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The Present Status and Current Understanding of Piezosurgery

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Abstract

Dentistry has undergone significant advancement and has seen several changing concepts over a decade. One such novel innovation is piezosurgery. Piezoelectric bone surgery or otherwise known as piezosurgery is a novel technique invented by Vercellotti in 1988 to overcome the limitations of traditional instrumentation in oral bone surgery by modifying and improving conventional ultrasound technology. Piezosurgery's patented, controlled three-dimensional ultrasound vibrations open up a new age for Periodontology, Implantology, Endodontics and Surgical orthodontics. The absence of macrovibration makes the instrument more manageable and allows greater intraoperative control with a significant increase in cutting safety in the more difficult anatomical cutting zone. Therefore the aim of this review is to describe peiezosurgical devise and its use in the field of periodontology and implantology in detail.

Keywords: Peizosurgery, Peizoelectric devise, ultrasonic, cavitation

Introduction

Ultrasonic vibrations have been used to cut tissue for two decades.[5] The instruments used for ultrasonic cutting of bone create microvibrations that are caused by the piezoelectric effect was first described by the French physicists Jean and Marie Curie, in 1880. The PiezoSurgery device uses low-frequency piezoelectric ultrasonic vibrations precisely cutting the bone without cutting the soft tissue. Piezosurgery's patented, controlled three-dimensional ultrasound vibrations open up a new age for Periodontology, Implantology, Endodontics and Surgical orthodontics. The piezosurgery device is essentially an ultrasound machine with modulated frequency and a controlled tip vibration range. The low frequency enables cutting of mineralized structures, not soft tissue. The piezosurgery tip vibrates within a range of 60-/200 mm, which allows clean cutting with precise incisions. Because the instrument's tip vibrates at different ultrasonic frequencies, since hard and soft tissues are cut at different frequencies, a "selective cut" enables the clinician to cut hard tissues while sparing fine anatomical structures (e.g., schneiderian membrane, nerve tissue). [10] As a result, implantology surgical techniques such as bone harvesting (chips and blocks), crestal bone splitting, and sinus floor elevation can be performed with greater ease and safety. Therefore the aim of this review is to describe peiezosurgical devise and its use in the field of periodontology and implantology in detail.

Historical background

Piezosurgery is based on the piezoelectric effect, first described by French physicists Jean and Mari Curie in 1880 as direct Piezo-Effect, which states that certain ceramics and crystals deform when an electric current is passed across them, resulting in oscillations of ultrasonic frequency. The vibrations obtained are amplified and transferred to a vibration tip which, when applied with slight pressure on bone tissue, results in a cavitation phenomenon – a mechanical cutting effect that occurs exclusively on mineralised tissue.

Shelley and Shelley 1986[12] described the Piezoelectric unit which work on ultrasonic vibrations similar to the commonly used ultrasonic system for calculus removal, however, a pulse of 50 kHz was added every 10 ns to the baseline frequency. This addition had given the unit the ability to cut through bone, but not soft tissues.

Piezosurgery an ultrasound device was introduced in medical practice by Vercellotti in 1988 for different procedures in application to hard tissue surgery. However, the ultrasonic cutting device developed by him was relatively underutilized immediately following its debut. In 1998[13], Torella et al. reported low cutting efficiency and performance and suggested only a thin and pointed headpiece could be used for the osteotomy and therefore, the sinus membrane could be easily injured by the headpiece during the surgery, and also the risk of burning the bone was too high in case of a bone wall thicker than 1 mm.

Vercellotti et al (2001)[14] developed a suitable device for routine work in oral surgery that particularly replaced conventional osteotomy instruments. Vercellotti in 2003[15] used this instrument in research on animals to compare its traumatic effect with that of traditional orthopedic surgery and reported that it allows for more precise cut and a clearer view of the surgical field because of its control over bleeding. Moreover, at histologic examination, the cut surfaces showed no signs of necrosis or pigmentation, whereas the presence of vital osteocytes was observed.

Hoigne et al (2006)[4], performed the first ultrasound osteotomy in hand surgery. The cut was highly precise and there were no vibrations of the bone. Bone healing was good and at no point were there any neurovascular disturbances.

Mechanism of action

Ultrasonic waves are mechanical waves which, because of the phenomenon of agitation, can induce the disorganization and fragmentation of different bodies. The ultrasonic vibrations can easily allow the segmentation of interfaces from solid to solid by means of distinct vibration, and solid-liquid by means of cavitation. Finally, as any intense energetic phenomenon, ultrasounds may cause thermal effects: it is possible to burn biologic tissues with ultrasounds, which explains the need to couple up ultrasonic instrumentation with an adequate irrigation to cool down the working parts of the tissue. Pierre Curie discovered piezoelectricity in 1881. Piezoelectricity is a physical phenomenon that is specific to certain crystals (eg, quartz) and is defined by the appearance of electrical charges on the crystal surface when submitted to mechanical constraint. Therefore, inverse piezoelectricity is the opposite phenomenon: when an electric current is applied to a crystal a mechanical deformation is induced. If the current is alternative, the crystals extend and retract alternatively. Finally, if the current is alternative and of an intermediate frequency, the crystals are then subject to mechanical oscillations of medium frequency: these intermediate frequency microvibrations create ultrasonic waves in gases and liquids. Practically, quartz crystals have long been abandoned in medical applications of piezoelectricity. Today we use piezoelectric ceramic chips made of Barium titanium or its equivalent. Indeed, its resistance to vibrations and resonance frequencies are more adequate for clinical applications.

Cavitation

Cavitation is a microboiling phenomenon occurring in liquids on any solid-liquid interface vibrating to intermediate frequencies. When the water jet comes in contact with the insert vibrating to intermediate frequencies, it is sprayed in a cavitation fog (ie, in irrigation bubbles exploding on surfaces to cleanse).

Parts of piezosurgical device

It consists of a shaft, an insert and a generator of intermediate frequency periodic current. Inside the shaft, the piezoelectric ceramic chips are piled up to generate intermediate frequency vibrations. If adequate inserts are plugged on it, it may even serve as a conventional detartrating tool. However the piezoelectric device differs from these conventional tools by 4 parameters: the generator's frequencies, and the insert's weight, hardness, and form.

The generator is composed of 3 settings in frequency:

- The first setting passes on 29,000 Hz frequencies to the insert, enabling conventional detartrating when used with the adequate inserts.
- The second setting uses 29,000 Hz modulated in 50,000 Hz every 30 ns to get a moderate cut effect. It remains inefficient for bone surgery, but is an excellent compromise for periodontal surgery.
- The third setting uses 29,000 Hz frequencies modulated in 50,000 Hz every 10 ns to obtain a maximum cut effect. This setting is the most interesting for us as it enables us to have a maximum resonance between the piezoelectric chips of the shaft and the inserts of corresponding weight, implying a maximum energetic output and optimum cut efficiency.

Each frequency setting may be associated with a different power depending on the work. In bone incisions, however, maximum power is needed to have a sufficient cut effect.

The hardness of the insert is increased by a superficial layer of titanium nitride sometimes diamond-coated, enabling the insert to face the hardest materials without breaking. Finally, the different forms of inserts permit a cut effect when the cutting edge transforms into a micrometric oscillating saw under the effect of ultrasonic vibrations.

Method of use

The most important part of the device is the piezoelectric handpiece, connected to the main unit, which has holders for the handpiece and irrigation fluids. A foot switch activates the interchangeable handpiece tips when an electric current is passed across them, resulting in oscillations of ultrasonic frequency. The vibrations obtained are amplified and transferred to a vibration tip which, when applied with slight pressure on bone tissue, results in a cavitation phenomenon – a mechanical cutting effect that occurs exclusively on mineralised tissue.[2] The piezosurgery unit is approximately three times as powerful as a conventional ultrasonic dental unit, allowing it to cut highly mineralised cortical bone. The frequency of vibrations and power of cutting, as well as the amount of irrigation, can be adjusted. The frequency is usually set between 25 and 30 kHz. This frequency causes microvibrations of 60– 210 μm amplitude, providing the handpiece with power exceeding 5 W.

Low mode is useful for apical root canal treatment in dentistry. High mode is useful for cleaning and smoothing bone borders.

Boosted mode is most often used in oral and maxillofacial surgery in osteoplasty and osteotomies. In the boosted mode, digital modulation of the oscillation pattern produces alternating high-frequency vibrations, with pauses at frequencies up to 30 Hz; which prevents the insert from impacting bone and thus avoids overheating, while maintaining optimal cutting capacity.

Light handpiece pressure and an integrated saline coolant spray keep the temperature low and the visibility of the surgical site high.[16] To increase cooling effectiveness, physiological sodium chloride solution at a temperature of approximately 4°C was used for irrigation. After prolonged cutting, the handpiece warms up so a short pause may be necessary to allow it to cool.[3] The cooling system is generally less efficient when cutting deep layers of bone because increased pressure on the bone decreases cutting speed, so interrupted cutting is advisable. In the case of a deep osteotomy, the combination of piezosurgery and subsequent use of a chisel is useful.

In use, the handpiece is guided firmly over the bone, but without excessive force. In contrast to conventional microsaws or drills, to which the surgeon must apply a certain degree of pressure, the piezosurgery device needs only minimal pressure, permitting a precise cut. Pressure acts in a clearly counterproductive manner, limiting movement of the instrument tip and generating a significant amount of heat. The sound of the cutting can be used as acoustic feedback for the force to be used. At maximum pressure, when the tip stops moving and only heat is generated, a tone warns that bone damage is imminent so cutting should be stopped immediately. The translation speed, the speed of the tip in contact with bone, has an effect on the cutting power. High-level surgical control is required for piezosurgery, because the strength required to cut bone effectively is far less than that required for a drill or oscillating saw. This different bone cutting principle requires a change of habits from those used in conventional osteotomy and osteoplasty techniques.

Advantages

1. Precise cutting and safety
2. Great control of the surgical device
3. Bleeding-free surgery site
4. Selective cutting and minimal operative invasion
5. Faster bone regeneration and healing process
6. No risk of emphysema
7. Decrease in post-intervention pain
8. Reduced traumatic stress

Disadvantage

1. Increased operation time.

Precautions

The use of irrigation is essential, not only for the effect of cavitation, but also to avoid overheating.[13] The intensity of the cooling liquid can be adjusted depending on different preparations.

A. Medical application of piezosurgery

a. Otological Surgery

In otological surgery, bone is usually cut by manual or motorised instruments. Salami et al (2007)[8]. reported various operations using piezoelectric devices on patients under general anaesthesia with orotracheal intubation; stapedotomy and chain replacement using a prosthetic implant in the stapes footplate hole, antrotomy, classic mastoidectomy of the intact canalwall, posterior tympanotomy, decompression of the facial nerve, and excision of a glomus tumour of the middle ear.

b. Orthopaedic and hand surgery

A piezoelectric device was used for an osteotomy to correct a 45^{o} post-traumatic deformity of the 5th metacarpal neck to avoid postoperative complications.[9]

c. Neurosurgery

Schlee (2005)[10] reported the successful use of piezoelectric surgery technique spared soft nerve tissue, avoided coagulative necrosis, improved the visualisation of the surgical field, and resulted in a more precise cut. Kotrikova et al (2006)[6] showed that piezoelectric surgery used after osteotomy in high-risk patients, avoided perforation of the dura.

B. Application in dentistry

a. Maxillofacial surgery

1. Reconstructive surgery

Crosetti et al (2009)[2] claimed that the main advantages of using piezosurgery technique are: precision in performing osteotomies close to important soft tissues such as the inferior alveolar nerve or the dura mater; minimal bleeding from soft tissues surrounding the osteotomy line; and minimal trauma to the bony part of the flap, necessary for reconstruction.

2. Orthognathic surgery

The piezosurgery has been used for minor orthodontic microsurgical procedures, and for orthognathic surgeries such as BSSO, surgically assisted rapid maxillary expansion (SARME) and Le Fort I osteotomy .[7]

b. Orthodontic Surgery

Corticotomy-facilitated (CF) orthodontics simplifies orthodontic treatment in adult patients and makes it possible to accomplish complex movements in relatively short periods. The precision of the piezosurgery micro-saw permits a safe corticotomy around the root.

c. Endodontic surgery

Ultrasonic surgery became established in Endodontics (Walmsley et al 1992)[17] after initial reports by Catuna in 1953[1] on the use of high-frequency sound waves to cut hard dental tissue. Ultrasonic oscillations can also be used to remove root canal fillings and fractured instruments from root canals (Ward et al 2003)[18].

d. Application in implant therapy

The introduction of piezoelectric surgery to implant dentistry offers an alternative technique to implant placement that professes to address some of the shortcomings of the conventional system.[11] Therefore, recently various investigators applied piezoelectric system for ridge augmentation, maxillary sinus elevation, nerve lateralization and preparation of implant site. They have compared the efficacy of piezoelectrical device with conventional instruments to find out added benefit of this new device over the conventional instrument commonly used for ridge augmentation, maxillary sinus lift, nerve lateralization and for preparation of implant site.

Conclusion

Piezoelectric devices are an innovative ultrasonic technique for safe and effective osteotomy or osteoplasty compared with traditional hard and soft tissue methods that use rotating instruments because of the absence of macrovibrations, ease of use and control, and safer cutting, particularly in complex anatomical areas. Its physical and mechanical properties have several clinical advantages: precise cutting, sparing of vital neurovascular bundles, and better visualisation of the surgical field. Piezoelectric bone surgery seems to be more efficient in the first phases of bony healing; it induces an earlier increase in bone morphogenetic proteins, controls the inflammatory process better, and stimulates remodelling of bone as early as 56 days after treatment. Currently, long term results following piezosurgery, which would allow for a critical evaluation of this new surgical method, are still lacking.

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