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Maxillary sinus and success of dental implants: an update

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The maxillary sinus augmentation procedure has been gaining more acceptance among dental professionals. The aim of this review article is to provide an update about various aspects of anatomy, physiology, and common pathological conditions of the maxillary sinus and their clinical relevance to the sinus augmentation procedure and subsequent implant placement.

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Patients suffering from tooth loss in the posterior maxilla are often subject to esthetic, functional, and psychological complications.[1] Maxillary sinus augmentation (also known as *sinus lift*) procedures have become increasingly popular procedures prior to placement of dental implants in posterior maxillae that have suffered severe bone loss due to sinus pneumatization, alveolar bone atrophy, or trauma.

For a clinician to master this surgical procedure, he or she requires a thorough knowledge of sinus anatomy, physiology, pathology, and surgical techniques. Furthermore, advances in the field of bone regeneration necessitate a careful review of available products and their limitations.[2] In addition, many clinical trials and reviews have investigated the success and survival of dental implants in different regions of the mouth, but there is little research on implants after sinus augmentation.[3-5]

This article will discuss different aspects of the maxillary sinus, including sinus development, anatomy, physiology, and pathology. The sinus augmentation technique, including elevation procedures, regenerative materials, possible complications, postoperative instructions, and post-augmentation implant success and survival rates, will also be reviewed.

Development, anatomy, and physiology of the maxillary sinus

The maxillary sinus, the largest paranasal sinus, serves many functions, including air conditioning, pressure damping, vocal resonance, and the reduction of the weight of the skull or growth of the face. It exists in most placental mammals and archosaurs.[6] It is located within the bone of the maxilla on each side of the nasal cavity and communicates with the nasal cavity through an opening (called an *ostium*) that is located high on the medial wall and opens into the semilunar hiatus of the middle nasal meatus on the lateral nasal cavity.[7]

The maxillary sinus starts to develop as early as the tenth week of gestation as invaginations of the mucosa and extension from the primitive ethmoid infundibulum.[8] During childhood, the maxillary sinus has periods of rapid growth: the first spurt is between birth and 3 years of age, and the second one is between 7 and 12 years of age.[8] The level of the sinus floor, determined by its cephalocaudal pattern of growth, continues to grow until it reaches the level of the floor of the nose at 9-12 years of age.[9,10] The floor of the antrum in dentate adults may reach approximately 1 cm below the nasal floor.[11]

The increase in the sinus as a person ages is called *pneumatization*, which results in a pyramidal structure in which the base is oriented toward the nasal wall and lateral apex extends into either the zygomatic process of the maxillary bone or the zygoma.[10,12] Anteriorly, the sinus extends to the canine and premolar area; the most inferior point of the floor extends to the first molar region. The roof is formed by the orbital floor and transected by the course of the infraorbital nerve that exits through the infraorbital foramen.[13] Behind the posterior wall is the pterygomaxillary fossa, which contains several important structures, such as the internal maxillary artery, sphenopalatine ganglion, and the greater palatine nerve. The process of pneumatization usually leaves a thin bone in both the occlusal and lateral walls (especially above the canine in the canine fossa) of the posterior maxilla.[12]

The average dimensions of the maxillary sinus are 33 mm in height, 23-25 mm in width, and 34 mm in the anteroposterior axis; the average volume is 15 mL.[14]

The blood supply to the maxillary sinus mainly comes from the branches of the maxillary artery, including the posterior superior alveolar and the infraorbital arteries, which anastomose in the lateral antral wall.[12] Additional blood supply to the inferior part of the sinus may come from the greater palatine artery.[15] Nerve supply to the sinus is derived from the second division of the trigeminal nerve (maxillary nerve V_2) through the superior alveolar nerve.[12] Venous drainage runs anteriorly into the facial vein, posteriorly into the maxillary vein, and into the jugular vein (via the dural sinus system). The lymph drainage occurs via the infraorbital foramen and the ostium.[11]

Maxillary sinus septa were first mentioned by Underwood in 1910.[16] He described them as barriers of cortical bone that arise from the floor or the walls of the sinus and may divide the sinus into several recesses.[17] Based on their origin, septa can be further subdivided into primary septa, formed during maxillary development and tooth growth, or secondary septa, acquired during the pneumatization of the maxillary sinus after tooth loss.[18]

The sinus is internally lined with a thin respiratory ciliated epithelium that is continuous with the epithelium of the nasal mucosa; however, the antral mucosa is thinner (approximately 1 mm thick) and less vascular.[11] The sinus epithelium possesses cilia that serve in the transportation of fluid secretions toward the ostium. This lining of the maxillary sinus cavity is called the *schneiderian membrane* (also known

as the *sinus membrane*).[19] This membrane is usually elevated when insufficient bone height is present during dental implant installation in the posterior maxilla.

Pathological conditions

In general, maxillary sinus diseases can be classified as inflammatory, mucocele, odontogenic, neoplastic, or granulomatous vasculitis.[20]

Inflammatory disease is the most common pathological condition involving the maxillary sinus. Usually inflammatory diseases are a consequence of upper respiratory tract infections that are viral in origin.[20] Symptoms may include pain and discharge. On the other hand, chronic inflammatory disease of the sinus is usually bacterial in origin and rarely causes pain, except during exacerbation.[20,21]

Mucoceles are epithelium-lined cystic masses usually resulting from obstruction of the sinus ostia.[22] They may result in a completely filled sinus and can lead to bone expansion due to pressure.[20]

Odontogenic sinusitis accounts for approximately 10%-12% of maxillary sinusitis cases.[23] It can occur when the schneiderian membrane is violated by conditions related to dental pathology of the maxillary bone, infections of the maxillary teeth, trauma to maxillary teeth, or by iatrogenic causes such as dental extractions, incorrect placement of dental implants, and maxillary osteotomies in orthognathic surgery.[24]

In a 2011 study that compared different diagnostic methods for maxillary sinus pathology, the authors found that the most common radiographic findings were, in descending order, mucosal thickening, mucous cysts, and occupation of the whole sinus.[25] The authors concluded that conventional computed tomography (CT) can be considered a reliable method for the diagnosis of maxillary sinus pathology.[25] Other diagnostic methods include panoramic radiographs, 3-dimensional cone beam CT, and magnetic resonance imaging.

Carmeli et al assessed the correlation between maxillary sinus inferior mucosal thickening and sinus outflow obstruction.[26] They evaluated 280 CT scans for 560 maxillary sinuses and found that an irregular mucosal thickening of more than 5 mm, mucosal thickening with a circumferential appearance, and complete mucosal thickening are associated with an increased risk of sinus outflow obstruction.[26] In such cases, a consultation with an ear, nose, and throat specialist is recommended. However, any degree of thickening with a rounded mucosal appearance is associated with a low risk of sinus obstruction.[26]

Radiographically, pathological lesions on the sinus may have the following characteristics: soft tissue lesions that are usually radiopaque without a corticated margin; sinus walls that present a thin, continuous white line (in benign disease); resorbed sinus walls and a discontinuous corticated outline (in malignant, infectious, or expansile disease); or resorbed roots of the maxillary teeth (in malignant or rapidly expansile diseases).[20]

Sinus elevation procedure

The elevation of the sinus floor is an internal augmentation of the maxillary sinus, intended to increase the vertical bony dimension of the lateral maxilla to allow placement of dental implants in sites with insufficient alveolar bone height.[1] The procedure was introduced by Tatum at an Alabama dental implant conference in 1976 and was subsequently described by Boyne & James in 1980.[27,28]

The classic sinus lift procedure consists of the preparation of a window in the lateral maxillary sinus wall. This window is then luxated inward and upward with the schneiderian membrane to a horizontal position, thus forming a new sinus floor.[1] The space underneath the membrane is filled with different graft materials according to the specific case. When bone height is sufficient to achieve primary stability (approximately 4 mm), implants can be inserted simultaneously. However, if the grafted bone has to remodel, implants should be inserted in a subsequent procedure.[1]

There are 2 main approaches for maxillary sinus floor elevation: the lateral antrostomy approach and the crestal approach.

Lateral antrostomy approach

This approach starts with a crestal (or paracrestal, slightly palatal to the midcrest) incision in the alveolar ridge.[27] A full-thickness flap is then raised to allow access to the lateral sinus wall. A round bur is used to create a U-shaped trapdoor on the lateral wall of the maxilla. A CT scan should verify that the height of this trapdoor does not exceed the width of the sinus. An antral curette is used to gently lift the sinus membrane from the bony floor in 3 directions (anteriorly, posteriorly, and medially); lifting proceeds from the apicodistal to the coronomesial direction in order to release the tension on the membrane. The space is then grafted. Implants are then placed either simultaneously (1-stage) or after a delayed period of up to 12 months (2-stage) if graft maturation is necessary. The recipient site should not be overfilled, as that may lead to membrane necrosis.[12,27]

The 1-stage procedure is less time consuming; however, it is more technique sensitive. The procedure's success relies heavily on the amount of residual bone. One of the drawbacks of the 1-stage technique is that it requires a large flap for surgical access.[12]

Crestal approach

This technique begins with a crestal incision.[29] A full-thickness flap is then raised to expose the alveolar ridge. Next, an osteotomy is performed, starting with an osteotome of the smallest size, which is tapped in place in the bone with a mallet or drill. More osteotomes of gradually increasing size are then used to expand the alveolus and compress the bone. Once the largest osteotome has been placed, prepared bone grafting material is added to the osteotomy so that it presses on the sinus membrane. This additional pressure causes the elevation of the membrane. Additional grafting material may be used to achieve the desired amount of elevation. An implant—slightly larger in diameter than the osteotomy—is then inserted in the site.[12,29]

The crestal approach technique is a less invasive procedure, improves the density of the maxillary bone, and has the potential to allow the use of less autogenous grafting material. The disadvantage to this approach is an increased risk of misaligning the long axis of the osteotome during the sequential osteotomy.[12]

Other techniques for sinus augmentation have been introduced over the years. The original techniques involved rotary appliances, such as surgical handpieces or high-speed handpieces. These devices were specifically modified for sinus lifting by Wood & Moore, who reported their hinge osteotomy technique in 1988.[30,31] In 1997, Smiler reviewed multiple technique

variations for sinus elevation.[31,32] Then in 2001, Vercellotti et al introduced the piezoelectric technique (already used in Europe) to the United States.[31,33] Lozada et al described the Dentium Advanced Sinus Kit technique (Dentium) in 2011.[31,34]

The piezoelectric osteotomy procedure involves cutting a window in the alveolar bone. This can be done with great simplicity and precision—avoiding the risk of perforating the membrane—because of the shape of the bone scalpels, which work with ultrasonic modulating vibrations.[34] The piezoelectric device has the ability to automatically cease surgical action when the scalpel comes into contact with nonmineralized tissue.[34] Separation of the membrane is achieved by the ultrasonic vibrations of the piezoelectric device and by the hydropneumatic pressure of the physiologic solution used in a piezoelectric cavitation.[34] A recent review of the lateral window technique concluded that piezoelectric devices result in dramatically fewer occurrences of intraoperative bleeding and membrane perforation than do rotary diamond burs.[31]

Sohn et al compared 2 piezoelectric cutting inserts (a saw and a round diamond) for the lateral window technique.[35] The authors found that both devices effectively created the lateral bony window and that their membrane perforation rates were not significantly different. However, the saw insert demonstrated greater precision and easier repositioning of the lateral bony window as a barrier than did the round diamond.[35]

Other advances in the piezoelectric technique include specialized safe-cutting drills and diamonds, hydraulic pressure, and balloon elevation techniques.[31]

Surgical procedure and anatomical considerations

Flap design

The flap should be designed to minimize disturbance of the blood supply, and the surgical site needs to be securely covered.[1] As previously mentioned, the incision is usually made midcrestally or paracrestally through the keratinized, attached mucosa. The infraorbital foramen should be avoided; precautions should be taken not to injure the neurovascular bundle during the preparation of the door and retraction of the flap.[1]

Ideally, the shape of the door should follow the inner shape of the maxillary sinus, which usually is curved. Radiographic and clinical evaluations of the extent of the maxillary sinus can be used to plan the shape. If the lateral sinus wall consists of thick bone, the whole lateral sinus wall should be thinned out. It has been suggested that rounded corners be approached with a wide cranial hinge base in order to reduce the risk of damaging the membrane.[1] The door luxation is best performed with finger pressure so that the surgeon can feel resistance and avoid the use of a sharp instrument.

Schneiderian membrane

The thin schneiderian membrane should be kept intact to prevent the loss of graft material into the sinus and to keep the sinus blood supply intact.[19]

In smokers, the schneiderian membrane may appear atrophic and be extremely thin and fragile. Chronic sinusitis and allergies may result in a thick membrane. These conditions are considered contraindications to the sinus lift procedure, and therefore must be addressed during preoperative planning.[12,24] Previous sinus surgery may also be a contraindication to sinus floor elevation since scar tissue does not allow for the preparation of healthy, intact mucosal tissue.[19,24]

Detachment of the schneiderian membrane is a delicate procedure and usually is performed with special instruments (designed by Tatum in 1986) that work in different directions with different angles and blades.[27] The membrane should be freed totally from the caudal area to enable lifting of the sinus; however, the distal side of the sinus might extend considerably.[12,27] As previously mentioned, overfilling of the sinus may cause membrane necrosis, as well as sinusitis and the potential loss of the graft into the sinus.[12,27] Sinus floor convolutions and root tip expressions can be difficult to negotiate when the membrane is luxated from the septa and at the longitudinal rims.

In a study of 20 patients, Aimetti et al found that the thickness of the sinus mucosa amounted to 1.26 ± 0.14 mm and 0.61 ± 0.15 mm in individuals with thick and thin gingival tissues, respectively, which may represent a reliable parameter to predict sinus membrane thickness in the future.[36] The authors suggested that further investigation was needed to support the preliminary data.

Maxillary sinus septa

An antral septum of the maxillary sinus is an anatomical variation found in 16%-58% of the population; a single septum is more common than multiple septa.[37] Septa divide the sinus into multiple recesses and eventually into smaller accessory sinuses. Sinus augmentation is complicated by the presence of septa, except when they present in the caudal area of the sinus; in these cases, augmentation may be performed normally.[37] If a septum is located higher than the caudal region, a clinician has multiple options: follow the contours of the sinus and create a W-shaped window, create 2 trapdoors, place a door on 1 side of the septum (usually the mesial side), or partially remove the septum after elevating the membrane.[37]

Park et al used CT scans to investigate the prevalence, location, height, morphology, and orientation of maxillary sinus septa in 200 patients (400 sinuses).[37] The authors found that 111 septa were present in 400 maxillary sinuses (27.7%), which corresponded to 37% of the patients. Among these septa, 25 (22.5%) were located in the anterior, 51 (45.9%) in the middle, and 35 (31.5%) in the posterior regions. Directional orientation analyses showed that 106 septa were buccopalatal, 4 were sagittal, and 1 was a transverse type. The mean heights of the septa were 7.78 ± 2.99 mm and 7.89 ± 3.09 mm in the right and left sinuses, respectively.[37]

Pommer et al conducted a meta-analysis for data published on maxillary sinus septa from 1995 to 2011.[38] A total of 8923 sinuses were investigated, and septa were present in 28.4%. However, when a diagnosis of a septum was based on panoramic radiographs, the diagnosis was incorrect in 29% of cases. The average septal height was found to be 7.5 mm. Interestingly, the prevalence of septa was found to be significantly higher in atrophic sinuses than in dentate maxillae. Of the septa that were found, 24.4%, 54.6%, and 21.0% were located in the premolar, molar, and retromolar regions, respectively. The orientation of the septum was transverse in 87.6% of the cases, sagittal in 11.1%, and horizontal in 1.3%. Only 0.3% of septa

were complete, dividing the sinus into 2 separate cavities. In addition, multiple septa were present in 1 sinus in 4.2% of patients, and bilateral septa were found in 17.2% of the patients.[38]

Rossetti et al reviewed data from 1966 to 2009 regarding anatomical and biomechanical aspects of atrophic maxillae for implant possibilities.[39] Findings revealed that previous use of a removable prosthesis is a risk factor for resorption of the posterior maxilla, with flabby tissues that correlated with the severity of resorption. In addition, the prevalence of septa was higher in atrophic maxillae. Female patients had less medullar bone quantity and connectivity than male patients.[39]

Sinus volume and dimensions

Kirmeier et al studied the reliability and the reproducibility of a semi-automatic virtual volumetric analysis technique on 36 CT scans of human maxillary sinuses.[40] The validation of the method revealed that the mean relative error was 0.364%. The authors concluded that CT scans are a reliable source for measurement of maxillary sinuses to determine sinus volume in patients.

Jun et al used CT scans to evaluate changes of the maxillary sinus volume in 173 patients (238 maxillary sinuses) according to their age and gender.[41] The authors found that the development of the maxillary sinus continued until the third decade in men and the second decade in women. Furthermore, the mean maxillary sinus volume in young adults was 24.043 mm^3 for males and 15.859 mm^3 for females, a statistically significant difference ($P < 0.05$). There was also a significant difference in the maxillary sinus volume before the sinus was fully developed. The authors concluded that a maxillary sinus operation that affects the bony structures before they are fully developed might negatively affect the sinus, a factor that needs to be considered before surgery.[41]

Kawarai et al used CT scans to study the size of the paranasal cavities in 20 healthy Japanese subjects and found that the volume of the right maxillary sinus was 23.6 ± 6.4 mL and 20.9 ± 6.8 mL in males and females, respectively.[42] The volume of the left maxillary sinus was 24.9 ± 7.6 mL and 21.1 ± 5.5 mL in males and females, respectively.[42]

Ikeda et al also used CT scans to measure the maxillary sinus volume of "normal" children and those with bilateral chronic sinusitis and then compared the results with findings obtained from adult patients.[43] The ethmoid infundibulum and middle meatus in children with bilateral chronic sinusitis were narrowed by inflammation, leading to impaired pneumatization of the maxillary sinus.[43]

Augmentation materials

Various grafting materials have been used for sinus elevation procedures. Based on their source, grafting materials can be categorized as *autograft, xenograft, allograft,* or *alloplastic*. These types may be used alone or in any combination for sinus augmentation. The biological rationale for using bone grafts is based on 3 different healing mechanisms: *osteogenesis,* the capacity of the graft to bring new bone-forming vital cells into the defect; *osteoconduction*, the capacity of the graft to serve as a scaffold for bone formation; and *osteoinduction*, the capacity of the graft contents to induce an osteoblastic differentiation of the host's undifferentiated cells.[44] Osteoconductivity is an essential mechanism in any grafting material, as it provides biomechanical support and stabilization to the coagulum in the first healing phase and a scaffold for the new bone that will form in the later phase.[45]

Autogenous bone (also known as *autologous bone* or *autograft*) is considered the gold standard graft material for sinus augmentation, because it has osteogenetic, osteoinductive, and osteoconductive properties in addition to its high biocompatibility. The main disadvantage of this bone type is the need for a second surgical site, which can cause donor site morbidity. Donor sites are either extraoral (such as the ilium, tibia, or cranium) or intraoral (such as the mandibular ramus, mandibular symphysis, and maxillary tuberosity).[46] Complications at donor sites include pain, gait disturbance, hernia, paresthesia, infection, antral perforation, dental injury, and fracture of the site.[46]

Allogeneic graft material can be obtained from tissue banks as either mineralized or demineralized bone.[46] Mineralized bone is less commonly used in sinus elevation procedures because of its lengthy process of bone formation. Demineralized bone is more commonly used due to the presence of bone morphogenetic protein that stimulates osteoinduction in adjacent undifferentiated cells to form new bone tissue.[46] However, the main concerns about use of this type of material include the high cost and the risk (albeit low) of disease transmission.[46]

Xenografts, especially deproteinized bovine bone (such as Bio-Oss, Geistlich Pharma North America, Inc.), are widely used and have been studied extensively both in vitro and in vivo.[46] Deproteinized bovine bone possesses osteoconductivity and can be used alone or in combination with other grafting materials. Bio-Oss is a bovine bone derivative that undergoes a low-heat (300°C) chemical extraction process by which all organic components are removed while the natural architecture of bone is maintained.[44]

Alloplastic grafting materials are easy to use and relatively less expensive than the cost of bone harvesting.[46] The most common alloplastic grafting materials are those composed of some form of hydroxyapatite, mainly calcium phosphate ceramics.[46]

Mesenchymal stem cells have recently been implemented in maxillary sinus augmentations with clinically promising results.[47] Mangano et al evaluated the literature pertaining to the effectiveness of cell-based approaches in maxillary sinus augmentation in humans.[47] The authors reviewed studies with at least 3-4 months' follow-up. They documented the potential for cell-based approaches in maxillary sinus augmentation and suggested further randomized control trials to clearly demonstrate the benefits of this approach.[47]

Postoperative instructions

The patient should be provided with both printed and oral instructions postoperatively.[48] These instructions should include application of ice and pressure to the site, elevation of the head, and rest for the patient.[49]

Although smoking is not an absolute contraindication, it is recommended that the patient cease the habit before, during, and after sinus augmentation and implant insertion because it has the potential to affect healing; several studies have shown higher failure rates among smokers.[49-53]

Actions that create negative pressure (such as blowing the nose or sucking through a straw) must be avoided by the patient during the first week after surgery.[49] If the patient does sneeze, he or she must keep the mouth open, so pressure is not exerted within the sinus.[48,49] Also, the patient should be warned against pulling back the lips to observe the surgical site, which could open the surgical incision line.[49]

The patient should be informed about which symptoms to expect shortly after surgery, including slight bleeding from the incision line the day of surgery and soreness, swelling, and bruising for several days postsurgery.[48] The presence of small bone particles or granules in the mouth or from the nose (with some bleeding) is not unusual.[49] In addition, the patient should be advised to take medications (such as anti-inflammatory drugs, antibiotics, and nasal decongestants) as prescribed by the surgeon.[49]

Outcomes

Implant success rate, survival rate, and risk evaluation

Several variables may alter the outcome of implantation in regions of maxillary sinus augmentation, including the technique used (lateral versus crestal approach, piezoelectric surgery versus rotary diamond burs); site factors such as local anatomy (height and width of the remaining bone, presence of septa) or the presence of pathological conditions prior to the procedure; the timing of implantation (simultaneous versus delayed); the time of functional loading (immediate versus delayed); the bone grafting materials used; the use or nonuse of a barrier membrane on the lateral window; and implant-related variables such as surface type, length, and width. Patient-related factors not directly connected to the augmentation need to be considered as well, including smoking, parafunctional occlusion, systemic conditions (such as bone diseases or diabetes), and oral hygiene.

Pal et al compared the effectiveness of the crestal approach and the lateral window approach for maxillary sinus augmentation.[5] Twenty-five implants (in combination with bone grafting material) were placed in 20 partially edentulous patients who required sinus augmentation to treat a deficient posterior maxilla. The researchers found that the gain in bone height was significantly greater after the lateral window technique (mean 8.5 mm) than after the crestal approach (mean 4.4 mm). However, they concluded that neither sinus elevation technique appeared to affect implant success rates.[5]

In 2 different systematic reviews, Pjetursson et al and Tan et al assessed the success of sinus floor elevation and survival of implants for both crestal and lateral window approaches.[3,4] When reviewing postimplantation follow-up data for procedures with the lateral window approach (12,020 implants), the authors found high implant survival rates (90.1% implant survival 3 years postimplantation) and low incidences of surgical complications.[3] They also found that rough surface implants with barrier membrane coverage of the lateral window showed the best results (98.3% implant survival after 3 years).[3] The same authors assessed the survival rate of implants placed in sinuses augmented via the crestal approach (4488 implants) and found an estimated survival rate of 92.8% for implants 3 years postimplantation.[4] Thus, both reviews showed comparable findings with high implant survival rates for the 2 approaches.[3,4]

In another systematic review, Rossetti et al found that implants supporting overdentures in reconstructed maxillae (of 5 mm or less) had higher risks for bone loss due to compromised peri-implant soft tissue health.[39]

In 2011, Baldini et al described a novel technique while using the crestal approach in 23 patients whose residual maxillary bone was approximately 7.5 mm.[44] The authors utilized osteotome or piezoelectric surgery techniques for sinus elevation and placed 34 implants. The patients were then followed for a mean period of 19.29 months. Although no statistically significant differences were found in bone levels attained after either the osteotome or piezoelectric surgery technique, the piezoelectric surgery technique was considered to provide less discomfort for the patient and greater convenience for the surgeon.[44] Furthermore, the use of piezoelectric devices instead of rotary diamond burs in the lateral window procedure dramatically reduces the incidence of bleeding and membrane perforation.[31]

When comparing different grafting types, Wallace & Froum showed that implants placed in sinuses augmented with particulate grafts have a higher survival rate than those placed in sinuses augmented with block grafts.[54] In addition, they found that the utilization of grafts composed of either 100% or a proportion of autogenous bone as a component did not affect implant survival.[54] However, a different systematic review showed that implant survival rates after a minimum loading time of 1 year were 88%, 81%, 92%, 95.6%, and 93.3% for autogenous bone (from the iliac crest), alloplastic materials, composite grafts, xenografts, and allografts, respectively.[55]

In terms of implant surface, several studies have provided evidence that rough-surfaced implants have a higher survival rate than machine-surfaced implants when placed in grafted sinuses.[3,31,54,55]

Kan et al studied factors that may have affected the survival rate of 228 implants placed in grafted sinuses of 60 patients.[56] Over a mean follow-up period of 41.6 months, the mean survival rate of implants was 89.9%. High failure rates were associated with nonthreaded implants, poor oral hygiene, and a history of smoking.[56] Several studies have indicated that smoking is associated with implant failure following sinus augmentation, especially when a simultaneous implant approach is used.[50,51,56] However, Peleg et al evaluated the effect of smoking on 2132 implants (627 in smokers versus 1505 in nonsmokers) and concluded that there was no statistically significant difference in the failure rates between the 2 groups.[52] Further studies are needed to investigate the effect of smoking on the success and survival rate of implants placed in sinus augmentation sites.

Sakka & Krenkel evaluated the surgical technique of sinus floor elevation with autogenous parietal bone grafting in conjunction with simultaneous implant placement in 70 patients (77 implants).[57] The results yielded a success rate of 94.8%, which is in agreement with results of other studies.[54,57] However, more long-term randomized controlled trials are needed to verify the success rates for simultaneous implantation following sinus elevation.

Although the relationship between diabetes and dental implants has been studied, relatively little is known about the influence of diabetes on the success rate of implants placed following maxillary sinus floor elevation. However, Hou et al compared the differences in bone formation after maxillary sinus floor elevation in 3 groups of rabbits (n = 5): those with controlled diabetes, those with uncontrolled diabetes, and healthy specimens.[58] The maxillary sinus floor was elevated via grafting with hydroxyapatite particles. Compared with the healthy control group, diabetic rabbits had significantly decreased levels of newly formed bone, blood vessels, osteoblasts, type I collagen content, and serum osteocalcin. However, insulin treatment reversed these decreases.[58] This study indicates the need for long-term, randomized, clinical trials that look at the effect of diabetes on implant success and survival rate following maxillary sinus elevation.

Table. Possible complications of sinus augmentation.

Complications	How to avoid
Perforation of sinus (schneiderian) membrane	Proper diagnosis (clinical and radiographic) Blunted instruments Minimally traumatic techniques (such as piezoelectric surgery) Extensive training
Infection	Clean surgical setting Sterile instruments Aseptic surgical site Avoidance of graft contamination
Bleeding	Knowledge of anatomy Minimally traumatic techniques (such as piezoelectric surgery)
Migration of the implant	Proper timing of procedure
Loss of the graft	Maintenance of intact sinus membrane; suturing Use of barrier membrane
Complications related to presence of preexisting antral pathoses	Proper diagnosis Consultation with specialist (eye, ear, nose, and throat)

Complications

Several complications may arise during or after sinus augmentation. The most frequently encountered surgical complication is perforation of the schneiderian membrane, which occurs in 7%-35% of sinus augmentation procedures.[59-61] Perforation of this membrane is most likely to happen at sharp edges and ridges, such as spines or maxillary sinus septa (also known as *Underwood septa*).[2] However, when the perforation is small and located in an area where the elevated mucosa folds together when the door is lifted, there is no need for further management, although use of biological glues might be considered.[1] If the perforation is larger and located in an unfavorable area, the perforation must be closed and covered to prevent loss of the graft.[1] This can be achieved by covering the defect with a resorbable membrane and a surgical adhesive (such as BioGlue, Cryolife, Inc.).[1] In cases where the membrane perforation is very large, further sinus lift should be abandoned and reentry might be considered.[1] The second surgery should not be performed for 6 to 8 weeks.[2]

Hernandez-Alfaro et al studied the prevalence of surgical complications and sinus membrane perforations.[62] They evaluated 338 patients who received 474 sinus augmentation procedures and a total of 1166 simultaneously placed dental implants. The researchers reported 104 (21.94%) perforations of the sinus membrane (19 bilateral). Of these cases, membrane perforations less than 5 mm were observed in 56 (53.85%), perforations between 5 and 10 mm were observed in 28 (26.92%), and membrane perforations more than 10 mm were observed in 20 (19.23%).[62]

If small vessels are found bleeding in the exposed membrane, it is best to let them stop spontaneously or to apply light gauze pressure.[1] Due to the presence of arterial anastomoses of the alveolar antral artery, which branches from the posterior superior alveolar artery within the infraorbital artery on the lateral wall where an osteotomy will be performed, precaution must be taken to avoid massive bleeding.

Rosano et al investigated the prevalence, location, size, and course of anastomoses on 30 maxillary sinuses from 15 human cadaver heads and on 100 CT scans from patients scheduled for sinus augmentation surgery.[63] They found anastomoses in 100% of the cadaver maxillary sinuses by dissecting the sinus anterolateral wall. However, a well-defined bony canal was detected radiographically in 94 of 200 sinuses in the CT scans of the scheduled patients (47%). The mean vertical distance from the lowest point of this bony canal to the alveolar crest was 11.25 ± 2.99 mm in the CT scans. The canal diameter was less than 1 mm in 55.3% of the cases, 1-2 mm in 40.4%, and 2-3 mm in 4.3%. In 100% of the CT scan cases, the alveolar antral artery was found to be located between the schneiderian membrane and the lateral bony wall of the sinus, in the area selected for sinus elevation.[63]

Careful treatment planning, patient selection, and the appropriate sinus augmentation technique are essential to minimize the risk of implant migration into the maxillary sinus. Implant migration may occur several days postimplantation, at abutment connection surgery, or years later.[64] Once the displacement is diagnosed, the implant must be removed as soon as possible.[64]

Other complications are related to the presence of preexisting antral pathologies, such as rhinosinusitis, odontogenic sinus diseases, pseudocysts, retention cysts, and mucoceles.[64] Maxillary sinus diseases have to be recognized and managed with care before sinus augmentation procedures are initiated (Table).[64]

Changes in maxillary sinus physiology following augmentation

Research has shown that the augmentation procedure will not negatively affect the long-term function of the sinus.[65] In an endoscopic, histological, and microbiological prospective study on 17 patients

with a 9-month follow-up, it was found that maxillary sinus floor augmentation surgery with autogenous bone grafts did not appear to have clinical consequences in those patients who did not have preexisting maxillary sinusitis.[66]

Griffa et al assessed mucociliary function during maxillary sinus augmentation in patients who did not exhibit preoperative signs of maxillary sinusitis.[67] Ten patients underwent unilateral sinus floor elevation under local anesthesia and endoscopic control. Methylene blue was dropped on the floor of the maxillary sinus to evaluate mucociliary function in the ostium region during sinus augmentation. The authors observed that mucociliary function was preserved during the surgical procedure except in the detached area of the schneiderian membrane.[67]

Conclusion

Knowledge of the existing literature and extensive training are essential for clinicians who aim to perform sinus augmentation procedures. Careful presurgical planning will decrease the incidence of complications and unexpected anatomical and pathological situations. Several factors must be considered before this type of surgery is performed, including the age of the patient as well as the patient's oral hygiene habits and history of smoking.

Future research should concentrate on the following areas: volume of the sinus and its effect on the success of the grafting procedure and the implant; the use of mesenchymal stem cells for sinus augmentation; the effect of systemic diseases on the success of the augmentation procedure, grafting, and implants; and the effect of smoking on the success and survival rates of implants placed in sinus-grafted sites.

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References

1. van den Bergh JP, ten Bruggenkate CM, Disch FJ, Tuinzing DB. Anatomical aspects of sinus floor elevations. *Clin Oral Implant Res.* 2000;11(3):256-265.
2. Chanavaz, M. Maxillary sinus: anatomy, physiology, surgery and bone grafting related to implantology—eleven years of surgical experience (1979–1990). *J Oral Implantol.* 1990;16(3):199-209.
3. Pjetursson BE, Tan WC, Zwahlen M, Lang NP. A systematic review of the success of sinus floor elevation and survival of implants inserted in combination with sinus floor elevation. *J Clin Periodontol.* 2008;35(8 Suppl):216-240.
4. Tan WC, Lang NP, Zwahlen M, Pjetursson BE. A systematic review of the success of sinus floor elevation and survival of implants inserted in combination with sinus floor elevation, II: transalveolar technique. *J Clin Periodontol.* 2008;35(8 Suppl):241-254.
5. Pal US, Sharma NK, Singh RK, Mahammad S, Mehrotra D, Singh N, Mandhyan D. Direct vs. indirect sinus lift procedure: a comparison. *Natl J Maxillofac Surg.* 2012;3(1):31-37.
6. Witmer LM. The phylogenetic history of paranasal air sinuses. In: Koppe T, Nagai H, Alt KW, eds. *The Paranasal Sinuses of Higher Primates: Development, Function and Evolution.* Chicago: Quintessence; 1999:21-34.
7. Moore WJ. *The Mammalian Skull.* Cambridge: Cambridge University Press; 1981.
8. Nunez-Castruita A, Lopez-Serna N, Guzman-Lopez S. Prenatal development of the maxillary sinus: a perspective for paranasal sinus surgery. *Otolaryngol Head Neck Surg.* 2012;146(6):997-1003.
9. Davis WB. Anatomy of the nasal accessory sinuses in infancy and childhood. *Ann Otol Rhinol Laryngol.* 1918;27:940-967.
10. Lawson W, Patel ZM, Lin FY. The development and pathologic processes that influence maxillary sinus pneumatization. *Anat Rec (Hoboken).* 2008;291(11):1554-1563.
11. McGowan DA, Baxter PW, James J. *The Maxillary Sinus and its Dental Implications.* Oxford: Wright, Butterworth-Heinemann Ltd.; 1993:1-25.
12. Woo I, Le BT. Maxillary sinus floor elevation: review of anatomy and two techniques. *Implant Dent.* 2004;13(1):28-32.
13. Rodella LF, Buffoli B, Labanca M, Rezzani R. A review of the mandibular and maxillary nerve supplies and their clinical relevance. *Arch Oral Biol.* 2012;57(4):323-334.
14. Karmody CS, Carter B, Vincent ME. Developmental anomalies of the maxillary sinus. *Trans Sect Otolaryngol Am Acad Opthalmol Otolaryngol.* 1977:84(4 Pt 1):723-728.
15. Solar P, Geyerhofer U, Traxler H, Windisch A, Ulm C, Watzek G. Blood supply to the maxillary sinus relevant to sinus floor elevation procedures. *Clin Oral Implants Res.* 1999;10(1):34-44.
16. Underwood AS. An inquiry into the anatomy and pathology of the maxillary sinus. *J Anat Physiol.* 1910;44(Pt 4):354-369.
17. Maestre-Ferrin L, Galan-Gil S, Rubio-Serrano M, Penarrocha-Diago M, Penarrocha-Oltra D. Maxillary sinus septa: a systematic review. *Med Oral Patol Oral Cir Bucal.* 2010;15(2):e383-e386.
18. Krennmair G, Ulm CW, Lugmayr H, Solar P. The incidence, location, and height of maxillary sinus septa in the edentulous and dentate maxilla. *J Oral Maxillofac Surg.* 1999; 57(6):667-671; discussion 671-672.
19. Stammberger, H. Nasal and paranasal sinus endoscopy. A diagnostic and surgical approach to recurrent sinusitis. *Endoscopy.* 1986;18(6):213-218.
20. Bell GW, Joshi BB, Macleod RI. Maxillary sinus disease: diagnosis and treatment. *Br Dent J.* 2011;210(3):113-118.
21. Erkan M, Aslan T, Ozcan M, Koc N. Bacteriology of antrum in adults with chronic maxillary sinusitis. *Laryngoscope.* 1994;104(3 Pt 1):321-324.
22. Capra GG, Carbone PN, Mullin DP. Paranasal sinus mucocele. *Head Neck Pathol.* 2012;6(3):369-372.
23. Maloney PL, Doku HC. Maxillary sinusitis of odontogenic origin. *J Can Dent Assoc.* 1968:34(11):591-603.
24. Mehra P, Murad H. Maxillary sinus disease of odontogenic origin. *Otolaryngol Clin North Am.* 2004;37(2):347-364.
25. Maestre-Ferrin L, Galan-Gil S, Carrillo-Garcia C, Penarrocha-Diago M. Radiographic findings in the maxillary sinus: comparison of panoramic radiography with computed tomography. *Int J Oral Maxillofac Implants.* 2011;26(2):341-346.
26. Carmeli G, Artzi Z, Kozlovsky A, Segev Y, Landsberg R. Antral computerized tomography pre-operative evaluation: relationship between mucosal thickening and maxillary sinus function. *Clin Oral Implants Res.* 2011;22(1):78-82.
27. Tatum H Jr. Maxillary and sinus implant reconstruction. *Dent Clin North Am.* 1986;30(2):207-229.
28. Boyne PJ, James RA. Grafting of the maxillary sinus floor with autogenous marrow and bone. *J Oral Surg.* 1980;38(8):613-616.
29. Summers RB. Sinus floor elevation with osteotomes. *J Esthet Dent.* 1998;10(3):164-171.
30. Wood RM, Moore DL. Grafting of the maxillary sinus with intraorally harvested autogenous bone prior to implant placement. *Int J Oral Maxillofac Implants.* 1988;3(3):209-214.
31. Wallace SS, Tarnow DP, Froum SJ, et al. Maxillary sinus elevation by lateral window approach: evolution of technology and technique. *J Evid Based Dent Pract.* 2012;12(3 Suppl):161-171.
32. Smiler DG. The sinus lift graft: basic technique and variations. *Pract Periodontics Aesthet Dent.* 1997;9(8):885-893; quiz 895.
33. Vercellotti T, De Paoli S, Nevins M. The piezoelectric bony window osteotomy and sinus membrane elevation: introduction of a new technique for simplification of the sinus augmentation procedure. *Int J Periodontics Restorative Dent.* 2001;21(6):561-567.
34. Lozada JL, Goodacre C, Al-Ardah A, Garbacea A. Lateral and crestal bone planing antrostomy: a simplified surgical procedure to reduce the incidence of membrane perforation during maxillary sinus augmentation procedures. *J Prosthet Dent.* 2011;105(3):147-153.
35. Sohn DS, Moon JW, Lee HW, Choi BJ, Shin IH. Comparison of two piezoelectric cutting inserts for lateral bony window osteotomy: a retrospective study of 127 consecutive sites. *Int J Oral Maxillofac Implants.* 2010;25(3):571-576.
36. Aimetti M, Massei G, Morra M, Cardesi E, Romano F. Correlation between gingival phenotype and Schneiderian membrane thickness. *Int J Oral Maxillofac Implants.* 2008;23(6):1128-1132.
37. Park YB, Jeon HS, Shim JS, Lee KW, Moon HS. Analysis of the anatomy of the maxillary sinus septum using 3-dimensional computed tomography. *J Oral Maxillofac Surg.* 2011;69(4):1070-1078.
38. Pommer B, Ulm C, Lorenzoni M, Palmer R, Watzek G, Zechner W. Prevalence, location and morphology of

maxillary sinus septa: systematic review and meta-analysis. *J Clin Periodontol.* 2012;39(8):769-773.
39. Rossetti PH, Bonachela WC, Rossetti LM. Relevant anatomic and biomechanical studies for implant possibilities on the atrophic maxilla: critical appraisal and literature review. *J Prosthodont.* 2010;19(6):449-457.
40. Kirmeier R, Arnetzl C, Robl T, Payer M, Lorenzoni M, Jakse N. Reproducibility of volumetric measurements on maxillary sinuses. *Int J Oral Maxillofac Surg.* 2011; 40(2):195-199.
41. Jun BC, Song SW, Park CS, Lee DH, Cho KJ, Cho JH. The analysis of maxillary sinus aeration according to aging process; volume assessment by 3-dimensional reconstruction by high-resolutional CT scanning. *Otolaryngol Head Neck Surg.* 2005;132(3):429-434.
42. Kawarai Y, Fukushima K, Ogawa T, et al. Volume quantification of healthy paranasal cavity by three-dimensional CT imaging. *Acta Otolaryngol Suppl.* 1999; 540:45-49.
43. Ikeda A, Ikeda M, Komatsuzaki A. A CT study of the course of growth of the maxillary sinus: normal subjects and subjects with chronic sinusitis. *ORL J Otorhinolaryngol Relat Spec.* 1998;60(3):147-152.
44. Baldini N, De Sanctis M, Ferrari M. Deproteinized bovine bone in periodontal and implant surgery. *Dent Mater.* 2011;27(1):61-70.
45. Polimeni G, Koo KT, Qahash M, Xiropaidis AV, Albandar JM, Wikesjo UME. Prognostic factors for alveolar regeneration: effect of a space-providing biomaterial on guided tissue regeneration. *J Clin Periodontol.* 2004; 31(9):725-729.
46. Tiwana PS, Kushner GM, Haug RH. Maxillary sinus augmentation. *Dent Clin North Am.* 2006;50(3):409-424.
47. Mangano FG, Tettamanti L, Sammons RL, et al. Maxillary sinus augmentation with adult mesenchymal stem cells: a review of the current literature. *Oral Surg Oral Med Oral Pathol Oral Radiol.* 2013;115(6):717-723.
48. Stern A, Green J. Sinus lift procedures: an overview of current techniques. *Dent Clin North Am.* 2012;56(1): 219-233.
49. Misch CE, Resnik RR, Misch-Dietsh F. Maxillary sinus anatomy, pathology and graft surgery. In: Misch CE, ed. *Contemporary Implant Dentistry.* 3rd ed. St. Louis: Mosby Elsevier; 2008:905-974.
50. Strietzel FP, Reichart PA, Kale A, Kulkarni M, Wegner B, Kuchler I. Smoking interferes with the prognosis of dental implant treatment: a systematic review and meta-analysis. *J Clin Periodontol.* 2007;34:523-544.
51. Lin TH, Chen L, Cha J, et al. The effect of cigarette smoking and native bone height on dental implants placed immediately in sinuses grafted by hydraulic condensation. *Int J Periodontics Restorative Dent.* 2012;32(3):255-261.
52. Peleg M, Garg AK, Mazor Z. Healing in smokers versus nonsmokers: survival rates for sinus floor augmentation with simultaneous implant placement. *Int J Oral Maxillofac Implants.* 2006;21(4):551-559.
53. Levin L, Schwartz-Arad D. The effect of cigarette smoking on dental implants and related surgery. *Implant Dent.* 2005;14(4):357-361.
54. Wallace SS, Froum SJ. Effect of maxillary sinus augmentation on the survival of endosseous dental implants. A systematic review. *Ann Periodontol.* 2003; 8(1):328-343.
55. Aghaloo T, Moy PK. Which hard tissue augmentation techniques are the most successful in furnishing bony support for implant placement? *Int J Oral Maxillofac Implants.* 2007;22(Suppl):49-70.
56. Kan JY, Rungcharassaeng K, Kim J, Lozada JL, Goodacre CJ. Factors affecting the survival of implants placed in grafted maxillary sinuses: a clinical report. *J Prosthet Dent.* 2002;87(5):485-489.
57. Sakka S, Krenkel C. Simultaneous maxillary sinus lifting and implant placement with autogenous parietal bone graft: outcome of 17 cases. *J Craniomaxillofac Surg.* 2011;39(3):187-191.
58. Hou CJ, Liu JL, Li X, Bi LJ. Insulin promotes bone formation in augmented maxillary sinus in diabetic rabbits. *Int J Oral Maxillofac Surg.* 2012;41(3):400-407.
59. Schwartz-Arad D, Herzberg R, Dolev E. The prevalence of surgical complications of the sinus graft procedure and their impact on implant survival. *J Periodontol.* 2004;75(4):511-516.
60. Shlomi B, Horowitz I, Kahn A, Dobriyan A, Chaushu G. The effect of sinus membrane perforation and repair with Lambone on the outcome of maxillary sinus floor augmentation: a radiographic assessment. *Int J Oral Maxillofac Implants.* 2004;19(4):559-562.
61. Barone A, Santini S, Sbordone L, Crespi R, Covani U. A clinical study of the outcomes and complications associated with maxillary sinus augmentation. *Int J Oral Maxillofac Implants.* 2006;21(1):81-85.
62. Hernandez-Alfaro F, Torradeflot MM, Marti C. Prevalence and management of Schneiderian membrane perforations during sinus-lift procedures. *Clin Oral Implants Res.* 2008;19(1):91-98.
63. Rosano G, Taschieri S, Gaudy JF, Weinstein T, Del Fabbro M. Maxillary sinus vascular anatomy and its relation to sinus lift surgery. *Clin Oral Implants Res.* 2011; 22(7):711-715.
64. Chan HL, Wang HL. Sinus pathology and anatomy in relation to complications in lateral window sinus augmentation. *Implant Dent.* 2011;20(6):406-412.
65. Timmenga NM, Raghoebar GM, Boering G, van Weissenbruch R. Maxillary sinus function after sinus lifts for the insertion of dental implants. *J Oral Maxillofac Surg.* 1997;55(9):936-939; discussion 940.
66. Timmenga NM, Raghoebar GM, Liem RS, van Weissenbruch R, Manson WL, Vissink A. Effects of maxillary sinus floor elevation surgery on the maxillary sinus physiology. *Eur J Oral Sci.* 2003;111(3):189-197.
67. Griffa A, Berrone M, Boffano P, Viterbo S, Berrone S. Mucociliary function during maxillary sinus floor elevation. *J Craniofac Surg.* 2010;21:1500-1502.

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