Piezoelectric surgery in oral and maxillofacial surgery

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Abstract

Introduction

Piezoelectric device or piezosurgery device was originally developed for the atraumatic cutting of bone by way of ultrasonic vibrations and as an alternative to the mechanical and electrical instruments that are used in conventional oral surgery. Over the past two decades, an increasing amount of literature has shown that piezoelectric devices are innovative tools and that there is extensive indication of their use in dental implantology and oral and maxillofacial surgery. Recent publications have also shown the benefits of their use in craniofacial surgery, plastic and reconstructive surgery, head and neck surgery, neurosurgery, ophthalmology, traumatology, and orthopaedics. Key features of piezosurgery include the selective cutting of bone without damaging the adjacent soft tissue (e.g. vessels, nerves or mucosa), providing a clear visibility in the operating field, and cutting with micron sensitivity without the generation of heat. The cutting characteristics of piezosurgery are mainly depending upon the degree of bone mineralization, the design of the insert being used, the pressure being applied on the handpiece and the speed of movement during usage. Therefore, a novice user must know these factors and adapt their operating technique in order to utilize the advantages of piezosurgery.

This critical review summarizes the basic operating principles of piezoelectric devices and outlines the application areas in oral and maxillofacial surgery that piezosurgery can be utilized supported by clinical examples.

Conclusion

Piezosurgery can create clear vision of the surgical area from pressurized irrigation and cavitation effect. Disadvantages can include large initial costs. The number of studies covering this topic is insufficient; thus, further research needs to be conducted to enable us to learn more and clarify any misconceptions.

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. In recent times, the instruments that are being used for bone surgery have evolved to include motorized devices that can run on air pressure or electrical energy.

Motorized devices that make rotary, reciprocal or oscillatory movements 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, 2, 4, 5 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. This is of particular importance in the success of dental implants. The water jet device was developed by Schwieger et al.3 to cut through bone by spraying water at high pressures. It was not adopted in clinical practice.

The hard tissue surgery applied by deploying mid-infrared wavelength lasers can yield successful results in dental and bone applications. The thermo-mechanical ablation of erbium laser leads to ejection of mineral particles with preserved mineral structure and without any thermal damage. Although, there are still some problems with the application of laser in bone surgery such as depth control, the studies on mid-infrared wavelengths are promising and progressing increasingly.

Piezoelectric bone surgery is a relatively new alternative for bone-related procedures in oral and maxillo-facial surgery.6

The application of piezosurgery within dental surgery, implantology and maxillofacial surgery has been described in the current literature.6 Authors have argued that piezosurgery should take a place in the surgical armamentarium of a surgeon that deals with bone procedures. This critical review describes the current status of the application of piezosurgery within oral and maxillofacial surgery facilitated by the use of clinical case examples.

Discussion

The authors have referenced some of their own studies in this review. These referenced studies have been conducted in accordance with the Declaration of Helsinki (1964) and the protocols of these studies have been approved by the relevant ethics committees related to the institution in which they were performed. All human subjects, in these

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Creation of piezoelectric effect and ultrasonic vibration

The piezoelectric effect is the creation of electrical tension on some crystal and ceramic materials such as quartz to which a mechanical pressure is subsequently applied. The material in question will expand and then contract leading to an ultrasonic vibration. Also known as ‘pressure electrification’, it has been defined by the term ‘piezo’ derived from ‘piezein’, meaning pressure in Greek language.

The cutting of hard tissue with ultrasonic vibrations that are formed by the piezoelectric effect was first described by Catuna in 1953 and then by Volkov and Shepeleva in 1974. In 1981, its application was described by Aro et al. in orthopedic surgery, and Horton et al. in oral surgery. The first model of current piezoelectric devices is still being developed and heavily discussed in studies by Vercellotti et al. Piezoelectric devices operate with principles that are similar to the piezoelectric dental scaler devices, commonly used in the dental practice, but the ultrasonic dental scalers are not capable of cutting through hard tissues. The most innovative feature of the piezoelectric device is selective cutting. Although piezosurgery cuts mineralized tissues such as bones, it does not cut soft tissues such as vessels, nerves and mucosa.

Piezoelectric devices typically consist of a handheld device (handpiece), a base unit and a foot pedal. There are different-shaped inserts that correspond to different applications that can be screwed into the handpiece. The handpiece is controlled by a foot pedal with settings that can be adjusted on the base unit. The first model of piezoelectric devices was developed by Vercellotti et al. and is generally called as ‘Piezosurgery’ in reference to the first model (Figure 1).

Mechanisms of action of piezoelectric devices

The following effects are considered as the distinguishing features of piezoelectric surgery: cavitation, heat, formation of bubbles, ultra massage, electrical, and acceleration. The cavitation effect of piezoelectric surgery is crucial in bone surgery. Cavitation is the formation and the immediate implosion of cavities within a liquid (i.e. small liquid-free zones, ‘bubbles’). These bubbles are formed as a consequence of the forces that are acting upon a liquid. It typically occurs when a liquid is subjected to a rapid change in pressure, leading to the formation of cavities within the liquid where the pressure is relatively low. In piezoelectric surgery, the cavitation phenomenon describes the process of vapourization, bubble generation and subsequent implosion (growth and collapse of bubbles) into many minute fractions of its original size (microscopic gas bubbles) that will occur in a flowing liquid as a result of the decrease and increase in pressure that is caused by the ultrasonic vibrations. In ultrasonic osteotomy, the cavitation phenomenon helps to maintain good visibility in the operative field by dispersing a coolant fluid as an aerosol that causes the blood to essentially be washed away. Furthermore, the cavitation effect will bring about haemostasis, which results in a bloodless surgery. Walmsley et al. has suggested that the cavitation effect fragments the cell walls of bacteria, and therefore has an anti-bacterial efficiency (Figure 2).

Cutting characteristics of piezoelectric devices

A number of piezoelectric devices with similar mechanical parts are available, each having specific cutting characteristics. The cutting characteristics of piezoelectric devices are determined by the type of insert, the size of the vibrational head, and the frequency and intensity of vibration. The most common types of piezoelectric devices are ultrasonic dental scalers, which are commonly used in the dental practice, and piezoelectric devices used in the oral and maxillofacial surgery. The cutting characteristics of piezoelectric devices can be divided into three categories: soft tissue cutting, hard tissue cutting, and bone cutting. Soft tissue cutting is performed using high-frequency vibration with low intensity, whereas hard tissue cutting is performed using low-frequency vibration with high intensity. Bone cutting is performed using high-frequency vibration with high intensity, which causes the cavitation effect and constant irrigation provide a contemporary picture of novel piezosurgery principles. Cavitation effect and constant irrigation provide a bloodless surgery that ensures a clear visibility of the surgical site.
available on the market and newer versions in development. Typically, devices will come with pre-set settings for the intended procedures. These settings may vary between the different brands and it is, therefore, down to the clinician to know the basic action principles of piezosurgery and to build up his own device preferences from experience.

The cutting characteristics of piezosurgery are dependent upon the degree of bone mineralization (density), the design of the insert, the pressure applied on the handpiece during use and the speed of movements during use. The frequency of ultrasonic vibrations (Hz), the level of power (W) and the water spray are three adjustable settings that should be set in accordance with the intended procedure.

Bone mineralization (density)
Positive correlation exists between the cutting efficiency of piezosurgery and the level of bone mineralization. The degree of bone mineralization is used to determine the frequency of vibration (Hz) that the device should be set to for an effectively cutting the bone. Low frequency of vibrations may be chosen in low mineralized bone, whereas high frequency of vibrations, up to 30 Hz, may be chosen in highly mineralized bone. In addition, alternating with pauses provides for optimal cutting in highly mineralized bone. Alternating high frequencies with pauses prevents the insert from being lodged in the bone, thus avoiding overheating.

Insert design
There is a range of inserts (tips) available on the market and newer ones are in development. Tips can vary in size, shape and material. Insert design may impact on the level of power (W) that should be set for an intended procedure. For the effective cutting of highly mineralized bone with a saw-shaped insert, high power levels are required.

Pressure applied on the handpiece
In contrast to the conventional microsaw or drills that can require a significant level of pressure, piezosurgery requires only minimal pressure. Claire et al. observed that excessive pressure on the piezosurgery insert led to a reduction in oscillations and hence the cutting ability. The results of their experimental study recommended that a contact load of 150 g provide the greatest depth of cut.

Speed of handpiece movements
Piezosurgery inserts should be moved forwards and backwards continuously at a high speed with minimum pressure. Slow movements over the bone and excessive pressure on the handpiece will decrease the

Figure 3: Implantsite preparation can be performed with a specifically designed set of piezosurgery inserts in lieu of conventional drills (A). An internal serum flow canal inside the inserts ensures constant irrigation and cooling of the bone during the preparations (B).

Figure 4: Basic preparation sequences of piezosurgical implant site. Cutting insert with a 2-mm diameter used for pilot osteotomy (A); cylindrical diamond-coated insert with 2.4-mm diameter used for differential preparation (B); cutting insert with 3-mm diameter used for final preparation (C) and an implant being inserted (D). There is still a need of using the final drill of the selected implant system in order to tightly accommodate the implant into its socket.
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Figure 5: 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).

Applications of piezosurgery in oral and maxillofacial surgery:
- In dento-alveolar procedures:
  - Separating the tooth roots.
  - Hemi-section, root amputation.
  - Periodontal surgery.
  - Apical resection and endodontic treatments.

In dental implantology:
- Implant socket preparation.
- Alveolar ridge splitting and expansion.
- Re-contouring of alveolar crest.
- Mental nerve reposition.

In maxillary sinus bone grafting surgery:
- Preparation of bone window with lateral approach.
- Atraumatic dissection of sinus mucosa.
- Internal sinus floor elevation.

In maxillofacial bone surgery:
- Harvesting of autogenous bone grafts.
- Alveolar decortication and corticotomy.
- Orthognathic surgery.
- Alveolar distraction.
- Removal of cystic and tumour-like lesions.

micro-movements and cause an increase in the bone temperature.

Clinical applications of piezosurgery in oral and maxillofacial surgery

In 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. In working around the mandibular canal or maxillary sinus, piezosurgery may prevent nerve damage; even in the case of accidental contact with the working insert tips. Piezosurgery also permits planning of the root surfaces and the removal of inflammatory tissue in periodontal operations.

Figure 6: Piezosurgery has an indication in the dissection of the thin and delicate soft tissues such as sinus membrane with special inserts. A rounded, dull, bell-shaped or curette-shaped insert can be used to elevate the sinus membrane at the beginning of the dissection during sinus bone grafting.
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In maxillary sinus bone grafting surgery
Another intra-oral use of piezosurgery is in sinus bone grafting surgery. Piezosurgery can be used during the preparation of a bony window and in atraumatic dissection of a sinus membrane with a lateral approach (Figures 6 and 7). Perforation of the sinus membrane is the most common complication of sinus bone grafting and Wallace et al. reported that piezosurgery could minimize sinus perforation rates.

In harvesting of autogenous bone chips
Autogenous bone chips can be harvested from intra-oral sources with the use of piezosurgery. There is an inconsistency in the literature with some authors favouring the use of piezosurgery with regards to the number of living cells, such as osteocytes, and others that scrutinize the use of piezosurgery owing to the lower percentage of living cells when compared with conventional techniques.

In harvesting of mandibular ramus block bone graft
In dental implantology and maxillofacial surgical procedures, the mandibular ramus area is frequently preferred as an autogenous bone graft. 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. For piezosurgical bone cutting, a 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 (Figure 8).

In harvesting of iliac block bone graft
Iliac bone grafts are frequently preferred in the reconstruction of jaw

Figure 7: Maxillary sinus can be reached by lateral approach using 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).

In dental implantology
Piezosurgery has extensive applications in dental implantology. It can be used in hard tissue procedures, such as implant site preparation and ridge split, and in soft tissue procedures such as maxillary sinus lifting.

As a new technique, implant site preparation can be performed with a specifically designed set of piezosurgery inserts (Figure 3). Piezosurgical site preparation allows for the selective enlargement of only one socket wall. This is called ‘differential ultrasonic socket preparation’ by Vercellotti. Piezosurgical site preparation provides a similar primary stability and short-term survival rate of an implant when compared with conventional site-preparation techniques. Stelzle et al. emphasized that the applied load on the handpiece may increase the preparation speed but may also increase the negative thermal effect on the bone. Therefore, it is recommended that a maximum load of 400 g is used during implant site preparation (Figure 4).

Piezosurgery is a predictable method that can be used to perform split-crest procedures without the risk of bone thermo-necrosis, and it also carries a reduced risk to the damage of the adjacent soft tissues (Figure 5). Bone cutting efficiency is satisfactory with the current devices because of the enhanced vibration power, especially in soft type IV bone.
In orthognathic surgery

The application of piezosurgery in orthognathic surgery has gained popularity among oral and maxillofacial surgeons. It has been used for sagittal split ramus osteotomies, Le Fort I osteotomies, and surgically assisted rapid maxillary expansion and minor microsurgical procedures\textsuperscript{23-25}. Landes et al.\textsuperscript{23} conducted a large study on 90 patients in which piezosurgery was performed in orthognathic surgery. The study concluded that surgery time remained the same and the amount of blood lost was decreased in the case of Le Fort I osteotomies when compared with conventional methods. They also observed that the piezosurgery tips were unable to reach all of the desired positions and the additional use of chisels was required for the final separation of the nasal septum and dorsal lateral nasal cavity, and the pterygo-maxillary suture in some cases (Figure 11).

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\textsuperscript{26,27}. One clear advantage of piezosurgery over conventional techniques is that it allows for careful 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\textsuperscript{26} (Figure 12).

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 case reports. It provides a bloodless and clear surgery during osteotomies and fixation of the bone graft. Usage may provide obvious advantages that include the good adaptation of grafts\textsuperscript{22} (Figures 9 and 10).

Figure 8: 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).

Figure 9: A block-bone graft can be harvested from iliac crest using a saw-shaped piezosurgery insert (A). The ridge of the iliac crest can be divided in two halves to harvest a monocortical bone block. As a modified method, lower horizontal bone cut performed with dual-angled saw insert (B).
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Reaches the same conclusion as of Pavlikova et al. that sufficient clinical studies are not available at this point in time to perform a meaningful meta-analysis. 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 osteocytes and it induces an earlier 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.

References

6. Pavlikova G, Folkan R, Horka M, Hanzelka T, Borunská H, Sedý J. Piezosurgery in the oral and maxillofacial surgery. A survey of publications in literature 28–30. The case that was presented by Yaman et al. is rather outstanding in view of the fact that it reveals 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 (Figures 13 and 14).

Conclusion

Only 10 of 152 papers met the inclusion and exclusion criteria. Most studies on the use of piezosurgery are case reports and clinical experiences of surgeons that rarely adhered to the recommendations of the International Committee of Medical Journal Editors. Therefore, this critical review
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Figure 14: Lateral maxillary wall was removed using piezosurgery and direct access to tumour was ensured (A). The extremely hard tumour was excised in small pieces with piezosurgery and no harm was done to the adjacent important anatomical structures (B). Following tumour excision (C), the bone defect on the lateral sinus wall was reconstructed again using piezosurgery by means of harvesting bone graft from mandibular ramus area.