RESEARCH PAPER

Applications of Piezoelectric Device in Endoscopic Sinus and Skull Base Surgery

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ABSTRACT

Endoscopic sinus and skull base surgery has evolved significantly with advances in visualization and powered instrumentation, aiming to improve surgical precision while minimizing complications. Among these innovations, piezoelectric devices represent a valuable addition to modern rhinologic and skull base surgery. This review highlights the principles, mechanisms, and clinical applications of piezoelectric technology in endoscopic sinus and skull base procedures. Piezoelectric devices operate through ultrasonic microvibrations that selectively cut mineralized tissue while preserving adjacent soft tissues such as dura, nerves, blood vessels, and the Schneiderian membrane. This selective action enhances surgical safety, particularly when operating near critical structures including the orbit, optic nerve, internal carotid artery, and anterior skull base. Compared with conventional drills and curettes, piezosurgery provides improved surgical control, reduced bleeding, enhanced visibility, and lower risk of thermal and mechanical injury. Clinical applications include removal of thick bony partitions, skull base osteotomies, optic nerve decompression, management of fibro-osseous lesions, and assistance in endoscopic tumor surgery. Histological and experimental studies suggest improved bone healing and preservation of osteocyte viability following piezoelectric osteotomy. Despite its advantages, piezosurgery is associated with higher cost, longer operative time, and a learning curve that may limit widespread adoption. In conclusion, piezoelectric technology offers a safe and precise alternative to conventional bone-cutting instruments in endoscopic sinus and skull base surgery, particularly in anatomically high-risk areas. Further clinical studies are warranted to better define its cost-effectiveness and long-term outcomes.

Keywords: Piezoelectric surgery; Endoscopic sinus surgery; Skull base surgery; Ultrasonic osteotomy; Powered instrumentation

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INTRODUCTION

Functional endoscopic sinus surgery (FESS) is a stable procedure for the rhinologist, although ESS is a stable procedure, the basic principles have remained the same, technological advancements enhance our ability to deliver safer, faster surgery with improved outcomes for the patient. With the advent of the Hopkins rigid endoscopes, dawned the era of endoscopic surgery. And, technology was focused on improving image quality using higher quality prisms and angulation by introducing wide angled 0, 30, 45 and 70 scopes (1).

Next to the introduction of the Hopkins rod, developments in good-quality traditional cold-steel instruments supported the establishment of ESS. The traditional Blakesley grasping and Grunwald through-cutting instruments formed the backbone of the sinus surgery tray and remain strongly embedded in the modern practice (2). However, unlike the developments in visualization (Hopkins rods and camera systems) and powered instruments, developments in hand instruments have taken a back seat (3).

Then, the motorized handpieces appeared and became available to the modern ESS surgeon and improved dramatically in recent years. Modern handpieces will accept not only microdebrider blades, but also drill burs. This allows the irrigation and suction systems to remain attached to the same hand piece, reducing operative time as well as the number of instruments required (4). The transnasal endoscopic approach is increasingly being used for skull base surgery, and one of the most serious complications during skull base surgery is injury to related blood vesseles as internal carotid artery (ICA), which is potentially fatal complication, and also injury of

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the optic nerve may occure that may cause blindness, and dural injury causing cerebrospinal fluid leak (5).

Piezoelectric Devices

Endoscopic surgery in the paranasal sinuses can present special challenges for otolaryngologists. One challenge is the need to remove thick bone from or in close proximity to the orbit or skull base (6). Current instrumentation has shortcomings in accomplishing this task. Curettes can remove small amounts of soft trabecular bone, but are less effective in removing thick lamellar bone. Undesirable torsional forces from curetting can back-fracture into the orbit or skull base, or injury of internal carotid artery or optic nerve, causing complications. Drills generate sufficient mechanical energy to reduce thickened bone, but have drawbacks (7). Most mechanical drills work along a straight axis, so their usefulness in accessing all areas of the paranasal sinuses is limited.

Advances in microdebrider technology have led to a variety of curved burs that now allow the surgeon to reach more areas within the sinuses (8). Importantly, when a drill or microdebrider device is used to remove thick bone on the lamina orbitalis or the lateral lamella of the cribriform plate, it is challenging to remove the last layer of bone without encountering the underlying soft tissue. Despite a better assortment of diamond burs, periorbital or dural breach can occur, risking orbital complications or cerebrospinal fluid leak (9). Drilling bone within the sinuses can also be associated with synechia formation, leaving further problem. And all surgeons dealing with craniotomies are aware that soft-tissue and nerve damage is still possible during osteotomy such in cases of fibro osseous lesions (10).

Fibro osseous lesions can develop in relation to the orbit, the optic nerve, ethmoid and sphenoid bone. During the development of the lesion at the level of the sphenoid sinus the compression and the proximity to the optic nerve may cause blindness. In these cases it is recommended to perform optic nerve decompression in order to prevent it (11).

This clinical problem has been addressed by new ultrasonic technology. By the same principles that have been used for many years to dissolve kidney stones without damaging the ureter, ultrasound vibrations have been used in maxillofacial surgery to remove the anterior maxillary bone without traumatizing the underlying sinus mucosa and to allow a sinus lift. To generate ultrasonic vibrations for surgery, electrical energy is applied to a transducer; this phenomenon is known as the “piezoelectric effect”, as the word piezo is Greek for “push” (12).

The piezoelectric effect was first described by Jacques and Pierre Curie in 1880 implying that under a mechanical force certain crystalline minerals become electrically polarized. High frequency oscillations of the piezoelectric crystals are used to “cut” bone that way like microsaws (13).

Historically, piezoelectric devices have been employed in various surgical fields, including oral surgery and neurosurgery, demonstrating their versatility and effectiveness. Recent literature highlights their application in endoscopic sinus surgery, where they have shown potential for improving outcomes by reducing blood loss and enhancing visibility during procedures (14).

The advantage of this technique is that the cutting effect is reserved to hard, crystalline mineral that is structured like bone, soft tissue like dura would not be affected because of its elasticity, as long as no additional pressure is applied (15).

In fact, histological studies in animal models revealed that the osteotomy performed with piezosurgery allowed a better healing of the bone, the protection of the surrounding soft tissue, and also an antiseptic action, with reduction in the level of bacteria (16).

Piezoelectric technology has been used in a host of surgical procedures for many years, including craniofacial, otologic, orbital, hand, and facial reconstructive surgery. This technology has greatly improved the success of sinus lift surgery, sinus bone grafting, and placement of dental implants. Given the close proximity of the orbit and brain to the paranasal sinuses and the need to avoid damage to these structures, it is easily apparent that piezoelectric ultrasound technology could be beneficial in other areas of sinus surgery (17).

Endoscopic Sinus Surgery

History of endoscopic procedures:

The first attempt at nasal endoscopy is largely credited to Hirschman in 1901. In this early work, a modified cystoscope was used to examine the sinonasal cavity. Subsequently, Reichert performed what would be regarded as the first endoscopic procedure; rudimentary maxillary sinus manipulations with a 7 mm endoscope through an oroantral fistula. In 1925, Maltz promoted use of nasal endoscopes for diagnostic evaluation of the sinonasal cavity and coined the term ‘sinuscopy’. The creation of the Hopkins rod system in the 1960s was perhaps the major turning point in the field of sinonasal endoscopy (18).

Using this new innovation, Messerklinger subsequently composed a landmark book in 1978 on diagnostic endoscopy of the nose from his work studying mucociliary clearance in fresh cadavers. The frequent failures of Caldwell-Luc surgery, the morbidity of frontal sinus osteoplasty and difficulties of performing headlight intranasal ethmoidectomy, there was a strong rationale for trying to improve surgical techniques for chronic rhino sinusitis (CRS) (19).

The relevance of the ostiomeatal complex (OMC) had been proposed by Naumann Proctor and Drettner, but it had previously not been adequately visualized, either on rhinoscopy or by plane film imaging. Messerklinger detailed the endoscopic anatomy and pathology of this region and also started to utilize polytomography to improve visualization of the anatomy and pathology. With improvements in imaging and endoscopic assessment, increasing emphasis was placed on anatomical aspects of the ostiomeatal complex and their potential impact on the pathogenesis of chronic rhinosinusitis. As scientific support for the importance of this region increased, several surgeons began performing select endoscopic procedures (19).

Therapeutic evolution:

As our knowledge of chronic rhino sinusitis pathogenesis has continued to evolve, it has further confirmed that chronic rhino sinusitis is rarely a simple disorder that responds completely to restoration of mucociliary clearance and ventilation. The importance of controlling environmental and inflammatory components cannot be overemphasized, and one important goal of surgical intervention is to increase access of the inflamed mucosa to anti-inflammatory topical therapies (20).

Given the increased emphasis on addressing host inflammation, surgical principles have generally evolved away from more focused procedures within the ostiomeatal complex to more complete frontoethmoidectomies with maxillary antrostomies and, when indicated, sphenoidotomy (21).

Advances in instrumentation:

Early surgical intervention was primarily performed with grasping instruments with little regard to mucosal preservation. Endoscopic follow up often revealed denuded bone that healed poorly. These regions of stripped mucosa often resulted in scarring, chronic inflammation, neo-osteogenesis and occasionally mucocele formation. For this reason, intranasal, fine, through-cutting instruments were developed. Such instrumentation allowed fine cutting of bone and mucosa without mucosal stripping (22).

Early in the endoscopic era, sphenoidotomy was performed by infracturing the anterior wall of the sphenoid sinus, a procedure with the potential for carotid artery or intracranial injury. The development of through cutting instruments, such as the straight mushroom punch, allowed widening of the natural os of the sphenoid after removal of the inferior third of the superior turbinate. Typically, it is our preference to perform a wide sphenoidotomy, extending to the skull base and medial orbital wall. As with the removal of other bony partitions, this can be achieved safely by first feeling behind the bony partitions prior to bone removal (23).

Originally, the telescopes most frequently utilized during endoscopic sinus surgery were the 0, 30 and 70°, 4 mm scopes, with the 2.7 mm endoscopes reserved for pediatric cases (24).

More recently, the addition of a wide-angle 45-degree scope with improved illumination in comparison to the 70-degree scope has, in the practice of the senior author, largely replaced the 30 and 70-degree endoscopes for many procedures (25).

The 2.7 mm telescope, although fragile, has been increasingly utilized for in office procedures because of its improved patient comfort. Image quality and light sensitivity has dramatically improved from single chip cameras to high definition cameras, and most recently 4k cameras, providing excellent imaging quality (26).

The newest high definition technology utilizes image enhancement algorithms automatically enhancing brightness, minimizing reflection and overexposure, and enhancing tissue contrast. Although multiple companies have introduced 3D endoscopes, but non of them have been widely adopted. This is due to the tendency for the technology to induce dizziness and headaches with prolonged use, as well as the issue of cost. The introduction of endoscope lens washing sheaths, initially utilized to wash the lens in conjunction with pulsed holmium laser use, has made a major difference in terms of maintaining visualization during routine endoscopic sinus and skull base procedures (27).

As endoscopic instrumentation and proficiency advanced, the indications for endoscopic approaches have expanded to include sinonasal tumors, skull base and orbital pathology. Beginning in the 1980s, surgeons had begun to perform endoscopic tumor resections, orbital decompressions, malignant tumor resections and pituitary procedures. The ability to perform skull base surgery was markedly advanced when the success of endoscopic CSF leak and skull base defect closure was demonstrated (28).

In the early 1990s, the first series of endoscopic pituitary surgery was published by Jankowski. From then on, interest grew and the procedure was further popularized by Jho and Carrau in 1996.48 With the subsequent adaptation of the Haddad flap for skull base reconstruction, the majority of pituitary surgeries are performed endoscopically today with reduced patient morbidity. Additionally, indications now extend to more extensive pathology such as meningiomas, craniopharyngioms and chordomas (29).

The first reported series of endoscopic orbital surgery was published in 1990. Initial applications were employed primarily for orbital decompression in Graves' orbitopathy. Indications have subsequently been extended to optic nerve decompression and removal of orbital tumors. A recent multi-institutional series demonstrated the success of endoscopic removal of orbital cavernous hemangiomas through a fully endoscopic approach. Maintenance of the correct direction of the eyes when focusing or at rest and symmetric orbital appearance was achieved in the majority of patients (30).

Endoscopic surgery for sinonasal tumors was initiated in the late 1980s. As initial opposition was encountered as a result of the piecemeal resection of tumors, many series today support endoscopic resection with comparable survival and recurrence rates to more classic open approaches (3).

The general principle of endoscopic tumor resection involves tumor debulking with meticulous care to identify the point of tumor attachment. An oncologic resection of the tumor attachment is then performed with wide negative margin. A dural margin is taken if disease abuts the skull base. It is essential that the oncologic margin is not compromised for the sake of an endoscopic resection. As instrumentation and expertise improves, endoscopic approaches can now be used successfully for tumors with intracranial extension (Fig. 3) (31).

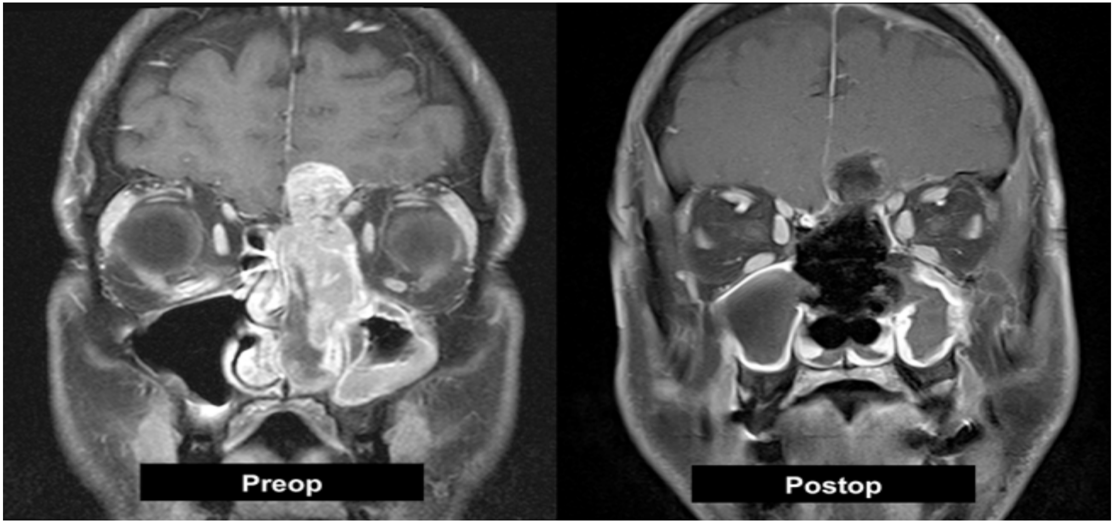

Figure (3) Preoperative MRI shows a sinonasal undifferentiated malignancy. Intraoperatively, the orbit and brain were not grossly invaded and a gross total resection was achieved purely via endoscopic approach (19).

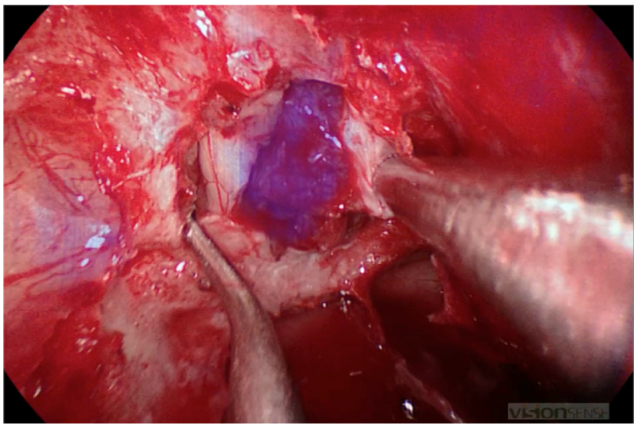

Figure (4) : Intraoperative view using high definition, real-time infrared fluorescence imaging. A novel radiolabeled compound was injected preoperatively in a patient with a planum meningioma. Intraoperative view after skull base osteotomy shows uptake from the tumor with surrounding brain and sinonasal tissue excluded (19)

Electrically powered instruments:

Microdebrider :

Defined as an electrically powered, cylindrical shaver that uses continuous suction for tissue removal, the microdebrider was first described in the medical literature by the House group as an instrument to morselize acoustic neuromas. It also became a popular tool among orthopedic surgeons as it was used in arthroscopic surgery. Setliff et al. In 1996 published articles describing the use of the microdebrider in ESS for the first time (32).

There have been many articles published on the use of microdebrider in ESS. The ability of the microdebrider to continuously suction blood away from the surgical field while removing tissue and thin bone have made it the most popular powered instrument used by modern rhinologists. For this reason, many herald microdebrider as one of the most significant technological advances in the field of rhinology (33).

All microdebriders consist of a hollow shaft with a rotating, or oscillating, blade within the inner cannula. Continuous suction applied to the inner cannula draws soft tissue and bone chips into the blade. The tissue is cleaved by the oscillation of the blade and suctioned away from the operative field toward the suction canister, where it may be captured in a filter (34).

Importantly, studies have shown that the tissue within the filter is histologically preserved for pathological examination. Some models have a serrated edge on the blade, which allows for better gripping of soft tissue and more aggressive tissue take down. In contrast, straight edges are considered less traumatic and more sparing of adjacent mucosal tissues. Blades can be set to continuously rotate (forward or backward) or oscillate (back and forth across the aperture) (34).

For soft tissue removal, the oscillation mode is used at slower speeds of 3000 to 5000 revolutions per minute (RPM) allowing the blade to stay open longer, and more soft tissue to be drawn into the aperture before it is cut. There are also specialized solid burr-like tips available for the microdebrider that allow a drilling action. These tips are beneficial when the surgeon encounters bone that is thicker than the conventional microdebrider blade is able to handle (Siam et al., 2018).

When used as a drill, however, the rotation settings are much slower for microdebriders than a conventional high-speed drill (15,000 RPM maximum vs. 80,000 to 100,000 RPM, respectively) and thus microdebriders are not as effective at removing thick bone expeditiously (35).

Microdebrider blades come in a variety of angles and offer rotating ports. This allows improved access to some hard-to-reach areas of the sinonasal tract. One example is the lateral recesses of the maxillary and sphenoid sinuses, another is the frontal recess. One drawback of using a curved blade is that there are increased rates of obstruction of the inner cannula with debris compared to that with straight cannulas (36).

Some models have a beveled guard on the tip of the blade, which can be used to penetrate into the substance of the turbinate and raise the soft tissue away from the turbinate bone, eliminating the need for another instrument change during the procedure. By sparing the surface respiratory epithelium, less crusting and synechiae formation occur following operation than that when cautery or surface-damaging techniques are employed for turbinate reduction. The incidence of osteitis of the concha, an uncommon complication of turbinate surgery, is also lower when this technology is used (36).

The ability to simultaneously suction blood away from the surgical field is especially advantageous during ESS for nasal polyps that can bleed considerably during removal. Significant bleeding intraoperatively can increase the risk of complications. Despite the progress of microdebriders and their effectiveness at continuously clearing blood from the field, one significant drawback to current platforms is that they do not actually decrease bleeding in any way. The most recent innovation in microdebrider technology now permits the added ability to control bleeding while retaining the shaving and suctioning capabilities of this class of instrument (37).

Like any other instrument, microdebriders have certain limitations that must be recognized if these tools are to be used effectively and safely. Microdebriders are heavier than conventional instruments and are electrically powered. This means that the tactile feedback during surgery is markedly diminished with microdebriders. This, in addition to the powered nature of these instruments and their use in close proximity to critical structures, has raised concerns about the safety of microdebriders in ESS (19).

Bhatti et al (2006) described two cases of ocular injury, one resulting in restrictive ophthalmoplegia and the other in transection of the medial rectus (38).

In both cases, it was argued that the strong suction of the microdebrider allowed orbital fat, or even extraocular muscles, to be pulled through a relatively small defect in the lamina papyracea and into the blade (38)

Berenholz et al (1998) described a case of subarachnoid hemorrhage after functional ESS using the microdebrider that was thought to be caused by the strength of suction. Although major complications from ESS are rare, complications that do occur related to microdebrider use may progress more quickly because of the powered nature and suction of this device. Finally, microdebriders carry the cost of the system and ongoing costs of disposable components (39).

Drills and burrs:

Endoscopic drills are used much less frequently than microdebriders due to the fact that the microdebrider is able to handle both the soft tissue and the thin bony partitions encountered with most routine endoscopic sinus surgeries. Procedures requiring the removal of thick bone beyond the capacity of the microdebrider led to the development of a variety of drills and burrs (40).

One major advantage of drills over traditional techniques for bone removal is that the drill requires relatively small amount of force to be applied by the operator, permitting expeditious, yet controlled bone removal. This is especially important in rhinologic surgery due to the proximity of crucial structures that must be preserved (40).

Endoscopic drills have a few key differences that specialize them for use in rhinologic surgery, and separate them from their otologic counterparts (41).

The drills themselves have been designed with a slimmer profile to permit simultaneous use with an endoscope in a narrow surgical field, and to facilitate movement through the nostrils. There is a protective sheath along the shaft of the drill burr to protect against collateral friction damage to adjacent tissues (including soft tissues of the nostril) (41).

Some also have a sheath to protect the posterior aspect of the burr offering further protection to adjacent structures. Continuous suction/irrigation has also been designed into handpieces to decrease the number of instruments the endoscopic surgeon must manipulate at one time (41).

Suction and irrigation features aim to not only improve visibility, but also function to cool the drill burr and drill–

tissue interface in an attempt to limit heat transmission (42).

There is still opportunity to make great steps in the arena of endoscopic drills. One fact common to all drills is that the number of flutes on the burr determines how aggressively the drill will take down bone. A burr with few deep flutes will cut very aggressively, resulting in the rapid take down of bone (43).

However, this does come at the expense of fine control. Speed of rotation will also affect how fast bone is drilled away.Faster rotational speeds actually improve control, beginners might find it surprising, as there is less chance for chatter or tear out (44).

Radiofrequency Ablation

Radiofrequency ablation (coblation) is a technology patented by ArthroCare (Austin, Texas , United States) in 1997, initially intended for use in cartilage ablation during arthroscopy. It was approved in 2000 by the U.S. Food and Drug Administration for use in otorhinolaryngology (45).

Coblation uses radiofrequency waves to energize electrolytes within a conductive medium (typically saline). This theoretically creates a plasma field, which disrupts molecular bonds within the surrounding tissues at relatively low temperatures (40 to 70°C as compared to over 400°C with monopolar electrocautery). As some studies suggest that a plasma field is unlikely to be created outside a vacuum, the decreased thermal damage during coblation has more to do with vaporization of the saline solution than creation of a plasma field. Regardless of the mechanism of action, there is significantly less penetration of thermal energy into the surrounding tissue with the use of this technology, which is advantageous when thermal spread to important structures is not wanted (46).

Coblation has also been described for use in transnasal tumor resection, where its hemostatic ability could provide ongoing bleeding control during removal of potentially well-vascularized soft tissue (47).

paucity of literature documenting clear advantages is due to associated expense, as well as a limited surgeon experience in the use of this technology for transnasal endoscopic procedures. It should be noted that radiofrequency ablation technology has only recently been introduced to the field of rhinologic surgery, which explains the paucity of data regarding this technology in the literature (48).

Ultrasonic Aspirators

The sinonasal cavity is bordered by relatively thick bone, with thin bony partitions dividing it into compartments. All surgeries on the sinuses or extending beyond the confines of the sinonasal tract therefore require the controlled take down of varying amounts of bone. Due to the close proximity of important soft tissue structures, it is crucial to take down bone with as little impact on the surrounding soft tissue as possible. A promising recent technological advancement in powered instrumentation impacting ESS has been the bone cutting ultrasonic aspirator (49).

Ultrasonic aspirators operate on the converse piezoelectric effect, whereby application of an electric charge to certain crystals creates a reversible mechanical deformation (direct piezoelectric effect refers to electricity being generated by mechanical stress on the crystals) (50).

❖ Piezoelectric Device

The piezoelectric potential was first described by the Curie brothers in 1880, when it was noticed that certain ceramics and crystals, when passed by an electric current, generated a self-oscillation frequency of the ultrasonic. It has been documented that these oscillations, if transferred to a vibrating peak applied to the bone tissue, can cause cavitation, a mechanical cutting that occurs only on mineralized tissues (51).

The piezosurgery works on the principle of piezoelectric effect which is based on cavitation effect and microvibration phenomenon. The crystals in the piezoelectric substances get deformed when it is placed in an electric field. The periodic changes in the polarity of field produces ultrasonic oscillations, which are amplified and transferred to a vibration tip to diverse solid, liquid or gaseous materials. The tip on the bone tissue with slight pressure generates a mechanical cutting effect called cavitation phenomenon. Usually, it produces a functional frequency of 20 kHz as in ultrasonic scalers. The addition of a 50 kHz pulse every 10 ns to this basal frequency increases the power of the receiver device allowing the bone cutting without damaging soft tissues (52).

Mechanism :

A piezosurgery unit consists of the following:

Piezoelectric headpiece.

Control unit to control the frequency of vibrations, power of cutting and the amount of irrigation.

Holders for the headpiece and irrigation fluids.

Foot switch which activates the handpiece tips.

Various types of headpiece tips including scalpel, saw, cone compressor, bone harvester drill are available. They are available in different sizes and shapes with titanium or carbide coating. Piezosurgery requires light handpiece pressure and an integrated saline coolant spray to avoid overheating of the bone and increase the visibility of the surgical site. The frequency is usually set between 25 and 30 kHz producing micro vibrations of 60–210 mm amplitude with power exceeding 5 W (53).

Addition of a 50 kHz pulse every 10 ns to this basal frequency increases the device power allowing the bone cutting more effectively. While cutting the deep layers of bone cooling efficiency can be increased by interrupted cutting or cooling the solution to 4 °C. The pressure applied, the speed of the tip in contact with bone and translation speed have an effect on the cutting power.

Piezosurgery devices require slight pressure to have precise cutting. The increased pressure limits the tip motion producing overheat and thereby bone necrosis (53).

Biological effects
The effects of piezoelectric devices on the bone structure and viability have a great importance in the success of regenerative surgery. Even though there have been various studies regarding the effects of piezoelectric surgery on bone structure and cellular viability, most of them showed that the gouge-shaped bone chisel, back action, enblock harvesting, rongeur pliers, and piezoelectric surgery offers the most efficient methods for harvesting the vital bone (54).

High pressure applied and high temperatures even for a short time may cause the necrosis of bony tissue. Recently, Stubinger et al (2010) also showed that autologous bone harvested with a piezoelectric device offers stable and aesthetic placements of oral implants after a 5-month's healing (55).

Applications:

Sinus Lift
The Piezoelectric Internal Sinus Elevation (PISE) technique is a surgical sinus augmentation technique in which an ultrasonic piezoelectric device with a specialized carbide tip is used instead of the surgical hammer and the hydraulic pressure from internally or externally irrigated saline to the sinus membrane makes its detachment from the sinus floor more easier. This carbide tip has an indicating line of bone depth while performing the osteotomy, thereby minimizing the membrane perforation risk (56).

After the sinus cortex perforation, bone grafts or substitutes mixed with platelet rich plasma or fibrin adhesives can be grafted into the prepared socket with amalgam carrier or small spoon shaped curette. Reduced incidence of Benign Positional Paroxysmal Vertigo (BPPV) and membrane perforation makes this technique more attractive alternative for direct or indirect sinus lift procedures (56).

In (2007) Wallace et al. reported only 7 of 100 cases of schneiderian membrane perforation in their study of sinus lift procedures using piezosurgery, whereas in (2005) Vercellotti et al. observed the membrane perforation in only 5% of patients. The additional bone grafts can be placed to elevate the sinus floor for the required height. 0.5–1 cm^3 of bone graft is usually recommended to elevate the sinus floor upto 5 mm for placement of a single dental implant. It offers a better choice for sinus floor elevation in the condition where at least 3-mm residual bone is available under the maxillary sinus floor (57).

Bone harvesting
Bone can be harvested in the form of bone chips or blocks which act as a guide for bone regeneration via osteoconduction and a space maintainer for the growth factors to promote the bone healing. Conventional methods of bone harvesting includes bone scrapers, rongeurs, gouge shaped chisels, trophies or enbloc harvesting. Recently piezosugical bone harvesting gains a paramount importance due to its wide range of benefits compared to conventional methods (58).

The piezoelectric device with osteoplasty No. 1 to osteoplasty No. 3 tips can be used with gentle scratching movements along the surface of the bone to obtain sufficient bone chip volume which is very difficult with conventional bone mills (53).

The bone chips obtained via conventional bone mills have lower particle size which get easily resorbed without fulfilling its role as a space maker or guide for bone regeneration whereas piezosurgery provides significant amount of bone with particle size of 500 μm at lower complication rate and minimal resorption rate (59).

The structure of piezosurgically obtained bone margins are less impaired compared to conventional methods. In (2006) Berengo et al. reported that piezosurgery retains a significant amount of viable osteocytes and osteoblasts. Even though it is a time consuming technique, piezosurgery still remain as one of the most easier and safer method for bone harvesting (60).

Distraction osteogenesis
Mandibular distraction osteogenesis considered to be a surgical option for Pierre Robin syndrome during the neonatal life. It offers a safe and effective option to relieve the airway obstruction and swallowing difficulty due to micrognathia and avoids the need of tracheotomy. As the piezoelectric osteotomy during the distraction procedure permits a clear micrometric selective bone cut and thereby preserving the osteocytes and periosteal tissues, this technique promotes the new bone formation with early release of morphogenetic proteins (61).

Clinical Applications of Piezosurgery in Maxillofacial, Craniofacial, and Reconstructive Surgery (With References)

Piezosurgery has become increasingly valuable in craniofacial and maxillofacial surgery due to its selective cutting of mineralized tissues while preserving soft structures. This precision enhances surgical safety, visibility, and control across multiple procedures.

Orthognathic Surgery

Piezosurgery is widely used in BSSO, Le Fort I/II osteotomy, and SARME. Numerous studies highlight improved safety, reduced thermal injury, and decreased postoperative swelling/hematoma (62).

In vitro evaluation showed only minimal intratrabecular debris in piezo cuts, confirming precise bone removal (63). Although conventional saws are faster, piezo devices offer superior control and soft tissue protection. Straight and thin piezo tips improve osteotomy speed (63). During Le Fort I, piezo scalpels allow accurate cuts between teeth while preserving bone and tooth vitality, although posterior access may be challenging (64).

Craniofacial Surgery (Craniosynostosis)
Piezosurgery provides high safety when working near the dura, brain, orbital contents, and neurovascular structures, offering a safer alternative to oscillating saws. Though the learning curve is longer, it provides bloodless fields and precise osteotomies in critical regions (53).

Reconstructive Surgery
It preserves the bony component and vascular supply of reconstructive flaps, improving flap viability during major reconstructive procedures (65).

Removal of Osteosynthetic Materials

Callus covering titanium plates often complicates hardware removal. Piezosurgery safely eliminates callus without damaging screw heads, improving removal efficiency (66).

Osteonecrosis Management
Piezoelectric devices are effective for removing necrotic bone in ARONJ. (67) showed piezosurgery limits further necrosis after debridement. Bilimoria/McGuire et al. (68) demonstrated that combining piezo debridement with L-PRF enhances healing in osteoradionecrosis. Minimally invasive flapless piezo surgery offers promising outcomes in Stage 1–2 MRONJ, enabling safe bone removal near the inferior alveolar nerve (69).

Rhinoplasty
Traditional chisel osteotomies can cause soft tissue and vascular damage. Piezosurgery offers precise osteotomies with reduced trauma, bleeding, and ecchymosis (70). New piezo inserts designed specifically for rhinoplasty further enhance bone stability and soft tissue preservation (71).

TMJ Osteotomies
The piezo scalpel allows safe osteotomy of the medial condyle and articular eminence, reducing the risk of internal maxillary artery and meningeal vessel injury—critical during condylectomy and TMJ ankylosis surgery (72).

Advantages:
Piezosurgery provides superior precision and safety during osteotomy due to its selective cutting of mineralized tissues while sparing soft tissues such as nerves, blood vessels, the Schneiderian membrane, and the dura (62). The cavitation and microvibration effects of the ultrasonic device create a blood-free surgical field, improving visibility and surgical accuracy (65).
It produces micrometric, highly controlled bone cuts with minimal pressure, reducing thermal and mechanical trauma, thereby preserving tooth vitality and minimizing postoperative swelling, bleeding, and hematoma formation (63). Reduced vibration and noise also increase patient comfort, especially during procedures performed without general anesthesia. Piezosurgery eliminates the need for chisels in many osteotomy procedures and decreases the likelihood of coagulation necrosis in bone fragments due to its minimal heat production and controlled cutting action (64).

Disadvantages:
Despite these advantages, piezosurgery remains an expensive technology and requires significant surgical expertise. The device is technique-sensitive, and inexperienced operators may still cause soft-tissue injury, especially around neurovascular structures. Its use may prolong operative time due to slower cutting speed compared to conventional rotary or oscillating instruments, particularly when surgeons are early in the learning curve. Mastery of piezoelectric tools demands a high level of surgical control and familiarity, which may limit its adoption in some clinical environments (73).

Complications of Endoscopic Sinus Surgery (ESS)
Endoscopic sinus surgery (ESS) is widely used for chronic rhinosinusitis, nasal polyps, and other sinonasal diseases. Although generally safe, its proximity to vital structures makes complications possible. These complications range from minor postoperative issues to major orbital, intracranial, or vascular injuries.

Orbital Complications

Orbital hematoma (retrobulbar hemorrhage): Occurs when the lamina papyracea or orbital vessels are injured. Proper identification of the uncinate process and maxillary ostium and careful review of CT scans help reduce risk. Management involves ophthalmology consultation, intraocular pressure control, and canthotomy if pressure exceeds 40 mmHg.

Optic nerve injury: Rare but severe; results from trauma during sphenoid/posterior ethmoid surgery or compression from orbital hematoma. Pre-operative CT evaluation for optic nerve or carotid dehiscence is essential.

Extraocular muscle injury: Typically involves the medial rectus. Avoiding aggressive maneuvers near the lamina papyracea reduces risk.

Skull Base & Intracranial Complications
Skull base injuries may cause cerebrospinal fluid (CSF) leaks, influenced by anatomic variation such as **Keros classification.** Small CSF leaks may be repaired with mucosal grafts, while larger defects require multilayer reconstruction. Postoperative evaluation includes CT imaging and testing for CSF leak.

Vascular Complications (Epistaxis)
Most bleeding is minor, but severe cases may require nasal packing, cauterization, arterial ligation, or embolization. Understanding sphenopalatine artery anatomy is critical.

Nasal & Sinonasal Complications

Synechiae: Preventable with middle meatal spacers, irrigation, and debridement.

Empty nose syndrome: Caused by excessive turbinate resection; preservation of ≥50% of the inferior turbinate is recommended.

Recurrence of disease: Results from inadequate antrostomy, middle turbinate lateralization, synechiae, or incomplete removal of bony partitions.

Prevention centers on detailed CT/MRI review, meticulous technique, navigation assistance in complex cases, and diligent postoperative care.

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