Case Study

Piezosurgery: Advancing Dentistry With Cutting-Edge Technology

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Abstract

Dentistry, an amalgamation of art and science and a calming force in medicine, has undergone substantial conceptual changes in the past decade. One noteworthy innovation in this field is piezosurgery, marking a genuine revolution in bone surgery by satisfying both biological and technical criteria.

Piezosurgery finds diverse applications, ranging from minor surgical procedures to intricate tasks such as implantology, plastic surgery, and reconstructive surgeries. Operating with a low-frequency modulated ultrasonic insert, it generates microvibrations within the range of 60-200 micrometers per second. This technique enables safe and precise bony incisions without causing harm to essential structures like nerves, mucosa, and vessels.

Noteworthy advantages of piezosurgery include overcoming technical challenges like visibility by establishing a bloodless field during surgery and simultaneously removing debris through an internal irrigation mechanism. This method ensures the safety of soft tissues, and the biological factors, including the release of certain cytokines, contribute to promoting bone healing and expediting patient recovery.

This in-depth evaluation favors piezosurgery over conventional tools, underscoring its clinical and biological attributes that contribute to the advancement of dental health.

Keywords: Cavitation, Implants, Osteotomy, Piezosurgery.

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Introduction

In recent years, dentistry has experienced significant advancements in its daily practice.[1] Modern diagnostic imaging techniques like Ultrasonography, Cone Beam Computed Tomography, and procedures such as Microsurgery, Implants, Lasers, and Nanotechnology have positioned dentistry at the forefront of the medical field.[2] These innovations have ushered in an era of painless dentistry.

The efficacy of any dental treatment modality hinges on the tools utilized for its execution.[3] Hard tissue cutting tools, such as micromotor handpieces and aerotors, play a crucial role in removing enamel, dentin, cementum, and bone. The quantity and quality of hard tissue removal significantly impact the post-operative outcome of dental surgical procedures, whether in implantology or periodontology.[4]

Traditional dental practices involved the use of hand cutting instruments like mallets and chisels, followed by rotary instruments equipped with various burs. These instruments generated considerable heat during bone cutting and necessitated extensive external irrigation. Additionally, they exerted substantial pressure on osseous Surgeries, consequently, posed a threat to the treatment of fractured and brittle bones.[3]

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In order to address the limitations of traditional tools, researchers have developed advanced therapeutic devices that leverage the principle of ultrasonic microvibrations to achieve precise and selective bone cuts while maintaining harmony with surrounding tissues.[4,5] A notable method embodying these ultrasonic properties is Piezosurgery, which represents a relatively recent alternative for bone-related procedures within the realm of dentistry. Utilizing devices operating on piezoelectric principles, Piezosurgery demonstrates significant potential, capable of making cuts through ultrasonic vibrations.[5,6]

These vibrations manifest as low-frequency modulated vibrations, typically ranging from 25 to 30 kHz. Importantly, they selectively cut the bone without causing damage to adjacent soft tissues, particularly delicate structures like the schneiderian membrane or a nerve.[6]

In practical terms, the devices operating on piezoelectric principles are commonly referred to as piezosurgery, a term derived from the name of the first device introduced to the market.[5]

History of Piezosurgery

The instruments employed for the ultrasonic cutting of bone generate microvibrations, a phenomenon resulting from the piezoelectric effect first described by French physicists Jean and Marie Curie in 1880 [7]. The utilization of ultrasonic vibrations for cutting hard tissue as a piezoelectric effect was elucidated by Catuna in 1953 and later by Volkov and Shepeleva in 1974.[8] Subsequently, its application in orthopedic surgery was outlined by Aro et al. in 1981,[9] and in oral and maxillofacial surgery by Horton et al. in the same year.[10]

Italian oral surgeon Tomaso Vercellotti made modifications to conventional ultrasonic technology.[6] In 1997, Mectron and Tomaso Vercellotti collaborated to develop the concept of piezoelectric bone surgery, marking a significant technological advancement by adapting ultrasound movement for bone cutting. Mectron produced the initial prototype device for piezoelectric bone surgery, which was utilized for the first extraction treatments. In 1999, Tomaso Vercellotti coined the term PIEZOSURGERY® for this innovative method. Mectron further enhanced the technology by introducing the second generation of the piezosurgery device in 2004, offering increased power compared to its predecessor. The third generation of the piezosurgery device was introduced in 2009. Currently, piezosurgery is widely and successfully employed in implant dentistry.

Working Principle of Piezosurgery

The term 'Piezo' is derived from the Greek word 'piezein,' which means pressure. Piezosurgery operates on the principle of 'Pressure Electrification,' wherein the application of electric tension across certain materials causes them to expand and contract, generating ultrasonic vibrations.[5]The materials utilized in this process are piezoelectrical crystals, including quartz, Rochelle salt, and specific types of ceramics. When subjected to an electrical charge, these crystals alternate between expansion and contraction, producing ultrasonic waves. As these waves are mechanical in nature, they can induce disorganization and fragmentation in different bodies. In dentistry, these ultrasonic waves are employed to segment interfaces from solid to solid through distinct vibrations and solid-liquid interfaces through cavitation.[6]

Various Piezoelectric oscillating tips are available for specific applications. For instance, a disc-shaped tip produces a plane ultrasonic wave, while curving the radiating surface in a slightly concave or bowl shape creates an ultrasonic wave that focuses at a specific point.[5]

The microvibrations generated by the piezoelectric unit occur at a frequency of 25 to 29 kHz, modulated with a low frequency of 10 to 60 Hz, and reaching up to 30 kHz at the highest.[4] The linear vibrations of the tips range horizontally between 60 and 200 micrometers and vertically between 20 and 60 micrometers.[11] The controlled speed of the ultrasonic tip's vibration is set at 60-200 mm/sec, targeting the cutting of only mineralized tissue without harming adjacent soft tissues.[12] Frequencies above 50 kHz are capable of cutting neurovascular and other soft tissues.[13] The vibration amplitude is adjustable in the range of 30-60 micrometers, allowing constant adaptation of the power required based on the resistance encountered by the tip. The device's power is set at 5W, as power and precision are inversely proportional. Therefore, 5W represents an ideal compromise between power and precision. The oscillating tip simultaneously dispenses coolant, producing a cavitation effect.[14]

Cavitation describes the process of vaporization, bubble formation, and subsequent implosion into many fractions of its original size due to the decrease in pressure resulting from ultrasonic vibration. When pressure increases, the voids implode, generating an intense shockwave.[14] The cavitation effect necessitates a low vapor pressure of the oscillating tip. This effect maintains bone temperature, removes debris, regulates hemostasis, and clears the field by bursting water bubbles under high pressure. This erosion and cleaning of the osseous crest increase visibility and ease of operation.[15]

Moreover, cavitation illustrates an antibacterial property, contributing to high predictability and low morbidity in bone surgery. This antibacterial property is attributed to the fragmentation of bacterial cell walls.[14]

The operation of the piezoelectric device can be outlined through the following key aspects:

- **Micrometric Cutting:** Accurate bone cutting with heightened tactile sensitivity.
- **Selective Cutting:** Precision in bone cutting without jeopardizing adjacent soft tissues.
- **Asepsis:** Utilization of sterile water.[4]
- **Cavitation Effect:** Enhancing intraoperative visibility and ensuring high predictability.
- **Minimum Surgical Stress:** Facilitating excellent tissue healing.[6,9]

Equipment

Vercellotti et al.[6] pioneered the development of the initial model of piezoelectric devices, commonly referred to as 'Piezosurgery' in homage to the first model. Typically, piezoelectric devices comprise a handheld device (handpiece), a base unit, and a foot pedal/switch connected to the main power unit. Various inserts of distinct shapes, corresponding to different applications, can be affixed to the handpiece. Controlled by a foot pedal, the handpiece settings can be adjusted on the base unit. The device includes a holder for the handpiece and features an irrigation system that produces an adjustable jet ranging from 0 to 60 ml/minute through a peristaltic pump. This system effectively removes debris from the cutting area, ensuring precision in cutting. It also creates a blood-free operating environment due to the cavitation of the irrigation solution[5], providing enhanced visibility, especially in complex anatomical regions. The device's control panel comprises only four buttons, facilitating user-friendliness and cost-effectiveness. Speed and irrigation can be regulated using the (-) and (+) buttons on the control panel. The continuous irrigation flow throughout the procedure is guaranteed by internal safety controls.[6,15]

When utilizing the piezosurgical handpiece, it is essential to exercise caution and avoid applying excessive load or pressure. The pressure exerted by the handpiece has an inverse relationship with bone temperature. Therefore, it is recommended to move the inserts continuously backward and forward at a high speed with minimal pressure.[5] To achieve maximum depth, a load of 150 grams is required.[16] Excessive pressures can diminish oscillations and consequently reduce cutting ability.

The cutting characteristics of piezosurgery are influenced by factors such as the degree of bone mineralization, its density, the insert design, and the pressure exerted on the handpiece.[17] Three adjustable settings—frequency of ultrasonic vibrations (Hz), power level (W), and water spray—should be configured in accordance with the specific procedure requirements.[5]

Insert Designs

The precision, predictability, and treatment outcomes of any surgical procedure are contingent on the design of the tools and the employed technique.[18] Various insert designs can be utilized based on the specific surgical requirements and type of procedure. The size and configuration of the inserts, along with their intended purpose, dictate the level of power needed. For instance, an insert with a saw-like shape, employed for cutting highly mineralized bone, necessitates a high level of power.[18]

Sharp Inserts: The keen edges of these instruments facilitate a gentle and effective cut on mineralized tissue. They prove valuable in osteotomy procedures like implant site preparation, osteoplasty, and other surgical techniques requiring a fine and well-defined cut.
Examples include Design No: OT-7, EX1, OP-3, IM2A, and IM3P.

Smoothening Inserts: These inserts feature a diamond surface coating that enables precise and controlled work on bony structures to achieve the final bone shape. They are particularly useful for preparing challenging and delicate structures, such as the sinus window or access to nerves.

Examples include Design No: OT5, OT-1, OT-4, and OP-4.

Blunt Inserts: Characterized by a blunt, dull, and rounded non-cutting tip, these inserts work wonders in atraumatic elevation of the sinus membrane during grafting procedures.[5]

Insert Tip Color: The color of insert tips is coded either as gold or steel. Gold insert tips are employed for treating bone, achieved by applying a titanium nitride coating to enhance surface hardness and increase the longevity of the insert tip. Steel tips are used for treating soft tissue or delicate structures, such as the roots of teeth.[4]

Applications of Piezosurgery

Piezosurgery has firmly established its presence in the medical field and has been applied in various surgical procedures, including rhinoplasty, orthopedic and wrist surgery, mastoidectomy, facial surgery, neurosurgery, traumatology, ophthalmology, head and neck surgery, as well as plastic and reconstructive surgery.[6,17,19,20]

The dental applications of piezosurgery can be classified based on different specialties:

Oral and Maxillofacial Surgery: Piezosurgery plays a significant role in oral and maxillofacial surgical procedures. It is particularly effective in cases that demand careful handling of delicate structures, such as soft tissues and fragments of a tooth. It is also valuable for dealing with impacted teeth in close proximity to anatomical structures.[5]

In oral and maxillofacial surgery, piezosurgery has been successfully utilized in a range of procedures, including atraumatic tooth extraction, enucleation of cysts and tumors, sinus lift procedures, alveolar ridge expansion, ridge augmentation, bone harvesting (chips and blocks), dentoalveolar surgery, atraumatic dissection of sinus mucosa, alveolar distraction osteogenesis, jaw resection, and TMJ ankylosis/ resection.[6,11,18,21]

Traditional forceps, with their vigorous movements during tooth extraction, can cause forceful tearing of Sharpey's fibers away from the bundle bone surrounding the socket. This disruption of blood supply and trauma to the extraction socket can lead to delayed healing.[21] Piezosurgery has addressed this issue by facilitating atraumatic extraction, resulting in faster healing and improved recovery. Recently developed ultrasonic vibrating 'Syndesmotomes' tips are designed for tooth and root extraction. The tip is inserted through the gingival sulcus into the space occupied by the periodontal ligament between the root and the socket. The periodontal fibers are cut up to or greater than 10mm. This approach achieves nearly atraumatic extraction, as severing the most apical fibers prevents a violent 'rip' to the coronal portion.[21]

In the field of implantology, piezosurgery finds application in various procedures, including implant socket preparation, recontouring of the alveolar crest, mental nerve repositioning, mobilization of the inferior alveolar nerve, simultaneous implant placement, and immediate implant placement after extraction.[22] Piezosurgery plays a symbolic role, delicately assisting in critical procedures such as alveolar ridge expansion, which entails the separation of palatal and vestibular bone flaps followed by implant placement.[23]

In sinus elevation procedures using traditional burs, complications like membrane perforation, intraoperative bleeding, and surgical trauma are common. To mitigate such risks, the use of a piezosurgical insert with a blunt tip proves useful for atraumatic membrane elevation, facilitating successful grafting procedures.[5,6]

Within endodontics, piezosurgery simplifies procedures such as hemisection, root amputation, apical resection, and endodontic treatment.[24] In the realm of periodontics, beyond routine scaling and root planning, piezosurgery is applicable in periodontal surgical procedures such as osteoplasty, osteotomy, crown lengthening procedures, and resective and regenerative surgery.[24]

In orthodontics, piezosurgery enables the successful execution of osteotomy, corticotomy, and orthodontic microsurgery.[5]

Biological Impact on Bone & Osseous Response To Piezosurgery

In any osseous surgery, the impact of mechanical instruments on bone structure and cell viability is crucial, as alterations in temperature can be detrimental and may lead to bone necrosis.[25] Erikson et al.[26] demonstrated that local bone necrosis occurs when the temperature exceeds 47°C for 1 minute due to contact with rotating tools.

Piezosurgery not only selectively cuts hard tissue but also induces a hemostatic effect on the surrounding tissues.[14,27,28] This technique preserves surrounding soft tissues, making it applicable in areas where bone is in close proximity to vital and delicate structures such as nerves, blood vessels, or the sinus mucosa.[6]

Microtopographic and histomorphometric studies have indicated that piezosurgery is preferred over other tools for harvesting vital bone.[25,26] The bone surface cut using the piezoelectric device exhibits perfect integrity with a clean, regular cut devoid of imperfections or pigmentation. Live osteocytes are present without any signs of cellular suffering.[29] Recently, **Stubinger et al.**[27] demonstrated that autologous bone harvested with a piezoelectric device from the zygomatico-maxillary region could be used for augmentation, resulting in stable and aesthetically pleasing oral implant placement after a five-month healing period.

Another histomorphological study revealed that piezoelectric surgery increases the concentration of Bone Morphogenic Protein (BMP-4), TGF beta-2, Tumor Necrosis Factor, and Interleukin-1, 10, while decreasing certain pro-inflammatory cytokines in the bone.[4,5,25] Consequently, neo-osteogenesis was consistently observed to be more active when piezosurgery was employed.[5] Harder et al.[30] noted that critical temperature rises only when the irrigation volume is as low as 20 ml per minute. Thus, piezosurgery holds significant potential in osseous surgery.[6,25]

Advantages

- Accurate and targeted bone cutting.
- Efficient and expedited healing process.
- Reduced invasiveness leading to decreased postoperative pain.
- Positive osseous response.
- Preservation of vital structures such as the Schneiderian membrane and nerves.
- Maintenance of asepsis through a sterile water environment.
- Enhanced tactile sensitivity.
- Surgery performed in a bloodless field with optimal visibility due to the cavitation effect.
- Absence of noise production during the procedure.
- No risk of emphysema.[31]
- Alleviation of traumatic stress.
- Applicability in pediatric and medically compromised patients.

Cumulatively, these factors contribute to increased patient compliance.

Disadvantages

The primary drawback of piezosurgical units is the extended operating time needed for bone preparation.[32]

Contraindications

While there are no absolute contraindications, the use of electrical pacemakers, whether in the patient or the operator, is considered a contraindication for piezosurgery. Age is considered a relative contra-indication for any surgical procedure.[4,33]

Conclusion

This review underscores the clinical significance of piezosurgery within the realm of dental sciences. Piezosurgery guarantees the three 'P's: Predictability, reduced postoperative pain, and heightened patient compliance. It is worth noting that the application of piezosurgical devices, a novel innovation, extends beyond the confines of dental surgery. It proves valuable in more intricate cases and addresses interdisciplinary challenges that intersect both medical and dental sciences.

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