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REVIEW

Orthodontic or surgically assisted rapid maxillary expansion

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Abstract

Purpose The purpose of this study was to present, compare, and discuss the techniques for rapid maxillary expansion.

Discussion The isolated transverse maxillary deficiency can be treated either orthodontically or surgically with rapid palatal expansion. In children and adolescents, conventional orthodontic rapid maxillary expansion has been successful when used before sutural closure. On the other hand, in skeletally mature patients, the possibility of successful maxillary expansion decreases as sutures close and the resistance to mechanical forces increases.

Conclusions The selection of an expansion technique depends on a number of factors. It is more likely to advocate surgery as the patient's age, transverse needs, or acceptance of the idea of surgery increases.

Keywords Palatal expansion technique · Rapid maxillary expansion · Transverse maxillary deficiency

Introduction

Previous short-term investigations have demonstrated that rapid maxillary expansion is able to eliminate a transverse discrepancy between the dental arches due to maxillary constriction [17, 36, 37, 44, 46, 67, 110, 124, 127]. Treatment-induced widening of the maxilla leads to the correction of posterior crossbites [49, 56], to the coordination of the maxillary and mandibular dental arches prior to orthopedic or functional treatment of class II and class III malocclusions [9, 116], and to a gain in arch perimeter in patients with tooth-size/arch-size discrepancies [1].

The isolated transverse maxillary deficiency can be treated either orthodontically or surgically with rapid palatal expansion.

Although conventional rapid maxillary expansion (RME) can be used in younger patients, the facial suture lines become significantly more interdigitated and become either partially or totally fused as individuals age. There is a great deal of variability in the initiation and progress of sutural closure, although the rate of closure increases in the third decade [95]. According to Baumrind and Korn [12], the maxillary sutures close around 14 to 15 years of age in females and 15 to 16 years of age in males.

After sutural closure or completion of transverse growth, orthopedic transverse maxillary expansion is largely unsuccessful because the expansion is primarily composed of alveolar or dental tipping with little or no basal skeletal movement [19]. In mature patients, RME also causes severe pain, periodontal complications, and gingival recession of the maxillary posterior teeth [13, 20, 48, 93].

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A variety of surgical procedures including surgically assisted rapid maxillary expansion (SARME) and segmental LeFort I osteotomies have been advocated in the treatment of transverse maxillary deficiency in skeletally mature patients. The decision to choose one surgical procedure over another has led to some controversy in the literature [102].

Maxillary expansion techniques

Orthopedic RME

After bonding the Haas appliance, the patient and their parents are instructed to activate the screws one-quarter turn in the morning and another one-quarter turn in the evening. The activation time varied according to individual needs (Figs. 1, 2, and 3). A period of 3 months of retention is necessary to allow normal histology of the suture to be reestablished and to prevent recurrence [33, 106].

SARME without pterygoid osteotomy (local anesthesia)

A Hyrax device is installed by an orthodontist prior to the surgery (Fig. 4). The patient undergoes ambulatory surgery with oral sedation and local anesthesia for bilateral blockage of the anterior, medium, and posterior superior alveolar nerves, nasopalatine nerve, and bilateral posterior palatine nerve. Incisions are made bilaterally over the maxillozygomatic crest. These osteotomies are performed above the dental apexes, aiming at preserving their vitality (Fig. 5).

A V-shaped incision is then made in the area of the superior labial brake and the osteotomy from the anterior nasal spine to the posterior nasal spine is performed, aiming at detaching the maxilla at the median palatine suture (Figs. 6 and 7). The palatine mucosa is protected by putting

Fig. 1 Orthodontic RME using Haas device. Before activation

Fig. 2 Orthodontic RME using Haas device. After activation

Fig. 3 Orthodontic treatment at the final phase

Fig. 4 A Hyrax device installed prior to the SARME with local anesthesia

the forefinger in the palate to feel the bone separation and the chisel's proximity. The Hyrax appliance is activated. Appliance activation is made four times for each day. The activation time varies according to individual needs. This retention period usually lasts for 6 months, using the Hyrax appliance to prevent recurrence (Fig. 8).

SARME with pterygoid osteotomy (general anesthesia)

A Hyrax device is installed by an orthodontist prior to the surgery. The patient undergoes surgery under general anesthesia administered through nasoendotracheal intubation. Local anesthesia with vasoconstrictor is used to minimize bleeding in the soft tissue.

A vestibular incision is made from the premolar area on one side to the other. The alveolar crest, as well as the sinus walls and the nasal floor, are deflected. The pterygoid osteotomy is performed bilaterally with an end-curved chisel. The osteotomy from the anterior nasal spine to the posterior nasal spine is performed, aiming at detaching the maxilla at the median palatine suture. The palatine mucosa is protected by putting the forefinger in the palate to feel the bone separation and the chisel's proximity. Another osteotomy runs from the nasal floor through the sinus wall and the tuberosity area to the pterygoid junction. The Hyrax appliance is activated. The activation time varies according to individual needs. This retention period usually lasts for 6 months, using the Hyrax appliance to prevent recurrence (Figs. 9, 10, 11, 12, and 13).

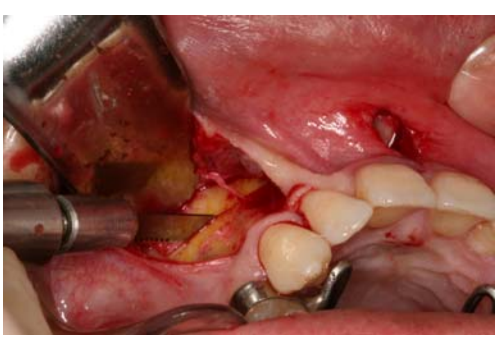

Fig. 5 Osteotomy at the lateral maxillary sinus wall. Note the partial incision

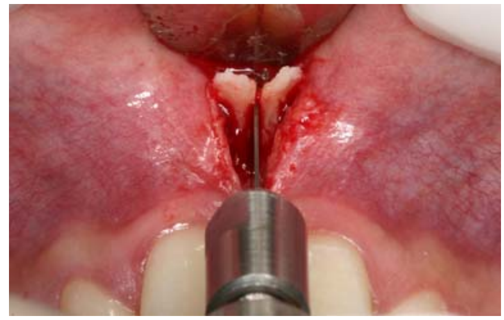

Fig. 6 V-shaped incision and osteotomy at the anterior nasal spine with micro-oscillating saw

Discussion

Initial definitions

Transverse maxillary deficiency, isolated or associated with other dentofacial deformities, results in aesthetic and functional impairment, such as difficulty chewing, owing to unilateral or bilateral transverse discrepancy and dental clustering or ogival palate and nasal blockage, leading to buccal breathing and apnea [20, 44].

Maxillary constriction together with a high palatal vault are two characteristics of the "skeletal development syndrome" [79]. Laptook [79] described other features of this syndrome as (1) decreased nasal permeability resulting from nasal stenosis, (2) elevation of the nasal floor, (3) mouth breathing, (4) bilateral dental maxillary crossbite along with a high palatal vault, and (5) enlargement of the nasal turbinates causing a decrease in nasal airway size.

An adequate transverse maxillary dimension is a critical component of a stable and functional occlusion [120]. Orthopedic rapid palatal expansion in skeletally immature

Fig. 7 Osteotomy from the anterior to posterior nasal spine with an osteotome

Fig. 8 Retention period with the Hyrax device. The appliance is covered with acrylic

patients is the procedure of choice to correct this condition in that age group. However, as skeletal maturity approaches, bony interdigitation increases as the sutures fuse [87, 88]. This leads to difficulty separating the maxillas with orthopedic forces alone and bending of the alveolus, dental tipping, and minimal maxillary expansion. The result is relapse despite overcorrection, pain, periodontal defects (a significant amount of gingival recession), periodontal ligament compression, and malocclusion [13, 20, 48, 93].

Historical basis

The use of rapid maxillary expansion in the treatment of transverse deficiencies in children solely through orthopedic devices was first described by Angell [5] in 1860. The patient, a 14-year-old girl with ectopic left upper lateral and premolars, was fitted with a unique appliance that featured two contra-rotating screws threaded left and right. It was neither cemented nor cribbed, but relied instead on pressure from the screws to hold it in place against the necks of the teeth. The baering surfaces were lined in soft gold so as not to damage the teeth. He gave the patient the following instructions: Keep the appliance as uniformly tight as possible by turning the screw. The *Dental Cosmos* article was a slightly edited version of a paper that was first published in the fledgling *San Francisco Medical Press* in January 1860 [113].

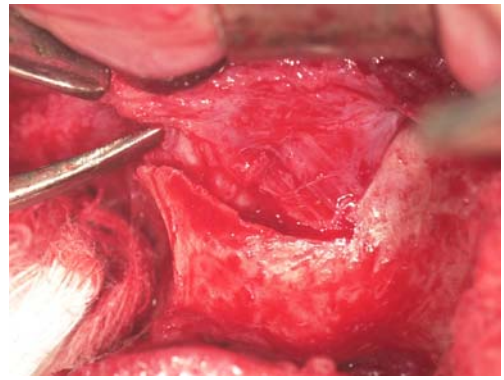

Fig. 10 Deflection of the nasal floor mucosa

Brown [26] first described SARME in 1938, performing only a midpalatal split. Haas [44] reintroduced the surgery with his appliance in 1961.

Advantages

Advantages of the SARME include improved periodontal health; improved nasal airflow [39, 64, 123, 125, 126]; elimination of the negative space, which results in less visible tooth and gum structure showing during smiling; a cosmetic improvement of the buccal hollowing second to post-expansion prominence at the site of the lateral wall osteotomy [55]; and bone apposition in the osteotomy site and reduced risk of dental version or extrusion compared with regular orthopedic care [64]. Also, tooth extraction for alignment of the arches is often unnecessary.

Several papers reported that hearing levels were significantly improved after the maxillary expansion period in patients with conductive hearing loss [29, 34, 62, 63, 79, 108, 112, 122]. Laptook [79] suggested that the orthopedic effect of the RME procedure helps improve hearing loss because of a more normal functioning of the pharyngeal ostia of the Eustachian tubes. Braun [24] observed that mouth breathing is an aberrant respiratory function and can cause extensive tracking to the most distant corners of the

Fig. 9 Condition before the SARME with general anesthesia

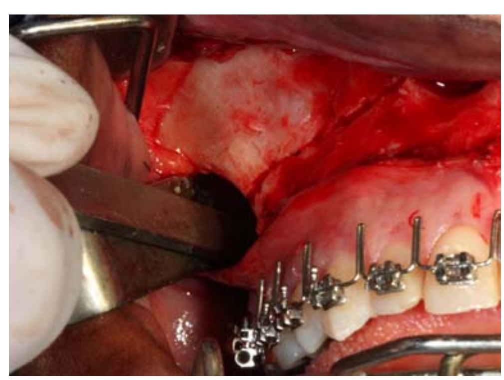

Fig. 11 Pterygoid osteotomy

Fig. 12 Protection of the palatine mucosa with the finger while doing the midpalatal osteotomy

system, from the Eustachian tubes to the middle ear, and may cause hearing loss. One of the causes of nasal stenosis was maxillary constriction [24].

Osteogenic distraction

A surgically assisted maxillary expansion procedure is essentially a combination of osteogenic distraction with controlled expansion of soft tissues [20, 128]. Some principles must be followed to ensure that bone repair occurs in osteogenic distraction: preservation of blood supply in the region; stability of the distractor and bone fragments set; adequate latent period; adequate rate and frequency of activation; and observance of the retention period [57, 58, 90, 109, 117].

The maintenance of the blood supply requires an appropriate surgical procedure, with careful manipulation of soft tissues and ensuring that the periosteum remains intact. Ilizarov [58] considers that the more rigid the distractor–bone fragments ensemble, the more efficient bone repair will be, with fewer possibilities for pseudoarthrosis. Latency is considered to be the time interval between osteotomy and the appliance start-up [109] and can vary from 0 to 14 days in experimental and clinical studies [4, 109, 117]. The activation rate is the amount of daily bone distraction (in millimeters); it varies from 0.25 to 1.0 mm, and the frequency represents the number of times the appliance is activated per day [57]. At the end of the distraction, a retention period is necessary for the neoformed bone tissue to acquire the necessary resistance to bear the recidivation forces (tipping). In experimental and clinical studies, this period can vary from 1 to 6 months [4, 33]. Experimental research with monkeys has proven that after 3 months of expansion, the neoformed bone tissue is still disorganized histologically and poorly mineralized, although the median palatine suture radiographic image looks normal [33]. As a result, they recommend a retention period of 6 months to promote good mineralization of the suture. Deficient retention, however, may cause discomfort for the patient as well as inadequate bone regeneration and infection [57].

Fig. 13 A little activation of Hyrax. Note the osteotomy that runs from the nasal floor through the sinus wall and the tuberosity area to the pterygoid junction

Maturation of the midpalatal suture

The issue of timing in dentofacial orthopedics is a fundamental aspect for an adequate treatment planning and for a reasonable anticipation of therapeutic outcomes both short term and long term [8]. Available information related to the ideal time for treatment of maxillary transverse deficiency by means of an orthopedic device mainly consists of studies of the growth and maturation of the intermaxillary sutural system. Melsen [87] used autopsy material to histologically examine the maturation of the midpalatal suture at different developmental stages. In the “infantile” stage (up to 10 years of age), the suture was broad and smooth, whereas in the “juvenile” stage (from 10 to 13 years), it had developed into a more typical squamous suture with overlapping sections. Finally, during the “adolescent” stage (13 and 14 years of age), the suture was wavier with increased interdigitation. In their 1982 study, Melsen and Melsen [88] also included observations of the “adult” stage of the suture that noted synostoses and numerous bony bridge formations across the suture. From these histological data, the inference is that patients who show an advanced stage of skeletal maturation at the midpalatal suture may have difficulty undergoing orthopedic maxillary expansion. Clinical support for the histologic findings by Melsen [87] is derived from the results of a study by Wertz and Dreskin [124] who noted greater and more stable orthopedic changes in patients under the age of 12 years.

Implant studies [22, 23] have demonstrated that the transverse growth pattern of the maxilla follows distance and velocity curves similar to those for body height with similar times of growth spurt and growth completion. Thus, treatment outcomes of rapid maxillary expansion need to be evaluated with respect to stages in skeletal maturation in order to detect possible differences between subjects treated before and after the pubertal peak.

The effects of maxillary separation by means of the Haas expander appear to reach anatomical skeletal regions far from the midpalatal suture only when treatment is delivered before the peak in skeletal growth velocity [7]. With increased age, the fulcrum of maxillary separation tends to be displaced more inferiorly, nearer to the activating force [127]. In children, the fulcrum may be as high as the frontomaxillary suture, whereas in adolescents, the fulcrum is much lower. These differential, age-dependent effects may be attributed to the increased resistance to maxillary separation by the circummaxillary structures because of increased calcification in the sutural skeletal structures.

Results of the study of Baccetti et al. [7] showed that RME treatment is able to induce significantly more favorable skeletal changes in the transverse plane when it is initiated before the pubertal peak in skeletal growth. This clinical finding agrees with histological data previously noted by Melsen [87] which demonstrated a higher level of response to mechanical stimuli in the midpalatal suture in preadolescent patients due to a lesser degree of interdigitation between the two halves of the maxilla.

Types of appliances

Two types of appliances for RME are most widely recognized in the literature, and the main difference between them is the presence or absence of an acrylic pad close to the palate. The tooth tissue-borne or Haas-type expander possesses this acrylic pad and is assumed to distribute the expanding force between the posterior teeth and the palatal vault. The tooth-borne or Hyrax expander does not include the acrylic pad and presumably delivers the force to the maxilla only by means of the appliance-supporting teeth [42].

Even though cephalometric and dental cast investigations have not demonstrated differences between the tooth-borne and tooth tissue-borne expanders [85, 100, 103], there is no consensus in the literature regarding the differences between the modes of action of the two appliances. The easier hygiene, greater comfort, and prevention of lesions to the palatal mucosa are the advantages of the hygienic appliance [21]. Advantages of the Hyrax expander include its ability to be placed and removed in the orthodontic outpatient clinic without local anesthesia. Dental anchorage gives rise to several complications, including damage to the teeth, possible loss of anchorage, periodontal membrane compression and buccal root resorption, cortical fenestration, and anchorage tooth tipping and segmental tipping [64]. On the other hand, the palatal acrylic expander is stated to be the only appliance that might lead to a significant expansion of the maxillary base [44–48]. Moreover, the absence of an acrylic pad is stated to allow relapse of the orthopedic effect during the retention stage [47]. Because the tooth-borne expander maintains only the dental arch expansion, the "bone would move through the teeth" [47]. No evidence has confirmed such assumptions.

Garib et al. [42] found that tooth-borne and tooth tissue-borne expanders tended to produce similar orthopedic effects and the tooth tissue-borne expander produced a greater change in the axial inclination of supporting teeth, especially in the first premolars, compared with the tooth-borne expander.

To help prevent the dental complications, several bone-borne devices (distractors) have been developed [52–54, 64]. These distractors are placed directly on the palatal bone during surgery. They are claimed to avoid several of the problems associated with the Hyrax expander including damage to the teeth, periodontal membrane compression and buccal root resorption, cortical fenestration, skeletal relapse, and anchorage tooth tipping [84, 91, 97]. The major advantage of the bone-borne devices is that the forces are acting directly to the bone at the mechanically desired level [52, 64], which prevents dental tipping and keeps segmental tipping to a minimum. The therapeutic spectrum is widened to include periodontally compromised or toothless patients as well as those with vertical growth pattern [52]. Bone-borne devices have several disadvantages, including a risk of damaging the roots of the dentition during placement of the devices, risk of loosening of the module or the abutment plates, and the need to remove the distractor under local anesthesia in the outpatient clinic after the consolidation period [64].

It has been suggested that the relapse is greater when a tooth-borne device is used. An explanation for this might be the tipping of the elements due to the tooth-borne fixation of the Hyrax expander [64]. Another contributing factor may be the tipping of the maxillary segments instead of parallel expansion due to the different position of the tooth-borne and bone-borne distractors relative to the "center of resistance" [25], the area where the maxillary halves are still connected to the skull after the corticotomy, the pterygoid region.

The results of the study of Koudstaal et al. [65] show that there is no significant difference between the two groups: the bone-borne versus the tooth-borne distraction. This leads to discarding the working hypothesis that in skeletally matured, non-syndromal patients with transverse maxillary hypoplasia, less tipping of the maxillary segments and increased stability in transverse dimensions at tooth and bone levels are achieved with a bone-borne device compared with a tooth-borne expander in SARME.

Activation frequency and activation rate

Surgeons should not expand the maxilla to its desired width intraoperatively as a one-stage procedure, as has been suggested [89]. Instead, this should be done in a slow, controlled fashion over days to weeks, depending on the amount of expansion required. Attempting to achieve all the needed expansion intraoperatively is not only a dangerous practice, greatly increasing the chances for the development of untoward fractures, but it violates the concept of a SARME as a technique to achieve distraction osteogenesis [78].

Studying the influence of the activation frequency and activation rate in expanded tissues, Ilizarov [58] has found that 0.5 mm per day results in premature bone consolidation, hindering the desired distraction. Performing activations with 2.0 mm per day, the author has observed soft tissue damage and bone pseudoarthrosis. The best results for soft tissues (periosteum, vases, nerves, muscles) and bone were obtained at a rate of 1.0 mm and a frequency of four times a day (i.e., 0.25 mm per activation).

Local or general anesthesia

Several authors have shown that surgically assisted maxillary expansion can be carried out using only sedatives and local anesthesia when a more conservative surgical technique is chosen [6, 13, 43]. General anesthesia is preferred for invasive techniques [17, 20, 27].

General anesthesia is imperative for broader surgical techniques that may incur excessive bleeding of the nasal mucosa, the maxillary sinus, the sphenopalatine, or the descendent palatine arteries [17, 20, 27]. The SARME may become more involved as the patient ages because the resistance to expansion becomes greater as the sutures become more interdigitated [87, 88]. This can lead to a more involved procedure where more of the maxillary articulations need to be released. The procedure in adults usually requires a general anesthetic and hospitalization, as opposed to being an outpatient procedure in younger patients [102]. For simplified techniques using restricted osteotomies only in the areas of greater resistance [43, 60, 98], surgically assisted maxillary expansion has proven to be possible with local anesthesia and minimum morbidity. This procedure can be carried out as an ambulatory procedure incurring less surgical time and lower costs [6, 43].

Indications

Both approaches (surgical and orthopedic) are clinically effective in expanding a narrow maxilla [3]. But surgically assisted maxillary expansion is unavoidable where the expansion of the maxilla is not possible orthopedically because of the patient's skeletal maturity [3, 17–19, 35, 43, 61, 92].

Transverse maxillary deficiencies of more than 5 mm in a skeletally mature patient arc are a strong consideration for SARME. The figure 5 mm is chosen because the orthodontist can camouflage discrepancies less than this size with orthopedic forces alone. If a discrepancy of more than 7 mm exists, SARME is definitely indicated [102]. In patients of mature skeletal age, SARME also should be considered whenever a narrow maxilla is associated with a wide mandible. The technical difficulty involved in narrowing the mandible, and its potential negative effects on the condyles, makes the maxillary procedure easier. The majority of transverse deficiencies also involve narrow, tapered dental arches pronounced in the canine region. To obtain a functional occlusion, intercanine width must be increased and the incisors retracted to produce an elliptical arch form. If extractions before orthodontics are not desired, SARME is an ideal procedure [102]. With SARME, space for the alignment of crowded maxillary incisors can be provided by maxillary expansion rather than premolar extraction. Thus, decisions about extraction should be postponed until after the expander is removed [30]. A V-shaped maxilla with a narrow anterior segment should be considered for SARME if extractions are not desired [14].

Orthodontic RME

The maxillary sutures close around 14 to 15 years of age in females and 15 to 16 years of age in males [12]. Published cases of adults treated by nonsurgical RME are few [46, 124]. Capelozza et al. [28] attempted sutural expansion in 38 nongrowing subjects with mixed results. Failure to expand, pain, swelling, or ulceration were frequent complications. Only 32% of the sample was free of complications.

Separation of the suture is rarely observed in adults, but this is not considered essential [50]. Contour tracings of the palates demonstrate dentoalveolar expansion as well as some dental tipping. The expansion starts at the apical third to midlevel of the palatal vault. Occasionally, a patient may show expansion across the top of the palatal vault, indicating that some of the width increase might have occurred across the suture. RME and rapid maxillary alveolar expansion (RMAE—as defined by Handelman [50], because the expansion appears to be centered in the alveolar process of the maxilla rather than in the body of the maxilla) probably represent a continuum: from young children who experience about half of their expansion in the base of the maxilla and half in the dentoalveolar complex, to older adolescents who experience a greater percentage in the alveolus, to adults whose expansion occur largely in the alveolus [50].

The Haas tooth-and-tissue-borne expander apparently has the ability, in adults, to expand the posterior dentition with its alveolar housing, perhaps by bending the alveolus with subsequent bone remodeling [50]. In his 1970 paper, Haas [46] suggested such a possibility. He stated that after the age of 18, it is often impossible to open the midpalatal suture. He emphasized the importance of using a tissue-borne as opposed to a tooth-borne expander and the need to reduce the expansion schedule in such cases. He suggested that a “height alveolar expansion” might be possible.

Since the posterior teeth are overexpanded, some decrease in transarch width is expected. Placement of an acrylic palatal retainer, on the same day as or soon after removal of the Haas expander, allows the retainer to act as a fulcrum for uprighting the posterior teeth and limits unwanted palatal relapse. Subjects are advised to use a maxillary retainer at night [50].

Children with unilateral crossbite usually have the ability to center the mandible following expansion of the maxilla. This clinical observation is less predictable in adults because the temporomandibular joints and condyles, in most cases, have accommodated to the shift of the mandible, which can no longer shift back when free of occlusal interference. The ability of the adult to center the mandible is variable; a few patients will center completely, most partially, and some not at all [50]. Unilateral surgical osteotomy of the maxilla on the crossbite side prior to RME has been advocated to allow unilateral expansion [16, 92].

It is important to remember that since the midpalatal suture is unlikely to split in adults, the appliance should be turned, at most, once per day. In children, the appliance is usually turned four times per day.

There is insufficient evidence to know if RME (or RMAE) would accelerate recession of the already compromised buccal periodontium, but caution is advised. SARME may be indicated in cases with maxillary deficiency and a significant tendency for gingival recession [50].

Studies of root resorption associated with RME have examined the roots of extracted anchor teeth in animals [121] and in children or adolescents [11, 40, 94, 114]. These reports show broad but shallow resorption areas on the buccal surfaces of the roots, most prevalent toward the cervical one third of the root. Barker and Sims [11] pointed out that these resorption sites cannot be seen in radiographs of the patient. Resorption sites on the buccal surfaces might be more significant in adult expansion patients.

Differences in surgical techniques

All of the maxillary articulations and suture lines have been found to contribute in different degrees to the resistance to maxillary expansion. This has led to multiple osteotomy and corticotomy designs for separation of the hemi-maxillas in skeletally mature individuals. Results differ based on the placement of the corticotomies and the timing and placement of the orthodontic devices, but all surgical procedures are more stable than orthodontic expansion alone [16, 19, 61, 83, 98, 101]. Early use of SARME was based on the hypothesis that the palatal suture was the main resistance to expansion and a midpalatal osteotomy was suggested [102].

Isaacson and Ingram [59] believed that the remaining maxillary articulations were more important sources of resistance to maxillary expansion. Timms [111] and Timms and Vero [115] carry out osteotomies only in the medium palatine suture because they believe it to be the main area of resistance to the lateral expansion of the maxilla. Lines [83] and Bell and Epker [16] thought that the principal regions of resistance to expansion were the frontomaxillary, zygomaticotemporal, zygomaticofrontal, and the zygomaticomaxillary sutures. Kennedy et al. [61] popularized the use of an osteotomy of the zygomaticomaxillary buttress as the major factor in overcoming resistance to maxillary expansion. Osteotomy only in the bilateral lateral wall, from the piriform opening to the maxillary tuberosity, without releasing the pterygoid lamina and with no osteotomy in the medium palatine suture was successfully used by Glassman et al. [43] and Antilla et al. [6]. Other authors prefer a combination of both techniques (i.e., osteotomies in the median palatine suture and in the bilateral lateral wall without releasing the pterygoid lamina) because they believe it facilitates the expansion of the maxilla and reduces the possibility of further complications [13, 93]. Some authors prefer subtotal Le Fort I osteotomy associated with median palatine suture osteotomy because they consider the results to be more stable in the long term [17, 20, 27].

According to the study of Shetty et al. [101], the lateral maxillary cuts appeared to decrease the resistance of the maxilla to transverse expansion, as evidenced by increased stress at the various other sutures, particularly the pterygomaxillary articulation, the frontonasal suture, and along the lateral nasal wall. Separation of the pterygomaxillary articulation was believed to result in a more substantial reduction in the resistance to maxillary expansion because it led to a marked increase in the stresses at distant locations, including the zygomaticofrontal suture, the inferior part of the lateral nasal wall, the zygomaticomaxillary suture and posteriorly along the zygomatic arch, and at the supraorbital and frontal bone regions. The fact that there was no appreciable increase in the stresses evidenced in the orbit and in the orbital surface of the sphenoid bone was an important finding after the pterygomaxillary dysjunction. It was the conclusion of Shetty et al. [101] that exclusive use of bilateral zygomaticomaxillary buttress osteotomies to facilitate SARME was inadequate. They believed that analysis of the stress patterns in the analog showed that the midpalatal and pterygomaxillary articulations were the primary anatomic sites of resistance to expansion forces. They therefore thought that complete midpalatal and pterygomaxillary osteotomies were essential to result in predictable maxillary expansion in adults. The greater concentration of stresses noted in the posterior aspect of the midpalatal suture of the analog indicated that this region provides significant resistance to expansion forces. A palatal osteotomy that extends to the posterior aspect of the hard palate was therefore thought to be more appropriate than a more limited anterior osteotomy. Moreover, the study of Chamberland and Proffit [30], with separation of the pterygoid junction, did not confirm previous reports of a hinge-type expansion with SARME, with more expansion anteriorly than posteriorly. This suggests that changes in recent years in the surgical procedure for SARME, which now includes surgical release of the pterygoid junction, may allow a similar anterior and posterior expansion. The data of the study of these same authors do not support the conclusion of earlier studies of SARME that this procedure produces more stable expansion than do segmental osteotomies.

Some authors have confirmed that it is unnecessary to carry out osteotomy in the pterygoid processes [38, 93, 98]. To minimize the surgical trauma, less invasive procedures combined with osteotomies in the bilateral zygomatic maxillary crest and median palatine suture were performed by Kaban [60] and Pogrel et al. [98].

The surgical technique that releases all maxillary joints is preferred by some authors [17, 20, 27] who affirm that the separation of the pterygoid processes, in all cases, is the purpose so as not to reduce the expansion in the posterior region because, contrarily to the maxilla, the sphenoid is a single bone with two articulated processes for each maxilla. According to Lanigan and Mintz [78], surgeons must give serious consideration to routinely including separation of the pterygomaxillary articulation as part of a SARME procedure to minimize chances for the development of aberrant fractures. Besides, a greater degree of ossification in the midpalatal synostosis has been noted posteriorly than anteriorly [95]. The pterygomaxillary dysjunction should be carried out via a technique that results in consistent, predictable, safe results, such as with the use of a micro-oscillating saw [74, 77]. The use of a curved pterygoid osteotome should be abandoned because its use can result in high pterygoid plate fractures, which have the potential to disrupt the contents of the pterygopalatine fossa [72, 74], and the use of the pterygoid osteotome has been associated with fractures that extend to the skull base and orbit [73, 74, 99].

In the study of Isaacson and Ingram [59], it was noted that a smaller load per activation was produced in the younger patients than in the older teenagers. Because the force values recorded from the expansion device gives an indication of the resistance of the facial skeleton to expansion, this suggests that the facial skeleton increases its resistance to expansion significantly with increasing age and skeletal maturity. Because patients in whom a SARME procedure is carried out tend to be older, a potential exists for even greater forces to be generated, which could be transmitted to distant anatomic sites if the sites of resistance to maxillary expansion are not appropriately released surgically [78]. These observations could stress the need for pterygomaxillary osteotomies.

Although simple procedures, such as midpalatal and/or zygomaticomaxillary buttress osteotomies, may be sufficient to facilitate maxillary expansion in the vast majority of patients, this may not always be the case, particularly in patients who present with abnormal anatomy. Unfortunately, it is impossible to predict preoperatively which patients will fail to respond successfully to a minimally invasive procedure [78].

SARME and Le Fort I

The similar stabilities of transverse expansion of the dental arches with SARME and segmental Le Fort I osteotomies provide some insight into the choice between procedures [30]. When only a transverse change is needed, SARME would be the treatment of choice. When a second phase of maxillary surgery to reposition the maxilla vertically or anteroposteriorly is required, the routine performance of a preliminary SARME procedure to obtain better transverse stability does not appear to be warranted [10]. Multisegmental osteotomies have been shown to result in greater transverse maxillary instability and relapse after the removal of orthodontic appliances, particularly when used to correct large transverse maxillary discrepancies [96]. Performing a preliminary SARME procedure decreases the risk of aseptic necrosis and relapse, particularly in those patients who have a major transverse discrepancy. An exceptionally narrow maxilla that requires major expansion across the posterior teeth may be an exception [102].

Even though SARME offers many advantages, segmentalized LeFort osteotomies may be indicated in certain circumstances. When transverse discrepancies coexist with vertical or sagittal discrepancies, a segmentalized LeFort osteotomy should be considered. Patients with moderate transverse discrepancies (<7 mm), apertognathia, and a severe curve of Spee should be treated with segmental orthodontics and alignment of the segments with a partitioned LeFort osteotomy [102].

Surgically assisted rapid maxillary expansion occurs primarily at the canines and less at the molars, whereas the segmental LeFort osteotomy produces more expansion in the molar region than at the canines. The former occurs because the posterior articulations of the maxilla are not separated with SARME. The lateral nasal walls and palatine processes are left intact, limiting posterior expansion [102]. Chamberland and Proffit [30] state that the surgical release of the pterygoid junction may allow a similar anterior and posterior expansion and that relapse in the amount of arch-width increase produced by SARME is comparable to the relapse with other expansion procedures.

Stability of the expansion

The long-term stability of the expansion is directly related to the skeletal maturity of the suture lines [101]. Krebs [66] showed that as sutures mature, the majority of orthopedic rapid palatal expansion occurs by dental tipping and alveolar bone bending rather than by skeletal movement. Relapse, with an open bite deformity, may result when fixation is removed. Post-treatment retention is likely to be an important factor in any study of stability [130]. Activation of an appliance against mature sutures can lead to the sensation of pressure, pain, and necrosis under the appliance. These forces can also result in periodontal defects as the teeth are pushed through the buccal cortical plate and lead to bony defects and gingival recession. These complications can be avoided by surgically releasing the osseous structures that resist the expansile forces [15, 105].

Dental and skeletal expansion

In prepubertal children and adolescents, loss of about one third of the maximum expansion across the first molars occurs after nonsurgical rapid palatal expansion [7, 51, 68, 69, 104, 130]. The P-A cephs in patients with palatal implants who underwent maxillary expansion demonstrated that approximately 50% of the expansion achieved by RME in children was skeletal and the remainder was dentoalveolar [67, 70]. Although the amount of relapse in dental arch widths with SARME is about the same as with nonsurgical RME in younger patients, there is a difference: With SARME, the skeletal change is much more stable than with RME [30].

According to Chamberland and Proffit [30], the width of the midline diastema at the maximum expansion point is highly correlated with the first molar expansion. This indicates that the development of a diastema is a predictor that adequate molar expansion is occurring. Even when skeletal expansion is obtained, the low correlation between skeletal changes and dental changes confirms that the maxillary segments often do not expand symmetrically [30]. Instead, some rotation occurs, with the teeth expanding more widely than the bone above, as explained by Byloff and Mossaz [27] and as demonstrated by Chung and Goldman [32]. This rotation of the maxillary segments or alveolar bending explains why the skeletal change at the maximal expansion point is only 47% of the dental expansion. Hence, the horizontal portion of the screw should be more than 3 mm away from the palatal mucosa to avoid impingement [30]. Krebs [67], using metallic implants, demonstrated that approximately 50% of the expansion achieved by RME in children was skeletal and the remainder was dentoalveolar. Hansen et al. [52] observed skeletal expansion in 91% in premolar and 85% in molar regions using a bone-borne expander.

According to Chamberland and Proffit [30], skeletal expansion with SARME involves about half the total intermolar expansion at the maximum expansion point. From that point, dental relapse occurs, but the skeletal expansion is stable so that at the end of treatment, about two thirds of the net expansion is skeletal. Handelman et al. [51] compared expansion with nonsurgical RME in younger versus older patients and estimated that skeletal expansion was only 18% in their adult group compared with 56% for younger patients. Baccetti et al. [7] showed that only 0.9 mm of skeletal expansion is achieved in RME patients treated during or after their peak in skeletal maturation, whereas 3 mm of skeletal expansion was obtained in a group treated before the peak of skeletal maturation. It is clear that with RME, the nature of expansion shifts from skeletal to dentoalveolar in mature individuals who are candidates for SARME. When changes largely involve tooth movement through the alveolar housing, it has been shown to be detrimental periodontally [93].

The skeletal expansion with SARME was quite stable in the study of Chamberland and Proffit [30]: The relapse was almost totally attributable to lingual movement of the posterior teeth. It was recommended previously that a 2-mm expansion beyond the desired result should be performed. Because a mean relapse of about 30% at the first molars can be expected, the authors concur that a 2-mm excess expansion is indicated in SARME patients with a typical expansion of 7 to 8 mm at the first molar. This is needed to compensate for buccal tipping of the entire posterior segment during expansion.

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Relapse

Isolated surgically assisted maxillary expansion in adults presents recidivation indexes varying from 4% to 50% [6, 13, 17, 27, 30, 93, 98, 107]. Some authors [20, 43] state that overcorrection is unnecessary while others [27, 98] advocate that to prevent undesired results and late relapse, it is necessary to promote an overexpansion during the treatment, varying from 0.5 to 2.0 mm on each side. De Freitas et al. [38] recommended an overexpansion index of

23% above the desired measurements to compensate for relapse. Given the similarity of relapse in intermolar width between the SARME and Le Fort I patients, it appears that routine overexpansion should also be part of the protocol for expansion with osteotomy [30].

There are two theories that may explain the relapse: (1) During maxillary expansion, the Hyrax appliance may not be strong enough to prevent teeth relapse (tipping) by action of the soft tissues of the jugal area [25], and (2) for a muscle to elongate during osteogenic distraction, the long axis of its fibers must remain parallel to the distraction axis. This does not happen in the case of the buccinator and the risorious muscles, which are perpendicular to maxillary expansion. These non-elongated muscles can therefore be negative factors regarding steady maxillary expansion [41].

As for bone-borne distraction, Matteini and Mommaerts [84], using the transpalatal distractor, and Zahl and Gerlach [129], using the palatal distractor, found overexpansion to be unnecessary because they detected no relapse on follow-up. These authors attributed the advocated lack of relapse to the fact that the forces of distraction are applied directly to the skeletal base. In the study of Koudstaal et al. [64], segmental tipping occurred in both the tooth-borne and bone-borne groups, suggesting that overcorrection is needed to counteract the tipping-related relapse regardless of the device used. A limitation of the study of the Koudstaal et al. [64] is that it was accomplished anatomic model (ten dentate human cadaver heads) and the distraction in this study was performed all at once. This is in contrast with the normal clinical situation in which distraction osteogenesis is performed gradually, thereby allowing the tissues the possibility to respond to the applied forces.

But some authors believe that satisfactory results and long-term stability after surgically assisted maxillary expansion depend on the orthodontist's ability to obtain a functional and stable occlusion [13, 20, 107].

Complications

Postsurgical complications may arise if the maxilla is insufficiently released or if the expansion device is improperly constructed. Inadequate bony release will be evident if the patient complains of excessive pain and pressure during activation of the appliance. This is due to force transmitted to the fused sutures. If expansion continues without adequate bony release, teeth and alveolar segments will tip and gingival recession will occur on the buccal surfaces [86, 102]. Root resorption with tooth-borne expanders in nongrowing subjects may occur [121]. Vanarsdall [119] stated that even children with maxillary transverse deficiencies are subject to dehiscence of bone and gingival recession following nonsurgical RME.

Intraoperative complications are uncommon with surgically assisted maxillary expansion. Hemorrhage is another complication that has been reported [2, 13]. The most common sources of hemorrhage after maxillary orthognathic surgery include the terminal branches of the maxillary artery, especially the descending palatine or sphenopalatine arteries, the posterior superior alveolar artery, and the pterygoid venous plexus [75, 76, 102]. The risk of intraoperative bleeding, although rare, exists if the pterygoid plates are separated. The descending palatine artery is particularly vulnerable to damage when a SARME is performed with either pterygomaxillary separation or a lateral nasal wall osteotomy [102]. Lanigan [71] states that separation of the pterygoid plates may infrequently cause excessive hemorrhage, thrombosis (which can lead to stroke), and arteriovenous fistulae between the carotid sinus and carotid artery. The cause of abnormal bleeding during maxillary orthognathic procedures can be either mechanical disruption of an artery or vein or secondary to a bleeding diasthesis. Turvey and Fonseca [118] showed that the mean distance from the most inferior part of the pterygomaxillary junction to the most inferior part of the internal maxillary artery is 25 mm. With a correctly positioned osteotome during the pterygomaxillary separation, the margin of safety for avoiding direct damage to the maxillary artery from the osteotome should thus be approximately 10 mm in the adult patient. Damage to the descending palatine artery can also be minimized by limiting the extent of the osteotomy posterior to the piriform rim to 35 mm in men and 30 mm in women [81]. It should be noted that these are mean values and do not take into account the range of normal anatomic variation.

A dramatic case of life-threatening recurrent hemorrhage was reported by Mehra et al. [86]. A case of an orbital compartment syndrome from a retrobulbar hemorrhage, resulting in permanent blindness, has been reported in a 34-year-old woman with transverse maxillary deficiency [82]. Based on this case report and the case reported by Lanigan and Mintz [78] of retrobulbar hemorrhage after the use of an expansion device, it is apparent that the forces associated with an expansion device can be transmitted widely within the craniofacial complex, which was demonstrated in details by Shetty et al. [101]. These forces have the potential to lead to aberrant fractures that can run to the base of the skull, orbit, and pterygopalatine fossa and could result in injuries to important neurovascular structures [78].

Complications related to the expansion appliance include breakage or loosening of the device, stripping or locking of the screw, and impingement on the palatal mucosa leading to vascular compromise and tissue necrosis [102]. A palatal tissue irritation from impingement of the expansion appliance on the palatal soft tissues may occur, at times leading to frank aseptic pressure necrosis [13]. In a series reported by Lehman and Haas [80], 3 of 56 patients (5.4%)

had some degree of palatal mucosal ulceration, while 2 of 56 patients (1.8%) developed frank pressure necrosis. In a series reported by Alpern and Yurosko [2], severe tissue irritation under the expansion appliance was noted in several cases, and three adult female patients developed palatal soft tissue aseptic necrosis.

Shetty et al. [101] have analyzed internal stress responses after SARME using a photoelastic analog of a human skull made from a birefringent cortical bone simulant. The orthopedic forces produced by the Hyrax appliance had deep anatomic effects, with internal stresses being manifested at regions distant from the site of force application. These forces were transmitted into the midface and craniofacial complex along the classic midfacial support struts—the nasomaxillary, the zygomaticomaxillary, and the pterygomaxillary buttresses. With propagation of the split along the midpalatal suture, an immediate alteration in the stress distribution throughout the craniofacial complex was noted. Completion of the midpalatal osteotomy produced a demonstrable increase in the stresses at the zygomaticomaxillary, zygomaticofrontal, and frontonasal sutures as well as along the anterior portion of the lateral nasal wall. In addition, there was a concomitant increase in the stresses observed in the orbital region, especially involving the orbital surface of the greater wing of the sphenoid bone.

Still in the experiment conducted by Shetty et al. [101] using the photoelastic analog, failure to separate the pterygomaxillary junction resulted in forces radiating across the pterygoid plates to deeper anatomic structures, including the body and greater wing of the sphenoid bone. A close anatomic relationship exists between the greater and lesser wings of the sphenoid bone, the sphenoid sinuses, and the inferior and superior orbital fissures. The sphenoid sinus is related laterally to the optic nerve as it traverses the optic foramen, the cavernous sinus, and the internal carotid artery. Therefore, sphenoid sinus fractures have the potential to lead to tears in adjacent soft tissue structures, resulting in carotid-cavernous sinus fistulae, injuries to the carotid artery, damage to the optic nerve, or injuries to cranial nerve III, IV, or VI leading to ophthalmoplegia.

Palatal tori also complicate SARME. Patients should have the torus removed 4 to 6 months before surgery. However, if removal at the time of SARME is planned, an appliance must be constructed on a model with the torus removed. Care should be taken to assure that the appliance is not impinging on the palatal mucosa and vascular pedicle after torus removal. There should be minimal periosteal stripping when a combined SARME and torus removal are done because a midpalatal incision will be required to remove the torus and this is an area of limited blood supply [102].

In a study of nonsurgical rapid maxillary expansion cases, Timms and Moss [114] showed histologic evidence of external root resorption and pulpal changes, including the laying down of secondary dentin and pulp stones. It is possible that similar changes could occur after SARME.

Bilateral lingual nerve injury after a routine and uncomplicated SARME procedure was reported [31]. The authors hypothesize that there was an aberration in the anatomic pathway of the lingual nerve in this patient and that two probable mechanisms could have been responsible for this transient injury: direct injury to the lingual nerve with the pterygomaxillary osteotomies or nerve compression from a hematoma in the pterygomaxillary region.

Conclusions

The selection of an expansion technique depends on a number of factors. In view of the costs, morbidity, risks, and patient reluctance to undergo surgery, each case should be evaluated to determine if a nonsurgical approach will provide an acceptable correction of maxillary transarch deficiency.

It is more likely to advocate surgery as the patient's age, transverse needs, or acceptance of the idea of surgery increases. Cases requiring more than 8 to 10 mm of expansion, severe unilateral posterior crossbites with diminished prospect of the mandible centering, and patients with significant gingival recession are likely candidates for SARME. SARME is a successful treatment modality for the adult patients requiring palatal expansion. It is well tolerated by the patients under local anesthesia.

Pterygomaxillary separation may be needed in cases with severe posterior transverse deficiency to obtain true bony expansion, particularly in older patients. Failure to do so can result primarily in dental expansion and increased postoperative relapse. Intraoperative complications are generally uncommon, but the risk of bleeding may increase if the pterygoid plates are separated from the maxilla.

Some overexpansion is suggested to eliminate the risk of relapse in the orthodontic and surgical approaches.

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