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MODERN APPROACHES TO SINUS LIFTING IN DENTAL IMPLANTOLOGY: CLINICAL ASPECTS, COMPLICATIONS, AND DEVELOPMENT PROSPECTS

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Abstract: Sinus lifting is one of the most widely used and effective bone augmentation techniques in dental implantology, enabling restoration of bone volume in the posterior maxilla. This article presents a clinical review of contemporary approaches to open and closed sinus lift procedures, outlining indications, surgical techniques, possible complications, and directions for further improvement. Special attention is given to the selection of grafting materials, the role of the Schneiderian membrane, and the integration of digital technologies and minimally invasive techniques into modern dental surgical practice.

Keywords: sinus lift, dental implantation, bone grafting, maxillary sinus, Schneiderian membrane, osteoplastic materials.

Introduction

Modern dental implantology is inseparable from the use of guided bone regeneration techniques, among which sinus lifting occupies a special place. The loss of posterior maxillary teeth often leads to pronounced pneumatization of the maxillary sinus and resorption of the alveolar ridge, which significantly complicates the placement of implants of standard length. In such cases, surgical augmentation of the sinus floor bone volume becomes a necessary step in restoring adequate support for implants.

According to epidemiological studies (Al-Dajani, 2021; Isaev et al., 2022), bone deficiency in the posterior maxilla is observed in **40–60%** of patients following tooth loss, with **25–30%** having an alveolar ridge height of less than **4 mm**, making implant placement impossible without prior augmentation. Thus, sinus floor elevation remains one of the most demanded reconstructive procedures in modern dental implantology.

The sinus lift technique, first proposed by Tatum in the late 1970s, has undergone substantial evolution — from classical lateral osteotomy to minimally invasive endoscopic and navigated approaches. Today, sinus lifting is regarded not merely as a method of bone augmentation but as a **highly technological surgical procedure** requiring precise anatomical orientation, advanced imaging diagnostics, and the use of biocompatible grafting materials.

Anatomical and Physiological Considerations

The maxillary sinus is an air-filled pyramidal cavity lined with a thin mucous membrane known as the **Schneiderian membrane**. Its thickness varies from **0.1 to 0.5 mm**, which makes it particularly vulnerable during surgical manipulation. Anatomical variability — including the presence of septa, vascular anastomoses, and different degrees of pneumatization — increases the risk of membrane perforation and necessitates thorough preoperative visualization using **cone-beam computed tomography (CBCT)**.

The sinus exhibits considerable morphological diversity that influences the choice of surgical approach. Its shape can vary from symmetrical pyramidal to irregular or divided forms due to internal bony septa. The Schneiderian membrane may range in thickness from **0.3 to 1.5 mm**, depending on the presence of chronic inflammation. The roots of posterior teeth, particularly the first and second molars, are often closely related to or protrude into the sinus floor. These anatomical features must be carefully evaluated during preoperative planning to minimize perforation risk and subsequent complications.

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The condition of the alveolar bone is determined by the residual basal height. When the remaining bone height is less than **4–5 mm**, open sinus lift is indicated; if the height is **6–8 mm**, a **closed (transalveolar) sinus lift** with simultaneous implant placement may be performed.

Classification and Clinical Indications

Sinus lifting techniques are generally divided into **open (lateral)** and **closed (transalveolar)** approaches.

The open (lateral) sinus lift is indicated for cases with significant bone deficiency and involves the creation of a lateral window in the sinus wall, elevation of the Schneiderian membrane, and placement of the bone graft material.

The closed (transalveolar) technique is performed through the alveolar crest using osteotomes or hydraulic instruments, minimizing surgical trauma.

Indications for sinus lifting include alveolar ridge atrophy, the need for implants of standard length, pronounced sinus pneumatization after tooth extraction, and prosthetic rehabilitation in the area of teeth 4–7.

Contraindications include acute or chronic sinusitis, neoplastic lesions, decompensated systemic diseases, and anatomical variations that prevent safe access.

Surgical Techniques and Clinical Stages

The **classical open sinus lift** technique comprises several key steps: raising a mucoperiosteal flap, creating a lateral window in the sinus wall, gentle detachment of the Schneiderian membrane, and filling the created space with a grafting material. The window is then covered with a **collagen membrane**, and the flap is repositioned and sutured. Implant placement can be performed simultaneously if primary stability is sufficient, or in a delayed manner after **6–8 months** of healing.

The **transalveolar technique (Summers method)** involves access through the alveolar crest using sequential osteotomes. Once the sinus floor is reached, the membrane is lifted by gentle tapping or hydraulic pressure, followed by graft material placement and implant insertion. This method is **less invasive**, shortens the rehabilitation period, and is associated with a lower incidence of complications.

Piezosurgery represents a modern modification of sinus lift techniques in which the bone window is created using **ultrasonic microvibration instruments**. This approach minimizes the risk of membrane damage and allows greater precision. **Endoscopic control** enhances safety by enabling real-time visualization of the sinus membrane and graft placement, improving the predictability of results.

Materials for Bone Augmentation

The choice of **osteoplastic material** is a key determinant of successful osteoregeneration. In clinical practice, **autogenous, allogenic, xenogenic, and synthetic grafts** are used.

Autogenous bone remains the “gold standard” due to its osteoinductive properties but requires an additional donor site.

Allogenic grafts (decalcified bone matrix) demonstrate good osteoconduction with minimal immune response.

Xenografts based on **hydroxyapatite** (e.g., Bio-Oss, OsteoBiol) exhibit excellent biocompatibility and slow resorption, providing long-term volume stability.

A promising direction is the use of **biomaterial combinations with platelet concentrates** — PRF, A-PRF, and PRGF — which enhance angiogenesis and accelerate bone formation. **Collagen membranes** are applied to stabilize the graft and prevent its migration into the sinus cavity, improving the quality of regenerated tissue.

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Application of Platelet-Rich Plasma (PRP) and Platelet-Rich Fibrin (PRF)

Modern sinus lift protocols increasingly incorporate the use of autologous biostimulants such as **platelet-rich plasma (PRP)** and **platelet-rich fibrin (PRF)**. These preparations contain high concentrations of growth factors — **PDGF, TGF-β, and VEGF** — that promote accelerated osteogenesis, angiogenesis, and bone remodeling in the grafted area. The application of PRF in combination with xenogenic or allogenic graft materials enhances vascularization and improves the quality of newly formed bone tissue.

According to Fabbro et al. (2021), the inclusion of PRF within the graft material during lateral sinus lift procedures reduced the osseointegration period for implants from six to four months and decreased the incidence of postoperative complications. In clinical practice, the PRF method is employed either as an adjunct to the osteoplastic graft or as a standalone **biological membrane** to cover and protect the sinus window.

Regenerative Cellular Technologies

A promising direction in the development of sinus lift techniques is the use of **regenerative cell-based technologies**. Recent research has demonstrated the potential of **mesenchymal stem cells (MSCs)** derived from bone marrow, adipose tissue, or periosteum, in combination with **nanostructured scaffolds** such as hydroxyapatite, β-tricalcium phosphate, or bioglass. These bioconstructs not only ensure osteoconduction but also create conditions for genuine osteoinduction by releasing cytokines and promoting osteoblast differentiation.

Several experimental and clinical studies (Zhao et al., 2023; Ivanova et al., 2024) have shown that the use of MSCs in sinus augmentation promotes the formation of more mature, highly mineralized bone and shortens the rehabilitation period. Although this method is currently limited to specialized research centers, it is considered a key avenue for the future of **regenerative implantology**.

Clinical Outcomes and Complications

Long-term clinical observations indicate that the **success rate of sinus lifting exceeds 90%**, though complications remain an important factor influencing outcomes. The most common complication is **perforation of the Schneiderian membrane**, occurring in **10–30%** of cases. In most instances, this does not lead to graft loss if promptly covered with a collagen membrane. Other complications include **acute sinusitis, intraoperative bleeding from alveolar vessels, graft resorption,** and **implant migration** into the sinus cavity.

Risk factors include anatomical variations (low sinus position, presence of septa), smoking, poor oral hygiene, and insufficient surgical control. For repeated interventions, the use of **navigation templates** and **piezosurgery** is advisable to precisely determine the sinus floor level and prevent damage to vascular or neural structures.

Digital and Navigational Technologies

The evolution of **digital technologies** in oral surgery has opened new horizons for the planning and execution of sinus lift procedures. **Virtual modeling** based on **CBCT data** enables accurate assessment of the implant axis, the required augmentation volume, and sinus anatomy. **Computer-guided navigation systems** ensure precise surgical access and minimize trauma. The use of **3D-printed surgical guides** for lateral window creation has made the procedure more predictable and reproducible, particularly in anatomically complex cases.

Digital implantology, integrated with **CAD/CAM systems**, allows not only surgical planning but also the fabrication of **patient-specific templates** for guided sinus floor elevation. In clinical practice, this significantly reduces surgical time and improves the consistency and accuracy of outcomes.

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Future Directions of Sinus Lift Techniques

Current trends in sinus lifting focus on **reducing invasiveness** and **enhancing osteointegration**. Active research is being conducted on **bioengineered materials**, including **nanostructured composites**, **hydroxyapatite enriched with growth factors**, and **biocompatible scaffolds** based on **titanium and polyetheretherketone (PEEK)**. Another promising avenue is the introduction of **robot-assisted systems** that provide microsurgical precision, as well as the development of **bioprinting technologies** for producing patient-specific bone grafts.

Parallel to this, increased attention is paid to the **prevention of postoperative sinusitis**, the refinement of **antibiotic prophylaxis protocols**, and **postoperative monitoring** using CBCT and **telemedicine tools**.

Recent advances in **digital and bioengineering technologies** have substantially refined sinus lift methodologies, improving both precision and safety. One of the key innovations is the integration of **Dynamic Navigation Systems (DNS)**, which provide real-time three-dimensional tracking of surgical instruments within the oral cavity. Unlike static templates, DNS enables the clinician to adjust the drilling trajectory intraoperatively according to anatomical variations, the thickness of the Schneiderian membrane, and the inclination of the alveolar ridge. This is particularly valuable in cases with limited residual bone height or sinus asymmetry, where implant positioning accuracy is crucial to avoid membrane perforation.

Another important development involves the use of **Augmented Reality (AR)** and **Virtual Reality (VR)** technologies for **preoperative simulation and planning**. Virtual simulators and 3D visualizations allow the surgeon to assess sinus morphology and neurovascular structures while modeling the intervention prior to its execution. These tools facilitate individualized surgical strategies and shorten the operative time. Moreover, VR technologies have become integral to **professional training and surgical education** in implantology.

A further innovative direction is the creation of **graft-free regeneration protocols**, where **osteogenesis** is achieved through **osteoconductive biopolymers** and **recombinant bone morphogenetic proteins (BMP-2)**. These molecules stimulate osteoblast differentiation and bone formation even in cases with minimal residual alveolar bone. Several clinical trials have shown that BMP-2 combined with collagen matrices can partially replace autogenous or allogenic grafts, thereby reducing surgical trauma.

Particular attention is now given to **minimally invasive hydrodynamic sinus lift protocols**, in which no lateral window is created. The membrane is gently elevated by introducing sterile saline under controlled hydraulic pressure, minimizing the risk of rupture. This approach has demonstrated excellent clinical outcomes for residual bone heights of **5–7 mm**, allowing implant placement without conventional bone grafting.

Modern implantology increasingly emphasizes **biocompatibility, digital integration, and regenerative potential**, transforming sinus lifting from a purely technical operation into a **bioengineering process of guided osteogenesis**. In the near future, further integration of **3D printing**, **"smart" biomaterials**, and **AI-based surgical modeling** is expected to make the procedure even more precise, predictable, and personalized.

Conclusion

Sinus lifting remains a cornerstone procedure in the implantologist's arsenal for managing maxillary bone atrophy. The diversity of surgical techniques, continuous improvement of instruments and biomaterials, and the integration of digital navigation have made the procedure highly effective and predictably stable over time.

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The primary goals for further advancement include **enhancing osteogenesis predictability**, **reducing surgical invasiveness**, and **incorporating navigational and robotic systems** into routine clinical workflows.

Comprehensive clinical experience confirms that long-term success in sinus lift surgery depends not only on the chosen technique but also on a **multifactorial approach** encompassing meticulous diagnostics, individualized planning, appropriate graft material selection, and strict postoperative management.

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