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Piezoelectric Surgery in Oral and Maxillofacial Procedures: A Contemporary Review

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Abstract

Piezoelectric surgery has emerged as a transformative tool in oral and maxillofacial surgery. Unlike traditional cutting instruments, piezoelectric devices utilize ultrasonic micro-vibrations to selectively incise mineralized tissues while sparing soft tissue structures. This innovative technology has been shown to improve safety, precision, and healing outcomes in procedures such as implantology, sinus augmentation, bone harvesting, and orthognathic surgery.

Piezoelectric systems function using high-frequency ultrasonic vibrations (typically 25–30 kHz) that enable micrometric bone cutting with enhanced control and minimal trauma. The ability to cut hard tissues while preserving soft tissues provides a major advantage in areas near critical anatomical structures such as nerves and blood vessels. The technique also reduces intraoperative bleeding and postoperative complications, leading to better healing and patient comfort. Furthermore, piezosurgery improves visibility in the surgical field by minimizing blood loss. Although the equipment cost and longer surgical duration are potential drawbacks, the overall benefits including improved precision, safety, and biological response make it a valuable asset in modern oral and maxillofacial surgical procedures. This review presents a comprehensive evaluation of the principles, instrumentation, biological effects, clinical indications, and limitations of piezosurgery, with evidence based comparisons to conventional techniques.

Keywords: Piezoelectric device; Ultrasonic bone surgery; Maxillofacial surgery; Alveolar bone surgery; Sinus lift; Selective bone cutting

1 Introduction

The evolution of minimally invasive surgical techniques has emphasized precision and tissue preservation. Piezoelectric surgery, introduced by Vercellotti in 1988, employs ultrasonic vibrations in the 25–30 kHz range to perform micrometric bone cutting while avoiding injury to adjacent soft tissues such as blood vessels, nerves, and mucosa[1]. The device consists of a cutting edge piezoelectric ultrasonic transducer mechanized by an ultrasonic generator competent of driving a range of resonant cutting inserts, a hand piece, and a foot switch connected to the main unit which supplies power and has holders for the hand piece and irrigation fluids[2,3]. It contains a peristaltic pump for cooling with a jet of solution that discharge from the inserts and also helps in removing rubble from the cutting area. The device has a control panel with a digital display to set the power and frequency modulation[4]. They also have several autoclavable tool-tips called inserts, which are titanium or diamond coated in various grades and move by microvibrations created in piezoelectric hand piece[5].This device is widely used in dentistry serving various applications such as root planing, removal of supra and subgingival deposits and stains from teeth, crown lengthening, atraumatic tooth extraction, ridge augmentation, sinus floor elevation, bone graft harvesting, lateralization of inferior alveolar nerve, implant surgery, and ridge expansion[6].

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1.1 History

The term "piezo" originates from the Greek word piezein, which means, "to press tight, squeeze." Jacques and Pierre Curie first discovered piezoelectricity in the year 1880 who found that applying pressure on various crystals, ceramics, or bone created electricity[7-9]. Gabriel Lippmann in 1881 found the converse piezoelectric effect, which was further investigated by various scientists. Mcfall *et al*., in 1961, evaluated the distinction of healing by comparison of rotating instruments and oscillating scalpel blade and found slow healing with no severe complication by use of these scalpel blades[10]. In 1980, Horton *et al*. stated that bone regeneration was better using ultrasonic device[11]. One year later, he evaluated the clinical utility of ultrasonic instrumentation in surgical removal of bone and observed mineralized tissue removal with ease and efficiency along with good acceptance by patients without any complications[12]. In 1998, Torella reported the better use of ultrasonic generator compared to magnetostrictive device because of its greater efficiency of cutting with less bone destruction[13]. In 1999, Dr. Thomas Vercelloti invented piezoelectric bone surgery in collaboration with Mectron Spa and published in the year 2000[14]. In 2001, Piezosurgery was introduced. In 2002, the device was approved for commercial use in Germany. In 2003, Vercelloli discovered the ideal frequency method for endodontic, orthopedic, neurologic, periodontal, and oral and maxillofacial surgeries[15,16]. In 2005, the US Food and Drug Administration extended the use of ultrasonics in dentistry to include bone surgery[17].

2 Mechanism of action

- Piezosurgery operates on the principle of the piezoelectric effect, a phenomenon first identified by Jean and Marie Curie in 1880[3]. At its core is ultrasonic transduction, generated by the contraction and expansion of piezoelectric ceramic elements. These vibrations are amplified and transmitted to the surgical tip, which, with gentle pressure and irrigation, selectively cuts mineralized tissues. Micro-streaming and cavitation are key advantages.

- Cavitation is a microboiling process at the solid–liquid interface under ultrasonic frequencies, forming vapor bubbles that implode, releasing energy for cutting and cleaning. Micro-streaming is the swirling of fluid around the vibrating tip, improving debris removal and visibility. Cavitation also promotes microcoagulation, reducing bleeding by causing bubble implosion and thrombus formation in small vessels.

- Selective cutting allows precise bone incisions while minimizing soft tissue damage, reducing bleeding. The handpiece connects to a central unit with a sterile irrigation system (0–60 ml/min) and footswitch activation. Tips vary in shape and design—sharp, serrated, and diamond-coated—for targeted anatomical use.

- Electric current deforms piezoelectric crystals, producing cutting–hammering micro-movements at 25–29 kHz with 60–210 μm[3] amplitude for powerful, precise cutting.

- Ultrasonic scalers, operating at 24–36 kHz, use similar piezoelectric principles to remove plaque and calculus by transmitting longitudinal vibrations for bone cutting via microscopic shattering.

2.1 Wave propagation

Ultrasonic testing relies on time-dependent deformations or vibrations in materials, categorized under acoustics. Materials consist of atoms that can vibrate around equilibrium positions, but acoustics focuses on collective particle motion generating mechanical waves. Under elastic stress, particles oscillate due to restoring electrostatic forces and inertia, enabling wave propagation. In solids, sound waves travel as longitudinal, shear (transverse), surface, or plate waves. Longitudinal and shear waves are commonly used. In longitudinal waves, particles vibrate parallel to wave direction, causing compression and expansion. Shear waves involve perpendicular particle motion and are weaker, typically generated by redirecting energy from longitudinal waves.

2.2 Piezoelectric transducer

Ultrasonic testing is based on converting electrical energy into mechanical vibrations and vice versa, a function performed by the active element in an ultrasonic transducer. This element, typically made of polarized material with electrodes, undergoes electrostriction when an electric field causes molecular realignment and dimensional change. Permanently polarized materials like quartz (SiO_2) or barium titanate ($BaTiO_3$) exhibit the piezoelectric effect, generating electric fields when mechanically deformed. Modern transducers use piezoelectric ceramics due to their efficiency, shape flexibility, and thermal resistance up to 300°C. Barium titanate was first widely used, followed by lead zirconate titanate (PZT), now the standard material.

2.3 Characteristics of piezoelectric transducers

Ultrasonic testing relies on converting electrical energy into mechanical vibrations and vice versa, occurring in the active element of the ultrasonic transducer. This element, made of polarized material with electrodes, enables bidirectional transformation. When voltage is applied, molecular alignment induces dimensional change—electrostriction. Permanently polarized materials like quartz (SiO_2) or barium titanate ($BaTiO_3$) exhibit the piezoelectric effect, generating electrical signals upon mechanical deformation. Modern transducers use piezoelectric ceramics for their strong piezoelectric properties, manufacturability, and temperature resistance up to 300°C. Barium titanate was the first widely used ceramic, followed by PZT compounds, which dominate today. Some still call the element the "crystal."

2.4 Cavitation

Cavitation refers to a microboiling phenomenon that occurs in liquids at any solid–liquid interface subjected to intermediate-frequency vibrations. This process involves the disruption of molecular cohesion within the liquid, leading to the formation of low-pressure zones. These zones gradually fill with vapour, resulting in the development of microbubbles that are on the verge of implosion. In the context of detartrating (scaling) instruments, cavitation takes place when the water spray interacts with the ultrasonically vibrating insert, typically operating at intermediate frequencies. This effect contributes to both the cleaning action and enhanced visibility during dental procedures.

3 Instrumentation

A piezoelectric unit comprises:

- Main console with digital controls to adjust power, frequency, and irrigation rate.
- -Handpiece containing piezoceramic transducers.
- Tips/Inserts: Over 50 types are available, classified as sharp, blunt, or smooth, with specific applications such as osteotomy (OT7), sinus lift (EL1), and periodontal therapy.
- Peristaltic pump: Delivers sterile saline at variable rates (up to 60 mL/min) for cooling and cavitation effects.

Insert tips vary in design and coating (e.g., titanium nitride or diamond), enhancing their specificity and efficiency. Customized kits are now developed for sinus elevation, lateral osteotomy, and implant site preparation, increasing clinical versatility.

4 Biological effects of bone cut by piezoelectric device

The mechanical instrument's effect on bone structure and cell viability is critical in regenerative surgery. Factors like cortical/cancellous bone response and surface roughness from different osteotomy techniques significantly influence healing[21]. In piezoelectric osteotomy, cutting speed is adjustable based on indication and tissue condition by modulating frequency and amplitude. Its low-amplitude cutting enables precision. A blood-free surgical site, offering improved visibility, may result from local overheating, coolant flow, cavitation, or intravascular thrombosis[22].

A study comparing piezoelectric (PS) and rotating drills (RD) for harvesting autogenous bone chips showed similar cell viability and differentiation. Outgrowth of osteoblast-like cells was observed in 88.9% (RD) and 87.9% (PS) samples, confirmed by alkaline phosphatase and osteocalcin staining. PS samples had larger particle size, but both techniques yielded biologically effective chips[23].

Another study assessed microbiological profiles of bone debris collected during piezosurgery and tested rifamycin SV's decontamination efficacy. Debris collected from 10 patients via bone trap showed that rifamycin significantly reduced bacterial contamination.

In periodontal resective surgery on dogs, piezosurgery (PS) was compared with carbide (CB) and diamond burs (DB). By day 14, CB/DB sites showed bone loss, while PS sites had bone gain. At day 56, PS-treated sites continued bone gain, while CB/DB sites showed renewed bone loss, favoring PS for healing and remodeling[24,25].

A study on mini-pigs showed improved osseointegration and lower inflammatory response with piezoelectric surgery compared to traditional drilling. PS sites had earlier increases in BMP-4 and TGF-β2, and reduced inflammatory cytokines. Sonke Harder et al. compared three ultrasonic bone surgery devices. Piezosurgery II and Piezotome showed higher cutting performance than SurgySonic, with Piezotome producing the lowest intraosseous temperature increase, indicating effective and safe cutting.

5 Clinical applications

5.1 Dento-alveolar procedures

Piezosurgery offers distinct advantages in procedures requiring precise manipulation of small bone segments or tooth fragments—such as tooth sectioning or retrieval of a fractured wisdom tooth that lies close to critical anatomical structures[26-28]

5.2 Tooth Extraction

Used in ankylosed or impacted teeth, allowing conservative removal with preservation of alveolar bone[29-31].

5.3 Implant Site Preparation

Improves precision in osteotomy, especially near the inferior alveolar nerve, and enhances implant stability[32].

5.4 Alveolar ridge splitting

piezoelectric surgery simplifies vertical and horizontal ridge-splitting procedures. It allows precise cuts without generating heat-induced bone necrosis and significantly reduces the likelihood of damage to surrounding soft tissues. Vertical or horizontal incisions of any shape can be made safely and accurately without harming adjacent structures. Additionally, the cavitation effect created during the procedure helps keep the surgical field clean, enhancing visibility[33].

5.5 Sinus Lift Procedures

The cavitation effect helps in safely elevating the Schneiderian membrane without perforation.

5.6 Bone Harvesting

Offers controlled harvesting of intraoral autogenous bone with reduced donor site morbidity and improved graft quality[34,35].

5.7 Orthognathic Surgery

Used in Le Fort I, II, III osteotomies, zygomatic reduction, and BSSO with reduced risk of nerve injury.

5.8 Periodontal and Periapical Surgery

Enables controlled debridement, root planing, and bone contouring[36,37].

5.9 Nerve Lateralization

Safe for displacement of inferior alveolar nerve during implant procedures[38,39].

5.10 Aesthetic facial surgery

In aesthetic facial surgery, especially rhinoplasty, precise lateral osteotomy is crucial to minimize complications like ecchymosis and edema. Traditional chisels, often unguarded and used blindly, can transmit excessive force, risking injury to nasal soft tissues, damaging vessels like the angular artery, and increasing bleeding and periorbital ecchymosis[40-43].

5.11 Distraction osteogenesis

Precision is essential during osteotomies for distraction, especially in regions near dental roots, periodontal structures, and vascularized soft tissues. The micrometric and linear vibrations of piezosurgery allow for extremely accurate bone cutting while minimizing trauma to surrounding hard and soft tissues. This precision enables surgeons to perform osteotomies without harming the flap, thus preserving vascular supply essential for optimal new bone formation[44,45].

5.12 Temporomandibular Joint (TMJ) Surgery

Piezosurgery also shows promise in the complex field of TMJ surgery, particularly in cases of TMJ ankylosis. Conditions like ankylosis often involve distorted anatomy, extensive bone remodeling, and proximity to sensitive structures like the maxillary artery. The various advantages of piezoelectric surgery allow for safer and more effective condylectomies[46,47].

6 Advantages and limitations

The key benefits of using piezosurgery in oral and maxillofacial procedures include :

- Enhanced visibility of the surgical site, owing to pressurized irrigation and the cavitation effect.
- Effective haemostasis achieved through the cavitation mechanism.
- Precise bone cutting with micrometric accuracy.
- Minimization of the risk of injury to surrounding soft tissues during hard tissue manipulation.
- Accelerated healing, as the technique preserves living bone and stimulates morphogenetic protein release.
- Simplified harvesting of autogenous bone grafts from intra- or extra-oral sources; the variety of angled inserts allows access to hard-to-reach areas.
- Absence of macro-vibrations ensures greater comfort for patients undergoing procedures under local anaesthesia.

Despite its advantages, piezosurgery has some limitations :

- It is contraindicated in patients with cardiac pacemakers.
- The initial cost of the equipment can be a financial concern.
- Surgical procedures may take longer when using piezosurgery.
- Clinicians may require additional training and practice to become proficient in its use for oral and maxillofacial surgeries

6.1 Comparative evidence

Compared to rotary and oscillating saws, piezosurgery demonstrates:

- Less heat generation, preserving bone vitality
- Lower incidence of membrane perforation
- Fewer postoperative complications

Meta-analyses and RCTs confirm improved patient-reported outcomes in terms of pain, healing time, and satisfaction[48-63].

7 Future of piezoelectric device

The future of piezoelectric surgery is poised for transformative growth, with innovations aimed at enhancing precision, usability, and integration with digital technologies.

7.1 Integration of Smart Technologies

One of the most promising developments is the incorporation of smart technology into piezosurgery systems. Potential features include:

- AI-assisted navigation and feedback systems for real-time intraoperative guidance
- Enhanced safety and precision through automated parameter adjustments
- Minimized human error and improved outcomes through digital decision support

These advancements are expected to streamline surgical workflows and increase the reliability of complex procedures[64-67].

7.2 Ergonomics and Accessibility

Future piezosurgery devices are likely to be:

- More ergonomically designed, reducing surgeon fatigue during lengthy procedures
- Wireless or cordless, improving maneuverability
- More customizable, allowing for tailored settings based on patient-specific or procedural requirements

Such user-friendly enhancements will broaden the scope of application and increase the adoption of piezosurgery across clinical settings[68,69].

7.3 Advancements in Ultrasonic Technology

Ongoing research is aimed at refining ultrasonic precision and minimizing invasiveness even further. Expected innovations include:

- Ultra-fine oscillation tips for microsurgical applications
- Improved cavitation dynamics for cleaner cuts with less collateral tissue damage
- Faster healing due to reduced cellular trauma and enhanced biocompatibility of new tool coatings

These developments may lead to novel surgical protocols, enabling procedures that were previously not feasible with traditional instruments[70,71].

8 Conclusion

The advent of piezoelectric surgery has heralded a paradigm shift in dental and maxillofacial surgical practices, offering a compelling alternative to conventional mechanical instrumentation. With its hallmark features—selective cutting, micrometric precision, and minimal trauma to soft tissues—piezoelectric technology has significantly enhanced both surgical accuracy and patient safety. From implantology and periodontology to bone grafting and orthognathic procedures, its applications have transformed clinical workflows and postoperative outcomes, fostering a more patient-centered surgical approach.

Looking ahead, the future of piezoelectric surgery appears promising, driven by continuous innovations in ultrasonic modulation, digital interfacing, and ergonomic refinement. The integration of artificial intelligence, real-time feedback systems, and robotics could further elevate its precision and adaptability. As these advancements materialize, piezoelectric instruments will not only evolve as surgical tools but also stand as emblems of modern dental innovation—redefining procedural standards and reinforcing the commitment to minimally invasive, high-performance care.

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