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Complications in surgically assisted rapid maxillary expansion: a systematic review of the medical literature.

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Abstract

Our aim was to perform a systematic open-access review of various complications reported for surgically assisted rapid maxillary expansion (SARME) procedures. There were 37 articles found in Pubmed using the search equation. Twelve articles were initially excluded according to the exclusion criteria. The 25 remaining articles were read in full for their descriptions of complications related to the SARME procedure in mature patients. The main reversible complications of SARME were infection, postoperative pain, and bleeding. There were also complications related to distractors, to secondary surgeries, and pterygomaxillary junction. The main non-reversible complications of SARME were associated with teeth, periodontal bone loss, and skull base fractures. Large field-of-view cone beam computed tomography (maxilla and skull base) should be implemented as initial planning tool to prevent many potential complications. The current trend for "minimally invasive" surgery in SARME might be, from an ethical point of view, transformed onto "minimally complicated" surgery as complication is still more harmful for any given patient than any potential perioperative surgical invasiveness.

Keywords: surgically-assisted, rapid, maxillary expansion, complications, palate

Introduction

Transverse maxillary deficiency is a dento-facial deformity clinically characterized by a unilateral or bilateral posterior crossbite [1], anterior dental crowding [1], excessive lingual inclination of the posterior teeth, a triangular dental arch, and a deep palate [2]. Transverse maxillary deficiency may occur as an isolated condition, resulting in functional implications, or associated with other aesthetical features, such as a narrow base of the nose, deep nasolabial folds, and hypoplasia of the zygomatic and paranasal area [2-5]. Transverse maxillary deficiency 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 apnoea [5, 6]. Maxillary constriction together with a high palatal vault are two characteristics of "skeletal development syndrome" [5, 7]; other features of this syndrome include the following: (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 the nasal airway size [5, 7].

An adequate transverse maxillary dimension is a critical component of stable and functional occlusion [5, 8]. Orthopaedic rapid palatal expansion is the procedure of choice to correct this condition in skeletally immature patients [5]. However, as skeletal maturity approaches, bony interdigitation increases as the sutures fuse [5, 9, 10]. This leads to difficulty separating the maxillae with orthopaedic forces alone, and bending of the alveolus, dental tipping, and minimal maxillary expansion can occur [5]. The result is relapse, despite overcorrection, pain, periodontal defects (a significant amount of gingival recession), periodontal ligament compression, and malocclusion [5]. Although most transverse maxillary deficiency can be resolved with orthodontics or segmental maxillary surgery, these approaches may not be successful in adults with select transverse problems [11]. Such problems include large transverse discrepancies (7 mm), narrow intercuspid dimensions, or maxillary arch length deficiency with crowding in postextraction cases [11].

Transverse maxillary deficiencies of more than 5 mm in the arc of a skeletally mature patient are a strong consideration for surgically assisted rapid maxillary expansion (SARME) [5]. A discrepancy of 5 mm is chosen because the orthodontist can camouflage discrepancies less than this size with orthopaedic forces alone [5]. If a discrepancy of more than 7 mm exists, SARME is definitely indicated [5]. In patients of mature skeletal age, SARME should also be considered whenever a narrow maxilla is associated with a wide mandible [5]. The technical difficulty involved in narrowing the mandible, and its potential negative effects on the condyles, make the maxillary procedure easier [5].

The recommended approach in such situations is surgically assisted palatal expansion (SARPE) or surgically assisted maxillary expansion (SARME) [11]. Advantages of SARPE include improved periodontal health, improved nasal airflow [5, 12-16], 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 [5, 17], and bone apposition in the osteotomy site and reduced risk of dental version or extrusion compared with regular orthopaedic care [5, 13]. Additionally, tooth extraction for alignment of the arches is often unnecessary [5]. Hearing levels were also significantly improved after SARME in patients with conductive hearing loss [5, 7, 18-23].

Orthopaedic maxillary expansion (OME) was first described in 1860 by Angell in a case report.[24-26]. Conventional OME before closure of the mid-palatal suture has been reported to be highly successful in young patients, but this technique is not indicated in skeletally mature individuals because suture closure and the completion of transverse growth limit the range of maxillary expansion [27]. OME can produce unwanted effects when used in a skeletally mature patient, including lateral tipping of the posterior teeth [28-32], periodontal membrane compression, buccal root resorption [26, 33-36], alveolar bone bending [29], fenestration of the buccal cortex [37-39], palatal tissue necrosis [40], inability to open the midpalatal suture, pain, and instability of the expansion. [26, 27, 29, 33]. Bell and Epker showed that attempting OME with a palatal appliance in a skeletally mature patient may lead to pain and necrosis of the palatal mucosa. [27, 41]. Timms and Moss [36] showed histologic evidence of external root resorption and pulpal changes, including the laying down of secondary dentin and pulp stones when performing OME [27, 33]. Mommaerts outlined an age-based treatment strategy for patients with maxillary constriction and stated that OME should be used to treat maxillary constriction in patients younger than 12 years, whereas SARPE is indicated in patients older than 14 years to release areas of bony resistance in the midface [26, 27, 31]. The general indications for SARPE include skeletal maturity, (extreme) transverse maxillary hypoplasia, unilateral or bilateral anterior crowding, the presence of buccal corridors ("black corridors") when smiling, and failure of OME [26, 27] The following have been reported in the literature as indications for SARME, and all apply to a skeletally mature patient with a constricted maxillary arch [26, 42, 43]:

1. To increase the maxillary arch perimeter, to correct posterior crossbite, and when no additional surgical jaw movements are planned [26];
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 [26];
3. To provide space for a crowded maxillary dentition when extractions are not indicated [26];
4. To widen maxillary hypoplasia associated with clefts of the palate [26];
5. To reduce wide black buccal corridors when smiling [26];
6. To overcome the resistance of the sutures when OME has failed [26].

SARPE/SARME is a surgical technique developed to correct transverse discrepancies in skeletally mature patients [44]. SARPE is generally indicated in adults to overcome the resistance of ossified sutures as the patient transitions into adulthood [44]. Under general anaesthesia, a Le Fort I osteotomy without down-fracture of the maxilla is performed in conjunction with a midpalatal osteotomy and palatal distractor setting [44]. For SARME, various surgical procedures, such as 1) exclusive osteotomy in the midpalatal suture [45], 2) bilateral osteotomy from the piriform rim to the pterygoid plate without palatal surgery [46], 3) subtotal Le Fort I osteotomy combined with median palatine suture osteotomy [47], 4) total bilateral maxillary osteotomy from the piriform rim to the pterygomaxillary fissure along with midpalatal split and release of nasal septum and pterygoid plates, and 5) three-piece SARME with complete mobilization [48], have been reported in the literature [49]. The rationale behind the more extensive surgeries is to facilitate the expansion of the maxillary skeleton, to minimize the expansion force on the anchor teeth and consequent problems such as root resorption, tooth extrusion, and periodontal diseases, and to reduce the chance of postsurgical relapse [26, 44, 50]. However, the more invasive SARME techniques are likely associated with more complications and morbidities [11, 27, 49].

Most methods consider the zygomaticomaxillary junction to be a major site of resistance and recommend corticotomy through the zygomaticomaxillary buttress from the piriform rim to the maxillopterygoid junction to release this resistance [27]. The mid-palatal suture has historically been considered the primary site of resistance [27]. The pterygoid plates are also sites of considerable resistance, but because osteotomy carries an increased risk of injuring the pterygoid plexus, some surgeons choose not to address this resistance, without losing much mobility [27]. When the pterygoid junction is not released, the opening of the maxillary halves is more V-shaped, with the apex of the V pointing dorsally [27, 44, 50-53].

Reviews on SARPE/SARME complications that are available on PubMed are not systematic and have no open access: Verquin et al., 2017 [1], Dergin et al., 2016 [27], Carneiro et al., 2013 [54], Williams et al., 2012 [11], Chrcanovic et al., 2009 [5], Suri et al., 2008 [26], and Lanigan et al., 2002 [33]. Our aim was to perform a systematic, and open access review of various complications reported for the SARME/SARPE procedure.

Materials and methods

We used only one database: PubMed, and one observer participated in the selection of articles. The search equation was set as follows: ("complications"[Subheading] OR "complications"[All Fields]) AND (("surgical procedures, operative"[MeSH Terms] OR ("surgical"[All Fields] AND "procedures"[All Fields] AND "operative"[All Fields]) OR "operative surgical procedures"[All Fields] OR "surgical"[All Fields]) AND assisted[All Fields] AND rapid[All Fields] AND ("palate"[MeSH Terms] OR "palate"[All Fields] OR "palatal"[All Fields]) AND expansion[All Fields]) 09.02.2019.

The inclusion criteria were English, and French language articles. There was no limit of publication date (articles starting from 1948). The exclusion criteria consisted of languages other than those selected. We also excluded situations involving syndromes, and cleft palate patients. Other non-SARME procedures to expand the palate of mature patients, such as animal and experimental studies, were excluded. Complications independent of the SARME procedure, such as postoperative nausea and vomiting (because of general anaesthesia) [1], and hospitalization due to iatrogenic gastric bleeding caused by NSAIDs [1] were excluded.

There were 37 articles found using the search equation. Twelve articles were initially excluded according to the exclusion criteria. The 25 remaining articles were read in full for their descriptions of complications related to the SARME procedure in mature patients.

Results

Reversible complications

Wound infections [1, 2, 11, 26, 27, 33, 53-56] were reported to occur 5 days to 4 months after surgery [11]. Infections were related to poor oral hygiene practice in some patients [2]. The fermentation of food residues on the surgical incision before it is fully healed can result in inflammation due to bacterial proliferation [2].

Williams et al., [11] reported rates of infection of 6.7% after surgical intervention [11]. The infection affected the vestibular mucosa and was located in the posterior range of the fornix, a site where food is compacted due to the natural movement of the tongue during mastication [11]. Infection was also described in the interdental osteotomy site (midline) [11]. Cultures showed Klebsiella, Prevotella, Staphylococcus species and oral flora, and were treated with oral antibiotics [11].

Maxillary sinusitis appeared after SARME up to six weeks postoperatively [1, 11, 26, 27, 53, 55-57]. The most common cause was unrecognized preoperative chronic sinusitis [58]. Fungal infection of the maxillary sinus after SARME is unusual [53]. The trauma associated with lateral nasal wall osteotomies may trigger fistula formation from the inferior meatus to the maxillary sinus, thus modifying the flora of the maxillary sinus by introducing a fungus [53].

Severe postoperative pain was reported in the majority of articles on SARME complications [1, 2, 11, 26, 27, 33, 53,-55, 59]. Severe postoperative pain is likely related to the extended loosening of bony sutures during surgery, leading to increased intra-operative and postoperative oedema and therefore pain [1]. Pain occurs on turning the expansion screw (during the distraction process) because of inadequate surgical release of maxillary articulations to allow expansion [33]. Pain and headache can persist up to 2 weeks after SARME [1, 27].

Bleeding/ haemorrhage is a frequent complication during and after the SARME procedure [1, 2, 11, 26, 27, 33, 53, 54, 56, 59]. Peroperative bleeding from a sinus artery was resolved by a Caldwell Luc approach and arterial ligature with sutures [33].

Another source of bleeding after SARME is injury to the nasal mucosa, which is primarily observed after mid-palatal suture separation and lateral nasal wall osteotomy [27]. Bleeding complications were observed early or delayed [1, 11, 27, 53, 55] postoperatively [27]. Early bleeding may have been caused by severe postoperative inflammation and trauma to the nasal mucosa during mid-palatal separation [27]. Because SARME is not a down-fracture procedure, nasal bleeding can be easily controlled with nasal packing, even if delayed [11], and should therefore be considered a minor complication if the patient does not suffer from coagulopathy [27].

The cause of haemorrhage in SARME could be a traumatic osteotomy of the lateral nasal wall [53]. During such an osteotomy, the osteotome should not be directed medially or superiorly to prevent possible damage to the inferior turbinate and the nasal mucoperiosteum [53]. Additionally, during SARME, the management of an injury to the descending palatine artery can be more difficult than in maxilla down fracture cases because it is not possible to view the vessel directly [53]. Moreover, the risk of haemorrhage is reduced if the surgeon remains in the subperiosteal plane when working laterally, thus not dissecting soft tissue [53].

The use of haemostatic measures such as electrocoagulation and tamponade with absorbable haemostatic gelatin sponges decreases the amount of intraoperative blood loss and postoperative bleeding in SARME [1].

Only one case of delayed life-threatening epistaxis after SARME was described by Mehra et al., [1, 33, 53, 60]. Orbital compartment syndrome from a retrobulbar haemorrhage, resulting in permanent blindness, was reported in a 34-year-old woman who underwent SARME [1, 33, 53].

A case of massive middle cerebral artery (MCA) infarct secondary to internal carotid artery dissection just superior to the bifurcation and M1 branch thromboembolism following a SARME procedure was described [56]. In this case, head and neck manipulation or spontaneous development may have caused an intimal tear of the internal carotid artery, resulting in dissection and subsequent thromboembolism affecting the entire right MCA territory [56].

Alterations in blood flow and injury to the branches of the maxillary nerve [26] have been reported to cause tooth numbness [1], and paresthesia of the upper lips [1], palatal gingiva [53], and infraorbital region [1, 27, 53, 56]. Bilateral involvement was attributed to transient pressure exerted by postoperative oedema [1]. Unilateral numbness is more likely to be related to intraoperative trauma due to stretching and blunt injury with tissue retractors (Le Fort I hooks) [27, 53], and has a worse prognosis [1]. However, over 80% of patients who had unilateral altered sensitivity of the infraorbital nerve postoperatively experienced a full recovery within 4 weeks of surgery [1], and the bilateral numbness resolved by 6 months after surgery [53].

Mehra et al. also described a temporary partial paralysis of the oculomotor nerve [55, 60]. Some cases of oedema [59], bruising [2], nasogenial sulcus haematoma: [55, 56], and large, aesthetically disturbing cheek haematoma [1, 27] were reported with spontaneous resolutions.

Complications related to distractors

Persistent pain when using a HAAS expander was due to over-compression of the hemi-palatine vault on the acrylic stop plate, which prevents the hemi-maxilla from tilting [2]. Apart from manufacturing causes, 2 factors can lead to excessive compression of the hemi-palate on the acrylic stop plate—expansion performed faster than the rate established in the expansion protocol, and insufficient surgical release of bone structures [2]. Pain due to such compression was relieved after extracting the expanding device and removing some material off the palatal surface of the acrylic plate [2].

The Hyrax appliance had not been placed prior to surgery in one patient; therefore, additional surgical time was required as the appliance had yet to be placed [1]. Two patients had difficulties activating the device, resulting in a lag of expansion of 1 week after starting the activation [1].

Extrusion of the teeth attached to the appliance were also observed [26, 27].

Bone-borne distractors were associated with loosening of the distractor [6, 26, 54, 55], rupture [26, 54], detachment or locking of the distractor cylinder [26, 54, 55, 62-64], and stripping or locking of the screw [26, 54].

For all appliances, a palatal tissue irritation was reported to be caused by impingement of the expansion appliance against palatal soft tissues [27, 33] which may lead to aseptic pressure necrosis [11, 26, 27, 33, 54]. One patient developed necrosis of the palatal tissue in the area of a palatal torus, which resolved with local wound care [11].

Reversible complications with a secondary surgery

Asymmetrical distraction/expansion can be seen as a result of incomplete osteotomies and missed lateral nasal wall osteotomies [1, 2, 11, 26, 27, 33, 43, 53-56, 59]. The meticulous release of all areas of major resistance during the surgical technique likely decreases the rate of asymmetrical and inadequate expansion [1, 27]. The wider the maxillary expansion performed, the more frequent the cases of asymmetric expansion are [2]. Asymmetrical distraction may resolve without additional treatment [11], or may need segmental maxillary surgery for correction [11].

Posterior excess of distraction was also observed and was corrected by postoperative orthodontic maxillary contraction before the second surgery [55].

A nasal septum deviation and flaring of the alar base [1, 26, 27] during distraction required corrective rhinoplasty surgery [27, 55].

Wound dehiscence at the anterior maxilla one week after surgery was described [53]. The wound was resutured, and no further problem was reported [53]. Palatal fibromucosa perforation due to osteotome displacement was corrected by suture but delayed the distraction for 4 to 5 days [53, 55]. Intraoperative mobility of the central incisor was resolved spontaneously or a bonding was applied to adjacent teeth [1, 55, 59].

Relapses of expansions have also been reported [11, 26, 27, 33, 53, 54].

Complications related to pterygomaxillary disjunction

When performing Le Fort I osteotomy, the pterygoid plates may or may not be separated from the maxilla [44]. This separation is termed pterygomaxillary disjunction (PTMD) or pterygoid disjunction [44]. When performing the disjunction, finger support is generally provided with the surgeon's non-dominant hand while the osteotomy is performed with the dominant hand [44]. This disjunction is performed primarily by the curved chisel technique, with particular attention paid to the vasculature in the posterior maxilla [44]. The descending palatine canal and the sphenopalatine fossa lie in that region, where several branches of the maxillary artery pass [44]. The lack of consensus among surgeons about the necessity of releasing pterygoid plates in SARME might be partly due to risk−benefit considerations [49]. It has been shown that PTMD increases the rate of associated morbidities and complications such as unpredicted fractures, bleeding, and tinnitus [33, 49, 57, 65]. Untoward fracture of the pterygoid plates, the posterior wall of the maxillary sinus, the skull base, and the orbit caused by PTMD have been well documented in the literature [33, 49, 54, 66-68].

In the experiment conducted by Shetty et al., [39, 69] 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 [33]. A close anatomic relationship exists among the greater and lesser wings of the sphenoid bone, the sphenoid sinuses, and the inferior and superior orbital fissures [33]. If the sphenoid sinuses are large, they can extend for a variable distance posteriorly into the body of the sphenoid bone, into the pterygoid plates, and/or into the roots of the greater wing of the sphenoid [33]. The sphenoid sinus is related laterally to the optic nerve as it traverses the optic foramen, the cavernous sinus, and the internal carotid artery [33]. 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 [33].

Another reported complication of PTMD is intraoperative and postoperative bleeding caused by injury to the terminal branches of the internal maxillary artery, especially the posterior superior alveolar artery and the pterygoid plexus [49, 27, 33]. Newhouse et al., [70] reported a case of internal carotid artery rupture with

consequent life-threatening haemorrhage caused by fracture of the pterygoid process at the base of the skull after PTMD [49]. The risk of bleeding increases when the pterygoid plates are separated from the maxilla [27]. Betts et al., pointed out that bilateral release of the pterygoid plates from the maxilla was as important as the release of the palatal sutures to allow posterior maxillary expansion [4].
However, when the pterygoid plates are separated from the maxilla, the most common sources of haemorrhage after SARME are the terminal branches of the maxillary artery, particularly the posterosuperior alveolar artery and the pterygoid venous plexus [27]. Turvey and Fonseca [71, 72] 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 [27, 71]. Thus, during pterygomaxillary separation, the pterygoid osteotomes must be correctly positioned, and anatomic variance should be taken into account to avoid direct damage to vascular structures [27]. Turvey and Fonseca [71] also recommended the use of an osteotome with an approximate width of 10 mm in adult patients and noted that the descending palatine artery is particularly vulnerable to damage when SARPE is performed with pterygomaxillary separation or lateral nasal wall osteotomy [27, 71]. Damage to the descending palatine artery can be minimized by limiting the extent of the osteotomy posterior to the piriform rim to 35 mm in men and 30 mm in women [4, 27].

Irreversible complications

Discoloration of a central incisor adjacent to the interdental osteotomy was observed [1]. Imaging showed a symmetrical midline osteotomy without separation of the alveolar bone from the incisor root [1]. Failure to identify an unusual midline osteotomy before appliance activation may result in an exacerbated periodontal injury and, in severe cases, tooth loss [1]. Tooth discoloration after interdental osteotomies has been found to be the result of direct intraoperative insult, transient hypoperfusion [26], or a combination of both, with resulting pulpal haemorrhage, death, and necrosis [1], and leakage of the pulpal degeneration products into the adjacent dentine layer [1].
Hypoprofusion, primarily involving the central incisors, is pronounced after SARME, reaching the nadir at postoperative day 3 and remaining at approximately 60% of normal at day 7 [11]. Appliance activation, which generally begun from postoperative days 5 to 7, can further compromise revascularization of the injured teeth [11]. Discoloration of one central incisor, adjacent to the interdental osteotomy, mostly occurred within the first 8 weeks [11]. Preoperative and postoperative imaging showed that the midline osteotomies were oblique and off center, resulting in a separation of the bone from the root surface of the discolored central incisor [11]. When symmetrical midline osteotomies were present, imaging displayed converging central incisor roots or minimal interdental spaces [11].
SARME is also related to devitalization of teeth and altered pulpal blood flow [1, 11, 26, 27, 56], with one or both central incisors [2] or canines affected [2].

Some patients developed catastrophic midline bony defects with associated loss of the central incisors [2, 11, 53]. The teeth and bone loss were secondary to eccentric midline osteotomies, which caused separation of the bone from the root surface of the central incisors followed by postoperative osteotomy site infections [11].

Apical root fracture of the central incisor during the SARME procedure was reported [59]. It was associated with 1-month- delayed postoperative pain in the upper central incisor. A root fragment was removed and orthodontic treatment was applied [59]. Chisel torsion movements were the main reason for apical root fracture [59].

Gingival recession mostly involved central incisors [1, 11] or teeth to which the expansion appliance was anchored [11], and was observed within two months of surgery [1, 2, 11, 26, 27, 55, 56, 62, 73, 74]. In several cases, gingival recession developed after the appliance activation caused the gingiva to detach from the mesial tooth surface [11].

Not disengaging areas of major resistance decreases the mobility of the maxillary halves and leads to a greater risk of asymmetrical, inadequate, or unsuccessful expansion and an increased risk of periodontal damage, since the distraction forces are not evenly distributed.[1]. Periodontal pockets [59], and periodontal bone loss [1, 2, 11, 26, 33, 53, 56] between the maxillary central incisors [11] were described. Most osseous defects were mild (2 mm), involved a small amount of crestal bone, and required no treatment [11]. However, 2 patients developed a catastrophic loss of interdental bone and ultimately required removal of the central incisors [1, 11].

These patients developed gingival-tooth detachment, eccentric midline osteotomies with separation of the alveolar bone from the root surface of a central incisor, and postoperative interdental osteotomy site infections [11]. One of these patients also had a discolored central incisor [11].

Such periodontal complications can occur for many reasons, including eccentric bony fracture, osteotomy site infection, rapid appliance activation in conjunction with inadequate expansion, or a combination of these factors. [11]

External apical root resorption [1, 11, 26, 27, 31, 55, 59, 75] of the upper central incisors was observed after SARME procedures. However, it is unclear whether the SARME procedure or the concurrent orthodontic treatment was the reason for these results [1].

Three patients reported excessive lacrimation [1, 27, 55, 56]. Of those experiencing excessive lacrimation, one patient showed unilateral effects for 1 day, and two patients reported bilateral effects for 1 and 4 days. Complaints lasting less than 1 week were not counted as complications [27].

Some authors reported a case of tinnitus after SARME with PTMD [1, 27, 56].

The development of a nasopalatine canal cyst was also described after SARME [26, 53, 76].

Nerve lesions, such as a lesion of maxillary nerve branches [1, 55], and bilateral lingual anaesthesia [26, 53] were reported.

Maintaining the vascular structures in the posterior maxilla is critical to prevent surgical bleeding as well as to avoid post-surgical haemorrhage and/or avascular maxillary necrosis [2, 11, 26, 49, 53, 56].

Finally, the most dangerous and irreversible complications were related to a fracture in the posterior aspect of the left maxillary sinus that extended to involve the left body of the sphenoid bone with fractures of the floor and roof on the left sphenoid sinus, resulting in the development of ptosis and ophthalmoplegia due to oculomotor, abducens and facial nerve palsies, which resolved 4 months after the initial maxillary expansion procedure [33, 54]. Some authors have also described a skull base fracture [1, 26, 27], including skull base fracture with orbital compartment syndrome, resulting in permanent blindness, following SARME [60].

Discussion

The results of this study emphasize that like any other surgical procedure, SARME is not free of risks and should be preceded by careful patient selection and planning [1]. As SARME complications can be life-threatening, surgery should be performed by experienced maxillofacial surgeons in hospitals rather than in private offices. A custom-made diagnosis and plan should be considered instead of standardized procedures. In particular, large field-of-view CBCT (maxilla and skull base) should be implemented as an initial planning tool to avoid many potential complications.

The role of preoperative CBCT in avoiding as many complications as possible should be the following:

- to discover any existing sinusitis or predisposing factors towards sinusitis,
- to check the anatomy of the inferior turbinate (hypertrophy),
- to visualize the descending artery canal and its distance from the pyrifom rim,
- to visualize variation in the infra-orbital foramen position and number of foramina (infra-orbital nerve),
- to visualize variation in the anterior and superior maxillary nerve canal (canal sinuousum around the pyriform rim),
- to visualise pterygoid plate anatomy, the presence of the pterygoalar ligament, joining the lateral pterygoid plate and the sphenoid bone wing (risk of conduction of a non-controlled fracture towards the skull base during SARME),
- to visualise incisor and canine root anatomy and the existing free space between the central incisors and/or central and lateral incisors (midsagittal osteotomy),
- to visualise external root resorption for maxillary teeth (orthodontic treatment versus SARME procedure),
- to visualise the naso-palatine canal and any developing cyst,
- to visualise the nasolacrymal canal and its position in relation to the anterior maxillary osteotomy line,
- to visualise the sphenoid bone, the sphenoid sinus and its anatomical variations and the pneumatisation extension of the sphenoid sinus (i.e., into pterygoid plates).

Moreover, postoperative care and patient instructions may prevent poor oral hygiene practice and the development of postoperative infection.

New types of SARME distractors, custom-made distractors, or one-piece distractors may be a better choice because they are easy and fast for surgeon to use.

Piezosurgery, rather than oscillating saw and/or osteotomes, and more accurate 3D planned and printed surgical guides for osteotomy lines might prevent dental and bleeding SARME complications.

Mechanical models (3D finite element models) may be developed in the future to compare SARME procedures using different types of distractors and distraction times, and to virtually verify 3D bone resistance areas, forces transmitted, and risks of transmitted fractures. These models may be further adapted and customized to a unique patient craniofacial skeleton.

No open-access studies on complications in SARPE or SARME surgery were found in the literature. This shows the difficulty accessing verified information, especially for private practice clinicians.

Finally, the current trend for "minimally invasive" surgery for these elective surgical cases might be, from an ethical point of view, transformed onto "minimally complicated" surgery as a complication is still more harmful for any given patient than any potential perioperative surgical invasiveness.

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Authors contribution:

Author	Contributor role
Olszewski R	Conceptualisation, Data curation, Investigation, Methodology, Resources, Validation, Writing original draft preparation, Supervision, Writing review and editing
Wisniewski M	Conceptualisation, Validation, Writing original draft preparation, Writing review and editing

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