Is Piezoelectric Surgery the New Gold-Standard in Oral Surgery and Implantology?
A Scientific Literature Review

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ABSTRACT

Mills, drills, burs and low-frequency oscillating saws were the only tools for bone-cutting for a long time and their use rarely questioned on their biological and physiological effects on bone. With the emergence of new technologies in bone-cutting - such as lasers and piezoelectric cutting devices - more and more experimental and clinical studies shed light on the differences in the bone healing-cycle when traditional instrumentation is compared to these new technologies.

A search in medical and biomedical databases was performed and molecular-biologic, micromorphologic, histologic, experimental and clinical comparative studies were selected, excluding case-reports and unclear methodology. Experimental and clinical findings were then summarized and compared against each other by the authors.

The differences in the micromorphologic, histologic, biologic and clinical effects resulting in a comparative overview with impact to the clinician’s daily routine-work.

The current state of secure knowledge, scientific literature suggests piezoelectric surgical tools for bone-cutting to provide the highest clinical precision, the least procedural bone-loss, an improved bone-healing and best “ease-of-use”.

KEYWORDS

INTRODUCTION

Surgical procedures in dentistry and Oral and Maxillofacial surgery (such as tooth removal, apicectomies, periodontal disease – management, guided bone regeneration (GBR), dental implant insertion, orthognathic surgery etc.) are performed traditionally with chisels, burs, osteotomes and low-frequency oscillating saws.

However, rotating or low-frequency oscillating instruments are very difficult to handle when used on cortical and trabecular bone due to its procedural high physical torque-moment. The result is a loss of tactile sensitivity due to the requirement of pressure on the handle-piece, difficulty in the determination of cutting depth and iatrogenic impairment in undesired areas due to a failure in the accurate judgment of the speed of a rotating bur or oscillating saw, particularly when ultimate precise osteotomies are essential.1 When chisels or osteotomes are used, labyrinthine concusion of the inner ear, positional vertigo or even brain concussion may occur.1-2

Major and unavoidable medical drawbacks of the use of motorized rotary, reciproc or low-frequency oscillating instruments in bone-cutting are enormous procedural bone losses, significant bone-necrosis due to overheating and the high risk of soft tissue injury to important anatomical structures such as the inferior alveolar nerve or maxillary sinus-membrane and deposition of metal shavings and bacterial contamination.4-7

Burs serrations are quickly filled with the squamous bone shavings and bacterial contamination.4-7

Although the use of rotating and low-frequency oscillating instruments deliver acceptable clinical results in the everyday surgical practice, their use is always highly traumatic on the microscopic, histologic and molecular level and their correct application is highly related to the surgeon’s manual capabilities. Rotating burs and low-frequency oscillating saws historically were the only common devices available to cut bone tissue in oral and maxillofacial surgery. By the end of the last century, piezoelectric surgical devices1,10 – well known in orthopedic surgery since 197411,12 and lasers of different wavelengths (Ne:YAG 1064nm, Ho:YAG 1980nm, Er:YAG 2940nm, Er:Cr:YSGG 2780nm, CO2 9400/10600nm, Excimer-LV 193nm) were introduced to clinical application also in oral and maxillofacial bone surgery.13-17

While piezoelectric surgical tools were specifically and originally developed and designed to cut bone, lasers were used for soft-tissue cutting and only few possible clinical applications and indications are known and verified for osteotomies of jaw-bones and none in orthopaedic surgery.7-15

Any tissue-cutting laser (Light Amplification of Stimulated Emission of Radiation) produces a coherent light beam of a specific wavelength mostly in the infrared (IR-heating) spectrum of electromagnetic waves. This infrared “heat-beam” then causes a sudden circumscribed microscopic explosive boiling of cell- and interstitial tissue-liquids (known as “photoacoustic effect”), leading to a thermo-mechanical ablation of soft-tissues and in case of bone, dentin and enamel to the explosive ejection of mineral particles. Once the liquid of the targeted tissue is consumed and fully evaporated, the mere heat of the laser beam causes heat-coagulation and shrinking of collagen-fibers similar to the electro-coagulation of tissues treated with electric knives and coagulator-devices (“electrocauter”). As consequence, oral soft tissues - composed of approximately 70% watery liquid- endure laser-radiation longer than bone, which contains only approximately 22% watery liquids, before the sudden exponential temperature-increase leads to heat-necrosis, microfractures and carbonization of bone and dentin (Fig.1).

This physical mode of action of lasers on different types of body-tissues requires a profound knowledge and a diligent and long training of the surgeon for a safe application. Moreover, lasers must not be used in vicinity of delicate soft-tissue-structures such as sinus-membranes and infraorbital, mental and mandibular nerve since they do not provide any kind of cutting-depth-control, thus limiting their application in oral and maxillofacial bone-surgery significantly.

Piezoelectric devices for bone-surgery-applications are based on the ultrasonic fast and precise unidirectional expansion and contraction of piezoelectric crystals when electrical voltage is applied to them.4 These precise oscillations at a rate of 27 – 32 KHz (27 thousand to 32 thousand unidirectional movements per second) are modulated in their amplitude and extend alternately from 30 – 60 micrometers to preserve the basic collagenous texture of bone.

Obviously, these small and precise unidirectional movements at ultrasonic speeds do not cause any adverse torque-forces due to the physical inertia and thus allow the surgeon a pressure-free and precise guidance of the ultrasonic surgical working tip on and in the bone. A physical effect caused by well-constructed Piezotomes in liquid-containing tissues and surrounded by the cooling saline-solution-flow is the so called “hydrodynamic cavitation effect”, which cannot be seen with the unaided eye because of its speed.27 Any solid body oscillations in liquids of ultrasonic speeds creates a partial vacuum on the opposite side of the direction of movement, decreasing the boiling-temperature of the liquid to room temperatures effecting into a strong and expanding gasous “cushion” around the oscillating working-tip (Fig.3).

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**REFERENCES**


**Figures**

1. Histology of enamel and dentin after Erb:YAG laser-beam impact (Trichrome staining) at 5W/10µs/3 pulses (Fig.1). 
2. A: Piezoelectric device “Piezotome II” (Satelec-acteon, France), B: frequency-modulation of piezoelectric devices for bone cutting to preserve the basic collagen-fiber structure (“Sharpey fibers of bone"

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*Smile Dental Journal | Volume 11, Issue 4 - 2016*
This is why cutting bone with Piezotomes is less a mechanical process like with burs, saws or chisels but more an atraumatic and microscopic precise separation of soft and hard-tissue layers by the separating pressurized gaseous “cushion” around the oscillating tip, gliding through the bone like a Hovercraft glides over water and similar to the photoacoustic effect created by infrared laser-beams. Contrary to laser-beams which can only focus on one single microscopic spot at a time and which create microscopic gas-bubble-explosions at approximately 100°C or more (overheated gas) Piezotome-working tips are flat-covered with gaseous bubbles at room-temperatures or below.21 (Fig.3)

Moreover, the hydrodynamic cavitation effect also causes less mechanical destruction of blood vessels compared to rotary instruments, which results in an almost bleeding-free surgical site. It also helps to maintain good visibility onto the surgical site by dispersing the coolant to rotary instruments, which results in an almost less mechanical destruction of blood vessels compared to rotary instruments.6,7

**HISTOLOGIC EFFECTS OF PIEZOELECTRIC SURGERY**

A scanning electron microscopy study comparing the traditional Lindemann-bur with sonic and ultrasonic instrumentation revealed “the use of ultrasonic instruments to result in extremely precise cuts and reduced bone damage. Lindemann bur showed less precision and higher bone damage both in cortical and in cancellous bone. In cortical bone, ultrasonic and sonic cuts showed nicely opened bone vascular canals, while Lindemann bur showed many canals closed by abrasions, exfoliation and cracks by dragging attrition. In cancellous bone, ultrasonic cut showed intact trabeculae and trabecular spaces free of debris, while sonic cut showed more debris accumulation in trabecular spaces. Lindemann bur showed huge quantity of bone debris that filled trabecular spaces.”20

A direct ex vivo histologic comparison of bone healing after cutting bone with rotary burs and two different piezoelectric devices (Piezotome I and Piezotome II, both ACTEON/ France) revealed a highly significant improvement of bone healing regarding bone-fill and bone mineral density in the osteotomy-gap in favor of both Piezotomes.21

Obviously, above all, the use of piezoelectric bone-cutting-devices macroscopically leads to significant less procedural bone-loss when compared to rotary instruments or lasers. (Fig. 4)

**CLINICAL AND MEDICAL EFFECTS OF APPLICATION OF PIEZOELECTRIC SURGICAL TOOLS**

**PATIENT MORBIDITY**

The TKW-Research-Group – specialized in clinical research and development of ultrasonic surgical tools and applications – were the first to investigate the practical clinical implications of the experimental results in a multicenter split-mouth study on the removal of impacted third molars.29

With the results of this first randomized clinical split-mouth study the authors were able to prove the enormous clinical impact the application of pure Piezotome-surgery provides for patients compared to the use of rotary instruments by a postsurgical reduction of swelling of more than 50% (Fig. 5) and pain (Fig. 6).

The initially doubted results of this clinical study were later on verified by numerous clinical studies with the same or a similar study-design.23,27

**SOFT TISSUE PRESERVATION**

Prior to experimental and clinical studies in dentistry and oral and maxillofacial surgery neurosurgeons discussed and evaluated the superior preservation of critical soft tissues such as the spinal cord and brain tissue when using Piezotomes (green) compared to traditional drilling techniques (red).30,31

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piezoelectric bone surgery is used\textsuperscript{38} with an ever increasing use of Piezotomes in spinal and skull-base surgery.

**Mucoperiosteal Flap Preparation**

Every oral surgical procedure starts with the preparation of a mucoperiosteal flap, up to now performed with conventional mucoperiosteal elevators. What is often forgotten is the fact, that only a fully intact periosteum (as the sole carrier of bone regeneration by osteoblast-induced mineralization of the initial callus-formation) provides the requisites for an undisturbed bone healing\textsuperscript{39} or a fast mineralization of the augmentation-site in GBR-procedures.\textsuperscript{40,41}

Experimental research lately revealed a significant improvement of microcirculation in the periosteum and a significant higher functional capillary density after surgery when mucoperiosteal flaps are prepared with piezoelectric devices in comparison to traditional mucoperiosteal elevators.\textsuperscript{42} The experimental results later on were verified by microscopic clinical studies proving the clean and uninjured separation of the periosteum from the bone when Piezotome-surgical preparation is performed (Fig. 7).

**Preservation of Critical Soft-Tissues in Dentistry, Oral and Maxillofacial Surgery**

As mandatory in neurosurgery also the dentist and oral surgeon by all means has to preserve the full function of critical soft tissues such as the mandibular, mental and infraorbital nerve as well as the periosteum of the sinus-membrane for successful sinuslift-procedures.\textsuperscript{43,44}

Comparative clinical studies (Piezotomes versus rotating burs, oscillating saws and chisels) proved the superior safety and preservation regarding an unaffected function of the mandibular/mental nerve in critical osteotomies adjacent to the mandibular nerve at removal of impacted third molars, cyst enucleation, complex osteotomies for bone-augmentation and in orthognathic surgery.\textsuperscript{33,34,46-48} (Fig. 8,9)

The unpunctured/unruptured preservation of the periosteum of the sinus-membrane is mandatory for prevention of post-surgical infectious sinusitis\textsuperscript{49} and successful subantral mineralized bone-regeneration (sinuslift).\textsuperscript{44,50,51} Clinical studies prove piezoelectric devices with special diamond coated tip-designs to significantly reduce the incidence of accidental intrageneric membrane perforations among surgeons with limited experience.\textsuperscript{52}

With piezoelectric surgical procedures the perforation rate of the sinus-membrane can be reduced from 24 – 56%\textsuperscript{53} with rotary instruments to 5%.\textsuperscript{54} (Fig. 10)

**Mandibular Nerve/Inferior Alveolar Nerve - Lateralization (MNL/IANL)**

A good alternative to vertical bone-augmentation in the lateral mandible (vertical bone distraction-osteogenesis, vertical block-grafting) - which in clinical studies and systematic reviews present a high short and long-term complication rate\textsuperscript{56,57} - would be the mandibular nerve/inferior alveolar nerve-lateralization (MNL/IANL). However, due to the lack of a clear view onto the surgical site, the lack of depth control with rotary and/or low-frequency oscillating saws and the enormous risk to unrecoverable damage the mandibular nerve this procedure is rarely performed and if, only by highly experienced and specialized surgeons.\textsuperscript{58,59} With the introduction of piezoelectric surgical devices and clear surgical protocols the risk of a permanent damage of the mandibular nerve and the period of neuritis or hypesthesia can be decreased significantly both by the excellent visibility of the surgical site, the perfect depth control of the osteotomies and the superior soft tissue safety of piezoelectric surgery.\textsuperscript{60-62}

![Mandibular Nerve](image)

![Application of piezoelectric bone-cutting devices in orthognathic surgery](image)

![Sinuslift (tHUCSL-INTRALIFT)](image)
**Simultaneously**, by an individual implant system, implant can be inserted in the osteotomy (if primary stability can be achieved). The surgical protocol for transcrestal sinus lift starts with the osteostomy application completed, wound closure, and minimal invasive crestal flap. Typical tissues are the INTRALIFT osteotomy, INTRALIFT, and bone augmentation (Fig. 12).

### HARD TISSUE PRESERVATION

As depicted in Fig. 4, piezoelectric ultrasonic bone-cutting allows highest possible precision in the design and depth of any kind of osteotomy with proven significant advantages regarding atraumaticity, speed and predictability of bone healing (11-13,27-28). By its explicit precision piezoelectric surgical tools allow a significant expansion of existing surgical protocols in bone surgery. The piezoelectric Piezotome allows highest possible precision in design and depth of any kind of osteotomy with proven significant advantages regarding atraumaticity, speed and predictability of bone healing (11-13,27-28).

#### Piezotome Enhanced Subperiostal Tunnel Technique

By its clean and predictable separation of periosteum from bone, keeping the full osteogenic potential of the periosteum intact, a well-known technique for vertical and lateral bone augmentation was revived: the subperiostal tunnel technique (PeSTT). Nowadays, the PeSTT technique allows highest possible precision similar to autologous bone block preparation (Figs. 12-13). Piezotome Enhanced Subperiostal Tunnel Technique (PeSTT) is a modified BS 4-tip, allowing highest possible precision similar to autologous bone block preparation (Fig. 13).

#### Routine Oral Surgical Procedures (impacted tooth removal, apicectomies)

Due to its property to cut bone almost lossless and with precise depth control piezoelectric bone surgery allows anatomy-preserving surgical procedures. Whereas in most surgeries of removal of impacted third molars tremendous amounts of bone get lost by milling with burs, pure piezoelectric-surgical removal without use of any burs allows a full restitution of the patients anatomy at the end of the surgical procedure avoiding large long-term bone defects in the retromolar area which might cause unpleasant food retention at chewing (Fig. 14).

**Defective healing of the alveolar crest after apicectomies with rotating burs – especially in the upper front, when later on the tooth finally has to be extracted and a dental implant inserted – is very common.** Following a piezo-surgical protocol with an anatomical correct full reconstruction of the resorption site, defective healing can be avoided. When later on the tooth might have to be removed, no additional buccal bone-augmentation procedures will be necessary. (Fig. 17)

### Autologous Bone-block Transplants

Since possible geometric dimensions and anatomic locations restrict intrasulcal bone block harvesting, procedural bone-loss in most cases is unacceptable and might lead to insufficient augmentations. Since with piezoelectric bone-scalpels almost no procedural bone-loss occurs, piezoelectric bone harvesting should be preferred. (Fig. 4)
Piezotome-enabled Distraction Osteogenesis

As reported the main cause of failure in distraction osteogenesis is based on the primary osteotomy, which with rotating and/or low-frequency oscillating instruments does not allow a perfect osteotomy design as well as leads to the common problems known for application of these instruments on and in bone. With the Piezotome, however, further clinical studies have to be undertaken with higher patient numbers to support this assumption.

Vertical Alveolar Crest-Split & Horizontal Distraction

One of the most common diagnoses in the course of dental implant planning is an insufficient alveolar crest width due to the natural and/or iatrogenic lateral atrophy of the alveolar ridge. Lateral oppositional bone-block grafting or - nowadays - the Piezotome enhanced subperiosteal tunnel technique allow to increase the width of the alveolar crest but need to be performed in two stages with longer healing periods. Similar to procedures in distraction osteogenesis the narrow alveolar crest can be split vertically and distracted horizontally, mostly with simultaneous implant insertion, but was limited to crest-width of minimum 3.4mm due to the procedural bone loss with rotating burs or mills and the need to prepare a mucoperiosteal flap. Due to the lack of depth control and imprecision of the vertical osteotomy with rotary instruments accidental fractures of the distracted buccal compacta were reported as well as secondary vertical bone loss of 3mm or more in the healing period.

With the Piezotome enabled Flapless vertical alveolar crest-split and horizontal distraction the indication for crest-splittings can be narrowed down to alveolar crest widths of 1mm. Monocortical Intersproximal Alveolar Ridge Corticotomy for Orthodontic Tooth Movement Acceleration

Orthodontic tooth movement is impaired by the physical presence of the coronal alveolar cortical bone surrounding the neck of the root. Therefore, it becomes necessary to disrupt this cortical bone via surgery to allow a faster orthodontic tooth movement. Following periodontal accelerated osteogenic orthodontics (PAOO) by corticotomy, a transient decalcification recalcification process of the alveolar occurs speeding up the orthodontic movement of teeth. Nevertheless, this surgical technique - performed with rotary instruments - needs the reflection of a full thickness mucoperiosteal flap, which leads to uncontrolled resorptions and cosmetic deficiencies in the healing period and is very traumatic both for soft and hard tissues as well as for the patient. Therefore, this surgical procedure is at least questionable from the medical standpoint.

With the introduction of the Piezocision-technique now an almostatraumatic buccal corticotomy without reflection of a mucoperiosteal flap can be performed providing all advantages for a precise and rapid orthodontic tooth movement while completely lacking the medical and esthetic disadvantages. The risk of lesions of the adjacent periodontal ligaments is considered very low due to the design of the Piezocision-tips for Piezotomes. In case of need of buccal augmentation, the Piezotome enhanced subperiosteal tunnel technique can be performed additionally.

Implant Site Preparation

Rotary drills remove bone and even when used at slow speeds inhere the risk of damage in the trabecular bone. Repeated use of implant drills lead to bluntness of the drills and therewith to higher necessary loads on the handpiece, which might lead to unwanted thermal effects in the bone.

Piezotome-enhanced Flapless Crest Split (initial alveolar crest-width: 1mm). A: initial top crestal mesial-distal mucoperiosteal incision. No mucoperiosteal flap is prepared, B: initial bone-lossless vertical mesio-distal osteotomy with CS 1 tip, C: initial horizontal distraction with CS 2 tip to allow easy vertical approach for next surgical step, D: mesial and distal buccal relief-osteotomies from inside of the mesio-distal osteotomy in buccal direction, E: step by step horizontal distraction of completed osteotomy with CS 4, 5 and 6 tip to a gap-width of 4mm, the buccal-distracted compact bone stays fully attached to the periosteum and therewith fully vital, F: state after implant-insertion (Q2-implant) and gap-filling with self-hardening biphasic bone-graft biomaterial (easygraft), G: crestal-gingival anatomy mostly allows gap-free tensionless wound-closure, H: final prosthetic result after 3,5 months.

(Fig. 18) Distraction osteogenesis-procedure with ultrasonic surgical devices: A: precise osteotomy of the alveolar-crest region to be distracted, B: control of proper bone-block-mobility (bone-block stays attached to periosteum palatal and coronal and therefore fully vital), C: distractor device attached, D: distraction completed, implant insertion with 120° angled ultrasonic tip SL 5.

(Fig. 19) Surgical protocol of the Flapless Piezotome enhanced Crest Split and Widening (PeCSCW). A: lateral view of anatomical prerequisites for PeCSCW procedure, B: depiction of the achievable postsurgical result.
Experimental assessment of differences between the use of piezoelectric surgery and a conventional drill concerning neo-osteogenesis and inflammatory reaction after implant-site preparation revealed more newly formed bone with an increased amount of osteoblasts to be visible on the piezoelectric implant site during the early phase (7–14 days). The investigated humoral factors BMP-4, TGF-β2 and IL-10 were increased in the piezoelectric group, while IL-1β and TNFα were not. In conclusion, the piezoelectric device stimulated bone-augmentation, peri-implant osteogenesis, and a reduction of proinflammatory cytokines.82–85

Therefore, implant-site preparation with piezoelectric surgical devices seems favorable to achieve clinically safer osseointegration.

Additionally, primary stable implant preparation finished, D: tips, diameter with ultrasonic cutters, A: incision, B: tooth-movement. If needed, after Piezocision-procedure is

CONCLUSIONS

In the light of this thorough literature-research and comparison to rotary mills, burs, low-frequency oscillating saws, chisels and infrared lasers Piezoelectric-surgery seems to outclass traditional instruments and lasers by far on clinical, histologic and micromorphologic level providing precise osteotomies, maximum soft-tissue preservation and improved bone-healing even in the surgical beginners hand and by this seems to be the new gold-standard in dentistry, oral and maxillofacial surgery.

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PIEZOTOME-APPLICATIONS IN THE DAILY DENTAL ROUTINE

TOOTH REMOVAL

Once all treatment possibilities to preserve a tooth are

CROWN LENGTHENING

In case the root of a tooth with crestal caries or intrabony crestal fracture can still be treated with a pin and a crown, a perfect margin has to be prepared for later impression. In case of crestal caries or a subcrestal fracture, crestal bone has to be removed carefully to allow the later preparation of the crown margins. The minimal invasive removal of crestal bone with rotary instruments challenges the dentist. As a better alternative nowadays, piezoelectric instruments should be used for this task especially in the early period of gaining manual experience.

An alternative to bone-destructive tooth-removal now is piezoelectric tooth-removal with piezoelectric ligament-cutters. Similar to the preparation of a mucoperiosteal flap with Piezotomes12,13 – the periodontal ligament consists of the same Sharpey-fibers attaching the tooth to the bone as the peristeme is attached to the bone14 – the periodontal ligament is precisely cut and the periodontal gap widened by the cavitation-effect without bone-loss, enabling an almost forceless removal of the tooth. (Fig. 23)

DISCUSSION

Obviously, the use of Piezotomes in the daily dentists as well as oral and maxillofacial surgeons’ clinical routine seems to be preferable since common disadvantages of the use of rotary mills and burs, low-frequency oscillating saws and chisels as well as lasers can be avoided. The thorough and deep research of the published literature did not reveal any hint of possible disadvantages of Piezotomes in the clinical routine, on histologic and on micromorphologic level. Contrary, the use of piezoelectric surgical instrumentation seems to provide significant advantages for both the dentist/surgeon and their patients, achieving higher and predictable success-rates in any kind of bone-surgery and less patient-morbidity.12,14 Furthermore, some highly invasive and manually challenging traditional surgical techniques can now be replaced completely by easy to learn and minimal invasive piezoeotomical surgeries.

One major criticism of piezoelectric surgery – the higher time-consumption for piezoelectric surgeries – was already disproved ten years ago in a prospective multicenter study.27 After a learning curve with higher time-consumption for routine-surgeries – which is common for any kind of new surgical technique to be learned by dentists and surgeons – time-spans for these procedures go back to normal level or even less. With the introduction of devices with higher power-output (average output: 25–30 W, top-device: 60 W) surgery-times are further reduced.

(FIG. 16) Piezoelectric-technique for improved orthodontic tooth-movement. A: Rationale of extraocclusal mucoperiosteal incision, B: incision-pattern in a typical case, C: Rationale of intraocclusal osteotomy with Piezotomes for Piezotomes, D: if needed, after Piezocision-procedure is completed a subperiosteal tunnel can be prepared for buccal bone-augmentation.

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