An overview of maxillary sinus elevation: Anatomically weak structures, complications, and managements

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Abstract. During implant surgery, when there's insufficient bone in the posterior maxillary region, maxillary sinus elevation is necessary. However, the maxillary sinus contains several anatomically weak structures. Since the surgery is complicated, insufficient understanding of the maxillary sinus anatomy and potential complications can lead to serious consequences such as sinus perforation, ultimately causing implant failure. Depending on surgical methods and indications, maxillary sinus elevation is primarily divided into elevation through alveolar ridge and lateral sinus floor elevation. During surgery, attention should be paid to the course of vessels and nerves, sinus floor morphology, bone thickness, mucosal positioning, and septa within the maxillary sinus. During the surgical process, some complications may occur, such as mucosal perforation, inflammation, bleeding, dizziness, etc. Clarifying their managements in advance helps to improve the success rate of implantation. This article reviewed the anatomically weak structures, potential complications, and their managements to offer clinical treatment strategies.

1. Introduction

Dentition defect not only causes displacement of adjacent teeth, bone resorption and soft tissue atrophy, but also damages aesthetics and masticatory function. Compared to traditional fixed bridge restoration of dentition defects, implantation is more easily accepted by patients in recent years, for its no injure to adjacent teeth. But there are two factors influencing implantation effect. One is that the serious bone resorption because of long-time maxillary posterior teeth loss, and the other is the low position of maxillary sinus floor. Up to now, maxillary sinus floor elevation is the most common method for repairing vertical insufficient bone mass. It improves the success rate of implant surgery by obtaining more bone tissue and providing stable support for the implant. It can also effectively avoid complications such as maxillary sinus perforation. According to the elevation from different anatomical positions, this surgery can be divided into two types: elevation through alveolar ridge and lateral sinus floor elevation. Since this surgery is complicated according to the anatomically weak structures in the maxillary sinus, the complications such as mucosal perforation and postoperative bleeding should be seriously paid attention to. Mastering the anatomical structure and the management of complications proficiently can help to improve the success rate of surgery. Therefore, this article provides a review of the complications in maxillary sinus elevation, in order to provide practitioners optional countermeasures.

1.1. Types of maxillary sinus elevation

1.1.1. Elevation through alveolar ridge. When the bone mass is sufficient in maxilla, but the height of the maxillary sinus floor is low, direct implantation can lead to maxillary sinus perforation. In this circumstance, special instruments can be used to lift the maxillary sinus floor and mucosa upwards through the alveolar ridge or extraction socket in order to meet the requirements of implant length. Transalveolar technique for sinus floor elevation requires sufficient bone mass, otherwise it can increase the probability of mucosal perforation. It is recommended that the least bone mass is 5mm below the sinus floor [1]. The World Dental Federation (FDI) has suggested that the recommended bone mass for transalveolar technique is at least 6mm. The impact method proposed by Summers is mostly applied, which including a bone chisel to strike the sinus floor through tooth extraction socket [2]. The advantage of this method is that it doesn't injure the bone wall, lessoning bleeding and making patients more comfortable. However, during the impact process, excessive force from the bone chisel may lead to mucosal perforation. Therefore, in recent years, more experts have tried balloon and ultrasonic bone knife instead [3].

1.1.2. Lateral window technique for sinus floor elevation. When the height of the bone below the sinus floor is severely insufficient, which means the remaining bone mass is less than 5mm, transalveolar technique cannot obtain sufficient implant space. In this case,

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choosing lateral window technique for sinus floor elevation is a safe and predictable method. This method is performed by opening a window on the lateral wall of the maxillary sinus, peeling off and lifting the mucosa from the bottom of the sinus, and then filling the lifting space with materials such as periosteal bone powder. Compared with the transalveolar technique for sinus floor elevation, the strength of this method is that it can be operated under direct vision, so that doctors can have a clearer surgical field of view, and is more controllable. But it may remove a significant amount of bone, resulting in significant trauma. In order to reduce the pain of patients, traditional diamond drills are gradually replaced into ultrasonic bone knives for window opening tools. However, the prognosis of surgery is still greatly influenced by factors such as the individual anatomy of the maxillary sinus, the shape and size of the window opening design [4]. The difference between maxillary sinus elevation and lateral sinus floor elevation is shown in Table 1.

Table 1. The difference between maxillary sinus elevation and lateral sinus floor elevation

	Maxillary sinus elevation	**Lateral sinus floor elevation**
Indication	Remaining bone height≥4-6mm;	Remaining bone height≤4-6mm;
Advantages	Less traumatic;	Able to operate direct visualization；clear surgical field;
Disadvantages	Unable to operate under direct observation; relatively small operating range.	Severe trauma and poor patient experience.
Complications	Mucosal perforation of the maxillary sinus; Nasal bleeding; Mucosal tear; Acute maxillary sinus inflammation; vertigo.	Perforation of maxillary sinus mucosa; Massive bleeding; Postoperative inflammation; Mild postoperative edema; Postoperative pain.

2. Anatomic structure and weak parts of maxillary sinus

The paranasal sinus, an osseous cavity enveloping the nasal cavity, encompasses four pairs of sinus: the maxillary sinus, frontal sinus, sphenoid sinus, and ethmoid sinus. These sinus structures are centrally positioned around the nasal cavity and intricately interconnected. Notably, the maxillary sinus, characterized as the largest among them, assumes a conical morphology with a thin bone wall. The sinus wall is directly ensconced by mucosa. And its predominant blood supply emanates from various branches of the maxillary artery, including the infraorbital artery, posterior alveolar artery, and posterior nasal artery, thereby establishing a robust vascular network. The inferior wall of the maxillary sinus is often separated by only a thin layer of bone from the roots of the second premolar and first and second molars of the upper jaw.

Research findings have elucidated that the average distance between the sinus floor and the root apex of the maxillary first permanent molar is very close. Significantly, 35% of patients have molars in close contact with the mucosa of the maxillary sinus floor [5]. Consequently, meticulous attention to the anatomical intricacies of the maxillary sinus is imperative during maxillary oral surgeries, encompassing tooth extraction and implantation, to avert complications like mucosa perforation. A profound understanding of the anatomic structure and weak parts of maxillary sinus is pivotal for ensuring the success of implantation surgery.

2.1. Maxillary sinus artery and nerve

The vascular supply to the maxillary sinus is extensive, predominantly supplied by branches of the maxillary artery and draining into the facial and maxillary veins through the pterygoid plexus. Notably, during maxillary sinus surgery, the anterior lateral wall vessels are particularly susceptible to damage. These vessels, comprising the posterior alveolar artery, infraorbital artery and the anastomotic branch from both internal and external arteries. This anastomotic branch runs in a concave shape in the apical area of the first maxillary molar, forming the lowest point. According to statistics, the average distance between this lowest point and the alveolar ridge top is 19 mm [6]. Hence, when conducting maxillary sinus elevation surgery, meticulous attention must be directed towards avoiding major blood vessels to prevent the occurrence of severe bleeding.

The nerves that innervate the maxillary sinus often parallel the main blood vessels. The vascular and nerve bundles in close proximity to the maxillary sinus include the infraorbital nerve, along with the anterior, middle, and posterior alveolar vascular and nerve bundles. The infraorbital vascular nerve bundle follows the junction between the lateral and upper walls, while the anterior vascular nerve bundle branches from the infraorbital bundle to innervate the anterior teeth and periodontal membrane. The posterior vascular and nerve bundles extend from the posterior wall of the maxillary sinus to the lower wall, curving downward towards the lateral wall, advancing forward. Additionally, the middle vascular and nerve bundles progress anteriorly from the posterior wall of the maxillary sinus to the lateral wall [7]. These three vascular nerve bundles anastomose in an arc shape, terminating at the apical region of the maxillary premolars. During maxillary sinus surgery, it is imperative to minimize destruction of the anterior wall bone to mitigate the risk of nerve damage and numbness in the operative area.

The main vessels of the maxillary sinus are depicted in Figure 1.

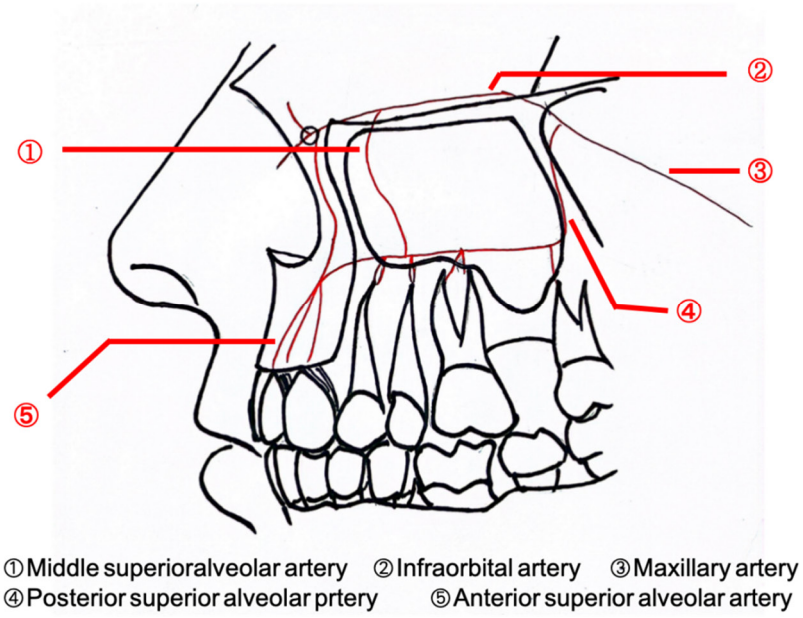

Figure 1. The main vascular course of the maxillary sinus

2.2. Morphology, bone thickness, and mucosal position of the maxillary sinus floor

Research indicates that the challenge of elevating the maxillary sinus floor is intricately linked to the sinus floor's shape, categorized as a deep concave sinus floor, shallow concave sinus floor, and convex sinus floor in ascending order of difficulty [8]. The concave sinus floor boasts a more substantial residual bone mass, whereas the convex sinus floor often presents insufficient bone height, necessitating elevation surgery. Additionally, an excessively thickened lateral wall bone can complicate mucosal and bone detachment, elevating the risk of mucosal perforation. Studies have demonstrated that the lateral bone wall of the maxillary sinus is thickest at the first molar, followed by the second premolar, and is thinnest at the second permanent molar [9]. Understanding the morphology of the maxillary sinus floor and the thickness of the lateral wall bone is instrumental for implant positioning and the selection of appropriate surgical techniques, contributing to the reduction of surgical complications, such as mucosal perforation.

The Schneiderian membrane envelops the interior of the maxillary sinus cavity, playing a pivotal role in maintaining and safeguarding the normal structure of the maxillary sinus. The average thickness of the sinus membrane, measured through anatomical and CBCT methods, is approximately 1.60 ± 1.20 millimeters [10]. When the mucosa of the maxillary sinus is in close proximity to the root apex, the risk of perforation escalates, potentially leading to inflammation.

2.3. Maxillary sinus septa (MSS)

The existence of maxillary sinus septa (MSS) stands out as a potential factor contributing to intraoperative maxillary sinus perforation. MSS manifests in two distinct types: primary septa occurring during tooth development and secondary septa resulting from maxillary sinus pneumatization following tooth loss. The molar area is particularly prone to MSS, with CBCT analysis and evaluation revealing an incidence of approximately 37.9%, indicating a relatively high prevalence. Furthermore, septa exhibit variations in directions, positions, heights, and shapes [11].

In a study conducted by Irinakis T, the mucosal perforation rate associated with maxillary sinus septa was 44.7%. Notably, when sagittal septa occurred in the molar area of the maxillary sinus floor, the surgery became more challenging, posing a significant risk [12]. This underscores that the presence and location of septa can elevate the likelihood of mucosal perforation. Utilizing preoperative CT scans aids in identifying the presence of MSS, contributing to a reduction in the probability of maxillary sinus mucosal perforation.

3. Complications and management methods of maxillary sinus elevation surgery

3.1. Perforation

The primary complication encountered during maxillary sinus floor elevation is mucosal perforation, predominantly attributed to anatomical factors such as low mucosal position, sinus floor septa. In clinical observations, it commonly presents as bloody bubbles within the extraction socket, often accompanied by ipsilateral nasal bleeding, along with patient complaints of nasal congestion and runny nose.

Despite meticulous preoperative imaging diagnosis and careful surgical procedures, studies have revealed that the complex anatomical structure contributes to a certain

probability of mucosal perforation [13]. Therefore, preemptively clarifying the treatment approach for perforation is crucial for timely intervention during the operation, mitigating the risk of more severe complications, such as inflammation.

Research suggests that the management of mucosal perforation is contingent upon the size of the perforation. For perforations less than 5mm, platelet-rich fibrin (PRF) or an absorbable collagen membrane can be employed for wound coverage. In cases where the perforation ranges between 5mm and 10mm, it is advisable to elevate the mucosa surrounding the perforation fully, thereby reducing tension, minimizing the perforation area, covering it with an absorbable collagen membrane, and subsequently performing bone grafting. Collagen membrane repair stands out as the widely accepted technique that does not compromise the implantation success rate. However, as the perforation size increases, the likelihood of subsequent implantation failure in this procedure rises [14]. Hence, for perforations exceeding 10mm, the perforation can be closed concisely, and further surgery may be postponed until after six months [15]. During perforation repair, careful stripping of the mucosa around the perforation is essential to alleviate tension and prevent further expansion of the perforation.

3.2. Postoperative inflammation

In reports, postoperative inflammation following maxillary sinus elevation surgery typically emerges within two weeks and is categorized into primary inflammation and secondary inflammation due to bone grafting material. Maxillary sinus mucosa perforation primarily underlies maxillary sinus inflammation, leading to nasal symptoms such as mucopurulent runny nose, diminished sense of smell, often accompanied by significant purulent secretion at the perforation site.

Early detection, prompt management, and antibiotic use are pivotal in treating maxillary sinus inflammation. For acute maxillary sinusitis post-surgery, incision and drainage, coupled with consultation with an otolaryngologist, can be employed. Clinical practice indicates that if the implant achieves good primary stability, acute inflammation does not significantly impact the success rate of implant surgery. In cases of chronic maxillary sinusitis, nasal cavity irrigation with physiological saline is a viable option. For severe instances, a lateral wall approach may be considered to remove bone grafting materials and implants, though this method inflicts substantial patient damage. Currently, functional endoscopic sinus surgery is emerging as a useful alternative [16]. In instances where the infection stems from bone grafting materials, Testori proposes a four-stage treatment: prolonging or altering antibiotic treatment, incorporating drainage tubes alongside antibiotic treatment, partial or complete debridement of bone augmentation materials, and surgical methods to entirely remove bone augmentation materials [17].

Although the incidence of maxillary sinus inflammation is low, the prevailing consensus is that managing maxillary sinus inflammation is intricate, the treatment duration is protracted, and there is a risk of implant loosening. Timely anti-inflammation treatment is essential, and bone grafting materials should be completely removed when necessary to mitigate the risk of further inflammation.

3.3. Maxillary sinus bleeding

The surgical area of the maxillary sinus, situated within the distribution of the maxillary sinus artery blood vessels and their branches, poses a risk of vascular injury during the lateral sinus floor elevation. Maxillary sinus bleeding not only hampers the surgical field of view and leads to complications such as mucosal perforation but also extends the surgical duration and diminishes the implantation success rate. Hence, meticulous care is imperative during the surgical process, emphasizing the avoidance of blood vessels, and necessitating a clearly defined protocol for emergency treatment.

The severity of bleeding and the chosen treatment approach are closely linked to the diameter of the blood vessels involved. If the damaged blood vessel's diameter is below 1mm, it generally does not impede the surgical process or prognosis, requiring only brief compression for hemostasis. However, in cases of blood vessel rupture exceeding 2mm, substantial bleeding may occur. Primary treatment methods encompass local compression hemostasis, ligation hemostasis, and the application of hemostatic materials; laser or electric knife hemostasis; and postoperative oral intake of hemostatic agents. Research indicates that maintaining an upright patient position can reduce intraoperative bleeding by 38% [18]. Surgeons should aim to avoid large blood vessels during the procedure, employing blunt separation of anatomical structures. The use of scissors and blades for cutting in areas outside direct vision is strictly prohibited.

3.4. Benign paroxysmal positional vertigo (BPPV).

When utilizing a punch for maxillary sinus elevation through the alveolar ridge, excessive impact force may lead to patient complaints of vertigo, a self-limiting complication known as benign paroxysmal positional vertigo (BPPV). Diagnostic testing, such as the Dix Hallpike test, can be employed to diagnose BPPV when both vertigo symptoms and nystagmus are present. BPPV is generally a self-limiting condition that typically resolves within a few days to months. However, its occurrence may impact patient compliance with treatment, necessitating proactive intervention once detected. Upon experiencing symptoms, the initial step is to seek diagnosis and treatment from an otolaryngologist. The Epley maneuver is a commonly employed repositioning treatment, offering a long-term and effective conservative approach to alleviate patient discomfort [19]. During surgery, oral surgeons should prioritize the prevention of BPPV and strictly avoid vigorous impacts on the bone wall.

Figure 2 provides a summary of the management strategies for the aforementioned complications.

Figure 2. The management of complications in maxillary sinus elevation surgery

4. Conclusion

When insufficient bone mass is available for implantation, maxillary sinus elevation surgery becomes crucial. However, the rich vascularity within the maxillary sinus and the intricate sinus cavity shape pose a risk of complications such as maxillary sinus perforation, inflammation, bleeding, and BPPV during the operation. Therefore, pre-surgical evaluation of anatomical weak structures through imaging data is imperative. During the surgery, gentle operations are recommended, and efforts should be made to avoid perforation. If necessary, an endoscope can be utilized for enhanced visualization. A comprehensive understanding of the maxillary sinus anatomy and strategies to manage potential complications can significantly enhance the success rate of implantation.

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