

# Piezosurgery Applied to Implant Dentistry: Clinical and Biological Aspects

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Piezosurgery is a new and modern technique of bone surgery in implantology. Selective cutting is possible for different ultrasonic frequencies acting only in hard tissues (mineralized), saving vital anatomical structures. With the piezoelectric osteotomy technique, receptor site preparation for implants, autogenous bone graft acquisition (particles and blocks), osteotomy for alveolar bone crest expansion, maxillary sinus lifting, and dental implant removal can be performed accurately and safely, providing excellent clinical and biological results, especially for osteocyte viability. The aim of this review was, through literature review, to present clinical applications of piezosurgery in implant dentistry and outline their advantages and disadvantages over conventional surgical systems. Moreover, this study addressed the biological aspects related to piezosurgery that differentiate it from those of bone tissue approaches. Overall, piezosurgery enables critical operations in simple and fully executable procedures; and effectively, areas that are difficult to access have less risk of soft tissue and neurovascular tissue damage via piezosurgery.

**Key Words:** *piezosurgery, osteotomy, bone, soft tissues*

## INTRODUCTION

**M**any studies have demonstrated the high success rate of dental implants regarding their function and esthetics.<sup>1-4</sup> However, dental implants will only be considered successful as part of the final rehabilitation that they support. Thus, the optimal placement of implants is critical. This focus on the final rehabilitation involves “reverse planning” wherein the placement of the implant should be related to finalization of the prosthetic restoration,<sup>5-9</sup> not necessarily where there is greater bone volume. This goal often means planning of the bone graft and the bone regeneration to increase atrophic areas.

Implantology offers a variety of techniques to increase bone volume,<sup>10,11</sup> including transplantation of particles and blocks of bone grafts from the chin and the mandibular ramus, iliac crest, and calvaria.<sup>12,13</sup> The techniques make use of rotary drills; oscillating saws; and more recently, piezosurgery, a process that uses ultrasonic vibrations in the application of cutting bone tissue.

Piezoelectric ultrasound was developed by maxillofacial surgeons. It uses radio waves that allow the ultrasound tips to oscillate and vibrate so that they can divide solid interfaces, such as bone tissue. The piezoelectric device is characterized by having ultrasonic vibrations with an average frequency of 25–29 kHz, an oscillation (amplitude) of 60–210  $\mu\text{m}$ , and power up to 50 W, thereby allowing selective cutting only in mineralized structures without damaging soft tissue.<sup>14-17</sup>

The ultrasound tips can be an effective tool with a greater precision and safety, thereby minimizing tissue trauma, in several clinical situations: bone

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collection; mandible sagittal osteotomies; fractured implant removal; lateralization of the inferior alveolar nerve; osteotomies in the maxillary sinus for grafting, osteotomy for osteogenesis distraction; alveolar crest expansions; and Le Fort I and segmented osteotomies.

The aim of this study was to highlight the clinical applications of piezosurgery in implantology and outline their advantages and disadvantages over conventional surgical systems and their biological aspects.

### MATERIALS AND METHODS

PubMed/Medline were the electronic resources used to review the biomedical literature, using the following key words: piezosurgery, piezoelectric surgery, ultrasonic vibration, and osteotomy, either disconnected or linked. In total, we found 240 relevant articles. As a criterion for selection of these studies, we included only the articles published in English; and, because piezosurgery is used in other areas of dentistry and medicine (eg, periodontal, endodontic, orthopedic, and neural surgery), we focused on the use of ultrasound in bone surgery, especially in implantology and maxillofacial surgery, plus some classical articles of surgical techniques in implantology. After reading the abstracts, we selected 50 articles that fit these criteria, with publication dates ranging from 1961 (the beginning of ultrasonic surgery in bone tissue) to 2009. Among them, we have 3 review articles, 12 case reports, 15 clinical trials, 2 *in vitro* studies, 3 *in vivo* studies, 2 mechanical studies, 5 editorial, and 8 classical articles of implantology.

### LITERATURE REVIEW

Piezoelectricity was discovered in 1881 by Pierre Curie. In 1961, McFall et al<sup>18</sup> performed the first ultrasound surgery in bone tissue.

The piezoelectric device for bone oral surgery (Mectron Piezosurgery, Medical Technology, Carasco, Italy) was developed in 1988 and was approved for commercial use in 2002 in Germany. In 2003, Vercellotti<sup>19</sup> revealed the ideal ultrasonic frequency method indicated for maxillofacial bone surgery and periodontal, endodontic, orthopedic, and neural surgeries. It is characterized, according to Leclercq et al,<sup>20</sup> as being a physical phenomenon

specific to certain crystals, such as quartz, that suffer from mechanical vibrations with such frequency that it generates cavitation, characterized by a disruption of the molecular cohesion of liquids, compared with ultrasonic waves.

The piezoelectric device, according to Vercellotti,<sup>21</sup> is characterized by presenting ultrasonic vibrations at a 29-kHz frequency, allowing selective cutting only in mineralized structures, without damaging soft tissue. A study<sup>22</sup> was performed on the piezoelectric device that converts the electrical current into ultrasonic waves; this device promotes a standard vibration with an average frequency of 29 kHz, an oscillation (amplitude) of 60–210  $\mu\text{m}$ , and power of up to 50 W, according to the bone density.<sup>23</sup>

Ueki et al<sup>24</sup> showed that the bone cut with piezoelectric ultrasound was effective in patients requiring maxillary orthognathic surgery, as it helps in the rapid palatal expansion, providing less surgical trauma and precise control during the osteotomy.

According to Chiriac et al,<sup>25</sup> the conventional disc cutters or drills may present some disadvantages compared with piezoelectric bone osteotomy, such as overheating and further damage to adjacent tissues. The emergence of surgical ultrasound has been shown to reduce the risk of damage to neural and vascular in-surgical removal of tumors in the spinal cord and skull.<sup>26</sup>

Using this new technique, Stubinger et al<sup>27</sup> analyzed the bone remodeling process after piezoelectric osteotomy, comparing it with bone remodeling via conventional techniques performed with cutters and saws. They also analyzed its future impact on surgical applications, considering the best biological results. Berengo et al<sup>28</sup> collected autogenous bone particles and analyzed them by histomorphometry, measuring the surface of the bone fragments and the percentage of necrotic and vital bone. According to some studies, piezoelectricity can be used in implantology to collect bone grafts,<sup>25,29,30</sup> in osteotomy for alveolar bone crest expansion,<sup>31,32</sup> and in sinus floor elevation and lateralization of the inferior alveolar nerve<sup>33</sup> with greater security than conventional techniques.

Vercellotti et al<sup>34</sup> studied the bone remodeling process after piezoelectric osteotomy, comparing it with conventional techniques performed with carbide and diamond series drills. They concluded

that piezosurgery provides more favorable bone repair. Moreover, other studies<sup>35,36</sup> showed that there is a reduction in the number of inflammatory cells and an increase in osteogenesis around piezoelectric ultrasound-installed implants compared with conventional drill systems.

### **Piezosurgery system**

Technically, the piezosurgery system tips resemble the conventional piezoelectric ultrasound tip (prophylaxis), consisting of the axis, insertion, and a generator of periodic intermediate frequency. Inside the central axis, the piezoelectric ceramic particles are stacked to generate intermediate-frequency vibrations. Active tips can be connected to the conventional piezosurgery system and may even serve as conventional tools for bacterial calculus removal. However, the ultrasonic piezosurgery system tips differ from conventional tools on four parameters: generator frequency, generator weight, hardness, and tip shape.<sup>22</sup>

The system built by Mectron Piezosurgery was the market pioneer ultrasonic tool.<sup>16</sup> It consisted of an intermediate-frequency generator and a bomb that allowed for irrigation during the operation. To get the desired cutting effect, changes were made in tips whose ultrasonic vibrations come into resonance with the piezoelectric ceramic particles of the axis, thereby allowing increased energy production and making the active tip action more efficient. The hardness of the tip is increased by a titanium nitride surface layer, sometimes diamond, allowing the tips to act on harder tissues without breaking. Finally, different forms of tips provide a better cutting effect when the tip turns into an electric micrometer saw under the influence of ultrasonic vibrations.<sup>16,22</sup>

### **Clinical applications of piezosurgery in implant**

#### *Maxillary Sinus Lifting*

Perforation of the Schneiderian membrane is a risk with traditional rotational procedures during the osteotomy for bone window confection or during membrane lifting. Piezosurgery can reduce this risk to a minimum.<sup>37,38</sup> An intact membrane is essential for graft stabilization and the absence of infectious pathology in the maxillary sinus. Several tips are available to perform the surgery with excellent

outcome. Selective cutting minimizes the possibility of membrane fenestration during osteotomy.<sup>31</sup>

The hydropneumatic pressure of the applied elements, through a cooling solution, helps in dissection of the maxillary sinus membrane. The method was illustrated in a study of 15 patients who underwent 21 piezosurgery osteotomies, with a success rate 95%.<sup>38</sup>

#### *Autogenous Bone Graft (Particulate and Block)*

Bone graft particles with a size of 500  $\mu\text{m}$  are ideal to bone regeneration, maintaining the osteogenic, osteoinductive, and osteoconductive ability. Piezosurgery is appropriate to collect the bone particles with the ideal size and with low heat generation, minimizing the possibility of thermal necrosis.<sup>29</sup> Traditional donor sites for block grafts are the mandibular, skull, and iliac crest.<sup>28</sup> In these surgical procedures, there is often a necessity of large surgical access to collect the ideal bone quantity and to protect the surrounding soft tissues and vital anatomical structures. In this aspect, piezosurgery is more precise and safe, because it requires the active tip to be of low amplitude in a small access area, thereby providing significant reduction of intraoperative bleeding. The technique's sensitivity also is highly advantageous in delicate surgeries. The risk of complications with inadvertent penetration in the mandibular canal or damage the adjacent teeth roots is practically eliminated in ultrasonic surgery. In contrast, conventional rotary instruments generate excessive heat during the osteotomies, and this heat may affect bone cell viability and lead to thermal necrosis.<sup>39</sup> Piezosurgery, in contrast, is characterized by the cavitation effect with abundant cooling solution, generating harmless thermal effect and resulting in better biological outcome.<sup>40,41</sup>

#### *Alveolar Bone Crest Expansion*

Piezosurgery shows good results in alveolar bone crest expansion,<sup>30</sup> and the bone can be separated without trauma. The entire osteotomy length can be expanded by inserting osteotomes. This scale approach allows the surgeon to achieve the depth necessary.

During the bone segmentation, there is an additional risk of undesired fractures, especially in predominantly hard (cortical) bone, when the osteotomy is performed with rotary drills and

oscillatory conventional saws. The method of piezosurgery decreases the risk of bone fracture, making bones more elastic after osteotomy with ultrasonic intermediate vibration, thereby minimizing complications.<sup>30</sup> Furthermore, the cavitation effect provides a clean and clear surgical field with excellent visibility, simplifying the surgical procedure.

#### *Lateralization of the Inferior Alveolar Nerve*

The use of piezoelectric surgery in lateralization of the inferior alveolar nerve is very interesting because it allows a safe osteotomy and an easy access to release the nerve.<sup>40</sup> The ultrasonic vibration allows the cleavage of cortical bone while preserving the adjacent soft tissue.<sup>30</sup>

The release of the inferior alveolar nerve involves inserting instruments meticulously through bone wall with difficult access. The risk of accidental damage of the inferior alveolar nerve during the osteotomy is minimized by the piezoelectric cutting.<sup>30</sup> Furthermore, the selective nature of piezosurgery with ultrasonic vibration frequency specific to hard tissues contributes to eliminating common complications and sequelae of conventional rotary instrument.<sup>30</sup>

#### *Removal of Osseointegrated Implants*

In some cases, full removal of osseointegrated implants is necessary, either by ectopic position because they are judged prosthetically unusable, or because the implant position implies major esthetic damage. It is difficult to break the bone-implant interface, and there is a high risk of fracture of peri-implant osseous walls during the operation.<sup>20</sup>

The piezosurgery ultrasonic tips allow efficient handling of this situation by the cleavage power of solid interfaces under the effect of ultrasound vibrations and by confection, via microabrasion, of thin bone trenches (grooves). However, the risk of fracture of the peri-implant osseous walls remains critical, particularly during the extraction phase itself, due to the application of twisting forces on the implant and on the alveolar bone.<sup>20</sup>

#### ***Biological aspects of piezosurgery in bone tissues***

The sensitivity of bone tissue to thermal injury has been documented, and the temperature threshold for tissue survival during osteotomy is established

at 47°C for 1 min.<sup>8,9</sup> Thus, the repeated use of burs, drills, and saws during osteotomies reduces cutting power and causes excessive trauma, with consequent increase in frictional heat.

Some studies were performed on the piezoelectric surgery effect on bone cell viability.<sup>42,43</sup> Different methods of collecting autogenous bone grafts were examined with microphotography and histomorphometric analysis of the particles' size, the percentage of necrotic and vital bone, and osteocyte number per unit of surface area.<sup>27</sup> The results showed that the best vital bone collection methods are chisels, osteotomes, and piezoelectric surgery. These results confirmed previous studies on the effects of the piezoelectric device on the morphology and cell viability after bone particle collection.<sup>24,33</sup>

Bone collected with a common spherical drill in a low- and high-speed handpiece, twist drill for implant, or bone scrapers is not appropriate for grafting, due the absence of viable osteocytes and the predominance of nonvital bone.

Vercellotti et al<sup>21</sup> compared the response of bone after osteotomy and osteoplasty made with a carbide drill, a diamond drill, and piezosurgery after 14, 28, and 56 days. They concluded the following. (1) The surgical sites treated with carbide drill and diamond drill had bone loss in 14 days, in contrast to piezosurgery, where there was an increase of bone tissue. (2) After 28 days, there was greater bone level and cementum and periodontal ligament regeneration in the 3 systems used. (3) At 56 days postsurgery, the piezosurgery system resulted in a increase of bone mass, whereas carbide and diamond drills resulted in a loss of bone tissue. This study showed the greatest ability of bone regeneration and effectiveness with piezosurgery.

In another histomorphological study, porous titanium implants were inserted into the minipigs tibia. The concentrations of morphogenetic protein 4 (BMP-4), transforming growth factor 2 (TGF-2), tumor necrosis factor, and interleukin-1 and interleukin-10 were evaluated in samples of bone tissue adjacent to implants. The analysis showed that neo-osteogenesis was consistently more active in bone samples of sites for implants prepared with piezosurgery, with an early increase in BMP-4 and TGF-2 and few proinflammatory cytokines in the bone around the implants.<sup>34</sup> Based on these results, the piezoelectric bone surgery technique seemed to

be more efficient than the conventional implant site creation. There was early proliferation of bone morphogenetic proteins and better inflammatory process control, and bone remodeling was evident in 56 days.

### DISCUSSION

The main disadvantage to the use of piezosurgery to collect bone tissue is its weakness and ineffectiveness against the cortical components.<sup>14,16</sup> However, the most common donor sites used for autogenous bone graft collection—chin, mandibular ramus, and parietal bone—are composed predominantly of cortical bone. Thus, in theory, the main indication for piezoelectric surgery is, in these terms, the main contraindication.

Clinically, it may be possible to adapt to the lack of cut efficacy in piezosurgery on hard bone (cortical) tissue through a slower progression and without pressure during the osteotomy. However, there is an accelerated wear and higher rate of fractures of the ultrasonic tips on corticomedullary bones.<sup>34</sup> The fracture of active tips has no consequence on the quality of the cut,<sup>24,44</sup> but it requires a careful replacement stock for tip control.

Despite this disadvantage, piezosurgery is characterized as the best method available in autogenous graft collection, even in cortical bone.<sup>24,32,45</sup> Ultrasonic vibrations favor the breakdown of solid interfaces and facilitate graft cleavage of the donor area. Bone block collection is made without using a chisel and hammer that is characterized by violent impact with the risk of undesired graft fractures complicating its use.<sup>42,43</sup> In deeper sites, the use of ultrasonic tips is extremely safe and effective, with the preservation of soft tissues and vital adjacent structures.<sup>32,46</sup>

Barone et al<sup>47</sup> conducted a comparative study between conventional drills and a piezoelectric osteotomy device and sinus membrane elevation to implant placement. All the maxillary sinuses were grafted using bone particles. On one side conventional diamond drills were used, and on the other side piezoelectric ultrasonic tips were used. The time required for the window osteotomy was higher with the piezoelectric osteotomy device. Sinus membrane perforations were smaller in percentage with the use of ultrasound (23% vs. 30%).

The techniques in advanced surgery and implantology, such as collecting particulate and block bone, alveolar bone crest expansion, and sinus floor elevation, can be performed more safely and easily with the piezoelectric device.<sup>40,41</sup> The selectivity and precision of the cut, and the operative field staying clean due to cavitation, are the main factors that differentiate this new technique from the conventional systems that are available.<sup>48</sup>

Kotrikowa et al<sup>49</sup> described piezosurgery applications in intraoral areas with indications of dental extractions, dental implants, bone grafts removal, preparation of bone window for maxillary sinus lifting, and inferior alveolar nerve lateralization. The results show that it is possible to work on bone tissue without damaging surrounding soft tissue with the piezoelectric method.

The main oral applications of piezoelectric surgery were demonstrated in nontraumatic removal of osseointegrated implants, bone graft removal at the symphysis and mandibular ramus, and lateralization of the inferior alveolar nerve. The piezoelectric device enabled these delicate manipulations to be performed safely.<sup>16,40,41,48</sup>

Leclercq et al<sup>20,22</sup> studied some clinical applications of the ultrasound piezoelectric technique, such as nontraumatic removal of osseointegrated implants, bone graft removal at the mandibular ramus and chin regions, and lateralization of the inferior alveolar nerve. They showed greater safety for the surgeon, thereby providing greater comfort for patients, and a reduction in trauma caused by drills, saws, and chisels. The piezoelectric procedure facilitated the manipulation near the inferior alveolar nerve. The device does have some shortcomings, including the tips being fragile and the longer operative time. Leclercq et al<sup>20</sup> also addressed the physical, technological, and clinical applications of piezoelectric surgery. Histological findings showed a decrease in bone thermal necrosis with piezoelectric surgery compared with other methods. They concluded that the piezoelectric ultrasound is a tool that will achieve, with efficiency, delicate surgeries and that in experienced hands, this method is less invasive.

Piezosurgery is a safe technique to perform osteotomies, replacing conventional rotary systems and oscillating saws. A study with children, aged 6 and 84 months, operated on for craniosynostosis and for an intraorbital tumor (hemangioma),

showed that piezosurgery was effective in regions with anatomical difficulties due to intraoperative visibility and selective cutting, preserving delicate anatomical structures such as neurovascular tissue and blood vessels that nourish the bone. For each surgical procedure, pain tolerance and thermal damage were evaluated. The main disadvantage of piezosurgery was operative time, being longer than that of conventional techniques. Moreover, increasing the pressure exerted by the operator on the piezo over the bone prevents the proper vibration of the tip, turning energy into heat and causing thermal damage in target tissues. The results demonstrated the effectiveness of ultrasound in piezoelectric osteotomy, particularly in pediatric neurosurgery and spinal cord surgery, both of which have a critical anatomy.<sup>15</sup>

Chiriac et al<sup>24</sup> investigated the influence of piezoelectric osteotomy in relation to intraoral bone morphology, cell viability, and differentiation. Samples of cortical bone particles were collected by ultrasound or conventional drills. The bone particles were compared by histomorphometric analysis. The study concluded that autogenous bone particles collected with ultrasound contained vital cells that differentiate into osteoblasts, compared with conventional osteotomies.

Ueki et al<sup>50</sup> evaluated the inferior alveolar nerve through neurosensors (sensitivity recovery) after bilateral sagittal split osteotomy using piezosurgery. The anatomical integrity of the inferior alveolar nerve was observed in all cases. The ultrasonic device used in bilateral sagittal split osteotomy allows neurosensory recovery of inferior alveolar nerve. The results showed fast return of sensitivity and preservation of anatomical integrity of the inferior alveolar nerve with the application of piezoelectricity.

According to Leclercq et al,<sup>20</sup> piezoelectric ultrasound is a surgical device capable of cutting hard tissue with precision. It uses ultrasonic microvibrations applied to the tips of titanium nitride. Because it is an agitation phenomenon, it may induce the disorganization and fragmentation of the solid-liquid interface through these vibrations. Like any energy phenomenon, it can cause thermal effects and possible burning of the biological tissues. The device is composed of active tips specific for periodontal surgery, tooth avulsion, maxillary sinus lift, and bone grafts (particulate and block). The

device provides facility for surgical applications by security, ease of access to difficult places, and lower risk of soft tissue injuries.

Labanca et al<sup>48</sup> corroborated the findings of Preti et al<sup>34</sup> and affirmed that the use of ultrasound for osteotomy reduces the damage of the osteocytes and promotes bone cell survival during bone collection. Furthermore, they found that the piezoelectric surgical technique is more effective in stimulating osteogenesis around the implant, thereby promoting a greater number of osteoblasts on implant receptor sites and reducing the local inflammatory precursors.

The cost of some fractured tips is widely rewarded by a surgical facility and offers security for both the surgeon and the patient. The use of a chisel and hammer often causes painful memories for the patient, even with experienced surgeons, and thus provides an advantage to the piezosurgery system. The use of ultrasonic tips as a protocol for autologous bone collection, as well as for alveolar bone crest osteotomies, should be systematic, thereby minimizing fracture risk when performing the undesired buccolingual expansion; for removal of osseointegrated implant, enabling smaller loss of bone tissue; for lateralization of the inferior alveolar nerve with less risk of injury to the neurovascular bundle and consequent sensory disorder and bleeding, and with faster and more efficient bone repair; and for maxillary sinus lift, with preservation of the sinus membrane and stimulation of osteogenic, osteoinductive, and osteoconductive abilities more effectively than conventional systems.

Therefore, piezosurgery belongs to the category of tools that transform critical operations in simple and fully executable procedures. Effectively, surgeries performed in difficult-to-access areas come to be of less risk to soft and neurovascular tissues. The prospects of using piezosurgery promise to revolutionize implantology, but the professional skill and training for its use should be taken into consideration, because the technique requires a longer surgical time compared with the use of conventional rotary and oscillating saws. This occurs when deep cuts into the bone are necessary, and the system is less efficient. Although the cutting speed decreased, temperatures rose, so pauses were necessary to let the system cool down. In these cases, the combination of piezosurgery for the initial incision and a chisel for the final osteotomy of

the bone was useful.<sup>14</sup> But the majority of studies agree that the piezoelectric device is extremely efficient and precise, and recommend its use. Piezoelectric tools will be an instrumental part of any procedure in maxillofacial surgery and implantology in the near future.

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