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Piezoelectric surgery: Twenty years of use

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Abstract

The use of ultrasonic vibrations for the cutting of bone was first introduced two decades ago. Piezoelectric surgery is a minimally invasive technique that lessens the risk of damage to surrounding soft 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 orthopaedics have been proposed. We review the different applications of piezoelectric surgery.

Keywords: Piezoelectric surgery; Osteotomy; Bone; Soft tissues

Introduction

Ultrasonic vibrations have been used to cut tissue for two decades.[1–4] However, it is only in the last five - six years that experimental applications have been used routinely for standard clinical applications in many different fields of surgery. It decreases the risk of damage to surrounding soft tissues and critical structures (nerves, vessels, and mucosa), particularly during osteotomy.[5–11]

The instruments used for ultrasonic cutting of bone create microvibrations that are caused by the piezoelectric effect first described by the French physicists Jean and Marie Curie, in 1880. 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 to 210 μm) cut only mineralised tissue; neurovascular tissue and other soft tissue is cut at frequencies higher than 50 kHz.[12–15] 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/minute 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.[16,17] 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.

We report the advances in piezoelectric surgery over the last twenty years and focus on its use in different surgical areas.

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. Relatively high temperatures, applied even for a short time, are dangerous to cells and cause necrosis of

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tissue. There have been several studies about the effect of piezoelectric surgery on bone and the viability of cells.[18,19]

Recently autologous bone that had been harvested by different methods (round bur on low and high-speed hand-piece, spiral implant bur on low-speed hand-piece, safe scraper, Rhodes back action chisel, rongeur pliers, gouge-shaped 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.[20] The results showed that the best methods for harvesting vital bone are: gouge-shaped bone chisel, back action, en-block harvesting, rongeur pliers, and piezoelectric surgery. It confirmed earlier studies the effects of piezoelectric devices on chip morphology and cell viability when harvesting bone chips.[21,22] 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 autologous bone from the zygomaticomaxillary region that had been harvested with a piezoelectric device could be used in augmentation for stable and aesthetic placements of oral implants after a 5-month's healing.[23] In another histomorphological study, porous titanium implants were inserted into minipig tibias. The concentration of morphogenetic protein (BMP)-4; transforming growth factor (TGF)-β 2; tumour necrosis factor α, and interleukin-1β and -10 were evaluated in peri-implant osseous samples. The analyses showed that neo-osteogenesis was consistently more active in bony samples from implant sites that had been prepared using piezoelectric surgery, and there was an earlier increase in BMP-4 and TGF-β 2 proteins, and fewer pro-inflammatory cytokines in bone around the implants.[24]

Applications of piezoelectric surgery

Oral and maxillofacial surgery

Parodontology and endodontic surgery

In dentistry, ultrasonic surgery became established in periodontology[25,26] and endodontics[27] after initial reports by Catuna in 1953 on the use of high-frequency sound waves to cut hard dental tissue.[28] Ultrasonic oscillations can also be used to scale subgingival plaque, and to remove root canal fillings and fractured instruments from root canals.[29]

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.[30] To treat loss of bone in the posterior maxilla or to let air into the sinus after tooth loss, or both, elevation of the sinus floor is usually most effective. Through a crestal or lateral approach, the Schneiderian membrane is raised without perforation, and the space between the bone and membrane filled by the new graft. Blus and Szmukler-Moncler did split-crest procedures using piezoelectrical surgery on 57 patients over a period of three and a half years. The aim was to place 230 implants (78 in the mandible and 152 in the maxilla) to rehabilitate nine full arches, three hemiarcades, 43 partial bridges, and 24 single crowns.[31]

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 is technically less sensitive, and the technique easier to master. 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 improves visibility.

Ninety-nine percent of the implants were placed and 96% survived after 2 months of loading. This compared well with classic procedures.[31]

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.[32–34] This was reported in a study of 15 patients who had 21 piezoelectric osteotomies, of which 95% were successful.[35] Piezoelectric surgery has also been used to reconstruct vertical and horizontal bone with a transplant from the zygomaticoalveolar ridge.[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 mobilisation 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.

Maxillofacial surgery

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.[40]

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.[41,42] 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 postoperative swelling and haematomas, were striking.

In aesthetic facial surgery there are many approaches to osteotomy. In rhinoplasty lateral osteotomy should be precise, reproducible, and safe. It should also minimise post-operative 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.[43]

Otological Surgery

In otological surgery, bone is usually cut by manual or motorised instruments. Salami et al. 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 (n = 9), antrotomy (n = 8), classic mastoidectomy of the intact canal wall (n = 12), posterior tympanotomy (n = 3), decompression of the facial nerve (n = 2), and excision of a glomus tumour of the middle ear (n = 2).

In all cases the piezoelectric device allowed rapid and easy intraoperative management, and precise cutting, particularly in critical anatomical areas.[44]

Neurosurgery

Operations on the neurocranium may injure the dura and cause the development of a fistula of cerebrospinal fluid. Schaller et al reported the successful use of piezoelectric surgery in the cranial base and spine in children. He showed that the technique spared soft nerve tissue, was avoided coagulative necrosis, improved the visualisation of the surgical field, and resulted in a more precise cut. Traditional oscillating saws that use macrovibrations, do not give the same control of cutting depth at the sides as they do in the centre. Craniotomy, orbitotomy, and posterior spinal laminotomy in selected cases, were all successful with uneventful postoperative recovery.[17]

Kotrikova et al showed that piezoelectric surgery used after osteotomy in high-risk patients, avoided perforation of the dura.[45]

Orthopaedic and hand surgery

A common problem in the removal of osteosynthetic material is the formation of a callus that covers plates and screws and makes removal difficult. Piezoelectric surgery allows the quick removal of callus from titanium osteosynthetic material, particularly, from the slots of the screws without damaging them. Screw-drivers can then be attached.[16]

In osteotomy and biopsies of bone, piezoelectric devices allowed precise cuts to be made in bony surfaces in animals.[35] Budd et al reported that bone could be cut precisely at an angle, but the system was less efficient for deep cuts.[46] As the cutting speed decreased the temperature rose, so it was necessary to pause to allow the system to cool down. In these situations, some authors suggest combining piezoelectric surgery for the initial incision with a chisel for the final osteotomy of the bone.[17]

In hand surgery standard oscillating saws may cause nerve lesions. A piezoelectric device was used for an osteotomy to correct a 45° post-traumatic deformity of the 5th metacarpal neck to avoid postoperative complications.[13] Its use resulted in a faster than usual recovery period of four weeks, and could be because there was limited retraction of soft tissue and minimal stripping of the periostium. The authors reported that when moving the device in different directions like a pen, the cutting was precise with no macrovibrations, and was therefore practical for operations using a magnifying lens. There was also no need to split the bone with a traditional chisel, and a clear view was obtained during the whole procedure in which automatic water irrigation was used. The drawback was the relatively slow sawing process, which took about 30 seconds (about 20 seconds longer than a traditional oscillating saw).

Conclusions

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.[24]

There are few limitations. Operating time for osteotomies is slightly longer than with traditional saws,[17] and increasing the working pressure impedes the vibration of devices that transform the vibrational energy into heat, so tissues can be damaged.[41,46] The technique can be difficult to learn.

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