Research article

Bone characteristics following osteotomy surgery: an *in vitro* SEM study comparing traditional Lindemann drill with sonic and ultrasonic instruments

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Abstract

Background and objectives. Osteotomy surgery is widely used in dental surgery for implant site preparation, bone grafting and GBR. In this study, the characteristics of bone surfaces were examined after bone osteotomy surgery performed with the Lindemann bur, sonic (Komet Sonosurgery) and ultrasonic (Mectron Piezosurgery) instruments.

Materials and Methods. Anatomic integrity and osteotomic precision were analyzed using Scanning Electron Microscopy (SEM) to observe vascular canals, microfractures, exfoliations and bone debris on cortical and cancellous surfaces cut with the 3 types of instruments.

Results. The use of ultrasonic instruments resulted in extremely precise cuts and reduced bone damage. The sonic instrument was precise in cortical bone but showed minor signs of bone damage in cancellous bone. 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.

Discussion and Conclusion. For all parameters, the ultrasonic cut offered the most precise and atraumatic bone cut. Ultrasonic and sonic instruments both showed more precise and less traumatic results than the Lindemann bur.

Keywords. Bone, osteotomy, piezosurgery, surgical instrument.

1. Introduction

Bone cutting technique is a determinant parameter for many applications in neurosurgery **[1]**, as well as orthopedic **[2]**, maxillofacial **[3]** and oral surgery **[4]**. In the past, bone was cut through the use of chisel and mallets or manual saws **[5]**, whereas

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rotating instruments, such as bur, rotating disk and saw powered by micromotor, now support this procedure **[6]**. Also, during the last 15 years, surgical bone techniques have undergone a considerable evolution with the introduction of vibrating instruments with sonic-ultrasonic frequencies (Piezosurgery, Mectron s.p.a., Carasco, Italy) and sonic instruments (Sonosurgery, Komet Dental, Lemgo, Germany)**[7,8]**. In dentistry, bone-cutting techniques are commonly used in periodontal and implant surgery **[9]**. Especially in implantology, many bone volume augmentation procedures are based on precise and safe osteotomies **[10]**. Thus, surgical decision-making depends on understanding the advantages and limitations of such surgical techniques as bur powered by micromotor, as well as Piezosurgery and Sonosurgery technologies.

In particular, the cutting action is the result of macro- or micromechanical shocks at different speeds. Saw, bur and disk use high-speed macro vibrations, which may cause bone trauma and damage by producing heat and debris **[11-13]** that may interfere with healing response **[12,14-16]**. Therefore, the cutting characteristics of a traditional instrument (the Lindemann bur) and of vibrating instruments are compared for their bone effects in the present article. More specifically, this *in vitro* study uses Scanning Electron Microscopy (SEM) to analyze the mechanical effects of surgical trauma on cortical and cancellous bone surfaces that result from the cutting action of different surgical instruments. Anatomic integrity and osteotomic precision were evaluated through observation of vascular canals, microcracks and micro-fractures, exfoliations and bone debris.

2. Materials and Methods

Two bovine ribs with dimensions of 25 x 4 x 1 cm were used to prepare 22 bone blocks to be cut with the different technologies. Bovine bone is commonly used as a model in biomechanics because its cortical thickness and cancellous density are similar to human bone. These blocks are characterized by an external dense cortical part, with a thickness of about 2 mm, while the inner part is mainly made of trabecular bone of medium density (D2-D3).

All cuts were performed by the same operator. Each bone rib was sectioned in the longitudinal axis with Piezosurgery 3 with insert OT7 to obtain a first specimen having a length of 25 cm. Each specimen was characterized by an external cortical layer, with a spongious part inside. In order to choose the part of the rib where cortical and cancellous bone have the same thickness in all samples, the specimen obtained was then cut longitudinally in two parts in order to expose internal bone structure. Then the parts of the bone with similar characteristics were chosen in order to obtain the same cutting conditions for each sample. Finally cuts were performed with different instruments, as follows:

- Lindemann Bur (Meisinger 161) powered by W&H handpiece S-11 (W&H GmbH, Bürmoos, Austria): the bone bur is a rotary cylindrical drill powered by a high-speed micromotor with a rotating speed of 20,000 - 40,000 rpm, with external irrigation.
- Piezosurgery: the Piezosurgery 3 system with insert OT7S-4 (Mectron s.p.a., Carasco (GE), Italy). Ultrasonic cut uses linear mechanical microvibrations at both ultrasonic and sonic frequency, ranging from 24 to 36 kHz, depending on the tip used and on the bone quality.
- Sonosurgery: Sonosurgery with insert SFS 101 (Komet Dental, Lemgo, Germany) is a sonic instrument that vibrates at a high frequency (6 kHz).

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Each specimen had dimensions of 1 x 1 x 0.5 cm. During the osteotomy, the cutting device was cooled with profuse physiological solution 0.9%, or water in the case of the sonic device, which was not equipped for saline irrigation. All of the specimens were then inserted in a can containing the physiological solution. Finally, the samples were prepared for SEM analysis. Samples were desiccated and covered with a thin gold layer for conduction, using a Polaron SEM coating system.

3. Results

3.1. Effects of the Lindemann bur on the bone

The cortical part was examined with 100X of magnification **(Figure 1A)**. SEM analysis showed that the cut was not precise, and several signs of extreme bone trauma were seen on the cut surface. Bone surface appeared extremely irregular. Microcracks and exfoliations of bone layers were also visible (15 for field of view). Many bone chips were spread over the bone surface. Cortical bone presented 2 pervious vascular canals for field of view.

The spongious bone showed trabecular fractures and several broken trabeculae. Most bone debris was still linked to the trabeculae and almost completely filled the medullary cavities by an average of 80% **(Figure 1B)**.

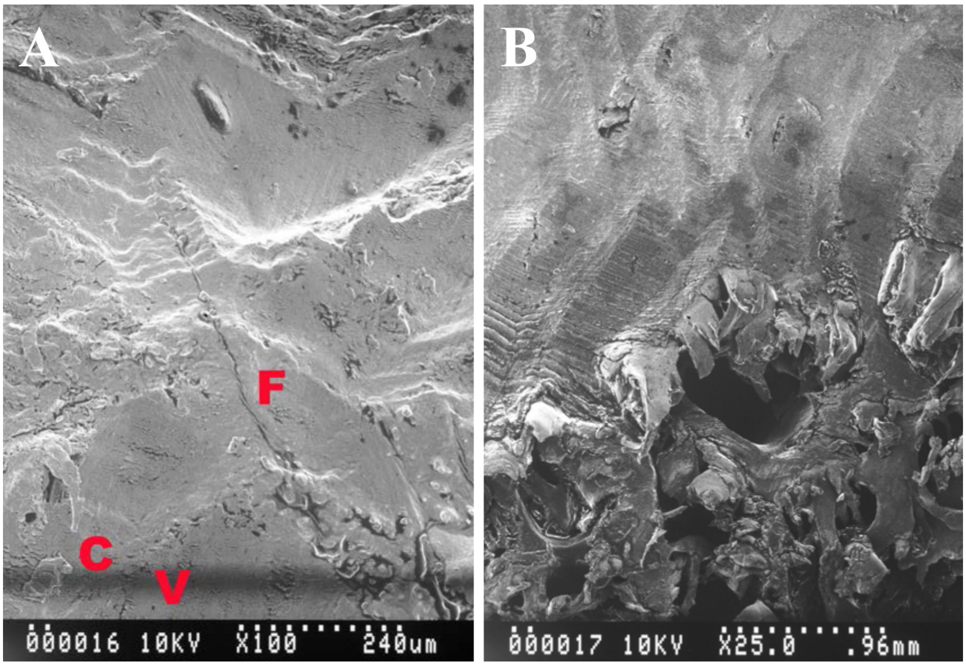

Figure 1. SEM analysis images showing the effects of Lindemann bur on the bone. (A) Effects of Lindemann bur on the cortical bone. The cut was not precise. Several deep abrasions due to the attrition of the cutting edges of the bur corrupted the bone surface, which appeared extremely irregular. Micro-cracks and exfoliations of bone layers were also visible (F). A lot of bone chips (C) were spread over the bone surface, hiding most of the bone vascular canals: only 2 pervious vascular canals for field of view (V) were visible (100X magnification). **(B)** Effects of the Lindemann bur on cortical and cancellous bone. The cortical-spongious junction was still preserved and fairly distinguishable. The deep abrasions of the cortical bone were in continuity with several big bone chips still attached to the bone trabeculae. The chips were mixed with detached bone debris and larger fragments that were almost completely filling the marrow spaces (25X magnification).

3.2. Effects of the Sonosurgery on the bone

The cortical part, seen with 100X of magnification, showed a precise cut, and the bone surface was smooth and regular **(Figure 2A)**. Microcracks and exfoliations of bone layers were visible (20 for field of view). Few bone chips were visible over the bone surface. Cortical bone presented 10 pervious vascular canals for field of view.

The spongious bone showed few trabecular fractures and unbroken trabeculae. Bone debris occupied medullary cavities with an extremely variable range at a mean of 45% **(Figure 2B)**.

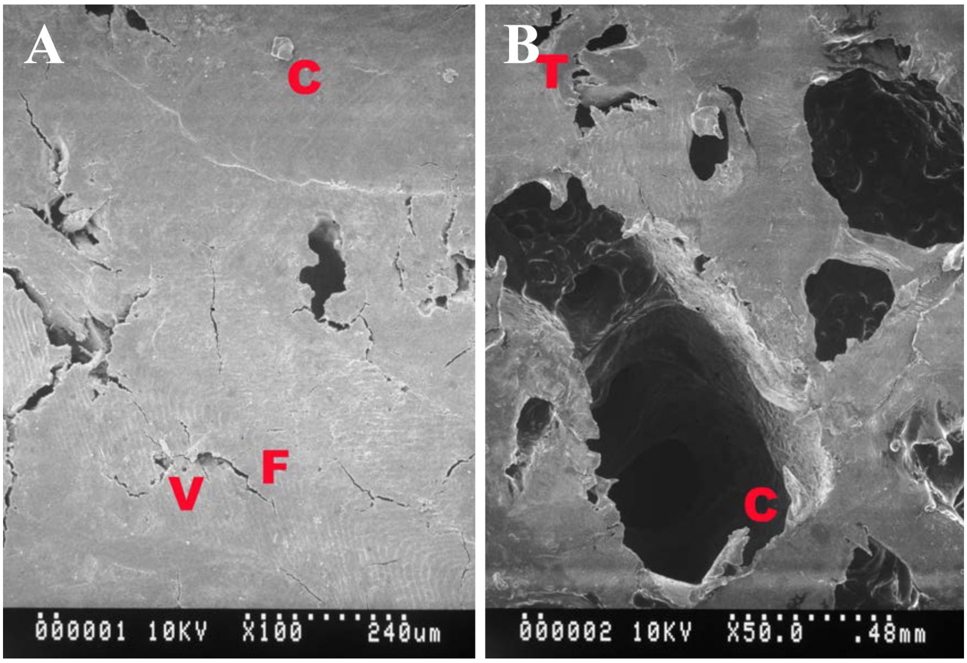

Figure 2. SEM analysis images showing the effects of Sonosurgery on the bone. (A) Effects of Sonosurgery on the cortical bone. The cortical part showed a precise cut, that left bone surface smooth and regular. Microcracks and exfoliations of bone layers were visible (20 for field of view)(F). Few bone chips were visible over the bone surface (C). Cortical bone presented 10 pervious vascular canals for field of view (V)(100X magnification). **(B)** Effects of Sonosurgery on the cancellous bone. The spongious bone showed few trabecular fractures (T) and unbroken trabeculae. Bone debris (C) occupied medullary cavities with an extremely variable range at a mean of 45% (50X magnification).

3.3. Effects of the Piezosurgery 3 with Insert OT7S-4 on the bone

The cortical part, seen with 100X of magnification, showed a precise cut, and the bone surface was well preserved, smooth and regular **(Figure 3A)**. Microcracks were also visible (15 for field of view). Bone debris was almost absent. Cortical bone presented 8 pervious vascular canals for field of view.

The spongious bone showed a very precise cut of the trabecular structure, and bone trabeculae appeared intact. The medullary spaces showed very little debris in the medullary cavities, about 15% on average **(Figure 3B)**.

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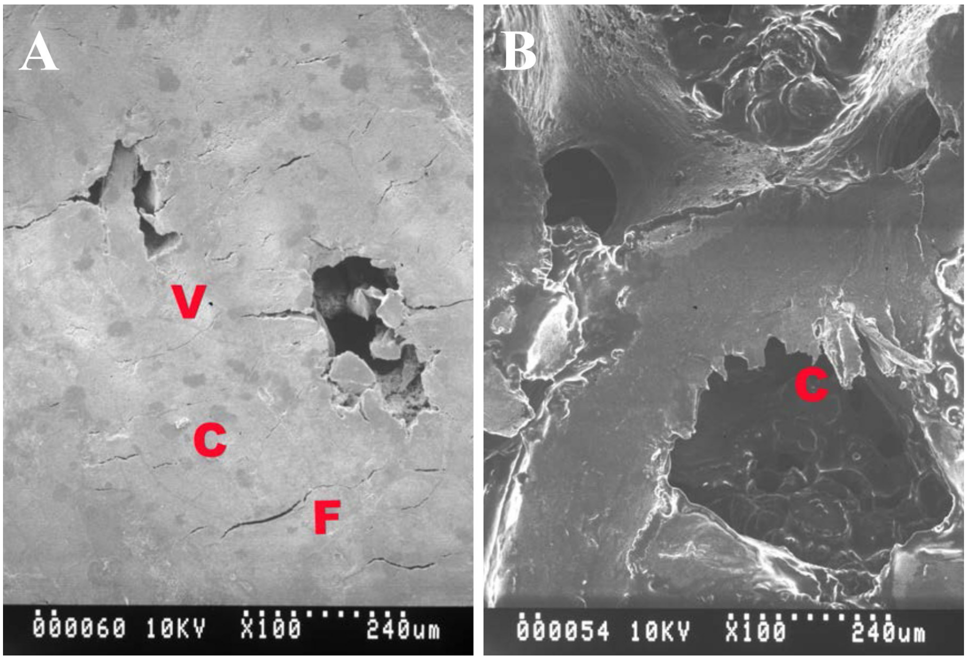

Figure 3. SEM analysis images showing the effects of Piezosurgery on the bone. (A) Effects of Piezosurgery with the insert OT7S4 on the cortical bone. The cortical part, showed a precise cut, and the bone surface was well preserved, smooth and regular. Microcracks (F) were also visible (15 for field of view). Bone debris (C) were almost absent. Cortical bone presented 8 pervious vascular canals (V) for field of view (100X magnification). **(B)** Effects of Piezosurgery with the insert OT7S4 on the cancellous bone. The spongious bone showed a very precise cut of the trabecular structure, and bone trabeculae appeared intact. The medullary spaces showed very little debris (C) in the medullary cavities, about 15% on average (100X magnification).

4. Discussion

Based on the results of the present study, cortical bone exhibits different behaviour in response to the cutting action when compared to trabecular bone. Traumatic damage to cortical bone was limited to microcracks, exfoliations of the bone layers and the formation of deep or superficial abrasions. Abrasions seem to be created by the attrition of the cutting edges on the bone walls. The accumulation of debris was also observed. Two types of debris can be noted: debris still attached to the bone surface and detached debris, which formed a smear layer that completely, or partially, covered the bone surface. The smear layer hid, or closed, most of the vascular canals of the cortical bone. On the other hand, trabecular bone reacted differently to the traumatic cut, probably because of the higher elasticity resulting from the presence of marrow spaces that disrupted the continuity of the mineralized surface of the bone. In spongious bone, this characteristic limited most damage to microcracks and exfoliations, while microfractures, sometimes incomplete, were often seen in trabeculae.

All the cutting devices analyzed in the present study are equipped with irrigation that is aimed to clean surfaces, remove detached debris, improve surgeon visibility and cool the cutting tip. Depending on its efficacy, irrigation seemed to clean most of the cut surfaces. Meanwhile, SEM images showed that both quantity and type of bone damage could be attributed to the cutting technique employed. Based on the amount and type of bone damage, when compared to bur, both cortical and cancellous bone cut with sonic and ultrasonic instruments showed more precision and a cleaner surface with reduced quantity of visible

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damage and lower debris accumulation. Cut surface obtained with the Lindemann bur appeared the most damaged **[17,18]**.

Osteotomies done with the Lindemann bur, showed a considerable accumulation of bone chips on the surfaces, most likely the result of the high kinetic energy used by this instrument and the necessity of applying more pressure during the cut. Among sonic and ultrasonic instruments, the more precise and cleaner cut was achieved by the ultrasonic instrument, while the sonic instrument showed more debris in trabecular bone. The sonic cut appeared more regular in cortical bone, while some lacerations of the trabecular structure were evident in cancellous bone. The ultrasonic instrument showed a more effectively reduced cutting trauma, especially in trabecular bone.

Compared to the bur, the sonic and the ultrasonic instruments showed clean-cut surfaces and the absence of smear layer, in both cortical and cancellous bone. The absence of smear layer was demonstrated by a higher number of visible opened vascular canals in cortical bone and less debris in cancellous bone. Opened vascular canals may improve nutrition during the early healing phase, while clean surfaces may limit inflammation and the need for implementing the cellular cleaning phase of the bone repair sequence. Although studies on ultrasonic implant site preparation and bone healing have shown the possible advantages of clean surfaces and ultrasonic cut **[19,20]**, more biological and clinical studies should be performed in order to clarify the role of bone debris and smear layer on surgically cut bone surfaces. Also, the healing of ultrasonically cleaned bone surfaces should be compared with the healing of surfaces treated with bur, which, in the present study, showed smear layer and a higher amount of bone fragments over bone surfaces and among trabecular spaces.

Sonosurgery seems a promising technique, but still needs technical improvements in order to solve some problems, related to the quality of the cooling solution and sterility. The sonic action, during cutting, produces heat that may cause bone damage, therefore a cooling spray is required. The sonic device is actually equipped of an effective cooling spray, but the cooling solution proposed by the producer is simply normal non sterile drinking water, the same that come from the standard faucet that may be not ideal for surgical applications. Drinking water is not the best for cell preservation, as it is too much hypotonic and also not sterile. *In vivo*, hypotonic solutions does not favorite cells homeostasis, causing a higher risk of tissue suffering and in the meantime the loss of sterility, which may produce contamination of the surgical area. Since it is a common knowledge that in bone surgery a sterile physiologic solution is preferable to non sterile water, the sonic device should be equipped with a sterile spray of isotonic solution. On the contrary the ultrasonic Piezosurgery system and the surgical handpiece for the Lindemann bur, are equipped with a pump which provides an external profuse spray of sterile isotonic saline solution (purified water with 0,9% Na/Cl). This isotonic, purified and sterile solution, without contaminants that can be found in the tap water, is more adapted for the surgical applications of these instruments.

5. Conclusion

In conclusion, the present study illustrates that cortical bone cut with the Piezosurgery ultrasonic device using OT7S-4 may be superior, as it preserves the bone surface and considerably decreases the presence of microfractures and smear layer. Furthermore, cleaning the bone surface with the cavitation effect of the cooling physiological solution should avoid closure of bone vascular canals, which likely occurs in standard cutting techniques by the compression of bone debris between bone surfaces and the cutting device.

In cancellous bone, ultrasonic cut with the Piezosurgery unit and OT7S-4 insert permits better cutting of the trabeculae and a reduction of 1) fractures that would otherwise weaken bone structure and 2) fragments compressed into the trabecular architecture. Sonosurgery offers also a clean cut with limited tissue trauma. Finally, the cut with the Lindemann bur is the most irregular and traumatic from the 3 instruments. The choice of the adequate instruments during bone surgery should therefore be influenced by these observed results, but also by many other practical considerations (speed of cut, ergonomy, irrigation solution). Further research is needed to understand how these parameters of osteotomy may influence the final bone healing.

Disclosure of interests

The authors have no conflict of interest to report.

Author Contributions

AR wrote the article and, together with GS (Signorini), had the idea to perform the study and prepared the protocol of the work. GS (Sammartino) participated to the elaboration of the design of the study and the revision of the manuscript. GF, FB and MC were in charge of the SEM analysis, morphometric measurements and statistical analysis. MS and GS (Signorini) prepared the samples, performed the cuts, participated to the data collection and to the elaboration of the manuscript.

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