Future Dental Journal

Volume 4 | Issue 2 Article 2

2018

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### Cover Page Footnote

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Future Dental Journal 4 (2018) 105–111

Contents lists available at ScienceDirect

Future Dental Journal

journal homepage: www.elsevier.com/locate/fdj

# Piezoelectric surgery: Applications in oral & maxillofacial surgery

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ARTICLE INFO

*Keywords:*
Piezoelectric surgery
Applications

ABSTRACT

The use of ultrasonic vibrations for the cutting of bone was introduced three decades ago as an alternative to the mechanical and electrical instruments that are used in conventional oral surgery. Technique that lessens the risk of damage to surroundings of tissues and important structures such as nerves, vessels, and mucosa. It also reduces damage to osteocytes and permits good survival of bony cells during harvesting of bone. Piezoelectric surgery was first used by oral and maxillofacial surgeons for osteotomies, but recently some specific applications in neurosurgery and orthopedics have been proposed.

We review the different applications of piezoelectric surgery in oral and maxillofacial surgery that can be utilized supported by clinical examples.

## 1. Introduction

The use of manual instruments such as the chisel, osteotome or gouge for hard tissue procedures in oral and maxillofacial surgery has a very long history. Recently, motorised devices have been used that can run on air pressure or electrical energy that have certain drawbacks that include: tissue necrosis due to the overheating of bone; a loss of fine-touch sensitivity due to the requirement of pressure on the handpiece; difficulty in the determination of cutting depth; iatrogenic impairment in undesired areas due to a failure in the accurate adjustment of the speed of a rotating head or saw; and the risk of soft tissue injury to important anatomical structures, such as the inferior alveolar nerve or maxillary sinus [1]. Eriksson et al. [2] showed that local bone necrosis would occur in cases where the temperature exceeds 47 °C for 1 min due to the contact of rotating tools, which play a role in the success of dental implants. Schwieger et al. [3] developed the water jet device to cut through bone by spraying water at high pressures, but not adopted in clinical practice.

Ultrasonic vibrations have been used to cut tissue for three decades [4,5]. Also known as 'pressure electrification', it has been defined by the term 'piezo' derived from 'piezein', meaning pressure in Greek language. Piezoelectric techniques were developed in response to the need for greater precision and safety in bone surgery than was available with other manual and motorised instruments.

Jean and Marie Curie, in 1880 were the first described the piezoelectric effect in which the instruments used for ultrasonic cutting of bone create microvibrations. The passage of an electric current across certain ceramics and crystals modifies them and causes oscillations. Voltage applied to a polarised piezoceramic causes it to expand in the direction of and contract perpendicular to polarity. A frequency of 25–29 kHz is used because the micromovements that are created at this frequency (ranging between 60 and 210 µm) cut only mineralised tissue; neurovascular tissue and other soft tissue is cut at frequencies higher than 50 kHz [6–8].

The first model of current piezoelectric devices is still being developed and heavily discussed in studies by Vercellotti et al. [7,9]. Piezoelectric devices usually consist of a hand-piece and foot switch that are connected to the main power unit. This has a holder for the hand piece, and contains irrigation fluids that create an adjustable jet of 0–60 ml/min through a peristaltic pump. It removes debris from the cutting area and ensures precise cutting. It also maintains a blood-free operating area because of cavitation of the irrigation solution, and gives greater visibility particularly in complex anatomical areas [8,10]. Piezosurgery inserts should be moved forwards and backwards continuously at a high speed with minimum pressure(Fig. 1).

A number of piezoelectric devices with similar mechanical parts are available on the market and newer versions in development. Typically, devices will come with pre-set settings for the intended procedures. There is a range of inserts (tips) available on the market and newer ones are in development that can vary in size, shape and material (Fig. 2). Claire et al. [11] recommended that a contact load of 150 g provide the greatest depth of cut, as they observed that excessive pressure on the piezosurgery insert led to a reduction in oscillations and hence the cutting ability.

Peer review under responsibility of Faculty of Oral & Dental Medicine, Future University.
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https://doi.org/10.1016/j.fdj.2018.09.002
Received 18 July 2018; Received in revised form 5 September 2018; Accepted 9 September 2018
Available online 11 September 2018

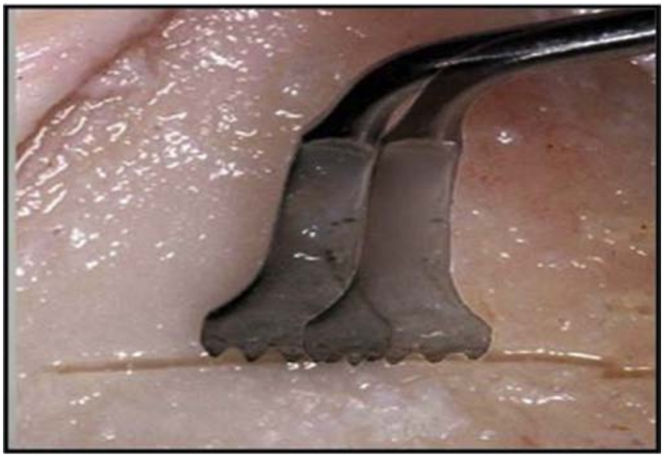

**Fig. 1.** Piezosurgery inserts should be moved forwards and backwards continuously at a high speed with minimum pressure.

## 2. Biological effects on bone cut by a piezoelectric device

The effects of mechanical instruments on the structure of bone and the viability of cells is important in regenerative surgery. Application of high temperatures for a short time, are dangerous to cells causing tissue necrosis. There have been several studies about the effect of piezoelectric surgery on bone and the viability of cells [12,13].

Recently autologous bone that had been harvested by different methods (round bur on low and high-speed handpiece, spiral implant bur on low-speed hand-piece, safe scraper, Rhodes back action chisel, rongeur pliers, gougeshaped bone chisel, and piezoelectric surgery) was examined using microphotography and histomorphometric analysis that evaluated particle size, percentage of vital and necrotic bone, and the number of osteocytes/unit of surface area [14]. The results showed that the best methods for harvesting vital bone are: gouge-shaped bone chisel, back action, enblock harvesting, rongeur pliers, and piezoelectric surgery. Bone that has been harvested with a round bur on low and high speed hand-pieces, a spiral implant bur, or safe scrapers, is not suitable for grafting because of the absence of osteocytes and the predominance of non-vital bone. Recently, Stubinger et al. showed that harvesting autologous bone with a piezoelectric device could be used in augmentation for stable and aesthetic placements of oral implants after a 5-month's healing [13–15].

The main advantages of piezosurgery in the oral and maxillofacial areas are:

- Clear vision of the surgical area from the pressurized irrigation and cavitation effect.
- Haemostasis is ensured through the cavitation effect.
- Bone sectioning can be performed with micrometric sensitivity.
- Avoiding the risk of damage to adjacent soft tissue while cutting through hard tissues.
- Healing occurs fast, because no damage is inflicted on the living bone morphogenetic protein release.
  - Piezosurgery provides the ease of harvesting intra- or extra-oral autogenous graft. Due to its inserts with various angles, it can be easily used in areas where it is difficult to see and reach.
  - Due to the absence of macro-vibrations, patients feel very comfortable during surgeries under local anaesthesia.

Some disadvantages of piezosurgery are:

- Use in patients with pacemakers is not recommended.
- Purchase of a device may initially be a financial burden.
- The duration of the surgical procedure is longer with the application of piezosurgery.
- To gain experience with piezosurgery in the oral and maxillofacial areas, more practice time might be required for clinicians.

## 3. Applications of piezoelectric surgery in oral and maxillofacial surgery

### 3.1. Dento-alveolar procedures

The use of piezosurgery has advantages in procedures that require a meticulous preparation of a small bone or a piece of a tooth: for example, tooth sectioning or the removal of a piece of a broken wisdom tooth that has a close relationship with an important anatomical structure [16,17].

### 3.2. Implantology

In oral surgery, particularly in implantology, bone can be augmented by harvesting (chips and blocks), splitting of crestal bone, and elevation of the sinus floor. To avoid autologous bone transplants in bone with good density, the alveolar ridge may be split [18]. To treat loss of bone in the posterior posterior maxilla or to let air into the sinus after tooth loss, or both, elevation of the sinus floor is usually most effective.

#### 3.2.1. Implant site preparation

Osseointegration process and the final outcome of implant rehabilitations are negatively affected by overheating during implant-site preparation. Different tips generate different temperatures, with the smooth tips creating the lowest temperature. There are other factors that will influence the temperature rise as well, such as the manner in which the cutting is performed and the particular features of the bone itself [19]. In this regard, Heinemann et al. compared different sonic and ultrasonic devices with rotary burs in parts of porcine jaws. In this study, piezosurgery showed the highest temperature rise, but as in the other devices, the osteocytes and the trabecular bone seemed to be intact [20].

As a new technique, implant site preparation can be performed with a specifically designed set of piezosurgery inserts (Fig. 3). Piezosurgical site preparation allows for the selective enlargement of only one socket wall. This is called ‘differential ultrasonic socket preparation’ by Vercellotti [9].

#### 3.2.2. Alveolar ridge splitting

Alternatives to the alveolar ridge split technique are the onlay bone grafts [21], guided bone regeneration [22,23], and horizontal distraction osteogenesis [24]. The principal disadvantages of onlay bone grafts are the invasiveness, the presence of an additional donor site related to the bone harvesting requirement, and the consistent resorption which the grafted bone undergoes in connection with the chosen donor site [25,26]. The main problems of the guided bone regeneration are the risk of exposure and collapse of the membranes and the risk of resorption which the grafting material encounters when the membrane is removed [27,28].

Classic ridge-split procedures involve razor-sharp bone chisels and rotating or oscillating saws. Chisels are driven into the bone by precise and gentle blows with a mallet. This is time-consuming and requires technical skill that is difficult to learn. Rotating saws are more rapid, but soft tissues such as the tongue, the cheek, or the lips can be affected during preparation for bony incisions, and adjacent teeth also make the operation difficult. Vertical incisions require more effort and care with these techniques, but are no problem with piezoelectric surgery; the split-crest procedure without the risk of bone thermo-necrosis, and it also carries a reduced risk to the damage of the adjacent soft tissues (Fig. 4). There is no risk of injury to soft tissue, and any shaped horizontal or vertical bony incision can be made easily without damaging adjacent structures. The effect of cavitation cleans the working area and

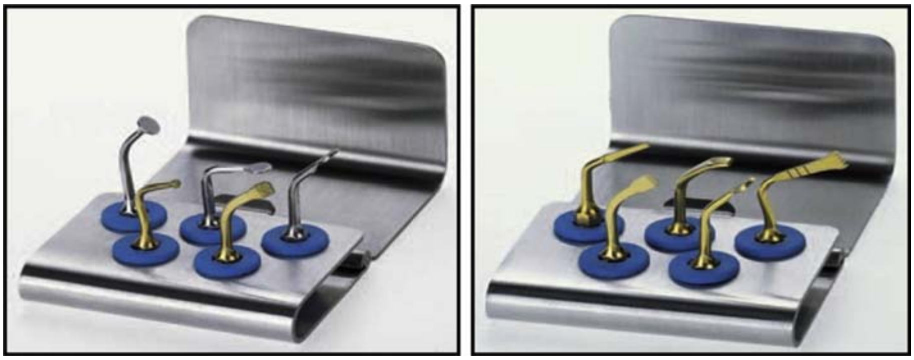

**Fig. 2.** Different piezosurgical inserts.

improves visibility [29,30].

#### 3.2.3. Sinus floor elevation

In edentulous patients with insufficient bone volume and therefore reduced height of the alveolar crest, a sinus-floor elevation is often the most suitable solution to prepare a sufficient donor site for implant insertion.

Raising the floor of the maxillary sinus to create an adequate site for implants is common. One risk is damage to the Schneiderian membrane, which can occur when doing an osteotomy with burs, or when the membrane is raised with manual elevators. The piezoelectric bony osteotomy cuts the mineralised tissue without damaging the membrane, and allows easy separation (Fig. 5) [10,31,32].

Although the lateral window is probably the most commonly used method, other techniques, including the approach from the crestal and palatal side, have been described [33,34].

#### 3.2.4. Lateralization of the inferior alveolar nerve

In a cadaver study conducted by Gowgiel, "the distance from the lateral border of the neurovascular bundle to the external surface of the buccal plate was usually half a centimeter in the molar and premolar regions" [35].

To keep the inferior alveolar nerve intact is essential for the patient's quality of life. The localization of the inferior alveolar nerve can vary distinctively in the edentulous mandible. The localization in the horizontal layer seems to be fairly stable. This accounts for the removal of deeply impacted wisdom teeth, which are often located close to the inferior alveolar nerve, as well as for the lateralization of the inferior alveolar nerve. This procedure is an alternative to the augmentation technique if implants are planned in an edentulous jaw [36].

Neurosensory damage to the ennervated area of the inferior alveolar can be an adverse effect of bilateral sagittal split osteotomy. To assess the sensitivity of the inferior lip and chin after mandibular bilateral sagittal split osteotomy in 20 patients using piezoelectric surgery, maxillofacial surgeons at Lyon showed that the inferior alveolar nerve in all cases was not affected, although there was no comparison with the standard technique for bilateral sagittal split osteotomy [37]. These results confirmed the findings of Metzger et al. who compared the use of piezoelectric devices with convention burs on soft and hard tissue for straightening or transposition of the inferior alveolar nerve in sheep [38]. Bovi reported mobilization of the inferior alveolar nerve with simultaneous insertion of implants [39]. Both studies reported less damage to soft tissues, particularly neurovascular tissue when using a piezoelectric device than conventional methods (Fig. 6).

### 3.3. Bone graft harvesting

Piezosurgery is also very useful for harvesting bone chips, which are produced at the optimum grain size for effectiveness and remain on the bone surface ready for collection. Two surgical tips are available for removal of cortical bone, eliminating the need for bone traps. These bone chips can be used alone or in combination with other graft material for guided bone regeneration purposes. Landes et al. (2008) assessed bone chips collected using piezosurgery and conventional burs and found no difference in the detrimental effect on the viability and differentiation of cells, but found piezosurgery was more economical in regard to quantity of bone harvested [40]. In comparison with surgical burs and microsaws, piezosurgery requires only an eatherlight touch allowing better operator sensitivity and control. As a result the clinician develops a better feel and precision for the cutting action, can feel the transition from cortical to cancellous bone and produces precise and clean cuts up to 1 cm deep. Consequently, the operator minimises trauma and wastage to the adjacent bone, creating grafts of optimum dimensions.

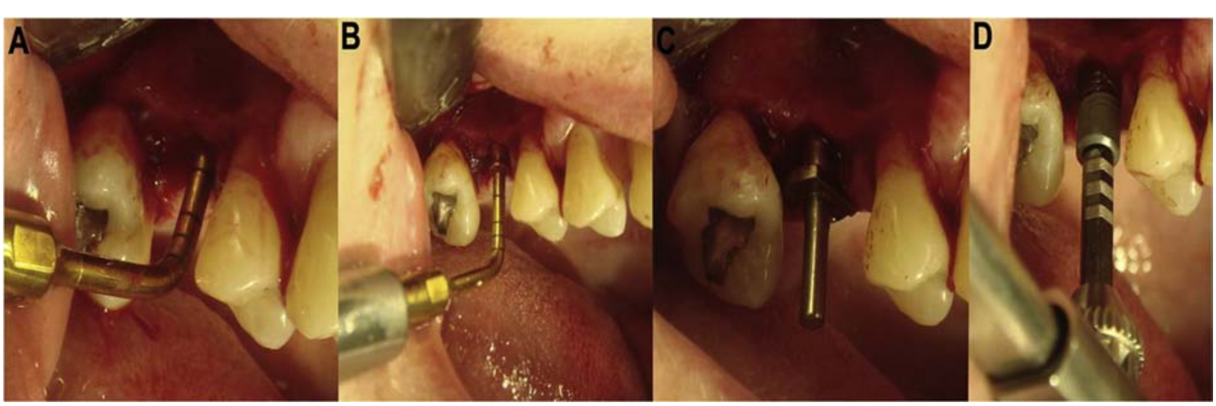


**Fig. 3.** Piezoelectric preparation of an implant site (right maxilla).
Notes: After definition of the initial implant length, widening of the implant hole, using different tips in an ascending order (A–C). Finally, control of the angulation and implant placement (D).

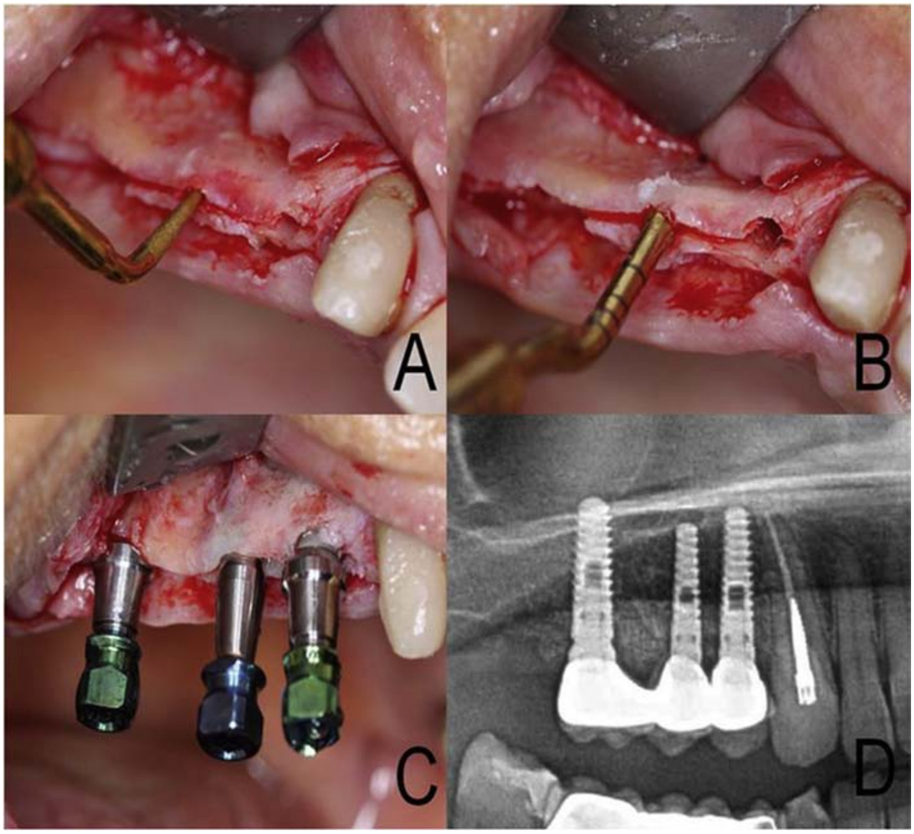


**Fig. 4.** Alveolar crest with horizontal bone deficiency can be split and expanded successfully using a thin saw-shaped piezosurgery insert for immediate implant placement (A and B). A maxillary ridge split that follows immediate placement of three implants with good primary stability (C). Panoramic radiograph shows no bone resorption after 3 years of loading of the implants (D).

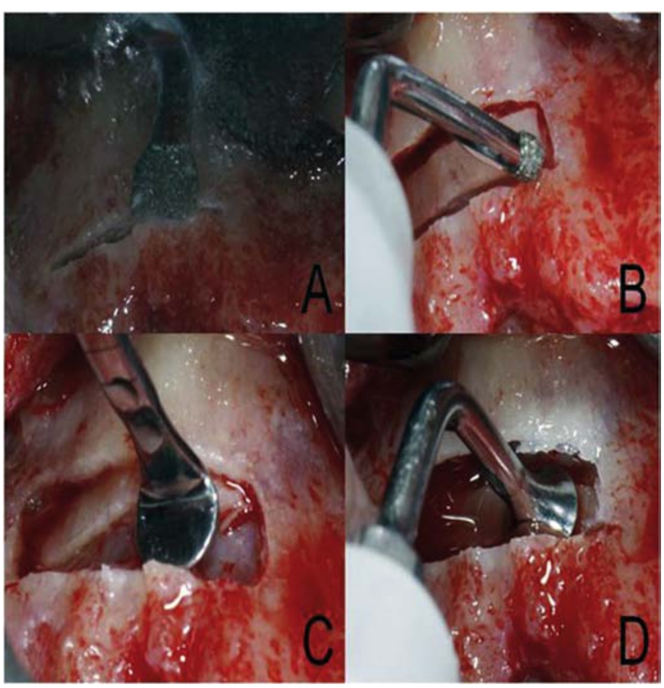


**Fig. 5.** Maxillary sinus can be reached by lateral approach using a piezosurgery. A bone access window can be prepared with a diamond-coated square or ball-shaped inserts (A and B), and the sinus membrane can be elevated with rounded soft tissue inserts (C and D).

**A) Mandibular bone block** is usually used as an onlay graft with the aim of increasing the bone thickness. It has been suggested that the use of a piezoelectric device would provide distinct advantages in the harvesting of a ramus graft [41]. For piezosurgical bone cutting, a

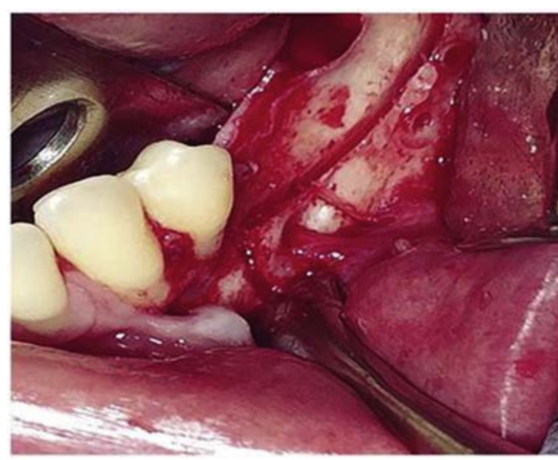

**Fig. 6.** Inferior alveolar nerve lateralization technique preventing injuries to the nerve at osteotomy time.

standard saw-shaped insert is usually preferred in an easy to see area in comparison to a dual-angled insert that is preferred in deep areas, especially for lower horizontal bone cutting during ramus bone graft harvesting (Fig. 7).

**B) In harvesting of iliac block bone graft** as is the case in the procedures of donor site and recipient site, piezosurgery usage may provide obvious advantages that include the good adaptation of grafts [42].

**C) Microvascular free bone flap harvesting** Shaping of vascularized bone flaps is routinely performed with the help of oscillating saws or rotating instruments. The use of mechanical instruments speeds up the osteotomy process but it poses the risk of damaging the vascular bundle that runs along the bone surface. Another field in which the piezosurgical device is applied nowadays is the harvesting of

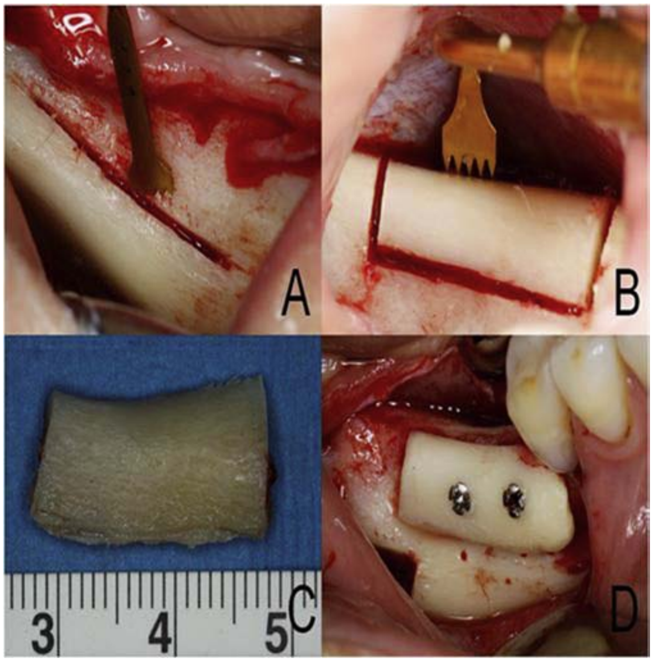


**Fig. 7.** Harvesting ramus bone graft can be achieved using a standard and dual-angled saw-shaped piezosurgery insert. Upper horizontal, anterior and posterior bone cuts can be performed using a saw-shaped insert (A), whereas lower horizontal cut can be performed with a dual-angled saw insert (B). Clean-cut edges of the harvested bone graft (C). Piezosurgery provides a bloodless and clear surgery during osteotomies and fixation of the bone graft (D).

microvascular free bone flaps. The piezoelectric device for mineralised structures, able to safely osteotomize the fibula without the need for any periosteal and pedicle dissection. Because protection of soft tissues is unnecessary with piezoelectric device, handling and shaping of the bone flap with the pedicle still connected to the donor site is clearly eased. In conclusion, this preliminary experience showed that segmentation of vascularized bone flaps with Piezosurgery is a valuable alternative to conventional cutting methods for the following reasons: 1) it improves the intraoperative safety of the procedure, ensuring an adequate periosteal blood flow to the bone segments; 2) it does not increase the overall operative time; 3) it does not interfere with bone flap survival and bone healing [43,44].

### 3.4. Orthognathic surgery

#### 3.4.1. Maxillofacial deformities

Ueki et al. did Le Fort I osteotomies to correct maxillofacial deformities using an ultrasonic bone curette to fracture the pterygoid plates on 14 patients with no damage to the surrounding tissue such as the descending palatine artery and other blood vessels and nerves (Fig. 8) [45]. Some authors have reported the use of ultrasonic devices for the cutting of bone in multiple-piece maxillary surgery to allow the surgeon to do surgically assisted rapid maxillary expansion under local anaesthesia. They emphasised the safety of the device and its slight indirect thermal damage to the bony surface and adjacent structures. Microscopic examination of bony fragments showed no signs of coagulative necrosis [46,47]. The vitality of pulpal teeth was maintained, and the temperature of the hand-piece was similar to that of other rotating and oscillating hand-pieces. There was little bleeding during the operation, and lack of damage to the main vessels and the reduction of post-operative swelling and haematomas, were striking.

#### 3.4.2. Aesthetic facial surgery

There are many approaches to osteotomy. In rhinoplasty lateral osteotomy should be precise, reproducible, and safe. It should also minimize postoperative complications, including ecchymosis and oedema. Chisels transmit a great deal of force to the underlying bone and soft tissues during lateral osteotomy. They are unguarded, used blindly, and are not usually perpendicular to the osteotomy line. They can therefore lacerate soft nasal tissue and damage the principal vessels, such as the nasal angular artery, and may increase the risk of bleeding and periorbital ecchymosis. Recently, Robiony et al. used piezoelectric devices for rhinoplasty and avoided these problems [48].

#### 3.4.3. Distraction osteogenesis

With ridges that require four to 5 mm of vertical height augmentation, or where the overlying soft tissue does not support osseous augmentation, distraction osteogenesis is a useful treatment alternative, with piezosurgery being an effective tool for distraction osteotomies [49].

When performing distraction osteogenesis in certain areas it is critical to complete the osteotomies delicately, because they are performed close to dental and periodontal structures, and to soft tissues that provide vascularisation. The advantage is that we can osteotomise as precisely as possible due to its micrometric and linear vibrations, and cause minimal damage to hard and soft tissues [50]. The use of piezosurgery can permit ideal osteotomy preparation without flap damage, providing abundant vascularisation that leads to successful new bone formation. Furthermore, it is possible to get direct visibility over entire osteotomies. The only minor limitation is the slightly longer time required for the operation (Fig. 9).

### 3.5. In enucleation of jaw cysts

Another area for the application of piezosurgery is the enucleation of jaw cysts. The use of piezosurgery for the treatment of jaw cysts and tumours is a new development and only a small number of applications have been reported in the literature [51,52]. One clear advantage of piezosurgery over conventional techniques is that it allows for careful

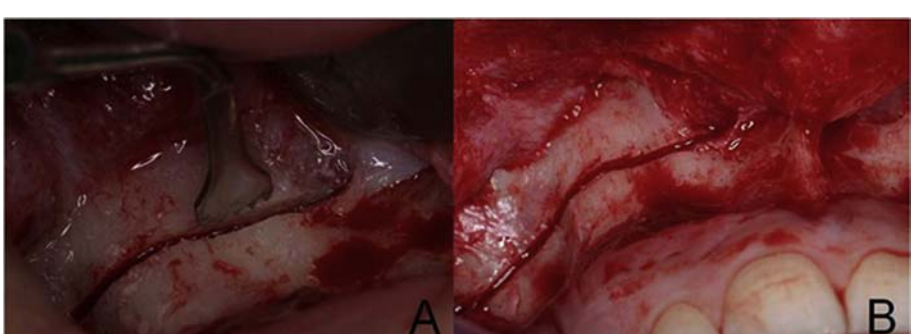


**Fig. 8.** Osteotomies necessary for the Le Fort I procedure can be achieved using piezosurgery (A and B). Lateral maxillary wall cuts can be performed using a standard saw-shaped insert, whereas medial wall cuts require a specifically designed insert.

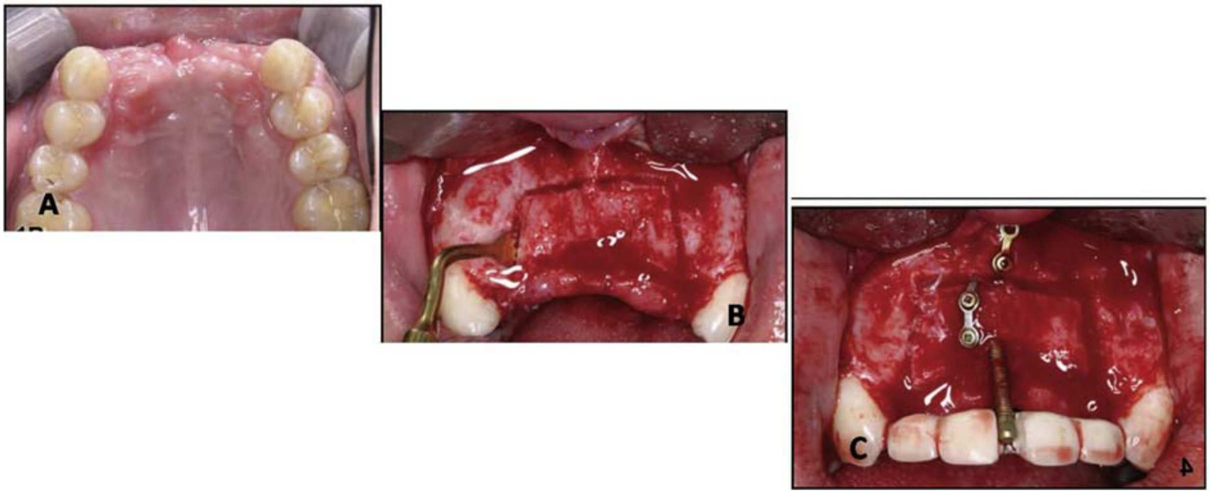


**Fig. 9.** A) Initial intraoral view showing the vertical and horizontal alveolar defect because of a traffic accident. B) A crestal incision was made along the alveolar ridge, and the labial mucoperiosteal flap was reflected maintaining the alveolar bone attached to the palatal periosteum. One horizontal and 2 vertical complete osteotomies were performed using Piezosurgery without any damage to the palatal periosteum. C) For vector control of segmented bone during distraction, a temporary resinbonded prosthesis was attached to the adjacent teeth. A groove in the prosthesis guided the direction of segmented bone during distraction.

removal of the thin bone laminate that covers the cyst and the meticulous handling of the cyst without tearing the epithelial wall. This may result in a reduction in the rate of postoperative recurrence and complications.

### *3.6. In resection of odontogenic tumours*

In the resection of odontogenic tumours, the application of piezosurgery is a contemporary approach that has been the topic of a small number of publications in literature [53–55]. The advantages of piezosurgery with regard to the protection of vital structures (e.g. neurovascular bundles) when surgery is within a close vicinity to those structures.

### *3.7. Temporomandibular joint surgery*

Temporomandibular joint ankylosis is the main indication for TMJ surgery in small animals, especially in cats. Condylectomy is a delicate procedure as the surgical access is narrow, the condylar process is elongated latero-medially, and the maxillary artery is located medial to the joint. When facing TMJ ankylosis, the normal anatomy is often distorted with severe bone remodeling and fusion. The author has had experience of power and hand instruments (chisel and rongeurs) prior to piezoelectric instruments for performing condylectomy. In his opinion, piezoelectric bone cutting instruments offer major advantage when dealing with this complex osteotomy. The LED illumination, continuous irrigation, precise cutting, and preservation of vascular structures allow a more effective and safer surgical procedure. Recently, this advantage was documented in the treatment of TMJ ankylosis in humans [56,57].

## 4. Conclusion

Piezosurgery can benefit the operator by allowing clear-cut precise osteotomies to be performed in a clear bloodless field without the risk of damaging soft tissues and nerves. The use of piezosurgery can equally benefit the patient by reducing postoperative swelling and trismus and speed up the recovery process. In addition, the lack of osteonecrosis caused by piezosurgery and the positive effects on bone healing and osteogenesis mean that piezosurgery is a valuable tool to have within your dental implant armamentarium. Piezosurgery appears to be an extremely advanced and conservative tool when compared with the existent methods for the treatment of bone and soft tissues.

## Conflicts of interest

The author has stated explicitly that there are no conflicts of interest in connection with this article."

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