CPQ Dentistry (2021) 1:6
Literature Review

The Use of MARPE Apparatus in the Treatment of Maxillary Atresia of Adult Patients: Literature Review

Gabriela Alessandra da Cruz Galhardo Camargo[1*], Diana de Souza Millan[2], Rogério Tupinambá[3], José Alexandre Alambert Kozel[3] & Celestino José Prudente da Nobrega[3]

[1]Pos Graduation Student of Faculty of Sete Lagoas, Facsete, Ortogeo, São José dos Campos, São Paulo & Post-Graduation Program in Dentistry, Health Institute of Nova Friburgo, PPGO - ISNF, Specific Formation Department, Fluminense Federal University, Nova Friburgo, Rio de Janeiro, Brazil

[2]Pos Graduation Student of Faculty of Sete Lagoas, Facsete, Ortogeo, São José dos Campos, São Paulo, Brazil

[3]Professor of Orthodontics of Faculty of Sete Lagoas, Facsete, Ortogeo, São José dos Campos, São Paulo, Brazil

[*]**Correspondence to:** Dr. Gabriela Alessandra da Cruz Galhardo Camargo, Pos Graduation Student of Faculty of Sete Lagoas, Facsete, Ortogeo, São José dos Campos, São Paulo & Post-Graduation Program in Dentistry, Health Institute of Nova Friburgo, PPGO - ISNF, Specific Formation Department, Fluminense Federal University, Nova Friburgo, Rio de Janeiro, Brazil.

Received: 01 April 2021

Published: 19 April 2021

Keywords: *Orthodontic Appliance; Maxilla; MARPE*

Abstract

Maxillary atresia is a common developmental problem among children and adults, and rapid maxillary expansion is the treatment of choice for atresia correction through bone remodeling. However, the expansion devices apply force to the teeth and the alveolar bone, with a resulting dental buccal inclination, which increases in magnitude as the palatal suture reaches more advanced degrees of skeletal maturation. In order, to avoid these effects, orthodontic miniscrews assisted rapid palatal expansion (MARPE) aims to concentrate forces in the region of the medial palatal suture and provides the opening of other facial sutures. Based on these purposes, this study reviews the literature about of the use of MARPE in Orthodontics between 2016 and February 2021.

Twenty articles were selected through the MEDLINE (Medical Literature Analysis and Retrieval System online databases), CINAHL (Cumulative Index to Nursing and Allied Health Literature) and Dentistry & Oral Sciences Source, using as keywords: Orthodontic appliance, Miniscrew-Assisted Rapid Palatal Expansion, MARPE. The results obtained showed us that the MARPE appliance is an effective technique to correct transverse maxillary discrepancies in patients without growth, providing suture expansion with reduction of side effects because of the device for palatal disjunction is supported by orthodontic miniscrews.

Introduction

Maxillary atresia is a dentofacial deformity in which a discrepancy of the maxilla is observed in relation to the mandible, in the transverse direction, and may present uni or bilateral posterior crossbite [1]. It consists of a narrowing of the upper arch, presenting a deep pointed palate, often associated with respiratory dysfunction [1]. Atresia is present in approximately 18% of patients in the mixed dentition stage and may be of skeletal and / or dento-alveolar origin [2].

The etiological factors related to atresia of the upper arch usually involve changes in the balance between the internal musculature (tongue) and the external musculature (lips and cheek), associated with deleterious oral habits of sucking, mouth breathing or low tongue posture [3,4]. According to MacGinnis *et al.*, [5] and Suzuki *et al.*, [6] the prevalence of transverse maxillary deficiency was between 8% and 23% in mixed and deciduous dentition and less than 10% in adults. This malocclusion represents a common problem found in clinical orthodontics [6]. Lee *et al.*, [8] cited that 9.4% of the entire population and approximately 30% of adult orthodontic patients have maxillary atresia related to posterior crossbite [7]. Lee *et al.* [8] reported that the maxillary atresia can manifest clinically in several ways (Figure 1).

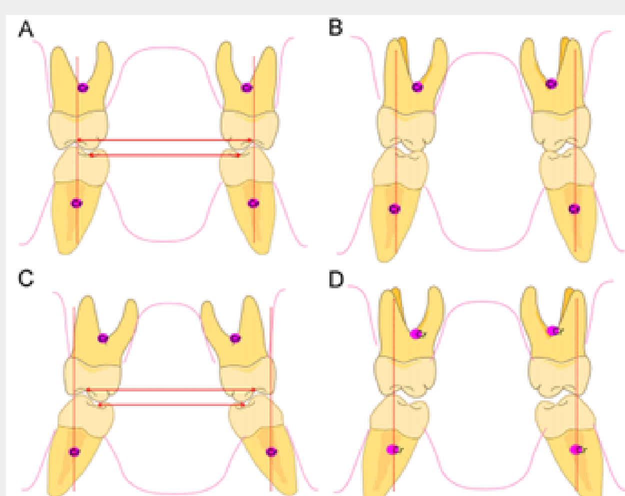


Figure 1: *Clinical manifestation of transversal problems. A - Ideal vestibular occlusion, B - Occlusion with insufficient ovejet, C - Transverse compensation, D- Open lingual occlusion. Lee et al., [8].*

Angelieri *et al.*, [9], suggested a suture opening classification, to avoid the side effects of maxillary expansion failure or surgically assisted rapid maxillary expansion for adolescents and young adults. The authors evaluated patients between the ages of 5.6- and 58.4-years using tomography and defined 5 stages of suture calcification. Stage A showed high density in the suture line, with no or little interdigitation; stage B, had the appearance of a cut-out suture with a high density of the suture line; stage C, 2 parallel lines, cut out and of high density close to each other, separated in some areas by small spaces of low density; stage D, completed fusion of the palatal bone, with no evidence of suture; and stage E, anterior fusion of the complete maxilla [9, 10]. Stages A and B were usually observed until 13 years of age, while stage C was observed mainly from 11 to 17 years old, but occasionally in younger and older age groups [9,10]. Fusion of the palatal (stage D) and maxillary (stage E) suture of the mid palatal suture was completed after 11 years in girls only [9,10]. From 14 to 17 years old, 3 out of 13 (23%) boys presented fusion of only the palatine bone (stage D) [9,10] (Figure 2).

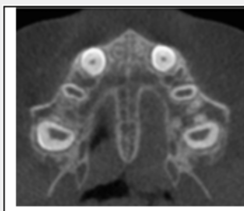
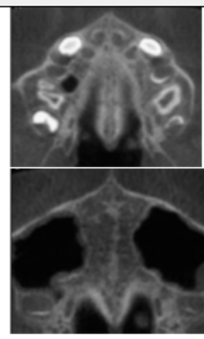
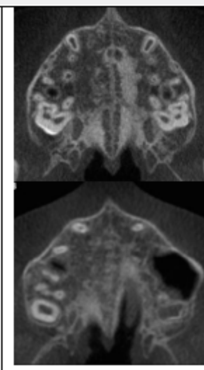
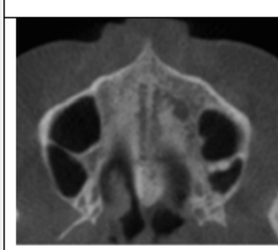
		
Stage A - High density on the structural line, little interdigitation.	Stage B - Appearance of cut suture with high density of the suture line.	Stage C - 2 parallel lines, cut out and of high density next to each other, separated in some areas by small spaces of low density.
		
Stage D - completed fusion of the palatal bone, with no evidence of suture.	Stage E - anterior fusion of the complete jaw.	

Figure 2: *Classification of Palatal Sutures.Angelieri et al., [9].*

However, Reis *et al.*, [11], found a significant, but weak correlation between the patient's age and the maturation stages of the suture (rs = 0.11 / p = 0.01) [11]. The authors evaluated the classification of suture maturation, considering the same stages A, B, C, D and E, previously proposed by Angelieri *et al.*, [9], in patients older than 15 years. Stage A was not observed in the sample [11]. Phases B and C represent, respectively, 1.03% and 34.09% of the sample, stage D was found in 16.63% of the sample while stage E was the most prevalent stage found (48.25%) [11]. For women, there was no statistically significant difference in the mean age between stages C, D and E (p = 0.4753). For boys, a statistically significant difference was observed, with the average age of individuals in stages D and E, greater for the maturation of the mid palatal suture than in the other stages (p = 0.0001) [11]. Katti *et al.*, [12], also used the classification by Angelieri *et al.*, [9], to evaluate the palatal suture. The authors believe that there is a great variation in the initiation time and in the degree of ossification and shape of the mid palatal suture in different age groups [12]. Although there has been an increase in suture closure with aging, age is not a criterion or a reliable method for determining the open or closed nature of the suture [12]. This discovery is important to provide an idea of how diverse the ossification of maxillary sutures is.

Haas introduced the Haas Expander in the United States in 1956 and was the first to report an increase in the rate of nasal width and perimeter of the arch with maxillary expansion [13]. This technique was soon accepted by doctors in patients with growth potential. However, the use of the expander was less predictable in patients over 15 years of age due to dental anchorage device [14]. The expansion performed after the peak of the pubertal growth spike could lead to more dental than skeletal changes with side effects of dental buccal tipping and often a clockwise rotation of the mandible [15-17]. In addition, the skeletal effect was limited to about 4mm of expansion, it would inevitably be compensated for by tooth inclination [17]. Skeletal expansion has been reported to account for only about 38% of total expansion, and the recurrence rate was 35% to 50% [17-21].

Rapid palate expansion (RPE) has been considered the preferred standard treatment when maxillary atresia is present, especially in young patients [22]. Rapid palatal expansion (RPE) techniques depend on a combination of orthopedics and dental expansion to correct skeletal disharmony [15]. Although the main objective of RPE is to divide the palate, the middle palatal suture, other maxillary sutures are also affected, and bone flexion and tooth inclination are common [20]. However, these movements not only assume a significant part of the total activation of the device, reducing the true expansion of the skeleton, but also provide for the clockwise rotation of the jaw and the opening of the bite [15].

Some limitations and side effects may occur when attempting to open the mid palatal suture in patients without growth, such as: ulceration of the palate mucosa, gingival recession, great buccal inclination of the supporting teeth, pain, and discomfort [23]. Surgically assisted rapid palatal expansion (SARPE) is an approach often used for the treatment of maxillary atresia in adult patients [8,23]. However, it is a surgical procedure, it has some degree of morbidity. In most cases, it requires hospitalization, a high cost, in addition to the fact that the patient could undergo two surgeries if there is an associated anteroposterior or vertical discrepancy [23].

In recent years, microimplant-assisted rapid palatal expansion (MARPE) has been developed to prevent undesirable dental effects and achieve skeletal results, this device is especially suitable for patients at the end of their growth or adults who are reluctant to the surgical procedure [6]. Although the MARPE technique represents a non-surgical alternative for the treatment of maxillary atresia in patients in the final phase of growth and adults, this technique may have limitations, due to the increased interdigitation of the medial palatal suture that occurs after puberty [6]. With advancing age, sutures are strongly interdigitated during the ossification process [6]. Recently, studies have proposed methods to assess the stage of skeletal maturation of the suture, since it is recommended that the dentoalveolar effect of the maxillary expansion procedure can be correlated with the maturation of the medial palatal suture [1,9,18,20,21,24]. To obtain skeletal results of MARPE, the force must be sufficient to overcome areas of resistance located in the middle of the face, such as the pillars of the pyriform opening, zygomatic sutures, pterygoid bone junctions and the mid palatal suture, which is the first that needs to be addressed [25,26]. Therefore, it would be advantageous to reduce any possible area of bone resistance during maxillary expansion with MARPE [6].

There are several types of MARPE device on the market, including the Maxillary Skeletal Expander (MSE), which is a particular type of MARPE device that differs from the others because it promotes the bi-cortical involvement of the four microimplants in the cortical bone of the palate and nasal floor [7,27,28] (Figures 3 and 4).

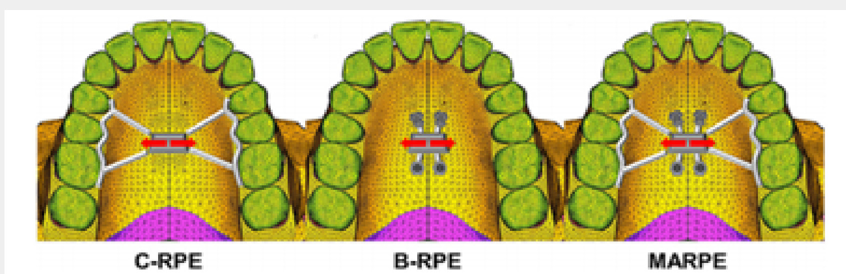


Figure 3: *Various models of conventional C-RPE expander device, B-RPE bone support (Bone Born) and MARPE device with bicortical fixation. Lee et al., [8].*

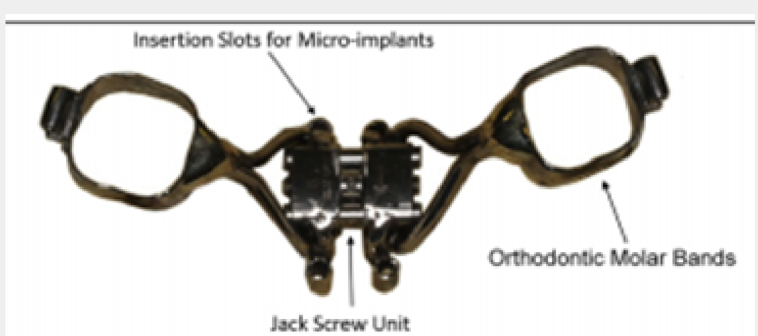


Figure 4: *Apparatus of MARPE with bi-cortical wrapping.Carlson et al., [28].*

Due to the greater interdigitation of the mid palatal suture after puberty, some authors claim that maxillary expansion in post-pubertal patients is not feasible and surgically assisted rapid palate expansion (SARPE) is necessary [29]. However, recent evidence suggests that successful expansion of the mid palatal suture in late adolescence may be possible with bone and dental palatal expanders [30, 31]. Although MARPE devices have been developed with the aim of improving the orthopedic effect of maxillary expansion, comparisons between dental and bone expanders have led to different results [29, 32].

Based on these purposes, the objective of this study was to carry out a chronological narrative literature review on the use of the MARPE device in the treatment of maxillary atresia in adult patients between the years 2016 to February 2021.

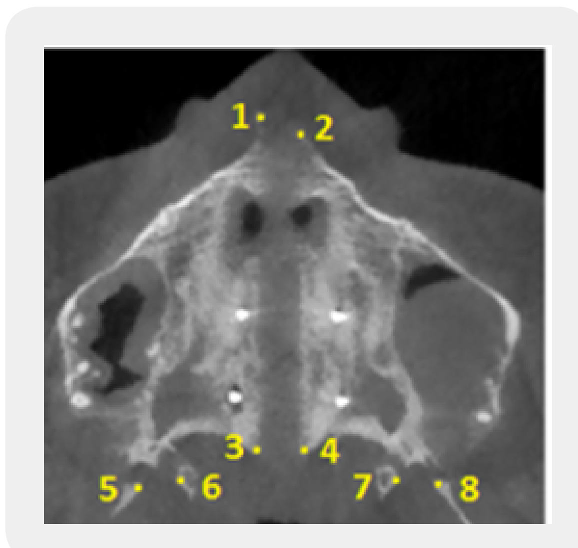


Figure 5: *Result of expansion after the use of MARPE, opening the suture in a parallel way.1-right anterior nasal spine, 2- left anterior nasal spine, 3- right posterior nasal spine, 4- left posterior nasal spine, 5- most medial points of the lateral plate of the right pterygoid process, 6- most lateral point of the medial plate of the right pterygoid process, 7- most lateral point of the medial plate of the left pterygoid process, 8 - most medial point of the lateral plate of the left pterygoid process. Cantarella et al., [29].*

Literature Review

According to Jason & Neto [7], the need for treat transverse deficiencies in patients with completed craniofacial growth has increased in recent years, due to the growing demand from adult patients in search of better facial and dental aesthetics. The transverse problem is commonly characterized by a posterior crossbite; however, it is quite common in Class II malocclusions, as compensation for the relationship between the maxilla and the narrowest part of the mandible, even when the crossing is not present. According to the authors, some studies show that approximately [7] 9.4% of the entire population and almost 30% of adult orthodontic patients have the problem [7]. This amount is relatively high and worrisome, due to the controversies related to non-surgical treatment in adults, the difficulty of treatment in the period of complete skeletal maturation, the consequent lack of stability in the post-treatment period and, also, because not all patients can afford to undergo surgical treatment or even be willing to do so [7]. The authors demonstrated classic orthodontic and orthopedic possibilities for the treatment of transverse discrepancies in adults, and the changes in the treatment plan and prognosis resulting from the incorporation of the most recent method of work (MARPE, Miniscrew-Assisted Rapid Palatal Expansion) [7]; as well as described the installation and activation of the device in this technique, in addition to discussing the pros, cons and indications of each treatment modality [7]. The authors conclude that the first criterion of choice must always be the need for correction, that is, whether there is functional or aesthetic impairment of the patient, through functional analysis and anamnesis. The professional's experience, thoroughness in the selection criteria and knowledge of the techniques are essential. In cases of uncertainty, it is best to perform a surgically assisted MRI procedure.

Carlson *et al.*, [28], reported a clinical case describing the use of the MARPE device to orthopedic transverse maxilla deficiency in an adult patient. Expansion forces transmitted through teeth in traditional rapid palatal expansion devices have created undesirable dental effects rather than true expansion, particularly in older patients with more rigid interdigitation of the medial palatine suture [32]. The authors reported that the 19-year-old patient had maxillary constriction with unilateral posterior crossbite. The MARPE device was used attached to the palate with 4 microimplants and was expanded by 10mm [33]. Transverse sections of pre-MARPE and post-MARPE conical beam computed tomography demonstrated 4 to 6mm of maxillofacial structures expansion, including the zygoma and nasal bone area and widening of the circummaxillary sutures [32]. The authors concluded that there was less buccal inclination of the dentition and the integrity of the alveolar bone was preserved [32]. This report demonstrated that the careful design and application of the MARPE device can achieve transverse expansion of the maxilla and surrounding structures in a patient beyond the age normally considered acceptable for traditional rapid palatal expansion [32].

Suzuki *et al.*, [19], reported that the mid palatine suture has bony margins with thick connective tissue interposed between them, and does not represent the fusion of the maxillary palatal processes only, but also the fusion of the palatine processes of the maxillary and horizontal bony laminae of the palatine bones [34]. The authors report that three segments must be analyzed by all clinicians: the anterior segment (before the incisor foramen, or intermaxillary segment), the middle segment (from the incisor foramen to the transverse suture to the palatine bone) and the posterior segment (after the transverse suture) to the palatine bone) [34]. The authors indicate that rapid palate expansion can be recommended for patients in the final stage of pubertal growth, in addition to adult patients with maxillary constriction [10]. According to the authors, this treatment modality can potentially avoid surgical intervention and when performed in association with rapid palatal expanders, it can enhance the skeletal effects of the latter [10]. Of the various designs of expansion devices, MARPE has been modified to allow its operational advantages and results to become familiar in clinical practice [10].

Brunetto *et al.*, [35], reported that transverse maxilla deficiency is a high prevalence malocclusion, present in all age groups, from primary to permanent dentition [10]. If not treated in time, it can worsen and evolve to a more complex malocclusion, hindering facial growth and development [10]. In addition to the occlusal consequences, the deficiency can also cause serious respiratory problems, due to the consequent nasal constriction usually associated [10]. In growing patients, this condition can be easily treated with conventional rapid palatal expansion [10]. However, adult patients are often subjected to a more invasive procedure, surgically assisted rapid palate expansion (SARPE). More recently, research has shown that it is possible to expand the maxilla in adult patients without having osteotomies but using microimplant anchorage. This new technique is called MARPE. The authors demonstrated the MARPE technique [10] developed by Dr. Won Moon and colleagues at the University of California - Los Angeles (UCLA). All the laboratory and clinical steps necessary for its correct execution are described in detail. For better understanding, a case report of an adult patient was made, detailing the entire course of treatment and the results obtained. The authors concluded that the demonstrated technique can be an interesting alternative to SARPE in most patients without growth with transverse maxilla deficiency [10].

Folco *et al.*, [36] compared two methods to measure changes in the transverse dimension following the alignment of the tooth by a self-linked passive system: Method 1 (M1), considered palatal reference points and Method 2 (M2) considered dental markings. The authors selected 12 patients of both genders, aged 15 to 24 years, with moderate crowding (Nance discrepancy 4 to 6mm), who were treated with the Damon System at the Department of Orthodontics, University of Buenos Aires [36]. Its pre- and post-treatment maxillary models were analyzed (24 models in all). Five measurements were made in each mold: intercanine width, first and second interpremolar width and first and second intermolar width, using the two measurement methods (M1 and M2) [36]. Both methods found that the average width increased, although this increase was less measured by M1 than by M2, with a statistically significant difference between the values ($p < 0.05$). M1 and M2 provided significantly different measurements for first and second interpremolar and first intermolar distances ($p < 0.05$) [36]. The values obtained using M1 (palatal markings for teeth) show less variation and provide information about changes in the dental arches without adding tooth inclination [36]. Considering M1, the greatest gain in the transversal dimension occurred in the distance between the first and second premolar, there was a slight increase in the intercanine distance and in the distance between the first molars [36].

Cantarella *et al.*, [29] evaluated MARPE devices that were developed with the objective of increasing the orthopedic effect induced by rapid maxillary expansion (ERM). The Maxillary Skeletal Expander (MSE) is a particular type MARPE device characterized by the presence of four mini-implants positioned on the posterior part of the palate with bi-cortical engagement [27]. The authors evaluated the effects of MSE on mid palate and pterygopalatine sutures in late adolescents, using conical beam computed tomography (CBCT). The specific objectives were to define the magnitude and sagittal parallelism of the opening of the mid palatal suture, measure the extent of the transverse asymmetry and illustrate the possibility of splinting the pterygopalatine suture [27]. Fifteen individuals (mean age 17.2 years; range, 13.9-26.2 years) were treated with MSE. Pre- and post-treatment CBCT exams were performed and overlapped [27]. A new methodology based on three new reference plans was used to analyze the sutural changes. The parameters were compared from pre to post-treatment and between genders in a non-parametric way using the Wilcoxon statistical test [27]. For the frequency of openings in the lower part of the pterygopalatine suture, Fisher's exact statistical test was used [27]. Regarding the magnitude of the opening of the mid palatal suture, splinting in the anterior nasal spine (ANS) and in the posterior nasal spine (PNS) was 4.8 and 4.3 mm, respectively [27]. The amount of splinting in the PNS was 90% of that in the ANS, showing that the opening of the mid palatal suture was almost perfectly parallel anteroposteriorly [27]. On average, half of the anterior nasal spine (ANS) moved more than the contralateral by 1.1 mm [27]. Openings between the lateral and medial plates of the pterygoid process were detected in 53% of the sutures ($P < 0.05$) [27]. No statistically significant differences were found for the magnitude and frequency of suture opening between men and women [27]. The correlation between age and the opening of the suture was insignificant (range R2, 0.3-4.2%) [29]. The authors concluded that the mid palatal suture was successfully treated by MSE in late adolescents, and the opening was almost perfect parallel in the sagittal direction [27]. Regarding the extent of transverse splintering asymmetry, on average half of the ANS moved more than the contralateral by 1.1mm [37]. The pterygopalatine suture was broken in its lower region by MSE, as the pyramidal process was removed from the pterygoid process [27]. The patient's sex and age do not show any significant influence on the opening of the suture for the age group considered in the study [29].

Al-Mozany *et al.*, [38] proposed a new treatment protocol using an alternating protocol of rapid maxillary constriction and expansion (Alt-RAMEC), together with a full-time protocol using Class III elastic coupled to the use of temporary anchorage devices (TADs) [38]. The aim of the study was to evaluate the dentoeskeletal and soft tissue profile effects of this new protocol in growing participants with retrognatic maxilla. Methods: Fourteen growing participants (7 men and 7 women; 12.05 ± 1.09 years), who had Class III malocclusions with retrognatic maxilla, were recruited. Pre-treatment records were made before starting treatment (T1). All participants received a hybrid device for rapid maxillary expansion supported by mini-implants (MARME) that was activated by the Alt-RAMEC protocol for 9 weeks [38]. Patients who received Class III elastics with full-time bone fixation, providing 400g / side, were used for maxillary protraction. When the positive overjet was reached, the protraction was stopped, and post-treatment records were made (T2). Linear and angular cephalometric variables were blindly measured by an investigator and repeated after 1 month [39]. The paired sample t test ($p < 0.05$) was used to compare each variable from T1 to T2 [39]. Treatment goals were achieved for all participants within 8.5 weeks of protraction. There was a statistically significant maxillary advancement (SNA 1.87 ° ± 1.06 °; Vert.TA 3.29 ± 1.54mm $p < 0.001$), while the mandibular base redirected significantly later [38] (SNB −2.03 ° ± 0, 85 °, Vert.TB - 3.43 ± 4.47mm, $p < 0.001$ and $p < 0.05$ respectively), resulting in a significant improvement in the mandibular relationship [39] (ANB 3.95 ° ± 0.57 °, $p < 0.001$; Wits 5.15 ± 1.51mm, $p < 0.001$). The angle of the Y axis increased significantly (1.95 ° ± 1.11 °, $p < 0.001$). The upper incisors were significantly proclaimed (+ 2.98 ° ± 2.71 °, $p < 0.01$), together with a significant retroclination of the lower incisors [39] (- 3.2 ° ± 3.4 °, $p < 0.05$). The combined skeletal and dental effects significantly improved the overjet [39] (5.62 ± 1.36mm, $p < 0.001$) and the soft tissue harmony angle (2.75 ° ± 1.8 °, $p < 0.001$). The authors concluded that Class III elastics, combined with the Alt-RAMEC activation protocol of the MARPE device, are an efficient treatment method for mild / moderate Class III malocclusions, but long-term stability needs to be monitored [38].

Suzuki *et al.*, [6] report that the MARPE technique has been considered an alternative to avoid surgical procedures [27]. To obtain skeletal results of MARPE, according to the authors, the strength must be sufficient to overcome the areas of resistance and the first suture that must be broken is the medial palatal suture, which becomes increasingly interdigitated after adolescence [27]. The authors suggested a new approach using a minimally invasive method called cortical punctures (CP) in association with MARPE illustrated by a case report of a 35-year-old Caucasian Brazilian patient with transverse maxillary deficiency [27]. The proposed treatment plan was started with orthopedic cross-section correction using the MARPE device. After many unsuccessful attempts to activate MARPE, cortical punctures were performed along the mid palatine suture [27]. The CP procedure in the mid palatal suture included 8 perforations (2mm apart), performed after pre-drilling followed by insertion of the mini implant (5 mm long thread and 1.8 mm in diameter) [27]. After CP and new protocol activation, the opening of the mid palatal suture was observed by CBCT images, showing skeletal results, suture division of 3.14 mm (premolar area) and 2.06 (molar area), increase of 4,3mm (premolar) and 3.03mm (molar) [34] in the width of the basal bone, 4.43mm (premolar) and 3.1mm (molar) in the width of the cortical bone and minimal dental effects (mean 1.2° inclination of the teeth) [27]. The authors concluded that the combination of MARPE and cortical punctures proved to be a non-surgical treatment option to correct cross-sectional deficiency in an adult patient. CP was able to weaken the interdigitation of the suture, facilitating the division [6].

Lee *et al.*, [40] consider that the balanced transversal relationship between the maxillary and mandibular dentition is a prerequisite for the establishment of normal occlusion, regardless of the patient's age [40]. There is high prevalence among adults, transverse maxillary deficiency does not appear to be diagnosed or treated properly, possibly due to the lack of diagnostic measures and treatment modality [40]. A cross-sectional perspective of the center of resistance can be useful for clinicians to understand the pattern and severity of the discrepancy [40]. In terms of treatment, non-surgical maxillary basal bone expansion can be facilitated based on an understanding of the complexity of the circummaxillary structure and the pattern of stress distribution [40]. According to the authors experimental results and clinical trials with MARPE were introduced. The authors report that non-surgical palatal expansion in young adults may be a useful modality exhibiting a high success rate of suture separation and clinically acceptable stability after expansion [40].

Moon [41] reports that Class III malocclusion can be treated in young patients who have skeletal discrepancy with the use of a face mask (FM), with or without palatal expansion, which is one of the traditional approaches [32]. This treatment modality involves the use of the upper dentition as an anchoring unit, often resulting in excessive enlargement of the upper incisors for forward movement of the upper dentition, and an increase in the vertical dimension of the lower face by buccal inclination and extrusion of the posterior maxillary dentition, especially in high angle cases [32]. In recent years, micro-implants (MI) have been incorporated with expansion and protraction devices in various ways that have been proposed to avoid undesirable dental side effects. A popular application is the use of a MARPE expander, incorporating the MI with an expansion device, to promote the expansion anchored in the bone, and by applying FM force against MARPE, to promote the protruding bone anchorage. Among MARPE's numerous projects, Maxillary Skeletal Expander (MSE) has unique features that produce unique treatment results [32]. MSE causes the entire middle face to expand, affecting all maxillary structures. When MSE is applied in combination with FM, almost negligible vertical side effects are observed, the existing anterior-posterior tooth compensation can be reversed, the maxilla advances efficiently in great magnitude, and skeletal protrusion is possible even in patients [32]. The combination of FM and MSE also resulted in some protraction even in mature patients, simulating a movement similar to a distraction, which gives hope to discover a new non-surgical orthopedic treatment modality for adult Class III patients.

Storto *et al.*, [37] evaluated changes in respiratory, inspiratory, and expiratory muscle strength, as well as skeletal and dental changes in patients diagnosed with transverse maxilla deficiency before and after expansion with MARPE [37]. Twenty patients (13 women and 7 men) were evaluated by breathing tests in three different periods: initial T0, T1 immediately after expansion and T2 after 5 months [37]. Tests included: maximum inspiratory pressure (MIP) and maximum expiratory pressure (MEP), peak expiratory oral flow and inspiratory nasal flow [37]. Cone-beam computed tomography measurements were performed in the upper arch, nasal cavity, and airways before and immediately after expansion [37]. The authors reported that there was a significant increase in MIP between T0 and T2 and MEP between T0 and T1 (P, 0.05) [37]. The peak of oral and nasal flow increased immediately after and 5 months, especially in patients with initial signs of airway obstruction (P, 0.05) [37]. In addition, after expansion, there was a significant increase in the nasal cavity, alveolar bone, and interdental width in the premolar molar region [37]. Molars showed statistically significant vestibular inclination (P, 0.05), but no difference was found for premolar inclination [37]. The authors concluded that the MARPE device significantly increased the volume of the airways. The skeletal changes promoted by MARPE directly affected the volume of the airways, resulting in a significant improvement in muscle strength and peak nasal and oral flow [37].

Oh *et al.*, [32] evaluated the skeletal and dental effects immediately after the completion of the maxillary expansion using three different types of expanders - traditional tooth anchored maxillary expander (TAME) and two different types of MARPE, bone anchored maxillary expander (BAME) and expander anchored in bone and tooth (MSE) using CBCT in adolescents [32]. In general, the MSE group showed much greater skeletal changes than the TAME and BAME groups, especially in the nasal floor, maxillary base, and palatal suture [32]. About 72-78% of the suture opening was in the posterior nasal spine (PNS), which indicates an opening slightly more anterior than posterior; however, relatively parallel. In the three groups, the largest transverse changes with expansion occurred in the crowns of the molars and the second major changes in the opening of the palatal suture in the anterior nasal spine (ANS). It is suggested that MSE may be a great alternative method to correct transverse skeletal maxillary deficiency [32].

Rego *et al.*, [42] presented expansion technique with MARPE in a patient in the final stage of growth, with transverse maxilla deficiency, as an alternative in view of the limited orthopedic effects of conventional expansion, when performed close to skeletal maturity. This technique involved the installation of a circuit breaker and four mini-implants in the posterior region of the palate, with the insertion direction of the mini-implants perpendicular to the palatal plane. The screw was opened for 16 days, with a protocol of 0.5´mm / day. On the eighth day, the appearance of the diastema between the central incisors was clinically observed and, after the end of the activation, the success of the procedure was verified, with significant gains in the transverse dimensions of the upper arch and minimal buccal inclination of the posterior teeth.

Zong *et al.*, [43] reported that conventional rapid palatal expansion (RPE) proved to be a reliable method for treating correction of transverse maxilla deficiency in young patients [43]. However, side effects, including tooth tilt and risk of periodontal problem, limited its application to young patients after the pubertal growth spurt [44]. Surgically assisted rapid palate expansion (SARPE), a supplement to RPE, can be applied to patients with a mature skeleton [44]. However, SARPE was an invasive method, and the morbidity, risks and costs related to surgical treatment can discourage many adult patients [44]. The use of the MARPE device can potentially prevent surgical intervention and is gaining popularity in the treatment of transverse maxilla deficiency (BAT) in young adolescent patients. However, the authors report that the literature on the skeleton and dentoalveolar changes with this device is scarce. To assess the immediate skeletal and dentoalveolar changes in the transverse dimension with the maxillary skeletal expander (MSE), a MARPE device with anchorage, was planned to use CBCT [44]. Twenty-two patients (11 men and 11 women, mean age 14.97 + 6.16 years) [43] with transverse maxilla deficiency were treated using MSE (Biomaterials Korea, Inc., Seoul, Korea) [44]. The device consisted of a central expansion screw that was welded to four tubes that served as guides for placing micro-implants [44]. The micro-implants were 1.8mm in diameter and 11mm in the longer length [44]. The authors reported that the greater the length of the micro-implants, the greater the bicortical anchorage of the palate and the nasal floor, reducing the force transmitted to the anchored teeth during expansion. The activation of the device varied with the patient's age and skeletal maturity [44]. The expansion was terminated when 2-3mm of suture opening was achieved [44]. CBCT scans were performed before treatment (T1) and immediately after expansion (T2) [44]. The measurements were made to assess the amount of total expansion, skeletal expansion, and angular tooth inclination in the region of the first molar [44]. A total expansion of 5.41 + 2.18mm was achieved, 59.23 + 17.75% of which was attributed to the expansion of the skeleton (3.15 + 1.64mm) with the first molars showing a buccal inclination of 2, 56 + 2.64° [44]. The authors conclude that the use of MARPE devices, such as MSE, can be used to correct jaws with transversal disabilities in adolescent patients with minimal dentoalveolar side effects [43].

Lee *et al.*, [44] evaluated changes in nasal tissues, including movements of reference points, changes in linear distances and volumetric changes, using three-dimensional (3D) stereophotogrammetry after MARPE in adult patients [44]. Facial data were digitized using a white light scanner before and after MARPE in 30 patients [44]. In total, 7 mm expansion was achieved over a 4-week expansion period [44]. The authors determined 10 soft tissue reference points using reverse engineering software and 3D vector changes measured at these points. In addition, they calculated the distances between the points to determine changes in nasal soft tissue width. The volumetric change in the nose was also measured [44]. The authors evaluated the reference points, except for pronasale and subnasale, which showed a statistically significant movement on the x-axis [44]. Pronasale, subnasale, alar on the right and alar on the left showed significant movement on the y axis, while all landmarks, except subnasale, showed significant movement on the z axis [44]. The width of the alar base, alar width and alar curvature width increased by 1.214, 0.932, and 0.987mm, respectively [44]. The average volumetric variation was 993.33mm3, and the value of the increase in relation to the average initial volume was 2.96% [44]. The authors concluded that most soft tissue landmarks around the nasal region show significant position changes after MARPE in adults [44]. The nose tends to widen and move forward and down [44]. The post-treatment nasal volume may also exhibit a significant increase over the initial volume [44]. The authors suggest that clinicians should thoroughly explain the expected changes to patients before the start of MARPE therapy [44].

Paredes *et al.*, [22] evaluated the skeletal expansion, flexion of the alveolar bone and tooth inclination after maxillary expansion, linear and angular measurements were performed using different craniofacial references [37]. The objective of this work was to quantify the differential components of the MSE expansion by calculating the fulcrum locations and applying a new angular angle measurement system [27]. Thirty-nine individuals with a mean age of 18.2 ± 4.2 years were treated with EPM [27]. Pre and post expansion. CBCT records were overlapped and compared [27]. The rotational fulcrum of the zygomatic-maxillary complex was identified by the location of the interfrontal distance and modified interfrontal distance [27]. Based on the fulcrum, an angular measurement method was presented and compared with a conventional linear method to assess changes in the zygomatic-maxillary complex, dentoalveolar bone and first maxillary molars [27]. Of the 39 patients, 20 individuals had at most the rotational fulcrum of the maxillary zygomatic complex [22]. points far from the interfrontal distance (101.6 ± 4.7mm) and 19 subjects at the points furthest from the modified interfrontal distance (98.9 ± 5.7mm) [27]. Linear measurements represented 60.16% and 56.83% of the skeletal expansion, 16.15% and 16.55% of the curvature of the alveolar bone, and 23.69% and 26.62% of the dental inclination to the right and left side [27]. Angular measurements showed 96.58% and 95.44% of skeletal expansion, 0.34% and 0.33% alveolar bone inclination and 3.08% and 4.23% of dental inclination for the right and left sides. The frontozigomatico, frontoalveolar, and frontodental angles were not significantly different (P> 0.05). The authors concluded that in the coronal plane, the center of rotation of the maxillary zygomatic complex was located in the region of the outermost and lowest point of the zygomatic process of the frontal bone or slightly above and parallel to the interfrontal distance [29]. Due to the rotational displacement of the zygomatic-maxillary complex, angular measurements should be the preferred method for assessing the effects of expansion, rather than the traditional method of measurement [27].

Thakkar *et al.*, [45] considered that the expansion with MARPE added a new dimension to the world of orthodontics for the adult population [45]. However, there are some limitations observed with the use of prefabricated MARPE, such as adaptation to the palate or adjustment of the mini screw in cases of high arched palate, which compromise anchorage and the result [45]. The authors used the digital workflow to print a MARPE in 3D with the aid of cone beam computed tomography, which would overcome the shortcomings of a prefabricated MARPE project and provide greater rigidity and anchoring value and predictable skeletal expansion [45]. concluded that the CAD-CAM project for MARPE has greater precision and is therefore a viability in the digital age. Clinically, MARPE is an efficient skeletal expansion device with better adaptation to the underlying anatomical structures (palate) [45].

Dzingle *et al.,* [46] reported that unilateral posterior crossbite typically presents as a narrow maxillary arch and a broad mandibular arch on the side of the crossbite [46]. Unwanted overexpansion and iatrogenic crossbite can develop as side effects if rapid expansion of the conventional maxilla is not performed [46]. Thus, unilateral maxillary expansion with unilateral posterior crossbite can help us avoid these side effects and improve the transversal relationship between maxillary and mandibular posterior dentition only on the affected side [46]. The authors described a case report on unilateral expansion supported by a mini-implant of the upper arch in a patient with unilateral posterior crossbite. The authors concluded that MARPE is an effective device for the correction of unilateral posterior crossbite without causing undesirable effects on the side that does not present a crossbite.

Jia *et al.*, [33] evaluated sixty patients with transverse maxillary deficiency during the post-pubertal growth spurt stage, the patients were randomly divided into MARPE and Hyrax groups [32]. Thirty patients (mean age: 15.1 + 1.6 years) were treated with the four-point MARPE device; 30 patients (mean age, 14.8 + 1.5 years) were treated with the Hyrax expander [32, 33]. Cone-beam computed tomography and plaster models were obtained before and after expansion [32]. The data were analyzed using paired t-tests and independent t-tests [32]. The success rates for the separation of the mid palatal suture were 100% and 86.7% for MARPE and Hyrax Groups, respectively. Palatal expansion and skeletal / dental ratio at the level of the first molar were greater in the MARPE group [32] (3.82mm and 61.4%, respectively) than in the Hyrax group (2.20 mm and 32.3%, respectively) (P, 0.01) [32]. Reductions in the height of the buccal alveolar bone and the buccal inclination of the first molars were lower in the MARPE group than in the Hyrax group (P, 0.01) [32]. The authors concluded that MARPE allowed greater predictability and greater skeletal expansion, as well as less vestibular inclination and loss of alveolar height in the anchor teeth [32]. MARPE was considered the best alternative for patients with skeletal deficiency of the maxilla during the post-pubertal growth spurt phase [32].

Calil *et al.*, [10] compared the dental and skeletal effects of the jaw after treatment with a self-ligating device and rapid maxillary expansion assisted by mini implant (MARPE). The sample consisted of 37 patients with Class I anti-tooth extraction malocclusion, divided into 2 groups: group 1 comprises 21 patients with a mean age of 19.55 years (standard deviation = 1.31) [32], analysis of orthodontic treatment with Damon self-ligating device, and evaluated until the end of the alignment and leveling stage [32]. Group 2 comprises 16 patients with a mean age of 24.92 years (standard deviation = 7.60) [32], with maxillary atresia, who underwent MARPE and evaluated after removal of the expander [32]. The buccal bone thickness; dental inclinations; and transverse distances of the maxillary arch, nasal base and jugular were measured in cone beam computed tomography scans before and after treatment [32]. The intergroup comparison was performed with the independent t test [32] The authors report that with the treatment, there was a decrease in the greater compliance in the buccal bone thickness of canines and premolars in the self-ligated group, the smaller vestibular premolars in the self-ligated group, being the inter canine and inter molar distances and width of the base [32]. nasal and enlarged jugula increases greater increases in the MARPE group than in the self-ligating group [32]. The authors conclude that MARPE treated more severe transverse skeletal maxillary discrepancies and better results than self-ligating devices in terms of vestibular bone loss, dilated teeth, and transverse skeletal maxillary enlargement. MARPE presentations more skeletal effects and self-ligating appliances, more dental effects [10].

Materials and Methods

Twenty scientific articles published between 2016 and February 2021 were selected through the MEDLINE (Medical Literature Analysis ans Retrievel Sistem online), CINAHL (Cumulative Index to Nursing and Allied Health Literature) and Dentistry & Oral Sciences Source databases, using as keywords: Orthodontic appliance, Miniscrew-Assisted Rapid Palatal Expansion, MARPE. Inclusion criteria were full texts, English and Portuguese, studies approved by the Ethics Committee and clinical cases. The exclusion criteria were review studies and editorial letters.

Discussion

This study evaluated, through a literature review, the use of MARPE apparatus in the treatment of maxillary atresia in adult patients. After analyzing the literature, it was possible to evaluate that the MARPE appliance is a solution for transversal correction of maxillary atresia, mainly for triangular palate and pointed palate, with great transversal discrepancy, upper teeth already verticalized on the rim, supporting teeth for ERM with periodontal deficiencies, including bone loss, absence of keratinized gingiva, gingival recessions and root resorption and even tooth lessness that require maxillary expansion for better implant positioning, in cases of oral rehabilitation [10,19,42].

The term maxillary atresia, although used by all authors in this study, is controversial according to Consolaro & Consolaro [47]. The authors consider that to induce reflections and discussions on the proper use of nomenclature in Orthodontics and Pathology, for cases in which the maxilla and mandible are small or smaller than usual, that is, anomalous, the conceptual meaning of the term "atresia". According to the authors, this term is not appropriate when applied to the maxilla and mandible to identify situations in which there was a development with insufficient growth to reach normal size. To identify a smaller maxilla and mandible, it is more appropriate and accurate to use the term hypoplastic maxilla or mandible. This is because atresia represents an anomaly due to obstruction of light or fire in hollow organs, which does not occur in the maxilla or mandible. Hypoplastic maxilla or mandible can also be called, appropriately and specifically, micrognathia.

However, the unpredictability of the disjunction is the same as in ERM, with the disadvantage of requiring greater training of the professional and having greater risks of fracture or loosening of the mini-implants, which can lead to longer and uncomfortable procedures for the professional and patient [42]. Even with these disadvantages, the use of the MARPE protocol is feasible for adult patients who do not want to undergo ERM, as this procedure has a higher morbidity inherent to the technique, cost and length of hospital stay.

Another relevant aspect to be highlighted and seen as an advantage of the MARPE protocol was the control of the buccal inclination of the posterior teeth, which showed an almost insignificant alteration. When forces are applied directly to the resistance center of the maxilla by means of mini-implants, and not to teeth, the force system becomes more favorable than in conventional expansion, as it allows a more homogeneous distribution of forces [7,10,41,42]. The success of the separation of the median palatine suture is 87% and can be observed clinically by the presence of the diastema and radiographically by the separation of the median palatine suture [40]. For Jia et al., [33], the suture opening index was 72.5% similar that reported by Oh *et al.*, [32].

On the other hand, the failure rate varies around 10%, and can be observed in patients with true bone suture obliteration [22,40]. The pterygomaxillary suture appears to be the greatest resistance factor for maxillary expansion [22,28]. In cases of rapid maxillary expansion, osteotomy may be indicated [28]. Cortical puncture, or micro-perforation, performed with drills or with a piezoelectric device can favor the opening of the suture and subsequent bone remodeling, both techniques have similar results [6]. According to Parades *et al.*, [22], the position of the MARPE screw can influence the opening suture flow.

Regarding the planning for making the MARPE device, Thakkar *et al.*, [45], suggest that the 3D method be used with the aid of CAD / CAM and CBCT for the design of the MARPE, as it guarantees greater precision of the results. However, Jason & Neto [7] reported success in making the MARPE device only with molding and assistance from CBCT. CBCT is an essential exam to measure the thickness of the palate and to plan the size of mini-implants and MARPE devices. However, the use of digital flow, association of intraoral scanning, CBCT and fingerprint must be considered for cost benefit and indication of the case [46].

Folco *et al.*, [36] and Jason & Neto [7] report that to assess the discrepancy between arcs it is important to quantitatively assess the difference between arc, that is, make an estimate in millimeters, measure the amount needed to achieve the result wanted. This analysis must be performed in the study models, the existing discrepancy in the upper and lower molars region must be measured, considering the final anteroposterior position of the teeth, because the greater the transversal discrepancy, the greater the need for skeletal disjunction of the maxilla, that is: as the opening or not of the suture is uncertain, the case becomes less predictable. Cantarella *et al.*, [29], Parades *et al.*, [22] and Calil *et al.*, [10] evaluated these distances by CBCT. Jason & Neto [7] report that in addition to this quantitative assessment, it is necessary to clinically assess the patient to assess periodontal conditions, unfavorable inclinations of dental structures and alveolar processes, or the association of these two elements, bone atresia, excessive jaw enlargement and presence of bone jaw atresia.

Regarding failures due to the local effects of the MARPE device, it appears to induce temporary mucosal inflammation when used for a long time. Another difficulty is hygiene around micro-implants, which may favor the risk of infection [6]. The movement of micro-implants can also lead to their loss and failures in fixing the MARPE [33].

As for the opening format of the mid palatal suture, Zong *et al.* [43]. They report that of the 22 patients evaluated, 15 presented parallel opening of the sutures, 4 presented the typical "V" shape and 3 presented the inverted "V". The openings of the parallel sutures were observed in patients who received MARPE and in "V" in patients who received SARPE. The authors reported that the zygomatic maxillary and pterygomaxillary sutures showed the greatest resistance to opening. Three failures regarding the fixation of the mini screws were treated with removal of the MARPE apparatus combined with the application of saline solution and hydrogen peroxide. Regarding pain, more than half of the patients experienced pain during the activation of MARPE, which was interrupted and restarted after the decrease in symptoms. The opening of the suture with the use of the MARPE device was parallel in most reports found [29,32,33].

Regarding activation failures, it is advisable for the orthodontist to perform the activation once a day, but if the activation is delegated to the patient, a form to control this activation must be provided, as it must not exceed the limit of the device as this can generate screw fractures and loss of control causing deformations [35].

Various protocols were used in the different articles evaluated, Lee *et al.*, [40] reported having activated the MARPE device for 8 weeks in a 42-year-old adult patient, and after the expansion he maintained restraint for 4 months. Carlson *et al.*, [28], performed activation with 2 shifts a day for the first 2 weeks until the appearance of a diastema; activation stopped when the patient reported some discomfort in the areas of the palate and nasal cavity and headache. The pain was resolved after a brief interruption of activation, and activation was resumed one activation per day. After 10mm of expansion with MARPE and verticalization of the molars, 6mm of expansion was gained in the first maxillary molars, and concomitantly 7mm was achieved in the maxillary canines. The expansion was stabilized for 3 months. Thakkar *et al.*, [45], used an expansion protocol of two and a half turns per day (total 0.8mm expansion per day) with a difference of 10-12 hours per day followed by the next 10-12 days. For unilateral activation of MARPE, U-MARPE, activation was performed with one lap per day for 2 weeks. The left side crossbite was corrected after expansion. The expander was stabilized for 5 months after the expansion [46]. The activation protocol tends to vary depending on the size of the transverse discrepancy.

Regarding the treatment of patients with skeletal class III malocclusion, which corresponds to the disharmony of the position and dimension of the components of the facial skull, maxilla, and mandible skeleton in relation to the skull base. The maxilla is atrophic, and the mandible is anteriorly advanced, characterizing class III. The use of the MARPE device contributed to the application of the Alt-RAMEC protocol, where maxillary expansion is performed with activation and deactivation, because due to this disarticulation it allows greater prostration of the maxilla that is associated with the minimum hourly rotation of mandibular rotation, this associated protocol the use of a class III rubber band proved to be efficient for the treatment of class III malocclusion [38]. Moon [41] also found promising cephalometric results after the use of MARPE and facial mask for treatment of skeletal class III in adolescent and adult patients.

Increased respiratory flow was also shown to be one of the advantages of rapid maxillary expansion with the use of the MARPE protocol. Before this protocol, surgical expansion was indicated, but after using this protocol, the results were as beneficial as those of surgical expansion [37]. Nasal obstruction is an important condition that needs to be treated because it prevents air flow, the patient has difficulty breathing and ends up performing mouth breathing, so the respiratory mechanism is compromised with reduced diaphragm activity and less muscle strength. The use of the MARPE device provided a 30.45% increase in respiratory flow, causing a positive impact on respiratory function, as patients tended to breathe more through the nose, altering the tongue posture and muscle dynamics, indirectly increasing nasopharyngeal breathing [37] and increasing the nasal floor [10]. Lee *et al.*, [44], evaluated changes in the soft tissue of patients who used the MARPE device by means of three-dimensional stereophotogrammetry and concluded that the device causes marked changes in the nasal region by moving the nose forward and downward and increasing the volume. The authors report that these changes should be discussed with the patient before placing the MARPE because they cause a change in the face.

Therefore, based on this literature review, we conclude that the MARPE device is efficient in the treatment of maxillary atresia, however more high methodological quality studies should be carried out to evaluate the positive and negative impacts of the MARPE device, as well as if the results will be maintained in terms of stability to the over time.

Conclusion

Based on the articles reviewed between 2016 and February 2021, we concluded that the MARPE device allows for of a safe, noninvasive and effective technique in the correction of transverse discrepancies of the maxilla in adult patients, providing expansion of sutures in a parallel fashion, with reduction dental side effects because the forces are dissipated over bone-supported orthodontic mini implants.

Bibliography

1. Pedreira, M. G., Almeida, M. H. C., Ferrer, K. J. N. & Almeida, R. C. (2010). Avaliação da atresia maxilarassociadaaotipo facial. *Dental Press J Orthod., 15*(3), 71-77.

2. da Silva Filho, O. G., Boas, M. C. & Capelozza Filho, L. (1991). Rapid maxillary expansion in the primary and mixed dentitions: a cephalometric evaluation. *Am J Orthod Dentofacial Orthop., 100*(2), 171-179.

3. Modéer, T., Odenrick, L. & Lindner, A. (1982). Sucking habits and their relation to posterior cross-bite in 4-year-old children. *Scand J Dent Res., 90*(4), 323-328.

4. da Silva Filho, O. G., Santamaria, M. Jr & Capelozza, Filho, L. (2007). Epidemiology of posterior crossbite in the primary dentition. *J Clin Pediatr Dent., 32*(1), 73-78.

5. MacGinnis, M., Chu, H., Youssef, G., Wu, K. W., Machado, A. W. *et al.* (2014). The effects of micro-implant assisted rapid palatal expansion (MARPE) on the nasomaxillary complex--a finite element method (FEM) analysis. *Prog Orthod., 15*(1), 52.

6. Suzuki, S. S., Braga, L. F. S., Fujii, D. N., Moon, W. & Suzuki, H. (2018). Corticopuncture Facilitated Microimplant-Assisted Rapid Palatal Expansion. *Case Rep Dent., 2018*(1392895).

7. Jason, M., Neto, F. H. S. (2016). Tratamento das discrepânciastransversaisemadultos: racionalização das alternativasortodônticas e ortopédicas. *Rev Clín Ortod Dental Press., 15*(6), 56-89.

8. Lee, K. J., Park, Y. C., Park, J. Y. & Hwang, W. S. (2010). Miniscrew-assisted nonsurgical palatal expansion before orthognathic surgery for a patient with severe mandibular prognathism. *Am J Orthod Dentofacial Orthop., 137*(6), 830-839.

9. Angelieri, F., Cevidanes, L. H., Franchi, L., Gonçalves, J. R., Benavides, E., *et al.* (2013). Midpalatal suture maturation: classification method for individual assessment before rapid maxillary expansion. *Am J Orthod Dentofacial Orthop., 144*(5), 759-769.

10. Calil, R. C., Marin Ramirez, C. M., Otazu, A., Torres, D. M., Gurgel, J. A., *et al.* (2020). Maxillary dental and skeletal effects after treatment with self-ligating appliance and miniscrew-assisted rapid maxillary expansion. *Am J Orthod Dentofacial Orthop., 159*(2), e93-e101.

11. Reis, L. G., Ribeiro, R. A., Vitral, R. W. F., Reis, H. N. & Devito, K. L. (2020). Classification of the midpalatal suture maturation in individuals older than 15 years: a cone beam computed tomographic study. *Surg Radiol Anat., 42*(9), 1043-1049.

12. Katti, G., Shahbaz, S., Katti, C. & Rahman, M. S. (2020). Evaluation of Midpalatal Suture Ossification Using Cone-Beam Computed Tomography: A Digital Radiographic Study. *Acta Medica (Hradec Kralove)., 63*(4), 188-193.

13. Haas, J. A. (1961). Rapid expansion of the maxillary dental arch and nasal cavity by opening the midpalatal suture. *Angle Orthod., 31*(2), 73-90.

14. Braun, S., Bottrel, J. A., Lee, K. G., Lunazzi, J. J., Legan, H. L. (2000). The biomechanics of rapid maxillary sutural expansion. *Am J Orthod Dentofacial Orthop., 118*(3), 257-261.

15. Chung, C. H. & Font, B. (2004). Skeletal and dental changes in the sagittal, vertical, and transverse dimensions after rapid palatal expansion. *Am J Orthod Dentofacial Orthop., 126*(5), 569-575.

16. Basciftci, F. A. & Karaman, A. I. (2002). Effects of a modified acrylic bonded rapid maxillary expansion appliance and vertical chin cap on dentofacial structures. *Angle Orthod., 72*(1), 61-71.

17. Rossi, M. D., Rossi, A. D. & Abrão, J. (2011) Skeletal alterations associated with the use of bonded rapid maxillary expansion appliance. *Braz Dent J., 22*(4), 334-339.

18. Garrett, B. J., Caruso, J. M., Rungcharassaeng, K., Farrage, J. R., Kim, J. S., *et al.* (2008). Skeletal effects to the maxilla after rapid maxillary expansion assessed with cone-beam computed tomography. *Am J Orthod Dentofacial Orthop., 134*(1), 8-9.

19. Suzuki, H., Moon, W., Previdente, L. H., Suzuli, S. S., Garcez, A. A., *et al.* (2016). Miniscrew-assisted rapid palatal expander (MARPE): the quest for pure orthopedic movement. *Dental Press J Orthod., 2*1(4), 17-23.

20. Lagravère, M. O., Carey, J., Heo, G., Toogood, R. W. & Major, P. W. (2010). Transverse, vertical, and anteroposterior changes from bone-anchored maxillary expansion vs traditional rapid maxillary expansion: a randomized clinical trial. *Am J Orthod Dentofacial Orthop., 137*(3), 304.e1-12; discussion 304-5.

21. Ladewig, V. M., Capelozza-Filho, L., Almeida-Pedrin, R. R., Guedes, F. P., de Almeida Cardoso, M., *et al*. (2018). Tomographic evaluation of the maturation stage of the midpalatal suture in postadolescents. Am *J Orthod Dentofacial Orthop., 153*(6), 818-824.

22. Paredes, N., Colak, O., Sfogliano, L., Elkenawy, I., Fijany, L., *et al.* (2020). Differential assessment of skeletal, alveolar, and dental components induced by microimplant-supported midfacial skeletal expander (MSE), utilizing novel angular measurements from the fulcrum. *Prog Orthod., 21*(1), 18.

23. Rossi, R. P., Araújo, M. T. & Bolognese, A. M. (2009). Expansãomaxilaremadultos e adolescentes com maturaçãoesqueléticaavançada. *Rev Dental Press Orthod and Orthop Facial., 14*(5), 43-52.

24. Grünheid, T., Larson, C. E. & Larson, B. E. (2017). Midpalatal suture density ratio: A novel predictor of skeletal response to rapid maxillary expansion. *Am J Orthod Dentofacial Orthop., 151*(2), 267-276.

25. Suri, L. & Taneja, P. (2008). Surgically assisted rapid palatal expansion: a literature review. *Am J Orthod Dentofacial Orthop., 133*(2), 290-302.

26. Möhlhenrich, S. C., Modabber, A., Kniha, K., Peters, F., Steiner, T., *et al.* (2017). Simulation of three surgical techniques combined with two different bone-borne forces for surgically assisted rapid palatal expansion of the maxillofacial complex: a finite element analysis. *Int J Oral Maxillofac Surg., 46*(10), 1306-1314.

27. Lee, R. J., Moon, W. & Hong, C. (2017). Effects of monocortical and bicortical mini-implant anchorage on bone-borne palatal expansion using finite element analysis. *Am J Orthod Dentofacial Orthop., 151*(5), 887-897.

28. Carlson, C., Sung, J., McComb, R. W., Machado, A. W., Moon, W. (2016). Microimplant-assisted rapid palatal expansion appliance to orthopedically correct transverse maxillary deficiency in an adult. *Am J Orthod Dentofacial Orthop., 149*(5), 716-728.

29. Cantarella, D., Dominguez-Mompell, R., Mallya, S.M., Moschik, C., Pan, H. C., *et al.* (2017). Changes in the midpalatal and pterygopalatine sutures induced by micro-implant-supported skeletal expander, analyzed with a novel 3D method based on CBCT imaging. *Prog Orthod., 18*(1), 34.

30. Pogrel, M. A., Kaban, L. B., Vargervik, K. & Baumrind, S. (1992). Surgically assisted rapid maxillary expansion in adults. *Int J Adult Orthodon Orthognath Surg., 7*(1), 37-41.

31. Lin, L., Ahn, H. W., Kim, S. J., Moon, S. C., Kim, S. H. & Nelson, G. (2015). Tooth-borne vs bone-borne rapid maxillary expanders in late adolescence. *Angle Orthod., 85*(2), 253-262.

32. Oh, H., Park, K. J. & Lagravere-Vich, M. O. (2019). Comparison of traditional RPE with two types of micro-implant assisted RPE: CBCT study. *Sem in Orthod., 25*(1), 60-68.

33. Jia, H., Zhuang, L., Zhang, N., Bian, Y. & Li, S. (2021). Comparison of skeletal maxillary transverse deficiency treated by microimplant-assisted rapid palatal expansion and tooth-borne expansion during the post-pubertal growth spurt stage. *Angle Orthod., 91*(1), 36-45.

34. Minervino, B., Barriviera, M., Curado, M. M. & Gandini, L. G. (2019). MARPE Guide: A Case Report. *The Journal of Contemporary Dental Practice, 20*(9), 1102-1107.

35. Brunetto, D. P., Sant'Anna, E. F., Machado, A. W. & Moon, W. (2017). Non-surgical treatment of transverse deficiency in adults using Microimplant-assisted Rapid Palatal Expansion (MARPE). *Dental Press J Orthod., 22*(1), 110-125.

36. Folco, A., Benítez-Rogé, S., Calabrese, D., Iglesias, M., *et al.* (2017). Method for evaluation of transverse dimension in self-ligating orthodontic treatment. A comparative study. *Acta Odontol Latinoam., 30*(3), 124-128.

37. Storto, C. J., Garcez, A. S., Suzuki, H., Cusmanich, K. G., Elkenawy, I., *et al.* (2019). Assessment of respiratory muscle strength and airflow before and after microimplant-assisted rapid palatal expansion. *Angle Orthod., 89*(5), 713-720.

38. Al-Mozany, S. A., Dalci, O., Almuzian, M., Gonzalez, C., Tarraf, N. E., *et al.* (2017). A novel method for treatment of Class III malocclusion in growing patients. *Prog Orthod., 18*(1), 40.

39. Almuzian, M., Almukhtar, A., Ulhaq, A., Alharbi, F. & Darendeliler, M. A. (2019). 3D effects of a bone-anchored intra-oral protraction in treating class III growing patient: a pilot study. *Prog Orthod., 20*(1), 37.

40. Lee, K., Choi, S. H., Choi, T. H., Shi, K. K. & Keum, B. T. (2018). Maxillary transverse expansion in adults: Rationale, appliance design, and treatment outcomes. *Semin in Orthod., 24*(1), 52-65.

41. Moon, W. (2018). Class III treatment by combining facemask (FM) and maxillary skeletal expander (MSE). *Sem in Orthod., 24*(1), 95-107.

42. Rego, M. V. N. N., Barros, H. L. M., Iared, W. & Ruellas, A. C. O. (2019). Expansãorápida da maxilaassistida por mini-implantes (MARPE) empaciente no final docrescimento. *Rev Clín Ortod Dental Press., 18*(1), 110-123.

43. Zong, C., Tang, B., Hua, F., He, H. & Ngan, P. (2019). Skeletal and dentoalveolar changes in the transverse dimension using microimplant-assisted rapid palatal expansion (MARPE) appliances. *Sem in Orthod., 25*(1), 46-59.

44. Lee, S. R., Lee, J. W., Chung, D. H. & Lee, S. M. (2020). Short-term impact of microimplant-assisted rapid palatal expansion on the nasal soft tissues in adults: A three-dimensional stereophotogrammetry study. *Korean J Orthod., 50*(2), 75-85.

45. Thakkar, D., Ghosh, A. & Keshwani, T. (2020). Digital Workflow for CBCT-Guided Customized Miniscrew-Assisted Rapid Palatal Expansion (3D Digital MARPE): A Clinical Innovation. *J Ind Orthod Socit., 54*(3), 262-266.

46. Dzingle, J., Mehta, S., Chen, P. J. & Yadav, S. (2020). Correction of Unilateral Posterior Crossbite with U-MARPE. *Turk J Orthod., 33*(3), 192-196.

47. Consolaro, A. & Consolaro, R. B. (2018). Jaws can be referred to as narrow or hypoplastic, but the term "atresia" is inaccurate. *Dental Press J Orthod., 23*(5), 19-23.