Surgically assisted rapid palatal expansion: A literature review

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Transverse maxillomandibular discrepancies are a major component of several malocclusions. Orthopedic and orthodontic forces are used routinely to correct a maxillary transverse deficiency (MTD) in a young patient. Correction of MTD in a skeletally mature patient is more challenging because of changes in the osseous articulations of the maxilla with the adjoining bones. Surgically assisted rapid palatal expansion (SARPE) has gradually gained popularity as a treatment option to correct MTD. It allows clinicians to achieve effective maxillary expansion in a skeletally mature patient. The use of SARPE to treat MTD decreases unwanted effects of orthopedic or orthodontic expansion. Our aim in this article is to present a comprehensive review of the literature, including indications, diagnosis, guidelines for case selection, a brief overview of the surgical techniques, orthodontic considerations, complications, risks, and limitations of SARPE to better aid the clinician in the management of MTD in skeletally mature patients. (Am J Orthod Dentofacial Orthop 2008;133:290-302)

Orthopedic maxillary expansion (OME) was first described over 145 years ago by Angell in a case report.[1,2] An accompanying commentary on the article suggested that the possibility of achieving OME was "exceedingly doubtful." After initially falling to disrepute, it was reintroduced in the middle of the last century by Andrew Haas.[3] Presently, OME has become a routine procedure in treating maxillary transverse deficiency (MTD) in a variety of malocclusions in young orthodontic patients. There is, however, a lack of definitive guidelines that would enable the orthodontist to select an age-appropriate procedure for treating MTD. OME can produce unwanted effects when used in a skeletally mature patient, including lateral tipping of posterior teeth,[4,5] extrusion,[6-8] periodontal membrane compression, buccal root resorption,[9-11] alveolar bone bending,[5] fenestration of the buccal cortex,[11-14] palatal tissue necrosis,[15] inability to open the midpalatal suture, pain, and instability of the expansion.[5,8,16-18] Several reasons have been speculated regarding factors that limit orthopedically induced maxillary expansion in skeletally mature patients. These are all related to changes with increasing age in the osseous articulations of the maxilla with the adjoining bones. However, a few reports in the literature contradict these findings and state that nonsurgical maxillary expansion is as successful in adults as it is in children.[19,20]

The incidence of MTD in the deciduous and mixed dentitions is estimated at 8% to 18% of patients having orthodontic consultations.[21] The incidence of MTD in the adult population or in skeletally mature people could not be elucidated from the literature.

Because of more complications after attempts to orthopedically alter the transverse dimension of the maxilla with advancing age, surgical procedures have been recommended to facilitate correction of transverse discrepancies. These procedures have conventionally been grouped into 2 categories: segmenting the maxilla during a LeFort osteotomy to reposition the individual segments in a widened transverse dimension, and surgically assisted rapid palatal expansion (SARPE).

The criteria for selection of either of these to correct the MTD have not been clearly defined. The preference of the surgeon often determines the choice of the procedure.

Our aim in this article is to present a comprehensive review of the literature, including indications, diagnosis, guidelines for case selection, a brief overview of the surgical techniques, orthodontic considerations, complications, risks, and limitations of SARPE to better aid the clinician in the management of MTD in skeletally mature patients.

Current standards for reviews require performing a

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meta-analysis on the subject. However, an exhaustive search of the literature on SARPE, did not unearth enough articles with strong study designs or common denominators to perform a meta-analysis.

INDICATIONS FOR SARPE

There is a lack of consensus among orthodontists and surgeons about the indications for SARPE. Although maxillary expansion might be required for many patients, an accurate diagnosis of MTD is somewhat ambiguous. This is further complicated by case reports in the literature about OME or other forms of expansion in adults.

The following have been reported in the literature as indications for SARPE, all applying to a skeletally mature patient with a constricted maxillary arch.[22,23]

1. To increase maxillary arch perimeter, to correct posterior crossbite, and when no additional surgical jaw movements are planned.
2. To widen the maxillary arch as a preliminary procedure, even if further orthognathic surgery is planned. This is to avoid increased risks, inaccuracy, and instability associated with segmental maxillary osteotomy.
3. To provide space for a crowded maxillary dentition when extractions are not indicated.
4. To widen maxillary hypoplasia associated with clefts of the palate.
5. To reduce wide black buccal corridors when smiling.
6. To overcome the resistance of the sutures when OME has failed.

PATIENT SELECTION

A thorough review of the literature shows significant disparities among clinicians regarding the criteria for case selection and the indications for SARPE. In this section, we will address the diagnostic procedures that are critical to proper case selection.

Diagnosis

The first step in the case selection process is determination of MTD. Unlike discrepancies in the vertical and the anteroposterior dimensions, diagnosis of MTD is difficult. There is much literature on the various methods used to diagnose this condition. Clinical evaluation, model analysis, occlusograms, and radiographic measurements have been recommended for an accurate assessment.

Clinical evaluation includes assessment of the maxillary arch form and symmetry, shape of the palatal vault, width of the buccal corridors on smiling, occlusion, and predominant mode of breathing (nasal or oral). Excessively wide buccal corridors, paranasal hollowing, or narrow alar bases usually suggest MTD. The soft-tissue thickness should also be evaluated because it can mask MTD. Unilateral or bilateral crossbite, severe crowding, a V-shaped or an hourglass-shaped occlusion, and a high palatal vault are additional visual parameters that can help the clinician make the first determination of MTD in a patient. Another factor that needs assessment is a mandibular shift on closure. This can often be a chin deviation with a unilateral crossbite. To identify the nature of a shift, it might be necessary to use a muscle deprogramming device such as a bite plate for a few days. These devices are needed more often for adults whose muscular kinesthetic memory and proprioceptive influences are ingrained. Such a deprogramming device allows the muscles to move the mandible in coordinated function that is undisturbed by deflective tooth contacts.[24,25]

Another aspect that needs determination is whether the MTD is relative or absolute.[26] This is essential in the evaluation of sagittal discrepancies (especially Class III malocclusion). An attempt is made to articulate and align the models in Angle Class I molar and canine relationship to evaluate arch coordination. Relative MTD implies that the apparent deficiency is the result of the discrepancy of the maxilla or both jaws in the sagittal plane. Absolute MTD implies a true horizontal width insufficiency.[26,27]

Study models should be used to thoroughly assess the arch form and the shape and make specific measurements to evaluate for MTD. Several indexes have been proposed by various authors to measure lateral discrepancies. The most common include the indexes of Pont, Linder-Harth, and Korkhaus.[28] Although these indexes offer a guide to diagnose MTD, they are population specific and not completely reliable. With the advent of digital models in routine clinical practice, additional tools can be used to evaluate arch form and tooth inclinations.[29] The evaluation of the buccolingual inclination of the posterior teeth is an essential part of the diagnosis. This allows a more accurate distinction between dental and apical base skeletal MTD. The digital models can be viewed in desired cross-sections that permit better visualization of the buccolingual inclination of the teeth. The digital models can also generate images for occlusograms[30,31] whereby the coordination of the maxillary and mandibular arches can be evaluated. They provide occlusal simulations and assist in the diagnosis of relative or absolute MTD.

Lehman et al[32] recommended a palatal or an occlusal radiograph as an essential tool to evaluate the ossification of the midpalatal suture. This, however, is unreliable because of the superimposition of other bony structures on the midpalatal suture and the lack of adequate visualization of the posterior part of the intermaxillary suture. This is relevant because histologic studies have shown that obliteration of the suture is more common in the posterior region of the intermaxillary suture. The value of an occlusal radiograph is also unclear, since studies have shown that the midpalatal suture does not offer much resistance to expansion.[5,33,34]

Betts et al[35] suggested that posteroanterior cephalograms are the most readily available and reliable means to identify and evaluate transverse skeletal discrepancies between the maxilla and the mandible. Using cephalometric landmarks as described by Ricketts,[36] they presented 2 methods for quantification of the MTD: maxillomandibular width differential and maxillomandibular transverse differential index.

These methods have been criticized because the transverse discrepancy between the maxilla and the mandible is measured on bony landmarks that are greatly separated from the dentition and the apical bases.

The advent of 3-dimensional imaging techniques is the most recent tool for diagnosis that have enabled an accurate visualization of the craniofacial region. It allows for evaluation of the spatial relationships of various areas of the jaws.[37] Cone-beam computed tomography can generate scans that enable the clinician to perform a 3-dimensional evaluation of the apical bases including horizontal sections of the apical bases at different levels. These images can help the clinician to make an accurate and detailed analysis of the nature and location of the discrepancy including asymmetries.

Age as criterion

The patient's age has been considered by most authors and clinicians as the fundamental basis for distinguishing the use of OME vs SARPE to treat MTD. However, conflicting views regarding when OME is successful and when to request surgical assistance for treating MTD are found in the literature. Epker and Wolford[38] recommended surgical assistance for maxillary expansion in patients over 16 years of age. Timms and Vero[39] used 25 years as the upper limit for recommending OME. Mossaz et al[40] arbitrarily recommended "after the second decade of life" for surgical assistance of maxillary expansion. Mommaerts[7] stated that OME is indicated for patients younger than 12 years, and, for those over 14 years, corticotomies are essential to release the areas of resistance to expansion. Alpern and Yurosko[15] suggested that sex should also be considered as a selection criterion. According to them, men over the age of 25 and women over 20 require surgical assistance for expansion.

Table I. Etiology of MTD

Habits–thumb sucking[108-111]
Obstructive sleep apnea[108-111]
Iatrogenic (cleft repair)[41,112,113]
Palatal dimensions and inheritance[114,115]
Muscular[108-111,116]
Syndromes
Klippel-Feil syndrome[117]
Cleft lip and palate[118,119]
Congenital nasal pyriform aperture stenosis
Marfan syndrome[119]
Craniosynostosis (Apert's, Crouzon's disease, Carpenter's)[119]
Osteopatia striata[75]
Treacher Collins[75]
Duchenne muscular dystrophy[116]
Nonsyndromic palatal synostosis[120]
Multifactorial

Further confusion is added by several case reports in which OME has been shown to be successful in much older adults.[15,41,42] These authors suggested that, although an orthopedic effect was not observed, slow expansion results in a combination of membranous warpage and some sutural stretching to provide the desired end result. They also suggested that slow expansion might not be as kind to the gingivae, but it is clinically adequate and stable.[43]

Determination of skeletal age is an important parameter for case selection.[44] It is possible that chronologically advanced patients in case reports whose OME was successful were skeletally immature. The reverse can also be true in chronologically younger patients with advanced skeletal maturity whose OME might be unsuccessful.

Medical history

In treatment planning and case selection for MTD, the patient's medical condition must be thoroughly evaluated (Table I). Investigations on cadaver skulls by Persson and Thilander[45] showed that ossification of the midpalatal suture has wide variations in various age groups. Since OME depends on the sutural patency and the flexibility of the craniofacial skeleton to adapt to controlled mechanical forces, it is essential to evaluate for medical conditions that can influence the results of OME. Several metabolic conditions have been linked to sutural synostoses. These include hyperthyroidism,[46,47] hypophosphatemic vitamin D-resistant rickets,[48] and mucopolysaccharidoses and mucolipidoses.[46,49] A common link in all these conditions is an underlying abnormality in bone metabolism. The medical history must be carefully evaluated, since developmental dynamics and environmental influences can affect the ability of a suture to respond to external force application. OME would either be unsuccessful or have unfavorable consequences as discussed earlier even in a chronologically young patient with such medical conditions. Synostosis in any of these metabolic disorders can be either simple or complex. Simple synostosis involves fusion of 1 suture, but craniosynostosis syndromes and metabolic disorders are associated with complex synostosis.

Individual variability with regard to fusion of sutures is significant. Recent evidence from molecular biology has shed light on the underlying mechanisms of suture fusion. These findings might have significant implications on the selection of treatment. Bony obliteration of the suture site is caused by premature or accelerated bone formation in the fibrous suture matrix. This can occur by increasing cell numbers, leading to increased cell density and inducing bony differentiation, or by directly inducing premature differentiation of cells. Cell numbers can be increased by stimulating cell proliferation or by inhibiting apoptosis. These cellular functions are controlled by various growth and transcription factors acting in concert or in parallel with each other. Several growth and transcription factors have been shown to play a role in regulating suture morphogenesis and patency, and, in many instances, the mechanisms by which they do so have begun to be elucidated. It can be hypothesized that a detailed medical evaluation including serology might elucidate biochemical profiles to assist in clinical diagnosis and decision making.

A detailed medical evaluation is also necessary from the standpoint of general anesthesia that would otherwise preclude the patient from elective surgery.

Amount of expansion

Betts et al[35,50] and others[51] have recommended that the amount of desired expansion is an important factor in case selection for maxillary expansion in adults. In general, an orthodontist can camouflage transverse maxillomandibular discrepancies less than 5 mm with orthopedic or orthodontic forces alone. When the MTD is greater than 5 mm, surgical assistance is essential. Although both SARPE and segmental osteotomy are used for surgically assisted maxillary expansion, segmental osteotomy is reported to be unstable, especially when more than 8 mm expansion is desired.[22] It is also essential to evaluate the buccolingual inclination of the teeth because that may either mask or aggravate the discrepancy at the apical bases.

Two-stage vs singular surgery

Surgical correction of MTD may be achieved by either segmental osteotomy or SARPE. Segmental osteotomy is the preferred choice for correction of MTD when a single surgical procedure is planned to correct all maxillo-mandibular discrepancies. Vertical and sagittal repositioning of the maxilla and the mandible can be done at the same time when correction of MTD is done with segmental osteotomy. On the other hand, correction of MTD is done as a first step with SARPE and a separate second surgery is necessary for discrepancies of the maxilla and the mandible in the other planes of space. Bailey et al[52] have recommended that SARPE should be used for patients with an isolated transverse deficiency when OME is not indicated, or with unilateral or asymmetric narrowing of the maxilla.

Although it might seem that the use of SARPE is limited, it is essential to compare the long-term stability, morbidity of a 2-stage vs a 1-stage procedure, and the psychological impact of 2 procedures on the patient rather than 1 procedure.

Proponents of SARPE have also hypothesized that post-SARPE orthopedic forces can be applied to the maxilla, since the 2 halves of the maxilla have been loosened. These forces might be valuable in correcting sagittal or vertical discrepancies without additional surgery. This, however, has not been used routinely because the prognosis is uncertain.

Periodontal status

Muller and Eger[53,54] and Muller et al[55] recently introduced the concept of periodontal biotype. They pointed out that it is essential to record the thickness of the gingival tissues during clinical evaluation of the periodontium. This is especially important because a thin and delicate gingiva might be prone to recession after traumatic, surgical, or inflammatory injuries. Histologic studies of the supporting tissues around extracted teeth that were initially used as appliance anchors have shown that a strong inflammatory response ensues during maxillary expansion. Orthodontic tooth movement can have a detrimental influence on the mucogingival complex, especially when the keratinized tissue and underlying bone appear to be thin. Therefore, evaluations of the gingival tissues and the biotype are essential to determine the ability of the tissues to withstand the pressure of OME; otherwise, surgical release of the sutures is needed to remove interferences to maxillary expansion. The selection of the appliance type (number of anchor teeth included or tooth-borne vs bone-borne appliances) might also depend directly on the periodontal biotype. These appliances are discussed in detail below.

Other uses of SARPE

A morphologically narrow palate has been associated with mouth breathing and altered neuromuscular patterns.[56-58] The consequences of ventilatory dysfunction are complex and thought to be related to sleeping disorders, including sleep apnea, nocturnal enuresis, and even conductive hearing loss. The association of these disorders with MTD has been studied in the young population in which OME produces promising outcomes. It can be hypothesized that similar associations between MTD in adults and some effects of ventilatory dysfunction exist in which SARPE might be useful. SARPE has been shown to produce a distinct subjective improvement in nasal breathing concurrent with an increase of nasal volume in all compartments.[59-67] The recovery of transverse growth discrepancy by surgical and mechanical enlargement produces substantial enlargement of the maxillary apical base and the palatal vault. These can have far-reaching implications and indications for SARPE.

APPLIANCES

A number of appliances have been used to correct MTD. Fixed appliances have been the mainstay in SARPE patients. Removable appliances are not recommended because they are effective only in the deciduous or early mixed dentition. Removable appliances also do not have sufficient retention and stability for intraoperative and postoperative use. Fixed appliances like the Haas, the hyrax, and the bonded palatal expander are recommended for use with SARPE. The Howe acrylic-lined bondable expander with a midpalatal jackscrew and the Minne expander,[7,68] consisting of a heavy caliber coil spring with 2 metal flanges soldered to the bands, are less frequently used. The force is generated by a jacksrew in all these appliances. Coffin springs, quad helices,[68] and magnets[69] have been suggested as means to apply expansion force in OME or slow expansion but are not used in patients undergoing SARPE.

The Haas appliance consists of acrylic palatal shelves that have been suggested to use the tissue support for producing more evenly distributed forces on the teeth and the alveolar processes. The hyrax has a metal framework that is less irritating to the palatal mucosa and is more hygienic. The hyrax appliance is constructed either as a 2- or a 4-banded appliance. In the 2-banded appliance, only 1 tooth on either side of the maxilla is banded (most frequently the first molars), and, in a 4-banded appliance, 2 premolars are included with the molars.[70] For most appliances, the pitch of the jackscrew is 0.25 mm, which is equal to a quarter turn.

Both the Haas and the hyrax palatal expanders can be constructed with a flat-plane occlusal-coverage splint. This type of appliance is bonded to the maxillary teeth, and its use has been recommended in patients with periodontally compromised dentition because it incorporates more anchor teeth. It can also be used for patients with symptoms of temporomandibular disorders.[35]

Mommaerts[7] suggested the use of a bone-borne titanium device with interchangeable expansion modules rather than a conventional tooth-borne appliance. According to him, conventional tooth-borne appliances produce greater loss of anchorage and more skeletal relapse both during and after expansion. Higher incidences of cortical fenestration and buccal root resorption are also observed with tooth-borne appliances compared with absolute bone-borne appliances. Orthodontic treatment can be initiated earlier in the postsurgical period with the bone-borne appliances than tooth-borne appliances.[71-73] The application of the bone-borne distractor does not depend on a complete dentition.[7,71]

A number of bone-borne distractors are now available commercially. These include the transpalatal distractor,[7] the Magdenburg palatal distractor,[74] MDO-R device (Orthognathics, Ltd, Zurich, Switzerland), and the Rotterdam palatal distractor.[75] They have been reported to have greater control of orthopedic movement than tooth-borne appliances. The pitch of the screw in most bone-borne distractors differs in its construction. The Rotterdam palatal distractor, for example, has a progressively reducing distraction for every activation. Thus, for the bone-borne distractors, the manufacturer's guidelines must be followed. The bone-borne appliances are contraindicated in patients with extremely low palates, because the nails of the abutment plates loosen more easily and the distractor is not stable. These are also contraindicated in patients with immunodeficiency conditions and prior radiation therapy.[75]

SURGICAL TECHNIQUE

The surgical technique for SARPE involving a midpalatal split was described in 1938.[76] In the first half of the 20th century, there was no significant evolution of surgical techniques for orthognathic surgery or SARPE. The improved management of infections allowed for increased surgical correction of skeletal deformities in the second half of the century. In 1959, Kole[77] advocated the use of selective dentoalveolar osteotomies to section the cortical bone and reduce the resistance to orthodontic movement. Converse and Horowitz[78] advocated the use of both labial and palatal cortical osteotomies for expansion in 1969. A LeFort I type of osteotomy with a segmental split of the maxilla and the placement of a triangular unicortical iliac graft for correction of maxillary constriction was presented by Steinhauser[79] in 1972.

Many surgical procedures have been designed to resect the areas of resistance to lateral expansion in the midface. The areas of resistance have been classified as anterior support (piriform aperture pillars), lateral support (zygomatic buttresses), posterior support (pterygoid junctions), and median support (midpalatal synostosed suture).

Initial reports described the midpalatal suture as the area of greatest resistance to maxillary expansion.[39,44,45] However, later reports highlighted the zygomatic buttress and the pterygomaxillary junction as critical areas of resistance.[34,80,81] Kennedy et al[81] studied the effects of selected maxillary osteotomies as an adjunct to OME in mature rhesus monkeys. They evaluated the influence of lateral maxillary and pterygomaxillary osteotomies with and without palatal osteotomy vs unoperated controls or palatal osteotomy alone and found significant differences. They concluded that reducing or eliminating the resistance to lateral movement by osteotomy allows for movement of the basal bone of the maxilla.

Timms and Vero[39] and Timms[82] suggested that there are 3 stages of surgical assistance for maxillary expansion based on the patient's age. Stage 1 (median osteotomy) is performed for patients aged 25 years or older, or younger if rapid maxillary expansion was tried and failed. Stage 2 (median and lateral osteotomies) is reserved for those aged 30 years and older, and stage 3 (median, lateral maxillary and anterior maxillary osteotomies) is for patients aged 40 years and older.

Betts and Ziccardi[50] recommended a total bilateral maxillary osteotomy from the pyriform aperture to the pterygomaxillary fissure along with a midpalatal split from the anterior to the posterior nasal spines. They recommended sectioning all articulations and areas of resistance—anterior, lateral, posterior—and median support of the maxillary arch. According to them, the osteotomy should be created parallel to the occlusal plane with a step at the maxillary buttress. An ostectomy in this region prevents interferences from the buttress to expansion. The osteotomy should be placed approximately 4 to 5 mm above the apices of the maxillary teeth. They also recommended releases from the nasal septum and the pterygoid plates. Lehman et al,[32] however, did not recommend a palatal split. According to them, the removal of the resistance from the zygomatic buttress is sufficient to remove resistance to expansion. This conservative technique was also suggested by other authors.[72,83] Bays and Greco[84] and Northway and Meade[43] recommended that no attempt should be made to separate the maxilla from the pterygoid plates to avoid invasion into the pterygomaxillary junction. According to them, such a separation requires extreme force and usually causes the plates to fracture. Pogrel et al[85] recommended only a midpalatal cut in addition to the transection of the lateral support. Most surgeons recommend a soft-tissue incision that exposes the bone for a direct cut with a bur, an osteotome, or a reciprocating saw. Occasionally, the midline split can be made by an osteotome between the central incisors without a soft-tissue incision.[84] Instead of the single midline split of the maxilla, some authors described 2 paramedian palatal osteotomies from the posterior nasal spine to a point just posterior to the incisive canal.[23,86]

Variations in surgical technique have also been recommended based on the patient's age, presence of palatal torus, missing teeth,[87] presence of or tendency toward an anterior open bite, need for a secondary LeFort osteotomy, extremely tapered arch form, and the requirement for only unilateral maxillary expansion.[35,50,88] Recently, endoscopically assisted SARPE and LeFort I osteotomy techniques have also been presented to reduce morbidity, especially in growing patients.[89]

From the review of the literature, it is apparent that there is no consensus about either the extent or the procedure for SARPE. There are also no conclusive means to determine the areas of resistance to lateral maxillary expansion or ascertain an individualization of the surgical cuts. The extent of surgery ideally should depend on the areas of resistance with some individualization.

The mandibular dentition should be decompensated before surgery to allow assessment of the amount of transverse expansion necessary, to establish arch coordination, and to assist in preventing postexpansion relapse with dental interdigitation.[35] The tooth-borne appliance should be placed preoperatively, and the appliance key must be in the operating suite to allow intraoperative activation.[35] If a bone-borne palatal distractor is to be used, the distractor is placed at the surgery after the maxillary articulations are transected.[7]

Appliance activation

Table II gives the various regimens reported in the literature. Most authors recommend that appliance activation should be started intraoperatively. This is done to ensure that the appliance is stable and that the areas of resistance of the 2 halves of the maxilla have

Table II. Chronological listing of studies reporting surgical procedures and treatment protocols (no studies used controls)

Author	*Study design*	*Sample* (m, *males;* f, *females; age in parentheses)*	*Surgical extent*	*Intraoperative protocol*	*Latency period*	*Postoperative protocol*
Tooth-borne appliances						
Kole (1959)[77]	Case report	n = 1	Lateral and palatal osteotomy.	Not reported.	Not reported.	Slow expansion.
Converse, Horowitz (1969)[78]	Case report (cleft patient)	n = 1	Lateral and palatal osteotomy.	Not reported.	Not reported.	Not reported.
Lines (1975)[34]	Case series	n = 3 m = 1 (20 y) f = 2 (17, 18 y)	Lateral and palatal osteotomy.	Not reported.	2-3 weeks.	Expander cemented 2-3 weeks after corticotomy. Expansion 0.8 mm for day 1, then 0.4 mm/day.
Bell, Epker (1976)[33]	Case series	n = 15 m = 5 (15-19 y) f = 10 (16-27 y)	Anterior, lateral, posterior, and midline cuts. Cuts are tailored if unilateral horizontal maxillary deficiency.	2 quarter turns (0.5 mm).	Not reported.	0.5-1.0 mm/day.
Lehman et al (1984, 1989, 1990)[32,91,105]	Case series	n = 18 (19-46 y) m = 7 f = 11	Focus on lateral nasal wall and pterygomaxillary buttress. Cuts not necessary through thin anterior wall of maxilla. Midline split as well.	2 turns intraoperatively.	Not reported.	0.5 mm/day.
Kraut (1984)[73]	Case series	n = 25 m = 11 (17-32 y) f = 14 (15-47 y)	Anterior, lateral, posterior, and midpalatal osteotomies.	Activate appliance until resistance encountered.	Not reported.	1 mm/day (0.5 mm in morning and 0.5 mm at bedtime). Reduce rate if ischemia or detachment of midline interdental gingival evident.
Glassman et al (1984)[72]	Case series	n = 16 m = 8 (15-44 y) f = 8 (18-34 y)	Anterior and lateral cuts.	4 turns (1 mm).	2 days.	0.5 mm/day (1 turn in morning and 1 in evening starting 3rd postoperative day).
Alpern, Yurosko (1987)[15]	Case series	n = 25 m = 7 (20-31 y) f = 18 (23-43 y)	LeFort I.	6-8 turns.	Not reported.	Not reported.
Bays, Greco (1992)[84]	Case series	n = 19 (30.2 ± 9 y) m = 3 f = 16	Anterior, lateral, and median cuts.	Maxillary segments mobilized aggressively; create 1.0-1.5 mm gap between central incisors.	5 days	0.25 mm every other day first 7-10 days, then 0.25 mm/day.

Table II. Continued

Author	*Study design*	*Sample* (m, *males;* f, *females; age in parentheses)*	*Surgical extent*	*Intraoperative protocol*	*Latency period*	*Postoperative protocol*
Mossaz et al (1992)[40]	Case series	n = 4 (21-35 y) m = 2 f = 2	Anterior, lateral, posterior cuts and a midline split.	1 mm.	Not reported.	0.25 mm/day.
Betts et al (1995, 2000)[35,50]	Review	n = 0	Anterior, lateral, posterior, and median cuts. Septal release.	1.0-1.5 mm and evaluation of independent expansion and mobility of both sides of maxilla.	5 days.	0.5 mm/day.
Banning et al (1996)[121]	Review	n = 0	Anterior, lateral, posterior, midpalatal osteotomies. Separate nasal septum.	2 mm.	Not reported.	0.25 mm/day.
Woods et al (1997)[22]	Review	n = 0	LeFort I, midline split, nasal spine attached to the septum.	2-3 mm (until blanching of incisal gingival tissues achieved, then turn back approximately 4 turns).	Not reported.	0.25 mm/day.
Schimming et al (2000)[83]	Case series	n = 21 (14-38 y) m = ? f = ?	Anterior and lateral cuts.	12 turns (3 mm), hold for 3 minutes, close 8 turns (2 mm).	Not reported.	0.25 mm/day.
Wriedt et al (2001)[67]	Case series	n = 10 (16.9-43.6 y) m = 5 f = 5	Complete bilateral paramedian osteotomy of the palate. Anterior and lateral cuts.	0.5 mm.	Not reported.	0.25 mm/day. Start activation on 1st or 2nd day after surgery.
Chung et al (2001, 2003)[92,122]	Case series	n = 14 (14-46 y) m = 3 f = 16	Subtotal LeFort I with a midpalatal split.	1.0-1.5 mm.	Not reported.	0.5 mm/day.
Lanigan, Mintz (2002)[102]	Case report	n = 1	LeFort I with a midpalatal split.	1 mm intraoperative expansion.	Not reported.	0.25-0.5 mm/day.
Anttila et al (2004)[123]	Case series	n = 20 (16.2-44.2 y) m = 6 f = 14	Osteotomy 5 mm apical to apices of teeth—anterior, lateral, and posterior.	3-6 turns (0.75-1.5 mm),	Not reported,	0.5 mm/day.
Bone-borne appliances (transpalatal distractors)						
Mommaerts (1999),[7] Pinto et al (2001)[124]	Clinical technique, case report (Mommaerts); prospective case series (Pinto)	n = 1 (Mommaerts) n = 20 (Pinto) (14-30 y) m = 9 f = 11	Median, anterior, and lateral for bilateral expansion. Septal cut only in unilateral expansion.	Peroperative expansion is performed until the buccal gingiva around central blanches, which occurs when the gap reaches 1.5-2 mm.	5-7 days.	0.33 mm/day.

Table II. Continued

Author	*Study design*	*Sample* (m, *males;* f, *females; age in parentheses)*	*Surgical extent*	*Intraoperative protocol*	*Latency period*	*Postoperative protocol*
Gerlach, Zahl (2003, 2005)[71,74]	Case report	n = 1	Osteotomy from pyriform aperture to pterygomaxillary fissure, curved osteotome to separate pterygoid plate. Midline cut is performed in patients over age 25.	2 mm expansion after fixation of appliance to check proper functioning of appliance and then reset to the starting position.	6 days.	0.4 mm/day.
Koudstaal et al (2006)[75]	Case series	n = 13 m = 8 (12-21 y) f = 5 (16-34 y)	Anterior, median, and lateral bony cuts without pterygoid disjunction.	Appliance is slightly activated to allow for the nails of the distractor is stabilized against the bone.	7 days.	1 mm/day.

been removed. Postoperative protocols vary between authors, and the activation rates are from 0.25 to 1 mm per day. The literature is unclear about how to determine the activation rate. SARPE has been compared with distraction osteogenesis of the long bones when an activation rate of 1 mm per day has been recommended. The difference, however, is that, in distraction osteogenesis of the long bones, a clean bony cut is made, whereas, in SARPE, the midline split is at the site of a suture and near the periodontal ligament of the maxillary incisors. Cureton and Cuenin[27] suggested varying the rate of expansion depending on whether a symmetrical fracture of the alveolar bone between the central incisors is obtained. They suggested that the expansion schedule should be tailored for every patient, depending on the symmetry of the bony fracture and the health of the gingival attachment. This is necessary to ensure posttreatment health of the maxillary midline interdental papilla and the adjoining gingiva. Expansion performed too rapidly can lead to mal-union or nonunion of the segmentalized maxilla; if the activation is too slow, premature consolidation will occur before achievement of the desired expansion.

The surgical corticotomy and the initial appliance activation intraoperatively are followed by a period of rest before starting expansion of the appliance. This rest period is called the latency period. This gives the tissues time to form a callus but is too short to allow for consolidation.[23] Callus distraction has been reported to create a regenerate that readily ossifies and stabilizes and thus provides increased stability.[90] Most authors agree that the latency period is essential, but slight variations in its exact duration were seen in the literature (Table II).

Orthodontic considerations and preparation

Before sending a patient for a SARPE, the orthodontist must ensure that there is enough space between the roots of the central incisors for a midline split. A periapical or occlusal radiograph should be taken, and the interradicular bone evaluated. If space is inadequate, preoperative root divergence must be created.[27] To ensure the postoperative and posttreatment health of the teeth, the patient should be seen regularly by a periodontist. The gingiva should be healthy between the central incisors. After expansion, a large midline diastema is present, and the central incisors should be moved reciprocally at a controlled and slow rate. A similar yet smaller diastema is obtained in patients who undergo OME when the teeth drift to close the space after expansion. No clear protocol is evident from the literature regarding the rate of midline space closure in SARPE patients. Occasionally, clinicians place a pontic tooth in the midline and slowly grind it down on the proximal surfaces to allow for the central incisors to move toward each other.

RETENTION, STABILITY, AND RELAPSE

The issue of long-term stability and relapse with SARPE has not been studied in detail in the literature. In general, most reports state that surgical expansion is more stable than OME.[73,81,84,91] Some authors recommended that retention is not necessary for SARPE, and the orthodontist can begin orthodontic treatment without a holding phase.[84] Other authors recommended a period of retention after expansion varying from 2 to 12 months.[23,40,43,72,73,92]

The relapse rates for SARPE vary from 5% to about 25%.[7,84,93,94] These rates are significantly lower than the relapse rate of OME, which can be as high as 63%.[68,95,96] The high rate of relapse associated with OME is due to its use in skeletally advanced patients. OME is neither predictable nor stable in older patients.

In a study by Berger et al,[93] both OME and SARPE were compared in an age-appropriate sample. The OME sample comprised subjects aged 6 to 12 years, and the SARPE group's ages ranged from 13 to 35 years. These authors found no difference in the stability of SARPE and OME. They, however, did not quantify the relapse amount in either group.

Most studies on SARPE discussed relapse as an issue that the clinician should be aware of but reported that the incidence of relapse is low. Few studies cite the need to overexpand with SARPE.[73,85,91] This is especially true for bone-borne appliances; the relapse was subjectively reported to be extremely low.[7,97]

RISKS, LIMITATIONS, AND COMPLICATIONS

SARPE procedures have traditionally been reported to have low morbidity especially when compared with other orthognathic surgical procedures.[84] However, many complications have been reported, and the surgeon and the orthodontist must be aware of these before recommending SARPE to a patient. Complications associated with SARPE reported in the literature include significant hemorrhage, gingival recession,[98] root resorption,[7,99] injury to the branches of the maxillary nerve, infection, pain, devitalization of teeth and altered pulpal blood flow,[100,101] periodontal breakdown,[27] sinus infection,[83] alar base flaring,[22] extrusion of teeth attached to the appliance,[72] relapse, and unilateral expansion.[102,103] Additional complications that are related to the expansion appliance include its impingement on palatal soft tissue, loosening (more common with bone-borne distractors[94]), and breakage and stripping or locking of the appliance screw.[51,103,104]

Palatal tissue irritation is a frequent complication of SARPE. This can be either due to impingement from the appliance or associated with a rapid rate of expansion that does not allow for adequate histogenesis of the overlying soft tissue. The incidence of frank aseptic tissue necrosis has been reported to be about 1.8%; at least 5% of patients have some palatal mucosal ulceration.[32,105] Hemorrhage can be life threatening[103] or require blood transfusions and an additional hospital stay.[15]

Occasionally, aberrant fractures of the maxillary articulation are seen. These are especially common when areas of resistance remain. Aberrant and asymmetric fracture of the interdental bone between the central incisors leads to increased mobility, gingival recession, dehiscence, and periodontal defects on the incisors.[22,27] Conservative surgical procedures (technique of Glassman et al[72]) are also known to produce fractures of the alveolar process.[83]

Some unusual complications that have been reported include orbital compartment syndrome resulting in permanent blindness,[106] bilateral lingual anesthesia,[104] and a nasopalatine canal cyst.[107] Like any other surgical procedure, SARPE is not free of risks, and careful planning and execution of treatment are necessary to ensure an acceptable outcome.

CONCLUSIONS

SARPE is a widely used procedure for the correction of MTD in skeletally mature patients. However, there is sparse information on many issues pertaining to SARPE. There are still no conclusive ways to identify the optimal equilibrium between extensive surgeries for adequate mobilization vs a conservative procedure with minimal complications. Advances in imaging techniques have added another dimension to the evaluation of bone density and surgical manipulation. These can assist in achieving greater precision and help standardize surgical techniques and orthodontic treatment protocols.

Molecular biology has also opened the doors to biological modulation of growth. It might be possible soon to use local cytokine therapy for sutural growth modification. Metabolic markers might enable us to predict tissue reactions and aid in patient selection. It is hoped that this review will provide impetus to investigators currently working in this area to develop sound study designs with attention to sample size (study sample and controls) and follow up with a strong analysis of the variables studied.

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