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Piezosurgery - Modern dentistry's innovative tool - A review article

Amjed Kadhim Al-Naaly

Ahmed Fadhel Al-Quisi

REVIEW

Piezosurgery - Modern Dentistry's Innovative Tool - A Review Article

Amjed K. Al-Naaly*, Ahmed F. Al-Quisi

Department of Oral and Maxillofacial Surgery, College of Dentistry, University of Baghdad, Iraq

Abstract

Background: **In implantology, piezosurgery is a novel and cutting-edge method of bone surgery. Various ultrasonic frequencies can be used for selective cutting, which preserves essential anatomical structures by only operating on solidified hard tissues. Piezoelectric osteotomy is a technique that can be used to precisely and safely prepare receptor sites for procedure implants, acquire bone grafts classified as autogenous (blocks and particles), perform osteotomies used for alveolar crest bone expansion, lift the maxillary sinus, and remove dental implants. Clinically and physiologically, the outcomes are outstanding, especially regarding osteocyte vitality.**

Objectives: **This review aims to highlight the advantages and disadvantages of piezosurgery compared to conventional surgical techniques and demonstrate its practical applications in implant dentistry through a literature review.**

Method: **Piezosurgery, piezoelectric surgery, ultrasonic vibration, Dental implant, and osteotomy were the search terms utilized to review the biomedical literature using PubMed and Medline, two electronic databases.**

Conclusions: **The procedure's significant advantages encompass precise bone cutting, preservation of soft tissues, minimal blood loss, a clear surgical area, low noise and vibration, and excellent patient comfort with utmost safety to the dental structures. With its unique ability to cut bone using ultrasonic micro-vibrations, piezosurgery offers a sophisticated and safe approach, delivering consistently reliable results.**

Keywords: Piezosurgery, Piezoelectric surgery, Ultrasonic frequency, Osteotomy, Implants

1. Introduction

Numerous studies have shown how successful dental implants are in function and appearance [1–3]. Dental implants, however, will only be deemed effective when they contribute to complete rehabilitation. As a result, implant placement must be done precisely. The ultimate rehabilitation is the topic of “reverse planning,” which states that the implant location should be based on the completion of the prosthetic repair rather than where there is more bone volume. Planning is usually required to accomplish this goal, as it involves bone regeneration and bone transplantation to increase atrophic zones [4–8].

Various techniques can increase bone density in implantology, including implanting blocks and particles of bone grafts taken from the chin, mandibular ramus, and iliac crest [9,10]. Other methods include oscillating saws, rotary drills, and, more recently, piezosurgery, which slices bone tissue using ultrasonic vibrations [11,12].

Maxillofacial surgeons invented piezoelectric ultrasound. It divides solid interfaces, like bone tissue, using radio waves to cause the ultrasonic tips to oscillate and vibrate. With a frequency range of 25–29 kHz, an amplitude (oscillation) of about 60–210 lm, and a power energy reach of 50 W, the piezoelectric device's ultrasonic vibrations enable it to cut only mineralized materials without harming soft tissue [13–16].

In many clinical scenarios, including bone collection, maxillary sinus osteotomies for grafting, osteotomies for osteogenesis distraction, bone lateralization of the inferior alveolar nerve, Le Fort I and segmented osteotomies, and fractured implant

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* Corresponding author at: Department of Oral and Maxillofacial Surgery, College of Dentistry, University of Baghdad, Baghdad, Iraq.
E-mail addresses: amjad.tayih2208@codental.uobaghdad.edu.iq (A.K. Al-Naaly), ahmed.fadhil@codental.uobaghdad.edu.iq (A.F. Al-Quisi).

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removal, the ultrasonic tips can be a helpful instrument with increased safety and precision, reducing tissue damage [17].

This study aimed to describe the advantages and disadvantages of piezosurgery over traditional surgical methods, as well as their biological features, and to emphasize the therapeutic applications of this technique in implantology.

2. Materials and methods

Whether or not they were related, the terms piezosurgery, piezoelectric surgery, ultrasonic vibration, and osteotomy were used to search the biomedical literature using PubMed and Medline. All in all, we found 240 relevant items. We chose these papers based on the following criteria: Since piezosurgery is widely used in medicine and dentistry fields (periodontic, endodontic, neural surgery, and orthopedic), the main focus of this paper was limited to English-language publications that concentrated on the use of ultrasound technique in bone surgery, specifically in maxillofacial and implantology, as well as some classic articles about surgical techniques in implantology.

Following an overview review of the abstracts, we identified 70 papers that met these requirements. These papers were published in 1961, when ultrasonic surgery on bone tissue first became possible, and in 2023. There are three review papers, twelve case reports, fifteen clinical trials, two in vitro investigations, three in vivo studies, two mechanical studies, five editorials, and eight traditional implantology articles.

3. Literature review

Pierre Curie discovered piezoelectricity in 1881. McFall et al. performed the first ultrasonic surgery on bone tissue in 1961 [18,19].

Germany licensed the Mectron Piezosurgery, Medical Technology, Carasco, Italy, a piezoelectric device for bone oral surgery, for commercial use in 2002. The device was invented in 1988. Vercelloti [19] found in 2003 that the ideal ultrasonic frequency technique was advised for periodontal, endodontic, orthopedic, and neurologic operations in addition to maxillofacial bone surgery. Unlike ultrasonic waves, Leclercq et al. describe it as a physical technique unique to some crystals, like quartz, that experience continuous dynamic vibrations under frequency, which cause cavitation, defined as a rupture of the molecular cohesion of liquids [20,21].

Vercellotti claims that selective cutting in mineralized structures is conceivable because the piezoelectric device can transmit ultrasonic vibrations at 29 kHz without damaging soft tissue. The piezoelectric device, which generates ultrasonic waves via electrical current, was the subject of a study. With a frequency estimated at 29 kHz, an amplitude of about 60–210 lm, and a power reaching 50 W, this device can produce standard vibrations, depending on the density of the bone [22–25].

According to Ueki et al., piezoelectric ultrasound-assisted bone cutting proved beneficial for patients undergoing maxillary orthognathic surgery. This method facilitates faster palatal extension, reduces surgical trauma, and allows perfect control throughout the osteotomy [26].

Chiriac et al. claim that conventional disc cutters and drills may have certain drawbacks, such as overheating and additional tissue injury, compared to piezoelectric bone osteotomies. It has been demonstrated that the use of surgical ultrasonography lowers the possibility of brain and vascular injury during the surgical excision of malignancies in the skull and spinal cord [9,27].

Stubinger and colleagues investigated the process of bone remodeling after piezoelectric osteotomy using this novel technique and contrasted it with bone remodeling carried out using traditional methods involving cutters and saws [28]. They examined its potential effects on future surgical applications while considering the most significant biological outcomes. Berengo et al. gathered and examined autogenous bone particles using histomorphometry. They also calculated the bone fragments' surface area and the ratio of viable to necrotic bone [29].

Some research claims that piezoelectricity can be employed with more security than traditional methods in sinus floor elevation, osteotomy for alveolar bone crest expansion, implantology to collect bone grafts, and lateralization of the inferior alveolar nerve [20,30–34].

Vercellotti et al. investigated bone remodeling following piezoelectric osteotomy and contrasted it with traditional methods utilizing drills from the carbide and diamond series [33]. In addition, they calculated the viable necrotic bone ratio and the surface area of the bone pieces.

Furthermore, compared to conventional drill systems, research using piezoelectric ultrasound technology revealed an increase in osteogenesis and a decrease in the number of inflammatory cells surrounding implants [19,35–37].

4. Piezosurgery system

From a technical standpoint, the tips of the piezosurgery system are similar to those of the traditional piezoelectric ultrasonic tip (prophylaxis); it consists of an axis, an insertion, and a periodic intermediate frequency generator [38]. As in Fig. 1.

In order to generate vibrations with an intermediate frequency, the piezoelectric ceramic particles are tightly packed inside the center axis. Active tips may function as traditional instruments for removing bacterial calculus when attached to a traditional piezosurgery system. Four factors, however, set the ultrasonic piezosurgery system tips apart from traditional instruments: tip shape, hardness, generator frequency, and generator weight [23].

The first ultrasonic tool on the market was the Mectron Piezosurgery System. It included a bomb that permitted watering during the operation and an intermediate-frequency generator. The intended cutting effect modifications were made to the tips so that their ultrasonic vibrations resonate with the axis's piezoelectric ceramic particles, increasing energy output and improving the effectiveness of the active tip action. The tip is strengthened with a surface layer made from titanium nitrite, or diamond, which prevents it from fracturing when working on more complex tissues. Finally, different tip morphologies yield better-cutting results when a tip is transformed into an electric micrometer saw using ultrasonic vibrations [15,23,39,40].

Fig. 1. Piezosurgical unit.

5. Piezosurgery's clinical uses in implant

5.1. Lifting the maxillary sinus

When performing typical rotating treatments, such as osteotomy for membrane lifting or bone window confection, there is a risk of perforation of the Schneiderian membrane. Piezosurgery can drastically lower this risk [41,42]. The membrane must remain intact to maintain the stability of the graft and prevent infectious disease in the maxillary sinus. Numerous suggestions have been offered to carry out the procedure with superior results. During an osteotomy, selective cutting reduces the chance of membrane fenestration [20]. The maxillary sinus membrane is dissected using a cooling solution and the hydropneumatic pressure of the applied elements. A study with 15 patients and a 95% success rate that involved 21 piezosurgery osteotomies served as an example of the technique [42,43].

5.2. Autogenous bone graft: block and particulate

Particles 500 lm are the perfect size for bone graft particles to preserve their osteogenic, osteoinductive, and osteoconductive properties during bone regeneration. Piezosurgery is the most effective method for gathering bone pieces of the proper size and producing minimal heat, which reduces the risk of thermal necrosis. The iliac crest, cranium, and mandible are the typical donor sites for block grafts [29]. Extensive surgical access is frequently required during these procedures to gather the optimal amount of bone and protect the nearby delicate tissues and significant anatomical features. It is safer and more precise because piezosurgery necessitates a low-amplitude active tip in a constrained access area, significantly reducing intraoperative bleeding. The sensitivity of the method is also beneficial for delicate surgeries. With ultrasonic surgery, there is virtually little chance of complications such as accidental tooth root damage or penetration into the mandibular canal. On the other hand, during osteotomies, typical rotational devices produce excessive heat, which may impair bone cell viability and result in thermal necrosis [44]. Piezosurgery produces a safe thermal effect that improves biological outcomes by using a large amount of cooling solution and the cavitation effect [45−47].

5.3. Expanding alveolar bone crest

Alveolar bone crest expansion is demonstrated to be positively impacted by piezosurgery, and the bone can be detached without breaking. Osteotomes can ultimately be inserted to lengthen the osteotomy. The surgeon can reach the required depth with this scale method—standard oscillatory saws. By using ultrasonic intermediate vibration to make bones more elastic following osteotomy, the piezosurgery technique reduces the chance of bone fracture and, consequently, problems. Additionally, the cavitation effect simplifies the surgical process by creating a clear, clean operative field with exceptional vision [32,48].

5.4. The inferior alveolar nerve's lateralization

Since it permits a secure osteotomy and nerve release, piezoelectric surgery is a particularly fascinating technique for lateralizing the inferior alveolar nerve [45]. The surrounding soft tissue is preserved, whereas the cortical bone can split apart due to the ultrasonic vibration [32]. Equipment must be carefully inserted through a difficult-to-access bone wall to release the inferior alveolar nerve. Piezoelectric cutting makes the inferior alveolar nerve less likely to be accidently damaged during an osteotomy. Furthermore, the capacity of ultrasonic vibration-frequency piezosurgery to be adjusted explicitly to hard tissues aids in the elimination of common rotary tool complications and their aftermath [32,49,50].

5.5. Osseointegrated implant removal

When osseointegrated implants are deemed prosthetically useless or when the implant position indicates significant cosmetic harm, complete removal of the implants may be required. There is a significant chance that the peri-implant osseous walls would fracture during the procedure, and it is challenging to breach the bone-implant interface [20]. The ultrasonic piezosurgery tips effectively manage this condition by using ultrasonic vibrations to cleave solid interfaces and create thin bone trenches (grooves) through microabrasion. Nonetheless, because twisting pressures are applied to both the implant and the alveolar bone during extraction, the chance of the peri-implant osseous walls breaking is still very high [20,51,52].

6. Piezosurgery's biological effects on bone tissues

Evidence shows that bone tissue is sensitive to heat injury, and 478C for 1 min is the temperature at which tissue will survive an osteotomy [8,9]. Consequently, regular osteotomy tools such as burs, drills, and saws increased frictional heat, causing increased stress and decreased cutting power.

Piezoelectric surgery's impact on bone cells' vitality has been the subject of some research [53,54]. Several methods of producing autogenous bone grafts were assessed in terms of particle size, the necrotic to vital bone ratio, and the quantity of osteocytes per unit of surface area using microphotography and histomorphometric analysis [29]. The outcomes demonstrated that osteotomes, piezoelectric surgery, and chisels are the most effective essential bone harvesting techniques. These findings supported earlier research on how the piezoelectric device affected the morphology and viability of the cells following the collection of bone particles [9,33,55].

Because there are few viable osteocytes and a significant percentage of nonvital bone, bone obtained using bone scrapers, twist drills for implants, or standard spherical drills in low- and high-speed handpieces is unsuitable for bone grafting. Vercellotti et al. used piezosurgery, a carbide drill, and a diamond drill at 14, 28, and 56 days to study the bone's response after osteotomy and osteoplasty. They arrived at the following deduction. Bone was lost from surgical sites treated with carbide and diamond drills for 14 days, but bone tissue was increased following piezosurgery. All three employed systems showed increased bone levels and periodontal and cementum regeneration after 28 days [34].

The use of piezosurgery technology increased bone mass 56 days after surgery, while the use of carbide and diamond drills caused bone tissue to be lost. This study demonstrated piezosurgery's highest level of efficacy and bone regeneration capacity [22]. The minipigs' tibias were implanted with porous titanium implants in a different histomorphological investigation. Samples of bone tissue next to implants were used to measure tumor necrosis factor, transforming growth factor 2 (TGF-2), morphogenetic protein 4 (BMP-4), interleukin-1, and interleukin-10. According to the study, Neo-osteogenesis was invariably active in samples from implant sites prepared by piezosurgery. The bone surrounding the implants also showed increased BMP-4 and TGF-2 and a lack of proinflammatory cytokines [33]. These results revealed that the piezoelectric bone surgery approach was better in terms of efficiency than the conventional implant site fabrication method. Increased bone remodeling, early bone morphogenetic protein proliferation, and better control of the inflammatory process were all shown in just 56 days.

7. Discussion

The primary drawback of piezosurgery harvesting bone tissue is that it is feeble and ineffective against the cortical components [13,15]. However, cortical bone makes up most of the bone found in the chin, mandibular ramus, and parietal bone, the donor sites most frequently employed for autogenous bone graft collection. In other words, the primary contraindication is also the primary indication for piezoelectric surgery.

Clinically, to compensate for the loss of cut effectiveness in piezosurgery on cortical or hard bone tissue, it can be adjusted by going more slowly and not applying pressure during the osteotomy [35]. However, there is faster attrition and a higher rate of ultrasonic tip fractures on corticomedullary bones. Active tip fracture does not affect cut quality but necessitates a cautious replacement stock to maintain tip control [26,56].

Even in cortical bone, piezosurgery is considered the best autogenous graft-collecting technique despite this drawback [26,33,57]. Ultrasonic vibrations favor both the graft cleavage of the donor area and the disintegration of solid surfaces. Bone blocks are collected without a chisel and hammer and are known for their firm impact. The possibility of unfavorable graft fractures complicates their use [53,54,58].

Ultrasonic tips are a safe and effective way to preserve soft tissues and important nearby structures in deeper sites [33,59]. Barone et al. compared piezoelectric osteotomy devices with traditional drills and sinus membrane elevation to insert implants. Bone fragments were used in the grafting of all the maxillary sinuses. Traditional diamond drills were employed on one side, and ultrasonic tips on the other. The window osteotomy required more time to accomplish with the piezoelectric osteotomy equipment. When ultrasound was used, the percentage of sinus membrane perforations was lower (23% vs. 30%) [60].

The piezoelectric device makes it easier and safer to carry out advanced surgical and implantology procedures such as sinus floor elevation, alveolar bone crest extension, and particle and block bone collection [45,46]. The primary characteristics that set this innovative technology apart from conventional systems are the cut's selectivity and precision and the operating field's ability to remain clean because of cavitation [61,62].

Kotrikowa et al. emphasized the versatility of piezosurgery in intraoral locations. It can be used for a variety of procedures including implants, bone graft removal, dental extractions, opening a bone window for maxillary sinus elevation, and inferior alveolar nerve lateralization. The research findings reveal that piezosurgery is a versatile tool that can treat bone tissue without compromising nearby soft tissue [63].

Piezoelectric surgery is mainly used in the mouth to remove osseointegrated implants without causing stress, remove bone grafts at the mandibular ramus and symphysis, and lateralize the inferior alveolar nerve. Thanks to the piezoelectric gadget, these exact modifications were safe [15,45,46,61,62].

Leclercq et al. investigated a few clinical uses of the ultrasonic piezoelectric method. These included lateralizing the inferior alveolar nerve, the non-traumatic extraction of osseointegrated implants, and removing bone grafts in the chin and mandibular ramus. They showed reduced trauma from drills, saws, and chisels and excellent surgeon safety, which enhanced patient comfort. The piezoelectric mechanism facilitated manipulation in the area of the inferior alveolar nerve. The gadget has certain drawbacks, such as the prolonged operation time and the brittle tips [20,23].

Leclercq et al. covered piezoelectric surgery's clinical, technological, and physical uses. Histological results demonstrated that piezoelectric surgery reduced bone heat necrosis compared to alternative techniques. They concluded that, in skilled hands, piezoelectric ultrasound is a less invasive technique that may effectively perform delicate procedures [20].

Osteotomies may now be safely completed with piezosurgery, which takes the place of oscillating saws and traditional rotary methods. Due to selective cutting and intraoperative visualization, piezosurgery was proven to be effective in anatomically problematic places in research involving children aged 6−84 months who had undergone craniosynostosis and an intraorbital tumor (hemangioma), which protected delicate anatomical structures like blood vessels supplying the bone and neurovascular tissue. The degree of pain tolerance and heat damage were assessed for every surgical procedure. The primary drawback of piezosurgery was its extended operating time compared to traditional methods. Furthermore, applying more pressure to the piezo over the bone inhibits the tip from properly vibrating, which converts energy into heat and damages target tissues via thermal shock. The outcomes showed that ultrasound is helpful in piezoelectric osteotomy, especially for spinal cord and pediatric neurosurgery, which both have critical anatomical features [14,64]. As shown in Table 1.

Chiriac et al. studied the effects of piezoelectric osteotomy on intraoral bone shape, cell survival,

Table 1. Comparison of piezosurgery and osteotomy in implant procedures.

Aspect	Piezosurgery	Osteotomy
Definition	Uses ultrasonic vibrations for bone cutting	Uses rotary instruments or saws for bone cutting
Precision	High precision, minimal damage to surrounding tissue	Good precision but more risk of damaging surrounding tissue
Healing Time	Generally faster due to less trauma	It may be longer due to greater tissue trauma
Bleeding	Minimal due to the cavitation effect	Can be significant
Heat Generation	Low, reduces the risk of bone necrosis	Higher, may increase the risk of bone necrosis
Comfort	Generally, it is more comfortable for patients	Maybe less comfortable due to higher trauma

and differentiation. Particles of cortical bone were extracted using either traditional drills or ultrasonography [64].

A histomorphometric approach was used to compare the bone fragments. The study discovered that autogenous bone particles retrieved via ultrasonography had necessary cells that differentiated into osteoblasts, in contrast to standard osteotomies [20]. Ueki et al. evaluated the inferior alveolar nerve after bilateral sagittal split osteotomy supported by piezosurgery employing neurosensory (sensitivity recovery).

In every instance, the inferior alveolar nerve's anatomical integrity was maintained. The ultrasonic device makes the inferior alveolar nerve's neurosensory recovery possible in a bilateral sagittal split osteotomy. Piezoelectricity was used to quickly restore sensitivity while maintaining the inferior alveolar nerve's anatomical integrity [65].

Leclercq et al. claim that a surgical tool called piezoelectric ultrasound can precisely cut through hard tissue. It makes use of ultrasonic microvibrations delivered to titanium nitride tips. Since it is an agitation phenomenon, these vibrations may cause the solid-liquid contact to become disorganized and fragmented. It may result in thermal impacts and even burning biological tissues, just like any other energy phenomenon. The tool comprises active tips explicitly designed for maxillary sinus lifts, avulsions of teeth, periodontal surgery, and block and fragmented bone transplants. The gadget makes surgical applications possible by reducing the risk of soft tissue injury, making challenging locations easier to access, and offering security [20].

Labanca et al. confirmed that employing ultrasound for osteotomy reduces osteocyte injury and increases bone cell survival during bone harvest, which corroborated the findings of Preti et al. Additionally, they discovered that the osteogenesis surrounding the implant is more effectively stimulated by the piezoelectric surgical approach, which increases the number of osteoblasts on implant receptor sites and reduces the antecedents of local inflammation [33,61,66].

Surgical institutions will often reimburse the expense of some cracked tips, which assures the patient and the physician. Even with skilled surgeons, using a chisel and hammer typically leaves the patient with unpleasant recollections, which is why the piezosurgery system has a benefit. The protocol for autologous bone collection and alveolar bone crest osteotomies should systematically utilize ultrasonic tips to reduce the risk of fracture during the undesirable buccolingual expansion to remove the osseointegrated implant, permitting less bone tissue loss, inducing faster and more effective bone repair, lateralizing the inferior alveolar nerve to reduce the risk of damage to the neurovascular bundle and the ensuing hemorrhage and sensory impairment [34].

Indeed, piezosurgery stands among the innovative instruments that streamline complex processes into easily implemented steps. It offers a safer approach, minimizing risks to soft and neurovascular tissues during procedures in hard-to-reach areas. The potential of piezosurgery to revolutionize implantology is immense, sparking curiosity and optimism. However, its application necessitates a higher level of expertise and training compared to traditional rotary and oscillating saws, potentially leading to increased surgical time in less effective systems that require deep bone incisions [67].

Temperatures increased even though the cutting speed was reduced. Therefore, breaks were required to allow the system to cool. In these cases, a chisel was used for the final osteotomy of the bone and piezosurgery for the initial incision [13]. **The main advantages of piezosurgery in the oral and maxillofacial areas are** [1] Clear vision of the surgical area from the pressurized irrigation and cavitation effect [2]. Hemostasis is ensured through the cavitation effect [3]. Bone sectioning can be performed with micrometric sensitivity [4]. Avoiding the risk of damage to adjacent soft tissue while cutting through hard tissues [5]. Healing occurs fast because no damage is inflicted on the living bone morphogenetic protein release [6]. Piezosurgery provides the ease of harvesting intra- or extra-oral autogenous graft [7]. Due to its inserts with various angles, it can be easily used in areas where it is difficult to see and reach [8]. Due to the absence of macro-vibrations, patients feel very comfortable during surgeries under local anesthesia.

Some disadvantages of piezosurgery are: [1] Use in patients with pacemakers is not recommended [2]. The purchase of a device may initially be a financial burden [3]. The duration of the surgical procedure is longer with the application of piezosurgery [4]. To gain experience with piezosurgery in the oral and maxillofacial areas, more practice time might be required for clinicians.

However, most researchers concur that the piezoelectric device is incredibly accurate and efficient, and they advise using it. Piezoelectric tools will play a crucial role in every process involving maxillofacial surgery and implantology.

7.1. Conclusions

Using ultrasonic micro-vibrations to cut bone in a sophisticated and safe manner, piezosurgery produces incredibly predictable results. Precise bone cutting, preservation of soft tissues, minimal blood loss, a precise surgical area, low noise and vibration, and good patient comfort with maximum safety to the dental structures are some of the main advantages of piezosurgery. Despite the extended intraoperative duration and specialized knowledge and training requirements, piezosurgery has made complicated surgeries simple and highly achievable, especially in remote areas. Following Piezosurgery, wound healing, and post-operative recuperation are advantageous for establishing ideal bone regeneration. With the rapid advancement of technology, the piezosurgical device holds great promise as a modality with a wide range of applications across dental specialties, sparking excitement for the future of dental procedures.

Ethical statement

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