Ultrasonic vs. drill osteotomy.
A clinical and histologic study in the sheep mandible.

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Aim Most dental implants are positioned using a drilling surgery technique. However, dentistry recently experienced the implementation of piezoelectric surgery, but the implant site preparation using this tool is not reported in the literature. This study used qualitative histological examination to compare the osseointegration of implants positioned using traditional drills versus the piezoelectic bone surgery technique.
Materials and Methods Implants were inserted into the inferior edges of the six sheep mandible. Four implant sites were prepared in each side of the mandibular inferior edge by using traditional standardized drill preparation on the left side and preparations with ultrasonic milling on the right side. Two sheep were sacrificed at 2 weeks (T2), two at 4 weeks (T4) and the last two sheep at 8 weeks (T8).
Results Qualitative histological examination demonstrated that at time T2 in the piezo group the amount of crestal bone resorption is much less respect to the traditional drills used and the level of bone formation is much greater in the bone marrow spaces. At time T8 in the piezo group the amount of osseointegration in general is higher than the drill group, and no implant had signs of peri-implant bone resorption as did the drills groups.
Conclusions In light of the present histological experimental evidence and literature data, we can state that the piezo ultrasonic device is different in affecting morphology, amount of debris and structural damage and that the processes of repair and osseointegration are positively influenced by it both in timing and in morphology of bone regeneration.
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Key words: Ultrasonic osteotomies, dental implant, osseointegration, piezoelectric surgery.

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INTRODUCTION

Piezoelectric surgery uses a modulated ultrasonic frequency that produces highly precise and safe hard tissue cutting. Nerves, vessels, and soft tissues are not injured by the microvibrations, which are optimally adjusted to target only mineralized tissue. Piezoelectric surgery, which takes advantage of ultrasound vibration, was introduced in an effort to overcome some of the limitations of rotating instruments in bone surgery, while increasing the cutting precision.[1-2]
Ultrasound technology in bone surgery has been widely used in orthopedics, otolarhyngology, maxillofacial and oral surgery [3-10]. In the literature there are few studies concerning the capabilities and characteristics of ultrasonic technology in bone cutting.[1-10] The advantages and disadvantages of ultrasonic cutting compared to classical, traditional drills and saws were compared and oscillating and surgical scalpels were taken into consideration. The first study was published by Mazarow et al.[3] in 1960.
Some authors argue that this technique of bone cutting is likely to alter and improve the processes of bone healing, especially in the first weeks compared to conventional techniques[4].
In oral and maxillofacial surgery, the

technique of bone cutting using ultrasonic techniques has been reported in several surgical techniques: in the surgical removal of alveolar bone[9], harvesting intraoral bone blocks or chips [11,12], sinus lift[13] , to mobilize the inferior alveolar nerve[14,15].

The true benefit of using this technique during the healing of the cut bone has not yet been elucidated. Some authors have reported that this new technique has positive effects on the rate of bone repair and remodelling when surgical ostectomy and osteoplasty procedures are performed[10], and on chip morphology, cell viability, and differentiation derived from grafts collected from intraoral sites.[16]

Dental implants are positioned most commonly using traditional drills mounted on a turning motor powered handpiece. A recently published study, conducted on pigs, evaluated the biological effects of piezoelectric implant site preparation on the peri-implant bone healing.[17] The authors[17] report that in the early stages of the osseointegration technique appears to be more efficient in the first phases of bone healing; it induced an earlier increase in BMPs, controlled the inflammatory process better, and stimulated bone remodeling as early as 56 days post-treatment.

When drilling in hard compact bone, overheating may cause cell death and subsequent bone resorption. The application of rigorous saline irrigation and low speed drilling should prevent such an event. Moreover, the use of ultrasonic appliance to perforate hard compact bone could generate enough heating to induce bone resorption.

The possible effect of overheating should be more obvious when assessed in the compatct dense bone, than in cancellous bone.

The purpose of this study was to compare the development of osseointegration of implants and bone healing of implant sites prepared by a specifically designed ultrasonic tips in comparison to traditional drill implant sites preparation. The sheep mandible was chosen as the experimental model due to its characteristics of compactness and size consistency and maturity of the cortical bone.

MATERIALS AND METHODS

Surgery

The protocol for the study was submitted and approved by the Animal Ethical Committee at the Veterinary School of the University of Teramo (Teramo, Italy).

Six hybrid female sheep aged 4-5 years old were randomly selected. Exclusion criteria were general contraindications to implant surgery and active infection or severe inflammation in the area intended for implant placement.

One surgeon placed all implants. The animals were given thiopental (Thiopental; Hoechst, Austria) for induction of anesthesia as needed. After orotracheal intubation and ventilation, anesthesia was sustained with nitrous oxide-oxygen with 0,5% halothane. Physiologic saline was administered for fluid replacement. The inferior edges of the mandible were exposed through a skin incision of 15 cm in length. The skin and facial layers were opened and closed separately. After dissection of the soft tissues exposing the cortical edge, four implant sites were prepared in each side of the mandibular inferior edge by using traditional standardized drill preparation on the left side and preparations with ultrasonic milling on the right side. The preparation on the left was followed the standards of the implant company using profuse cold saline solution irrigation internally and externally, a pilot drill of 2 mm in diameter, intermediate drill of 2.8 mm in diameter, and final tapered drill of 3.8mm. (Figure 1)

Ultrasonic diamond-coated tips mounted on the machine with continuous irrigation of saline (EMS, ELECTRO MEDICAL SYSTEMS, Nyon Switzerland) with diameter (Ø 1,15 mm) for initial osteotomy, (Ø 1,95 mm and Ø 2,50 mm) for preliminary drilling, (Ø 2,80 mm and Ø 3,05 mm) for secondary drilling and (Ø 3,30 mm) for final osteotomy , were used on the right side. (Figure 2)

Profuse cold saline solution irrigation was used in each step of implant site preparation and placement. The wound was closed by a resorbable periosteal-muscular inner suture followed by a cutaneous silk 2-0 external suture.

Two sheep were sacrificed at 2 weeks (T2), two other sheep at 4 weeks (T4) and the last 8 weeks (T8). The sheep were sacrificed by an overdose of pentothal sodium (Thiopental; Hoechst, Austria).

Implants

Camlog implants (Alta-Tech Biotechnologies s.r.l., Sondrio, Italy) 3.8mm in diameter and 9mm in length were specifically utilized for this study. The implants were inserted perpendicularly in the inferior edge of the mandible. Cover screws were placed over the heads of the fixture. All the implants, were positioned after preparation of

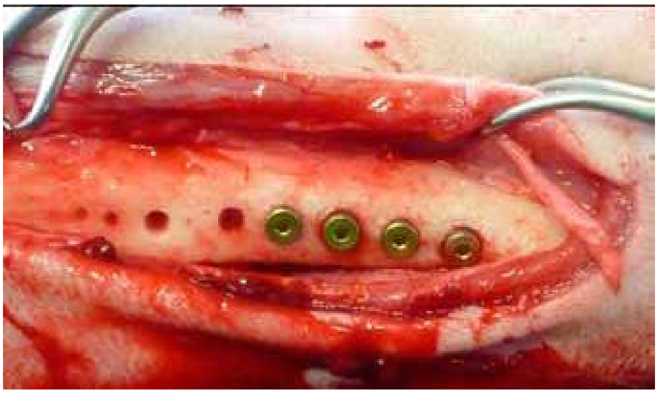


Figure 1. Left site, after dissection of the soft tissues exposing the cortical edge, four implant sites were prepared by using traditional tandardized drill preparation.

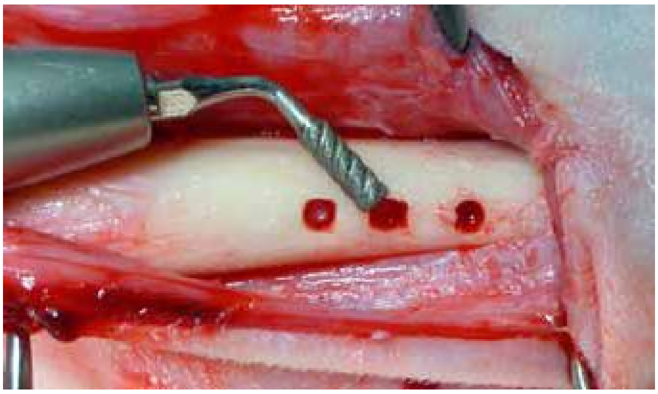


Figure 2. Right side, four implant were prepared by using ultrasonic diamond-coated tips.

the implant sites with the final tapered drill achieving a good primary stability. In total 48 implants were placed.

Histologic analysis

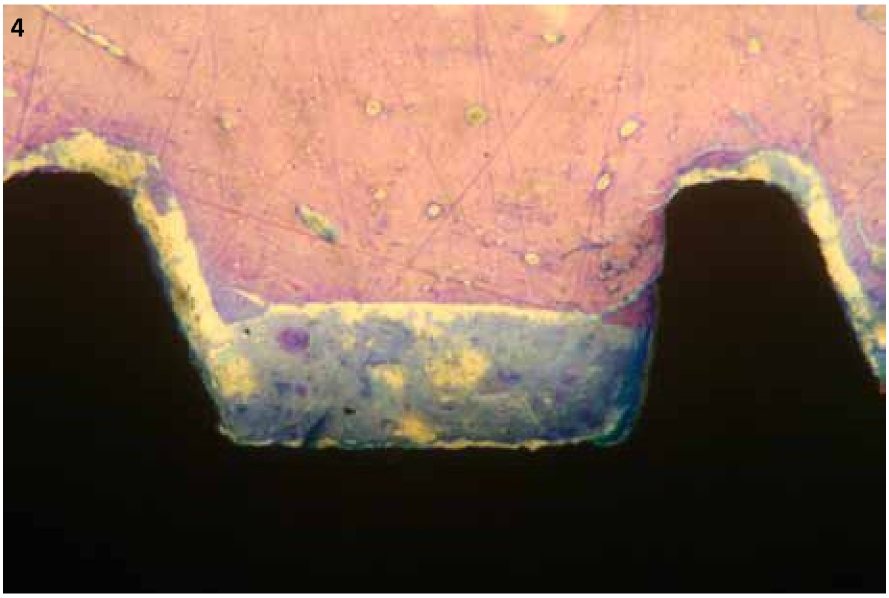
The specimens were immediately fixed in 10% neutral buffered formalin. After dehydration, the specimens were infiltrated with a methyl-methacrylate resin from a starting solution 50% ethanol/resin and subsequently 100% resin, with each step lasting 24 hours. After polymerization, the blocks were sectioned and then ground down to about 40 microns.

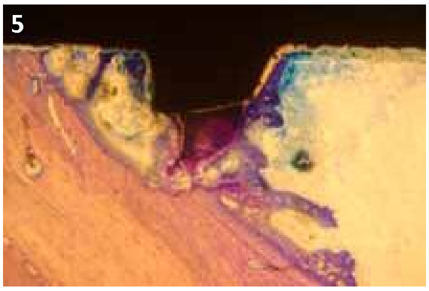
Toluidine-blue staining was used to analyze the different ages and remodeling pattern of the bone.

HISTOLOGIC RESULTS

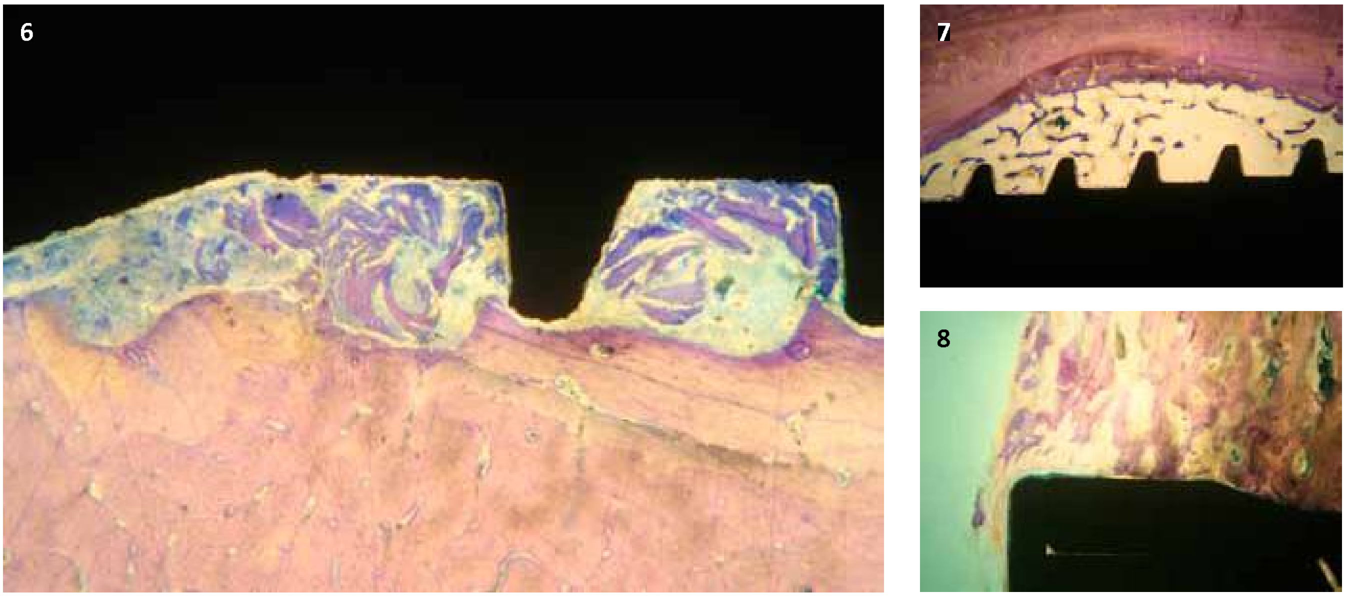
Drill osteotomy after 2 weeks of healing

We observed an initial crestal bone resorption in all specimens (Figure 3). In the interfacial gap, bone chips and debris generated by the insertion of the implant were still visible (Figure 4) in areas where new vascular tissues was not yet penetrated. On the other side, in areas closer to bone marrow spaces, in which blood supply was good, new bone formation with the incorporation of the remaining bone debris could be observed (Figure 5). In areas where the





Figures 3. Initial crestal bone resorption in all specimens (original magnification x50). **Figures 4.** In the interfacial gap, bone chips and debris generated by the insertion of the implant were still visible (original magnification x100). **Figures 5.** New bone formation with the incorporation of the remaining bone debris could be observed (original magnification x100).



Figures 6. Many chips are evident in the central canal of the mandible and a few chips at the bone-implant interface (original magnification x50). **Figures 7.** The bone formation was prevalent in the most apical area, particularly in the central medullary canal of the mandible (original magnification x25). **Figures 8.** Initial growth of new trabecular bone coronal to the implant neck (original magnification x25).

segregation of the interfacial space prevented the formation neovascular tissue the healing process was impaired and the entired space was occupied by debris of bone tissue and dead cells.

Piezoelectric osteotomy after 2 weeks of healing

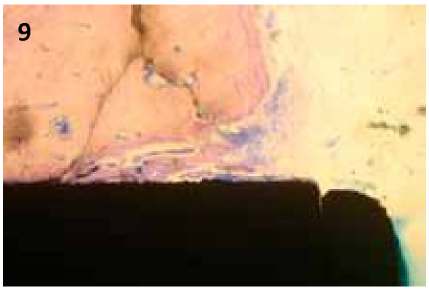
Many chips are evident in the central canal of the mandible and a few chips at the bone-implant interface (Figure 6). A gap of about 100-200 microns is often present in the coronal level containing few inflammatory cells (PMNs). In many cases, an immature periosteal callus was present at a distance from the implant site, while near to the implant only little new bone formation was visible. Also a periosteal osteoclastic bone resorption was noticed even at some distance from the implant site. There was, in some cases, a small amount of bone resorption at the interface, mainly at the crest. A minimum amount of bone resorption was sometimes observed along the wall of endosteal cortex. The bone formation was prevalent in the most apical area, particularly in the central medullary canal of the mandible (Figure 7). In some cases we observed initial growth of new trabecular bone coronal to the implant neck (Figure 8). Ultimately, the amount of crestal bone resorption was much less when compared to the drill osteotomies, while the amountl of bone formation was much greater in the medullary areas.

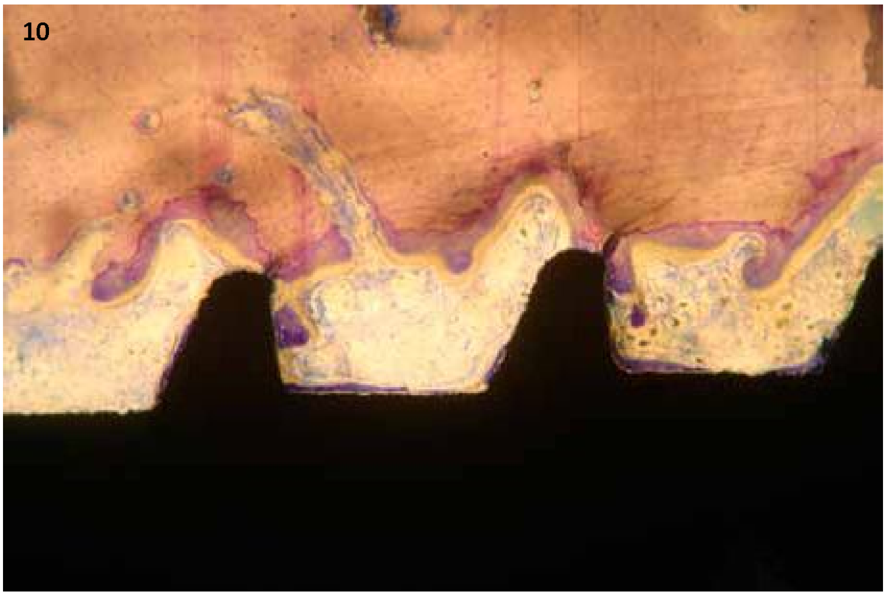
Drill osteotomy after 4 weeks of healing

Four weeks after placement, the processes of bone resorption were greatly reduced, while the process of bone formation was clearly initiated. At the crestal level, the small defects found in the first weeks were now undergoing repair by newly formed bone filling the gap (Figure 9). Even in the most apical areas, an initial formation of bone bridging between the implant surface and the surrounding cortical bone was found only where the implant was very close to the cortal walls (Figure 10). Osteoid bands covered a large part of the bone surfaces. In areas where the implant had been extremely compressed to the cortical walls not yet remodeled, bone chips and debris were still found (Figure 11). On the other hand, in areas where the process of remodeling had been more active, the bone damaged by the drilling had already been partially replaced by newly formed bone.

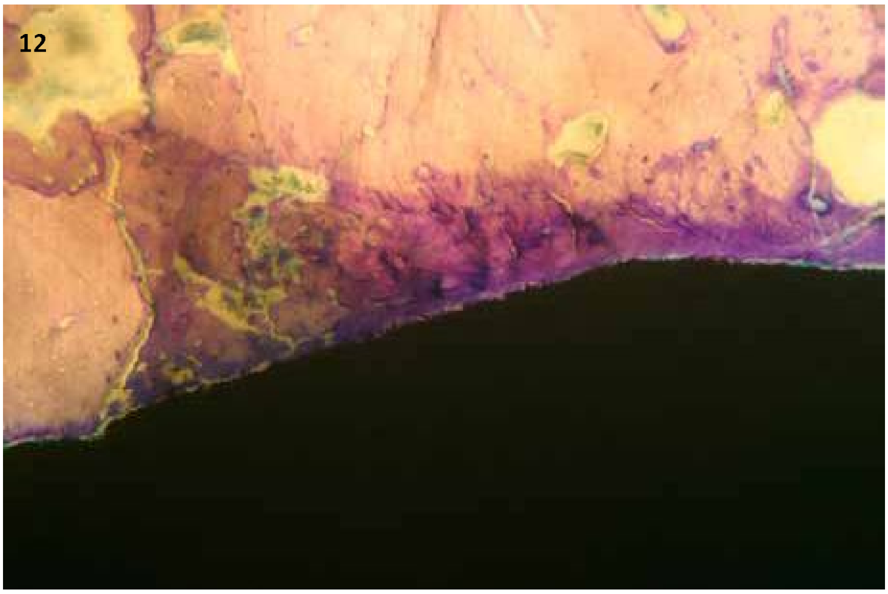
Piezoelectric osteotomy after 4 weeks of healing

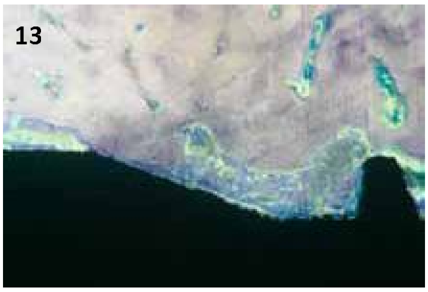
Four weeks after placement, resorption processes did not seem particularly active and the remodeling



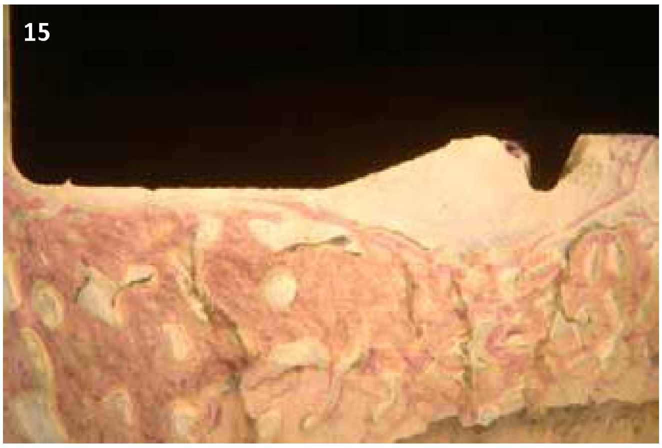


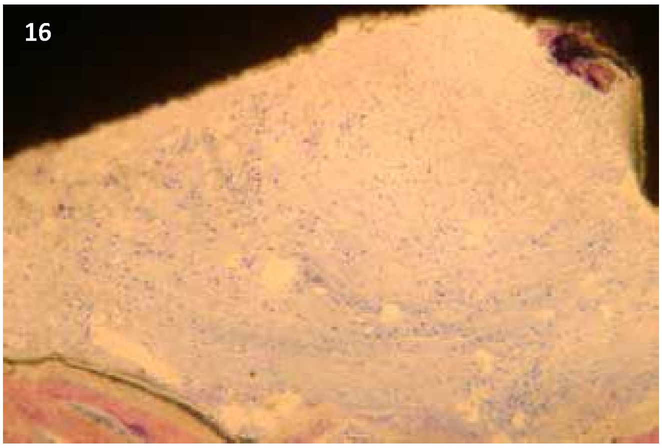
Figures 9. At the crestal level, the small defects found in the first weeks were now undergoing repair by newly formed bone filling the gap (original magnification x50). **Figures 10.** In the most apical areas, an initial formation of bone bridging between the implant surface and the surrounding cortical bone was found only where the implant was very close to the cortal walls (original magnification x50). **Figures 11.** Osteoid bands covered a large part of the bone surfaces. In areas where the implant had been extremely compressed to the cortical walls not yet remodeled, bone chips and debris were still found (original magnification x100).





Figures 12. Resorption processes did not seem particularly active and the remodeling process did not clearly replaced the interface cortical bone (original magnification x100. **Figures 13.** Bone debris were still visible at the interface more than in implants sites prepared with the traditional drills (original magnification x50). **Figures 14.** A tendency of the bone to grow in the crestal direction coronally to the cover screws was observed (original magnification x25).





Figures 15. Bone resorption at the cortical level with a very small quantity of osseointegration (original magnification x25. **Figures 16.** The cortical bone near the peri-implant site has undergone a process of bone resorption that resulted in a gap between 100 and 500 microns filled with fibrous tissue and a mild to moderate degree of chronic inflammatory infiltration composed of lymphocytes and plasma cells (original magnification x200).

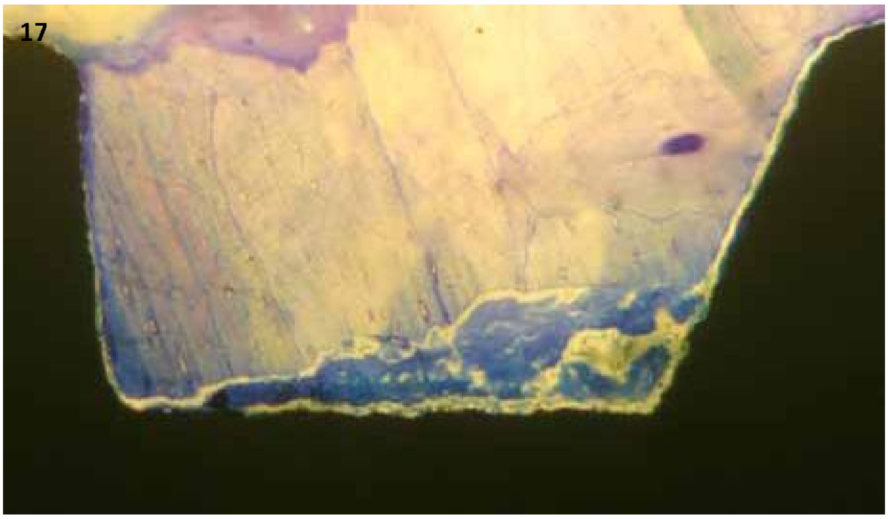
process did not clearly replaced the interface cortical bone (Figure 12). For this reason, bone debris were still visible at the interface more than in implants sites prepared with the traditional drills (Figure 13). In addition, a tendency of the bone to grow in the crestal direction coronally to the cover screws was observed (Figure 14). In the apical area, bone formation onto the implant surface was seen independently from the proximity of the cortical bone. At the cortical level, adaptation between implant and bone was fairly good, and the contact sites were strong being built partly around the newly formed bone and partly on native not remodeled bone. A periosteal bone formation was always found in crest at a distance from the implant.

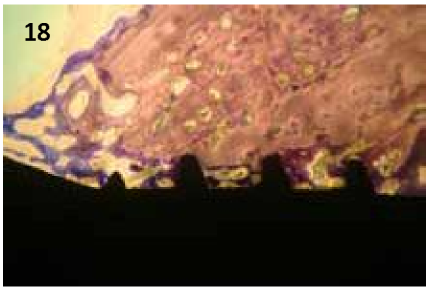
Drill osteotomy after 8 weeks of healing

The implants site prepared by the drills showed a degree of maturity comparable to the ultrasound group. There were no more bone chips in the central medullary canal of the mandible, nor at the interface. The interfacial gap was no longer visible because the bone remodeling and bone formation is eliminated. However, the cortical bone undergoes a major remodeling process that being still incompleted induced a remarkable porosity to the compact bone. There is a minimum amount of direct bone contact inside the central medullary canal of the mandible. In some cases, the growth of new trabecular bone coronal to the implant neck above the cover screw was apparent. In addition, two implants had a marked bone resorption at the cortical level with a very small quantity of osseointegration, which could be considered as a failure (Figure 15). The cortical bone near the peri-implant site has undergone a process of bone resorption that resulted in a gap between 100 and 500 microns filled with fibrous tissue and a mild to moderate degree of chronic inflammatory infiltration composed of lymphocytes and plasma cells (Figure 16).

Piezoelectric osteotomy after 8 weeks of healing

All the implants inserted with piezoelectric drill achieved a good level of osseointegration. Almost all of the cortical bone interface had been remodeled and replaced by newly formed lamellar osteonic bone and a significant activity of bone remodeling was still evident in the interface. In some sporadic areas it was still possible to observe unremodelled interfacial bone with debris from the drilling (Figure 17). The appearance of peri-implant cortical bone is still very porous due to the incomplete remodeling (Figure 18). Many bone surfaces appeared to be covered with osteoid and active osteblast bands. In most cases, the crestal bone showed the tendency to grow towards the coronal direction, and in some cases the newly formed bone had covered the screws (Figure 19). The amount of osseointegration in general is higher than the drill group (Figure 20). No implant in this group had signs of peri-implant bone resorption as in the previous group.





Figures 17. Bone resorption at the cortical level with a very small quantity of osseointegration (original magnification x25.x100). **Figures 18.** The appearance of peri-implant cortical bone is still very porous due to the incomplete remodeling (original magnification x25).

DISCUSSION

The present study reports the qualitative histological description of the osseointegration development of dental implants placed in a site prepared by the standard drill technique or by the piezoelectric tips. In the piezoelectric group, already after two weeks, the amount of crestal bone resorption is noticeably lower than the traditional drills and the level of bone formation is much greater in the bone marrow areas.

After eight weeks, in the group treated by the piezoelectric sugery the crestal bone showed the tendency to grow in the coronal direction, with osteoid formation and active osteoblasts. In some cases, the newly formed bone grew above the cover screw (Figure 19) . The amount of osseointegration in general was higher in the ultrasonic prepared group than the group prepared by the standard rotating drills (Figure 20). No implant, in this group, showed signs of peri-implant bone resorption. In the drill group, conversely, some bone resorption at the crest was evident, no signs of crestal bone growth was evident and some implants were completely fibro-integrated and considered as failure. Since 1960 numerous experimental studies have been published on the use of ultrasound technology in cutting bone tissue[3-5]. Scanning electron microscope (SEM)[6] studies of the cut surfaces showed that the cut the oscillating saw tended to form small bone fragments that detached from the cortical wall and left a smooth surface with parallel strips, and some microcracks, while ultrasonic cutting created a rougher surface. Histological analysis showed all the tested techniques produced a thin layer of necrotic bone with empty osteocyte lacunae probably because of the heat generated from the ultrasound equipment used at that pioneering time. In 1975, Horton et al.[4] demonstrated that the use of ultrasound was less traumatic than the use of rotating instruments in an experimental study on dogs. In 1981, Horton et al.[9] used ultrasonic instruments on 50 patients to perform extractions, osteoplastic surgery and periodontal bone therapy surgery. They concluded that ultrasound surgery allowed for the precise removal of bone tissue and controlled bleeding.

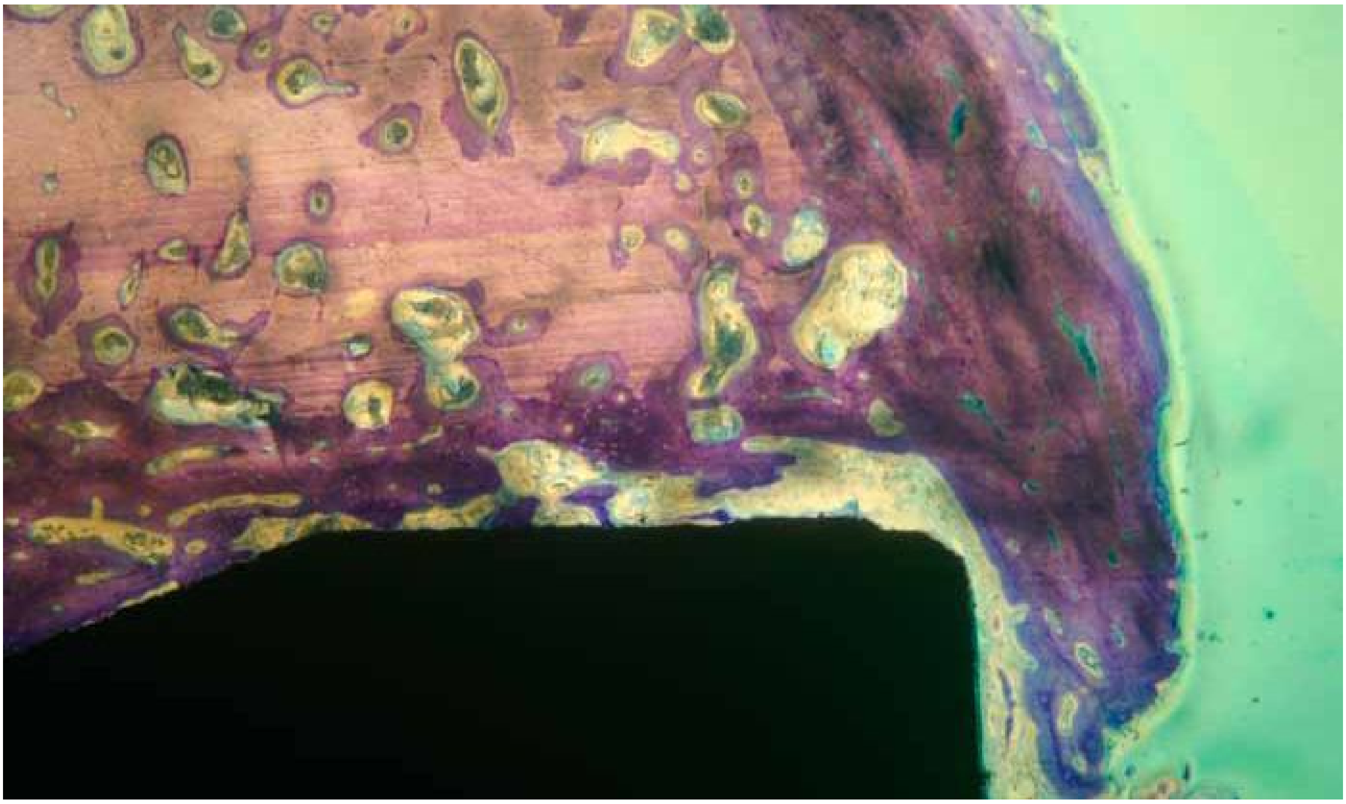
Moreover, Horton et al.[4] observed that the surface of the scalpel cut had rough edges and delamination along the planes of the adjacent lamellae. The separation was more prominent in areas adjacent to the bone marrow spaces. The ultrasonic and scalpel cuts were more irregular surface than those done by the bone chisels. In addition, delamination of the bone lamellae was more marked and no trace of overheating in the bone was found. In a similar study, Trisi et al. (unpublished data) compared cuts made in the calvaria of rabbits by piezosurgery, low speed drills and the oscillating saw. There were no signs of bone necrosis or osteocytic necrosis. The cut made with a piezoelectric tips showed a smooth and uniform surface with no signs of delamination of the lamellae or bone necrosis, while in the cut made with the drills or oscillating saw, much debris, and delamination of the lamellae and a more irregular bone surfaces was found. Piezoelectric tips produced an extremely linear and well defined cut both in the cortex and in the trabecular bone. Very few bone chips were present in the osteotomy space. The blood clot was located in the central area of the osteotomy without lateral dispersion.

The cuts made with the oscillating saw were irregular with considerable damage in the bony walls and dispersion of bone fragments in the adjacent marrow spaces, while bone fragments were not found in the cutting space. The blood clot was located throughout the entire area of the osteotomy as well as in the surrounding peripheral spaces. Fibrin clot adhering to the bony walls and a few white cells were also evident.

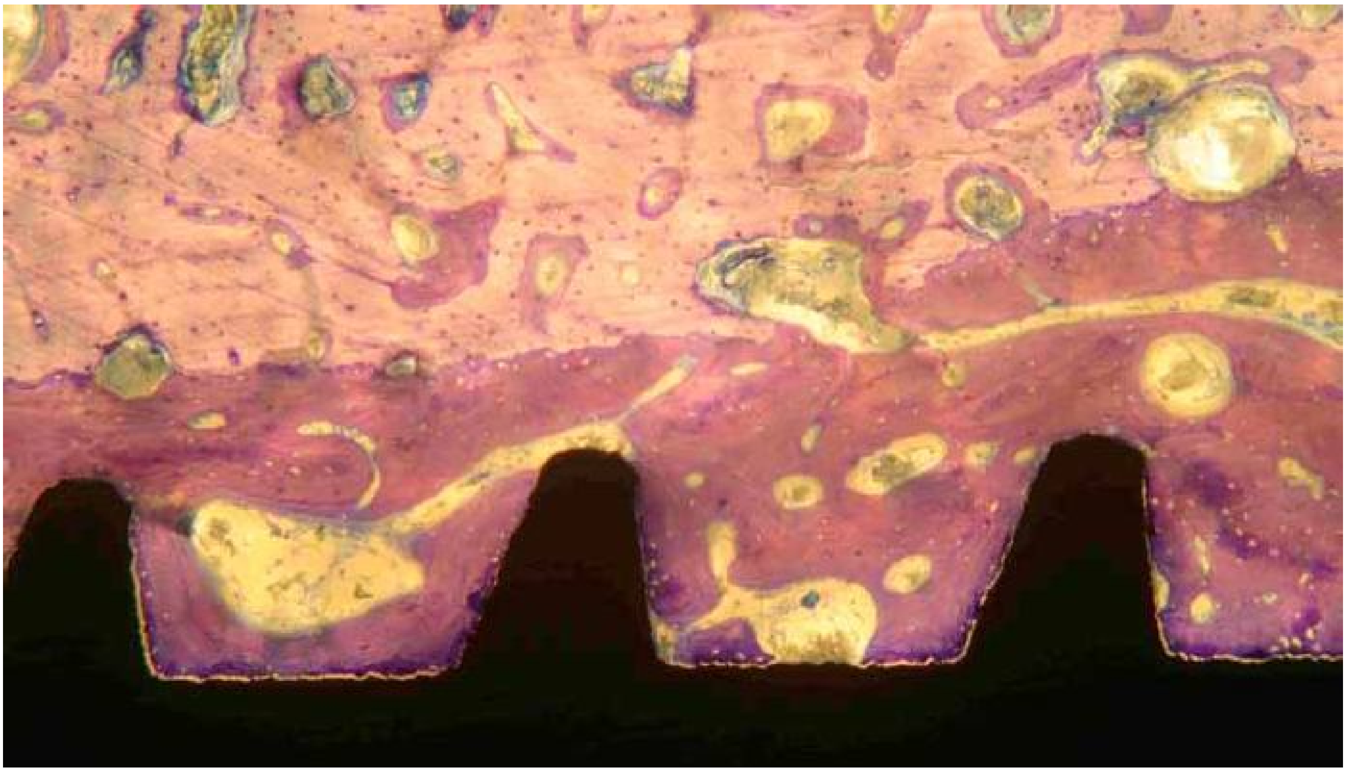
Similar results were obtained in a recent study[7] in which the cut surfaces were observed using different techniques. Following osteotomy with the ultrasonic device, the evaluation performed by light microscope showed a typical bone structure of the intact calvaria with an external cortex, the diploe and inner compact bone visible and well preserved. Instead, after osteotomy with conventional devices, the structure of the diploe had the following changes: the marrow spaces were filled with bone debris fragments and the trabecular structure was completely demolished. In addition, the SEM analysis revealed a condensed and grooved surface.

In a more recent study[8], three types of ultrasonic equipments were compared as to the bone cutting speed and the temperature variations. The results showed that the effectiveness of cutting varies widely between different devices and that during cutting increases in temperature does not exceed 1 to 3 degrees Celsius at the maximum for all.[8]

Aro et al.[6], in a histological study, found that the healing of defects using ultrasound instruments compared to oscillating saw, showed similar maturation processes at 6 weeks, while at 2 and 4 weeks, cutting with ultrasound showed a certain amount of connective tissue



Figures 19. The crestal bone showed the tendency to grow towards the coronal direction, and in some cases the newly formed bone had covered the screws (original magnification x25).



Figures 20. The amount of osseointegration in general is higher than the drill group (original magnification x50).

development resulting in a delayed healing.

In a comparative histological study between the surgical chisel and the ultrasonic instrument, Horton et al.[4] revealed numerous differences in the first weeks of healing that disappeared into the third month. Three days after cutting, the chisel and the ultrasonic defects had been filled by a fibrovascular granulation tissue with almost complete replacement of the blood clot. Cellular organization was found in some areas along the cut bone surfaces with good evidence of osteoid formation[4]. The defects produced by the drills still had the initial blood clot and an inflammatory infiltrate composed of polymorphonuclear leukocytes, while osteoclast activity was minimal and osteoid formation was not observed[4]. After seven days, the osteoclastic activity in cut areas produced by the ultrasonic device was significantly reduced. The new bone formation was now also evident within the defect. In general, the formation of new bone was more advanced in the defects created with a chisel in amount and maturity, while the bone formation in the drill defects was delayed. After 14 days of healing, the amount and maturation of bone defects in the chisels produced defects seemed to be more advanced when compared to those produced by the ultrasonic instrument. All samples evaluated at 28 and 56 days after surgery showed a progressively greater amount of bone formation. It became difficult to distinguish the differences between the three types of cuts. The ninetieth day, the original defects produced by the three instruments could no longer be distinguished from each other because of the significant bone remodelling.

In a similar study, Trisi et al. (unpublished data) did not observe substantial differences between the piezoelectric scalpel, the drill and oscillating saw in the first days following the surgery. At a distance of 7 and 14 days however, a difference in the amount of bone formation inside the wound was evident, since the cuts made with the drill and the piezo show the most complete degree of filling than the cuts made with the saw.

In the literature, we found only one study[17], conducted on pigs, which evaluates the biological effects of the healing of dental implants placed in sites prepared by piezoelectric surgery. The authors[19] reported that in the early stages of the osseointegration the piezoelectric technique appears to be more efficient in the first phases of bone healing, because it induced an increase in the amount of BMPs, a better controll of the inflammatory process, and stimulated bone remodelling as early as 56 days post-treatment.

CONCLUSIONS

In conclusion, we observed significant differences between different instruments for bone osteotomy. Using modern ultrasonic devices, the cut surface are smoother and more uniform without signs of delamination of the lamellae or bone necrosis, while in the osteotomies prepared by the drill or oscillating saw bone debris, delamination of the lamellae and irregular bone surfaces were observed. When analyzing the healing of implant site prepared by the piezoelectric device, repair and bone formation appeared faster and less aggressive than traditional drills. The bone growth in a coronal direction tended to cover the implant cover screws; while in traditional osteotomies we observed the formation of an infracrestral bony defect. In addition, while some implants in the sites prepared with drills showed signs of failure, none of the implant in the group treated by the piezoelectric system showed signs of severe bone resorption. Finally, in light of the present histological evidence and on the base of the literature data, we can affirm that the ultrasound osteotomies present different morphology, amount of debris and structural damage and that the processes of bone repair and osseointegration are positively influenced by the use of ultrasonic devices, both in timing and in morphology of bone regeneration.

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REFERENCES

1. Ercoli C, Funkenbusch PD, Lee HJ, Moss ME, Graser GN. The influence of drill wear on cutting efficiency and heat production during osteotomy preparation for dental implants: a study of drill durability. Int J Oral Maxillofac Implants 2004;19(3):335-49.

2. Harris BH, Kohles SS. Effects of mechanical and thermal fatigue on dental drill performance. Int J Oral Maxillofac Implants 2001; 16(6):819-26.

3. Mazarow HB. Bone Repair After Experimentally Produced Defects. J Oral Surg 1960;8:107-113.

4. Horton JE, Tarpley TM, Jr., Wood LD. The healing of surgical defects in alveolar bone produced with ultrasonic instrumentation, chisel, and rotary bur. Oral Surg Oral Med Oral Pathol 1975;39(4):536-546.

5. Mcfall Ta, Yamane GM, Burnett GW. Comparison of the cutting effect on bone of an ultrasonic cutting device and rotary burs. J Oral Surg Anesth Hosp Dent Serv 1961;19:200-209.

6. Aro H, Kallioniemi H, Aho AJ, Kellokumpu-Lehtinen P. Ultrasonic device in bone cutting. A histological and scanning electron microscopical study. Acta Orthop Scand 1981;52(1):5-10.

7. Maurer P, Kriwalsky MS, Block VR, Brandt J, Heiss C. Light microscopic examination of rabbit skulls following conventional and Piezosurgery osteotomy. Biomed Tech (Berl) 2007; 52(5):351-355.

8. Harder S, Wolfart S, Mehl C, Kern M. Performance of ultrasonic devices for bone surgery and associated intraosseous temperature development. Int J Oral Maxillofac Implants 2009;24(3):484-490.

9. Horton JE, Tarpley TM Jr, Jacoway JR. Clinical applications of ultrasonic instrumentation in the surgical removal of bone. Oral Surg Oral Med Oral Pathol 1981;51:236-42.

10. Vercellotti T, Nevins ML, Kim DM, et al. Osseous response following resective therapy with piezosurgery. Int J Periodontics Restorative Dent 2005;25:543-9.

11. Sohn DS, Ahn MR, Lee WH, et al. Piezoelectric osteotomy for intraoral harvesting of bone blocks. Int J Periodontics Restorative Dent 2007;27:127-31.

12. Happe A. Use of a piezoelectric surgical device to harvest bone grafts from the mandibular ramus: Report of 40 cases. Int J Periodontics Restorative Dent 2007;27:241-9.

13. Wallace SS, Mazor Z, Froum SJ, et al. Schneiderian membrane perforation rate during sinus elevation using piezosurgery: clinical results of 100 consecutive cases. Int J Periodontics Restorative Dent 2007;27:413-9.

14. Bovi M. Mobilization of the inferior alveolar nerve with simultaneous implant insertion: A new technique. Case report. Int J Periodontics Restorative Dent 2005;25:375-83.

15. Sakkas N, Otten JE, Gutwald R, Schmelzeisen R. Transposition of the mental nerve by piezosurgery followed by postoperative neurosensory control: A case report. Br J Oral Maxillofac Surg 2008;46:270-1.

16. Chiriac G, Herten M, Schwarz F, et al. Autogenous bone chips: Influence of a new piezoelectric device (piezosurgery) on chip morphology, cell viability and differentiation. J Clin Periodontol 2005;32:994-9.

17. Preti G, Martinasso G, Peirone B, Navone R, Manzella C, Muzio G, Russo C, Canuto RA, Schierano G. Cytokines and growth factors involved in the osseointegration of oral titanium implants positioned using piezoelectric bone surgery versus a drill technique: a pilot study in minipigs. J Periodontol 2007;78(4):716-22.