over traditional RME treatment, especially in older subjects.

These results suggest that traditional RME treatment is highly effective at achieving skeletal expansion in pre-pubertal patients. However, MPS separation is still possible in patients several years after the completion of their pubertal growth spurt. If skeletal expansion is required for patients who have reached late adolescence or early adulthood, then MARME treatment can be a beneficial treatment option. Due to the invasive nature and expense of mini-screw placement, the patient's age, maturation status, and other case-specific factors should always be taken into account when determining the benefits of MARME over traditional RME treatment.

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