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RESEARCH

Bone cutting performance and mechanical properties of piezo-surgical tips: a nano-indentation study

Piezocerrahi uçların kemik kesme performansı ve mekanik özellikleri: bir nano-indentasyon çalışması

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Abstract

Purpose: The aims of this study were to compare the mechanical properties of piezo-surgical tips such as nano-hardness, elastic modulus, surface roughness, and wear level, and to measure their cutting performance.
Materials and Methods: In this study, 31 piezo-surgical tips were used, three for control and 28 for testing. The testing tips were equally divided into four groups with different numbers of osteotomies: the four-, 8-, 16-, and 32-osteotomy groups. The mean osteotomy duration was recorded during osteotomy. Scanning electron microscopy images of the tips in the test groups were obtained before and after osteotomy, and the wear level of the tips was measured.
Results: A statistically significant increase was observed in the nano-hardness of the piezo-surgical tips depending on the number of osteotomy (for 4-use; 22.47±1.67H and for 32-use; 28.49±3.42H). The elasticity value of the testing tips was in the range of 218.55±15.74E to 241.26±10.46E, and all of the values were significantly higher than those in the control group (174.39±13.53E). As the frequency of use increased, a significant increase in surface roughness was observed (from 16.67±1.50 to 56.12±2.60). A positive correlation was found between the frequency of use and the wear level of the tips, and between the surface roughness and wear level of the tips.
Conclusion: With the increase in the number of osteotomies, significant changes in the mechanical and physical properties of the piezo-surgical tips that affected their bone-cutting performance were observed.
Keywords: Piezosurgery, hardness, elasticity, osteotomy.

Öz

Amaç: Bu çalışmanın amacı piezocerrahi uçların nano-sertlik, elastik modül ve yüzey pürüzlülüğü gibi mekanik özelliklerini ve kemik kesme performanslarını kıyaslamaktır.
Gereç ve Yöntem: Bu çalışmada 3 adet kontrol, 28 adet test amaçlı toplam 31 adet piezo-cerrahi uç kullanıldı. Test grupları 4, 8, 16 ve 32 adet kemik kesisi yapacak şekilde oluşturuldu ve her grupta 7 adet uç yer aldı. Kesi boyunca ortalama süre kaydedildi. Uçlarda meydana gelen aşınmayı belirlemek için test grubunda yer alan piezocerrahi uçların kesi öncesi ve kesi sonrası SEM görüntüleri elde edildi.
Bulgular: Test grubundaki tüm uçların nano-sertliği kemik kesi sayısına göre istatistiksel açıdan önemli düzeyde artış gösterdi (4 kesi grubu için 22.47±1.67H; 32 kesi grubu için, 28.49±3.42H). Kullanıma bağlı olarak uçların elastikiyet değeri 218.55±15.74E ila 241.26±10.46E değeri arasında değişkenlik gösterirken, bu değerler kontrol grubundakinden daha yüksekti (174.39±13.53E). Kullanım sıklığı artıkça uçların yüzey pürüzlülüğünde 16.67±1.50'lik birimden 56.12±2.60'lık birime doğru anlamlı düzeyde artış meydana geldi. Uçların aşınma miktarı ve kullanım sıklığı arasında ve aşınma miktarı ve yüzey pürüzlülüğü arasında pozitif korelasyon gözlendi.
Sonuç: Piezocerrahi uçların kullanım sıklığı artıkça mekanik özelliklerinde nano-düzeyde önemli değişiklikler olmakta ve bu değişiklikler kesi performansını etkilemektedir.

Anahtar kelimeler: Piezo-cerrahi, sertlik, elastikiyet, osteotomi

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INTRODUCTION

The piezo-electric effect is a physical phenomenon defined as the electrical load on the surface of substances such as ceramics and crystals exposed to mechanical pressure. Piezo-surgery is a safe procedure in which bone osteotomies are performed with micro-vibrations generated by the piezo-electric effect[1].

In dentistry, piezosurgery systems have been applied in the clinical field in operations such as sinus lifting, obtaining autogenous bone blocks, alveolar ridge augmentation, implant surgery, crown-lengthening procedure, tooth extraction, cyst enucleation, exostosis removal, and apical resection[2]. Owing to its micro-metric and selective cutting, the piezo-surgical system not only protects soft tissues such as veins, nerves, and membranes but also prevents osteonecrotic damage[3]. Healing is faster with osteotomies performed using the piezo-surgery system than with traditional methods such as the use of burs. Rapid wound healing occurs because ultrasonic vibrations induce the release of bone morphogenetic proteins at the osteotomy site; thus, the bone is remodelled at earlier stages than normal[4,5]. Another important advantage of this system is the cavitation phenomenon[6,7]. Vibrations at the working tip cause foam formation in the irrigation solution. This foam offers an excellent field of vision by washing the operation site, removing the residues in the area, and clogging the ruptured/ruptured small blood vessels[8]. Moreover, piezo-surgery causes minimal damage to the bone; therefore, postoperative pain and oedema are less common[5]. It has tips made of different sizes, shapes, and materials that are connected to a handpiece. These tips can be coated with titanium or diamond. As with other materials used in dentistry, the tips have various mechanical properties such as hardness, strength, and elasticity. In addition, surface roughness, wear, and fracture toughness are also important features[8].

Nano-indentation has been used since the early 20th century to determine the properties of materials[9-11]. Nano-indentation is a technique for depth-sensing indentation tests involving a controlled application of force that induces local surface deformation[12,13]. It is widely used to collect information about the elastic modulus and hardness of these technical materials[14]. While the recess end of the device was moved on the surface of the material to be tested, load (*P*), recess depth (*h*), and time (*t*) data were obtained. The most common indentation tip used for analysis is the Berkovich tip, which is recommended in practice owing to its many advantages such as shape homogeneity, sharpness of the tip apex in the diameter range of 20 nm, and plasticity that will not cause cracks in small displacements[15].

The manufacturers provide information about the products which is used for purpose of the surgical procedures in dentistry field. The properties of piezo-surgical tips vary depending on the frequency of use. The wear characteristics of the tips may be associated with these parameters. We think that the changes on the piezo-tips may prolong the operation time in human and this condition may negatively affect wound healing in surgical site. Therefore, our hypothesis is that the mechanical properties of the tips will have changed depending on the frequency of use. The aim of this study is to compare bone cutting performance according to changes in the mechanical properties of piezo-surgical tips such as nanohardness, elastic modulus, and surface roughness

MATERIALS AND METHODS

This study was conducted in Department of Periodontology, Faculty of Dentistry and Technology Research & Development Center in Hatay Mustafa Kemal University. The Technology Research and Development Center is accredited to TS EN ISO/IEC 17025 of Turkish Standards. The study was not needed any ethical approval.

Allocation of the tips

Thirty-one piezo-surgical tips (US2 model, Woodpecker Ultrasurgery 2) were used in this study. The piezo-surgical tips were assigned to five groups, including osteotomy groups (P4, P8, P16 and P32) and control group (PC). The distribution of the tips to the groups is shown in Figure 1.

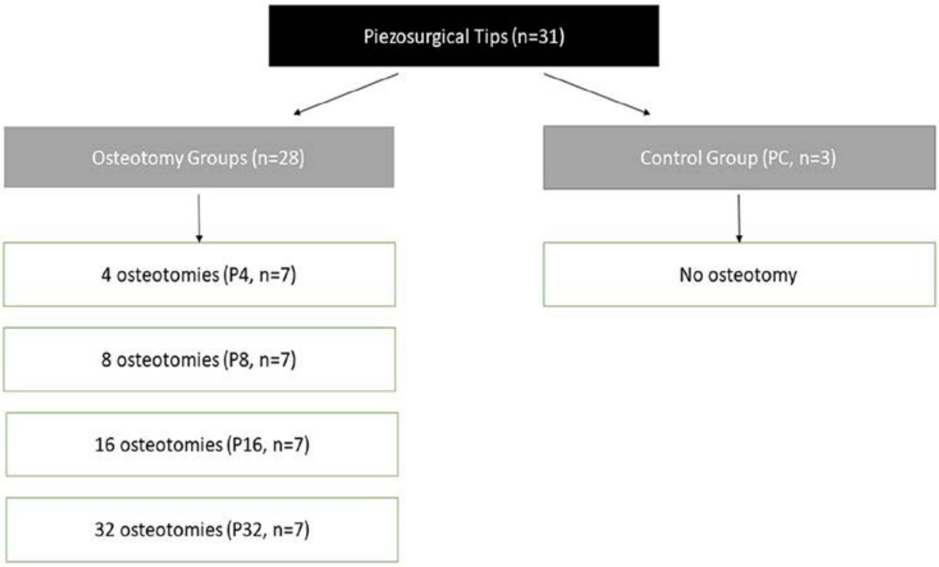

Figure 1. Distribution of piezosurgical tips according to the groups.

Obtaining bone blocks

Four bones were obtained from the left and right sixth and seventh ribs of freshly slaughtered bovines between the ages of 1 and 3 years. Seven bone blocks in length of 40 mm were formed from each rib, coded A, B, C, or D (Figure 2). The bone blocks related to the ribs in each group were numbered with the code of that group from 1 to 7 (e.g. for group A: A1, A2, A7; for group B:B1, B2,..B7; for group C:C1, C2,..C7; for group D: D1, D2,..D7). The cortical thicknesses of the blocks were measured from three proximal and distal points of osteotomy aspect using a calliper, and the average cortical thickness was calculated for that rib. The cortical thickness of the blocks should be at least 4.5 mm at each point.

The bone blocks were kept in 0.9% NaCl and −10ºC until the experiment day. The day before the procedure, the blocks were dissolved at +4ºC. Thereafter, the bone blocks were dried and fixed to plastic glass plates with cold curing repair acrylic. At least 15 guide lines, each 10 mm long and 2 mm apart, were drawn on the block and numbered 1 to 15 (Figure 2).

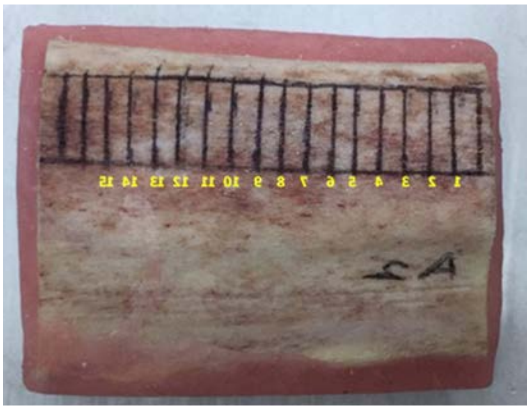

Figure 2. A bone block obtained from a rib. Note the guidelines for bone cuts.

Osteotomy apparatus

A block of 10×10×10 cm was fabricated from steel for upper stay plate. A 10×4×6 cm piece was removed from the middle part of the upper stay plate to constitute a U-shaped platform. Thus, it was easy to fix both the load cell and the lower stay plate to the upper stay plate with aid of screws. The lower stay plate of 20×4×20 cm in size was prepared from the steel block, as well. The load cell (Samiore Robot, up to 10 kg) which is a special sensor that converts the force applied to the device into electrical signals was used to measure the force applied during bone cutting test. Since the voltage value of the signals from the weight sensor was low, a highly sensitive card (HX711) was used as a signal amplifier. On one hand, the load cell was connected to the upper stay plate, on the other hand, a Plexiglas plate on which the bone block was attached with cold acrylic resin was fixed to the load cell with screws (Figure 3).

The Arduino software programme (IDE 1.8.19 version) was used to transfer the strength signals from the load cell to the computer. After connections between the load cell and HX711 were made, they were connected to the Arduino Uno card (Figure 3) using a cable to provide access between the load cell and the Arduino programme.

Insulation tape was used to prevent the cable connections from being disconnected and damaged (Figure 3). After the connections were completed, codes were entered into the Arduino programme, where we could measure the force signals in newton. Thus, a mechanism was designed to perform bone osteotomies precisely and transfer the applied load to the computer. The osteotomy apparatus was placed in a plastic box where the cooling solution used to reduce the heat generated at the piezo-surgical tips during the osteotomy. The liquid accumulated in the box was suctioned simultaneously using an aspirator.

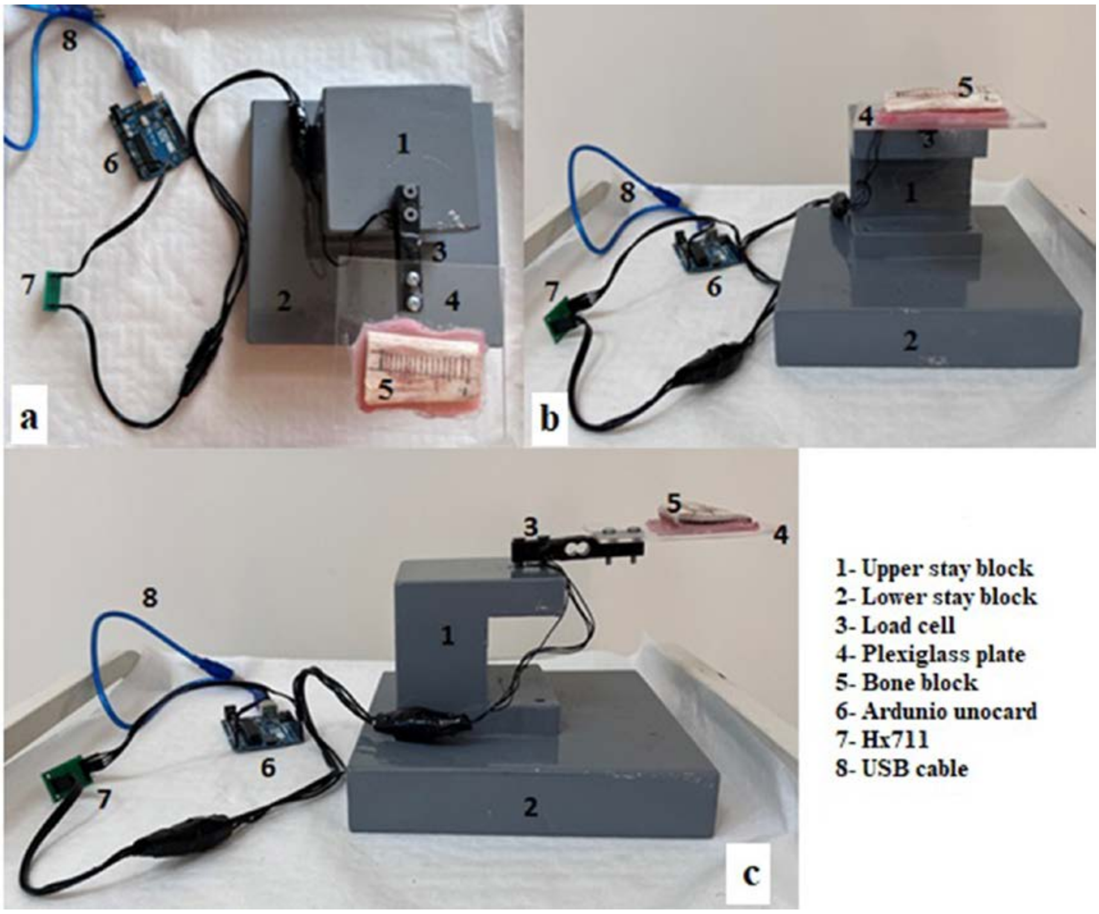

Figure 3. Osteotomy apparatus, (a) superior view, (b) frontal view, (c) lateral view.

Determination of osteotomy load and osteotomy duration

The calibration of the load cell was provided before osteotomy experiment on each block. The Arduino programme displayed on computer the load (newton per second) applied during the osteotomy and the duration of the osteotomy. The duration of the osteotomy was measured as the sum of the time when the load was actively applied, and the load was measured as the average of the force applied per second.

Osteotomy experiments

All osteotomies were performed by an operator, who had previous piezo-surgical experience (O.F.A), with the cooling irrigation by selecting the bone function and high bone density (24–30 kHz) settings using US2 model tips. Before starting the experiment, at least 50 osteotomies were performed on rib obtained from the same animal. The osteotomy experiments were made between 10:00 and 12:00 am. For each day, four bone blocks were selected as to one piece from each rib group, and the blocks were labelled with the same number (e.g. A1, B1, C1, and D1). The lines drawn on the bone block were allocated randomly to the osteotomy groups using a computer programme. On each block, one, two, four, and eight osteotomies were made for the P4, P8, P16, and P32 groups, respectively. Attention was paid to ensuring that all osteotomies were 10 mm long and at least 4.5 mm deep (up to the first point level on the tip) (Figure 4). The operator was allowed to rest for 15 minutes between the bone blocks. In the study, which lasted for 7 days, a total of 420 osteotomies were made on 28 bone blocks.

Scanning electron microscopy images

Scanning electron microscopy (SEM) images of the 28 piezo-surgical tips in the osteotomy groups were obtained by using a device (JEOL-5500/OXFORD Inca-X) in ×30 original magnification and 500-μm scale before the experiment (Figure 5a). After the osteotomies were completed, SEM images of the 28 piezo-surgical tips in the test group were obtained as before the procedure

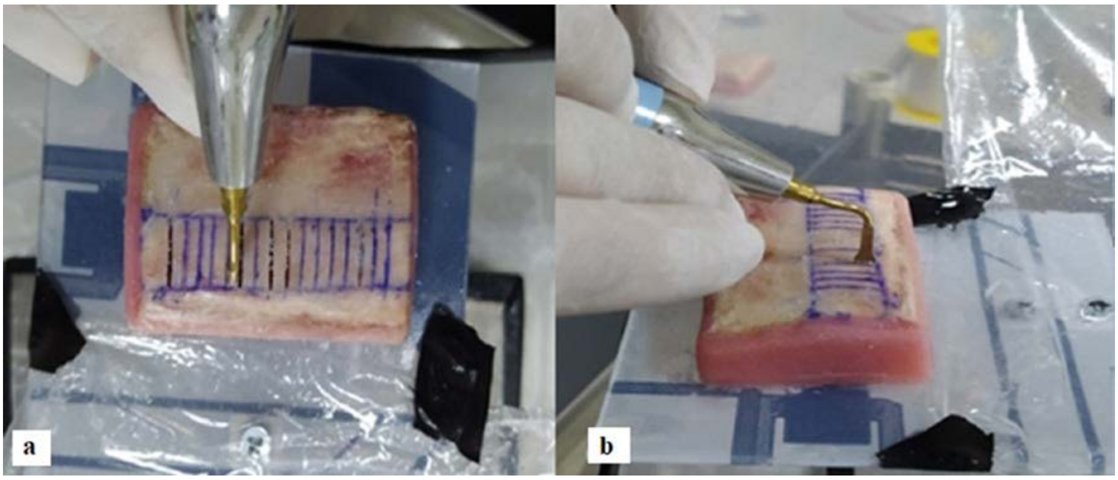

Figure 4. Osteotomy experiments, (a) superior view, (b) lateral view.

Measurement of wear level

Two separate SEM images obtained were transferred to the Adobe Photoshop programme (Adobe Photoshop CS6, Michigan, 2022). The images uploaded to the programme were set to overlap. By adjusting the opacity of the SEM image obtained after the osteotomy, the SEM image of the tip before the osteotomy was made clearer. Thus, the wear level of the tips was measured in two dimensions (Figure 5b). The AutoCAD software programme (AutoCad-2020, Autodesk, California, 2020) was used to calculate the wear area. The wear area in the overlapped images was calculated with the polyline area and hatch commands in the programme.

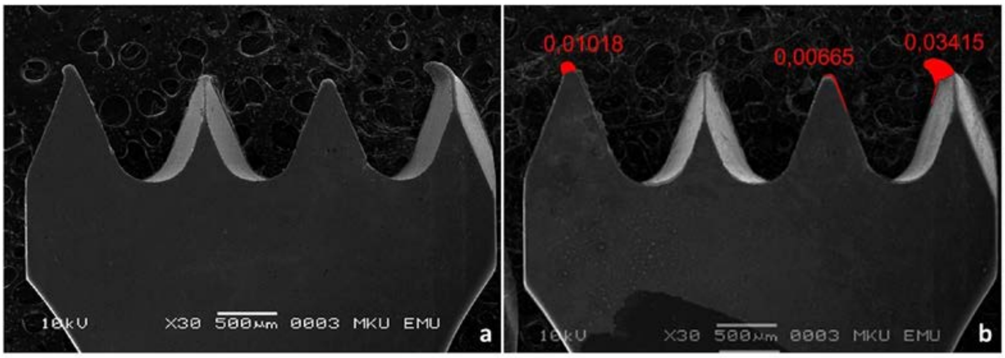

Figure 5. SEM images obtained for the measurement of wear level on the tips in osteotomy groups. (a) before osteotomy experiment, (b) two overlapped images before and after osteotomy experiment for the measurement wear level on a tip two dimensionally.

Measurement of nano-hardness, elastic modulus and surface roughness

A nano-hardness analysis was performed using the Hysitron Triboindenter TI 950 device to examine the mechanical properties (e.g. elastic modulus [*E*] and surface hardness [*H*]) of the piezo-surgical tips. A Berkovich diamond tip was used as the notch tip in the nano-hardness tests. The tests were performed under a maximum force of 6000 μN and a 3×3 analysis matrix in accordance with the Oliver-Pharr analysis method[16], using a force-controlled trapezoidal load function in which the load was increased linearly for 5 s, maintained constant for 2 s, and gradually lifted at 5 s. From the analysis results obtained, a load displacement curve was created, and the mechanical properties of the sample, such as hardness and elastic modulus, were calculated using the curve. The measurements were performed at five points of a lateral surface of each tip in all groups (Figure 6a). The average surface roughness was calculated automatically by taking the scanning probe microscopy image over a 10x10 μ area before nano-indentation test (Figure 6b). Changes in the surface roughness, nano-hardness, and elastic modulus of the piezo-surgical tips were compared with those in the control group. The all measurements were performed by a physicist (S.Ö).

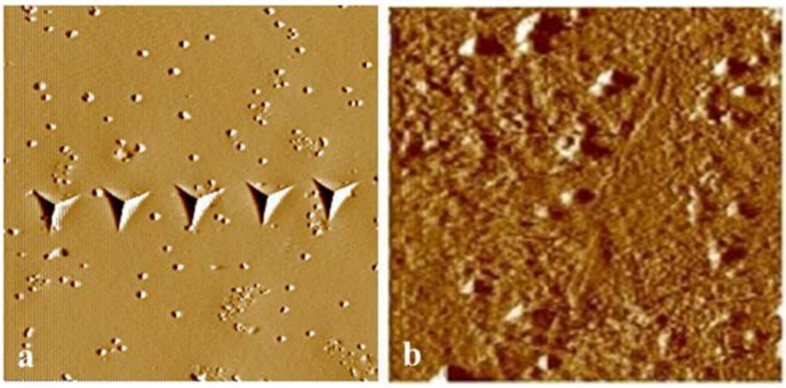

Figure 6. Mechanical tests of piezosurgical tips. (a) nano-indentation (before use), (b) surface roughness (after 32-use).

Statistical analysis

A statistical software package (SPSS 25.0, Chicago, 2017) was used for the analysis of the data. Continuous measurements were summarised as mean ± standard deviation, range values, and median values. The distributions were checked in the comparison of continuous measurements between the groups by using Shapiro-Wilks statistical test. Because the variables such as nano-hardness, elasticity, surface roughness, osteotomy load, wear level, osteotomy duration could not show normal distributions, the Kruskal-Wallis test was used in the comparison of multiple groups, and the Mann-Whitney *U* test was used in the comparison of paired groups and in the post-hoc analysis. The Spearman correlation test was used to determine the correlations between the continuous variables including not only the above-mentioned parameters, but also the osteotomy number. The statistical significance level was 0.05 for all tests.

RESULTS

In this study, the achieved power was calculated as 99% with a probability of error of 5% by using the effect size of the statistical analysis performed to evaluate the amount of wear occurring due to different numbers of osteotomies with a total of 28 samples (7 samples for each group).

All osteotomies were uneventfully completed. The average cortical thicknesses of the bone blocks used in this study varied between 5.00 ± 0.10 mm to 5.08 ± 0.09 mm (min-max= 4.80 mm -5.20 mm). There was no difference between the bone blocks obtained four ribs in terms of cortical layer thickness (p = 0.527).

When the mechanical properties of the tips were examined, the nano-hardness of the tips showed statistically significant differences between the osteotomy groups (p=0.007; Table 1). In the pairwise comparisons, significant differences were found between P4 and P16, P4 and P32, and P8 and P32 (p<0.05; Table 1). Generally, the nano-hardness of the tips increased depending on the increase in the number of osteotomies.

Data on the elastic modulus of the tips are shown in Table 1. The elasticity values of the tips were significantly different between the osteotomy and control groups (p=0.007). In the pairwise comparisons of the elasticity values, statistically significant differences were observed between the P8 and P32 groups (p<0.05). The surface roughness values showed statistically significant differences between the groups (p=0.001). Significant differences were also observed between all groups in the pairwise comparisons (p<0.05; Table 1).

Table 1. Mechanical properties of tips including nano-hardness, elastic modulus and surface rouhgness

Group	Nano-hardness	Elastic modulus	Surface roughness
P4	22.47 ± 1.67^{a}	229.72 ± 6.58^{a,b}	16.67 ± 1.50^{a}
P8	24.14 ± 3.13^{a,b}	218.55 ± 15.74^{b}	22.36 ± 3.62^{b}
P16	26.53 ± 2.29^{b,c}	228.72 ± 20.44^{a,b}	42.43 ± 7.30^{c}
P32	28.49 ± 3.42^{c}	241.26 ± 10.46^{a,c}	56.12 ± 2.60^{d}
PC	24.55 ± 2.39^{a,b,c}	174.39 ± 13.53^{d}	12.01 ± 0.60^{e}
p	0.007*	0.007*	0.001*

P; piezosurgical tip (for instance; P4, piezotips making four incisions on bone), PC; piezosurgical tips for control group. The differences between the groups were determined by Kruskal-Wallis test. Paired comparison was performed by Mann-Whitney U test. Same superscript letters show no difference between the two groups, but the different letters mean statistically significant difference between the groups. *; statistically significant (p<0.05)

When the data on wear levels were compared, there were statistically significant differences between the groups (p=0.001; Table 2). The highest wear level was obtained in the P32 group. Similarly, the wear level in the P16 group was statistically significantly higher than that in the P4 group (p<0.05; Table 2). Also, the mean load applied during the osteotomies is shown in Table 3. According to data, the osteotomy loads were homogeneous between the groups (p=0.858).

Statistically significant differences in osteotomy duration were found between the groups (p=0.01). While the highest mean osteotomy time was

77.33±5.77 s in the P32 group, these were 60.50±6.14, 63.97±13.26, and 72.91±9.42 s in the P4, P8, and P16 groups, respectively (Table 2). In the analysis of the differences in mean osteotomy duration between the groups, significant differences were found between P32 and P4, and P32 and P8 ($p<0.05$). Similarly, the mean osteotomy duration was significantly higher in the P16 group than in the P4 group ($p=0.018$; Table 2).

Table 2. Osteotomy load and duration during bone cuts and wear level of the tips in osteotomy groups

Group	Osteotomy load (N)	Wear level (µm)	Osteotomy duration (s)
P4	5.12 ± 0.86	0.03 ± 0.02^{a}	60.50 ± 6.14^{a}
P8	4.87 ± 1.22	0.04 ± 0.01^{a,b}	63.97 ± 13.26^{a,b}
P16	4.95 ± 0.98	0.06 ± 0.03^{b}	72.91 ± 9.42^{b,c}
P32	4.93 ± 0.98	0.15 ± 0.04^{c}	77.33 ± 5.77^{c}
p	0.858	**0.001***	**0.010***

µm: micrometer, N: newton, s: second. The differences between the groups were determined by Kruskal-Wallis test. Paired comparison was performed by Mann-Whitney U test. Same superscript letters show no difference between the two groups, but the different letters mean statistically significant difference between the groups. *; statistically significant ($p<0.05$)

The correlations in the study regarding nano-hardness, elastic modulus, surface roughness, wear level, average osteotomy duration, osteotomy load, and the number of osteotomies are shown in Table 3. Surface roughness showed positive correlations with nano-hardness and elastic modulus ($p=0.001$). Wear level showed positive correlations with nano-hardness, elastic module, and surface roughness ($p<0.05$). A negative correlation was found between osteotomy load and nano-hardness ($p=0.044$). Mean osteotomy duration showed positive correlations with nano-hardness, surface roughness, wear level, and osteotomy load ($p<0.05$). The number of osteotomies also showed positive correlations with nano-hardness, surface roughness, wear level, and osteotomy duration ($p=0.001$).

Table 3. Correlation of the data obtained from the surgical tips

Variables		NH	EM	SR	WL	OL	OD	ON
NH	r p	1 –						
EM	r p	0.323 0.076	1 –					
SR	r p	.557* 0.001	.568* 0.001	1 –				
WL	r p	.573* 0.001	.441* 0.019	.847* 0.001	1 –			
OL	r p	-.383* 0.044	0.026 0.894	0.018 0.928	0.145 0.462	1 –		
OD	r p	.453* 0.015	0.324 0.093	.656* 0.001	.693* 0.001	.448* 0.017	1 –	
ON	r p	**.696*** **0.001**	0.368 0.054	**.961*** **0.001**	**.833*** **0.001**	-0.087 0.66	**.635*** **0.001**	1 –

NH: nanohardness, EM: elastic modulus, SR: surface roughness, WL: wear level, OL: osteotomy load, OD: osteotomy duration, ON: osteotomy number, r: Spearman correlation, *: $p<0.05$ (statistically significant)

DISCUSSION

To our knowledge, this is one of the first study investigating the changes in piezo-surgical tips with their continuous use at nano-indentation level. The bovine rib was preferred for osteotomies. In the literature, bovine ribs have been widely used in in vitro studies owing to their similarity to human mandible in terms of bovine bone density, geometry, and cortical and spongiosis contents[17-20].

Many studies have been conducted on the properties of dental procedures performed with piezo-surgery[21,22]. The characteristics of the bone grafts obtained in studies that compared piezo-surgery with traditional methods such as the use of burs and saws have been examined[23,24]; even varied piezo-surgical tips have been compared[25].

Many studies have used cavity drills in implant applications. The analyses of cutting efficiency revealed that conditions such as design, diameter, composition and surface treatment, mechanical properties, milling rotation speed, drilling forces, cooling, and sterilisation process were effective in terms of enhancing the efficiency and durability of the drills[26-30]. Studies have shown that wear is a potential criterion in determining the life of implant drills[28,31]. In our study, the nano-hardness values of the tips were statistically different between the groups. When compared with that in the control group, the nano-hardness in the osteotomy groups decreased after four bone osteotomies but increased as the frequency of use increased. The elasticity of the tips did not change in relation to their frequency of use. However, the elastic values of the tips used were higher than those of tips that were never used. In the study conducted by Sartori et al[28] on bovine ribs, wear and surface roughness values were compared between drilling models. This study included three drilling models divided into five subgroups. In four of the subgroups, 10, 20, 30, and 40 osteotomies were performed, the other was evaluated as control (no use). The scanning electron microscopy analysis was used to evaluate surface roughness. It was observed a significant roughness level in each drilling model especially after 40 uses[28]. In our study, surface roughness was significantly different among the groups and gradually increased with use. In this respect, the results relation to the surface roughness of the tips used in our study was consistent with the results of above-mentioned study.

As data on the wear of piezo-surgical tips in the literature are limited, the results obtained from studies on implant drills were compared. In the study by Jochum et al[32], titanium-coated drills were evaluated according to the number of use. The cutter ends of the drills, for which electron microscopy images were obtained, expanded, and the drilling function decreased after approximately 40 uses. Therefore, in accordance with the results of their study, the authors concluded that drilling mills should not be used more than 40 times[32]. In a study by Carvalho et al[33], 200 consecutive osteotomies were created in rabbit legs with implant drills. Each drill was divided into six groups according to the number of osteotomies (0, 10, 20, 30, 40, and 50). After drilling was started using pilot drill, it was continued with 2.0, 2.8, 3.0, and 3.15-mm drills, respectively. SEM images were obtained to determine the wear level on the drills. A high correlation was observed between the wear levels of the drills and the number of osteotomies. The authors reported that the worn drills cause more tissue trauma after the 50th osteotomy and may adversely affect the osseointegration process[33]. In our study, significant wear occurred on the tips at the 16th osteotomy. As the frequency of use increased, a significant increase in wear was also observed.

Although wear level varies with the frequency of use of drills based on their brand and model, all drills are subjected to wear[19,28]. A study showed that the wear of drill lead to an increase in temperature during cavity preparation, and this would negatively affect wound healing. For this reason, drilling inserts should not be used above a certain frequency of use[34,35]. In our study, the wear values increased with the frequency of use, especially after the 16-use. This likely shows that the preparation time is longer with worn tips, resulting in more wear on the tips.

Studies have suggested that the applied force should be less than 400 g during bone cutting[5,6]. However, the optimum cutting efficiency is available from 300 to 500 g. A pressure exceeding 500 g leads to a sudden loss in cutting efficiency. The pressure inefficiently acts on the cutting process, limiting the movement of the device nose and generating a significant amount of heat[36]. In a study, Sartori et al[28] used a mechanism during osteotomy on bovine ribs, thus applying equal force in bone cuts. One notable limitation of our study is that the constant force arm was not used. However, this problem was overcome by registering the instantaneous force during the bone cuts and by allowing the operator to rest between the osteotomies. When the load values were compared in this study, no significant differences were found between the groups. Rashad et al[36] reported that the comparisons of heat generation were possible at loads of 5N and 8N. In our study, the mean load of 4 to 5N applied during osteotomy could be assumed in the range of force not generating heat in the piezo-surgical tips.

This study has also other limitations. For instance; the cortical bone thickness was not measured in the incision area on the bone block. Moreover, using the tips was used repeatedly without sterilization by autoclaving is another limitation. Several studies reported that the he process of sterilization as well as the number of performed osteotomies play a major role in the wear of the cutting edge and the performance of metallic tips such as implant drill[37,38].

Each dental material has different properties in terms of hardness, surface roughness and frequency of use. In addition to these properties, the manufacturers give about information the expiring date of the products. However, the characteristics of piezo-surgical tip may differ from surgeon to surgeon or patient to patient in non-parallel of the user guide. This is just a methodological study investigating the structure of the materials in nano-scale. In this study, repeated use of piezo-tips in bone surgery affects the mechanical properties of the tips such as hardness, elasticity and surface roughness. It has been observed that the tips were exposed to critical wear especially after 16-osteotomies. Based on the results, the cutting time of the piezo-surgical tips used in the study prolonged with the increase in the number of osteotomy. This might have occurred because of the increase in the wear and surface roughness of the tips after the 16-use. Given the standard sterilization procedures and tips of different brands, further studies are needed.

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