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Temperature and time variations during osteotomies performed with different piezosurgical devices: an *in vitro* study

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Abstract

Aim: The aim of this experimental *in vitro* study was to evaluate the effects of the piezoelectric device in temperature and time variations in standardized osteotomies performed with similar tip inserts in bovine bone blocks.

Methods: Two different piezosurgical devices were used the OE-F15® (Osada Inc., Los Angeles, California, USA) and the Surgybone® (Silfradent Inc., Sofia, Forli Cesena, Italy). Serrated inserts with similar geometry were coupled with each device (ST94 insert/test A and P0700 insert/test B). Osteotomies 10 mm long and 3 mm deep were performed in bone blocks resembling type II (dense) and type IV (soft) bone densities with and without irrigation. Thermal changes and time variations were recorded. The effects of bone density, irrigation, and device on temperature changes and time necessary to accomplish the osteotomies were analyzed.

Results: Thermal analysis showed significant higher temperatures during piezosurgery osteotomies in hard bone without irrigation ($P < 0.05$). The type of piezosurgical device did not influence thermal variations ($P > 0.05$). Time analysis showed that the mean time values necessary to perform osteotomies were shorter in soft bone than in dense bone ($P < 0.05$).

Conclusions: Within the limitations of this *in vitro* study, it may be concluded that the temperature increases more in piezosurgery osteotomies in dense bone without irrigation; the time to perform the osteotomy with piezosurgery is shorter in soft bone compared to hard bone; and the piezosurgical device have a minimal influence in the temperature and time variations when a similar tip design is used during piezosurgery osteotomies.

Piezosurgery has been used for several years in orthopedic surgery as well as in dentistry, especially in oral surgery and implantology as a method for performing osteotomies (Pavlikova et al. 2011; Pereira et al. 2014). Piezosurgical devices function via the application of electrical tension on crystals/ceramics which expand and contract, this movement is transferred as vibratory micrometric vertical and horizontal displacement of the cutting insert tip with a very precise section cut (Yaman & Suer 2013).

This technique has been promoted especially for the lateral window preparation during sinus lift procedures due to the beneficial effect of osteotomy without the damage of Schneiderian membrane because the low-frequency ultrasonic vibrations enable the cutting of mineralized tissue without damaging soft tissue structures (Wallace et al. 2007; Seshan et al. 2009). As piezosurgery results in a very precise bone cut, it can be used in small and delicate areas, where injuring neighboring soft tissues or vital structures might be of concern (Stübinger et al. 2008; Spinelli et al. 2014).

Previous studies have shown that there are several advantages of piezosurgery in the field of Dental Implantology such as higher ISQ values and thus greater implant stability than those placed with traditional drills (Stacchi et al. 2013), less bleeding (Jose et al. 2014), less postoperative swelling (Sortino et al. 2008), faster bone remodeling, and better bone healing than bone that was cut with a standard blade (Preti et al. 2007; Ma et al. 2013).

Not only does the bone heal more quickly after a piezosurgical procedure but also it improves the bone density (Di Alberti et al. 2010) and reduces levels of Hsp70 protein, which is a "cell stress marker," indicating lower stress levels in surrounding alveolar bone tissue than conventional surgery (Gülnahar et al. 2013).

Osteotomy procedures can be performed using different cutting devices and as consequence of cutting bone, micro fractures, and thermal changes must be expected (Noble 2003; Shank et al. 2012). As bone has low thermal conductivity, heat produced during treatment does not disappear quickly but rather remains around the osteotomies (Mustafa & James 1997) and has been demonstrated that if the temperature increases above 47 degrees Celsius over one minute, bone necrosis might occur (Lundskog 1972; Eriksson & Albrektsson 1983).

Recently, the thermal changes during bone piezosurgery were analyzed. Stelzle et al. (2012) in an *ex vivo* study in pig calvaria used piezosurgery for the preparation of implant beds of 6 mm depth and 3 mm diameter, and they reported that the load increased thermal variations and suggested avoiding excessive vertical pressure (>500 g) during the osteotomies to prevent temperatures above 47°C; in addition, Schütz et al. (2012) performed an *in vitro* study in pig jaws; they performed osteotomies of 3 mm depth with different piezosurgery inserts and with the same piezosurgical device; and they found that the type of insert have effect on the thermal changes during bone osteoplasties.

However, the literature lacks information regarding the effect of the piezosurgical device in temperature and time variations when using similar cutting inserts.

Therefore, the aim of this experimental *ex vivo* study was to evaluate the effects of the piezoelectric device in temperature and time in standardized osteotomies performed with similar tip inserts in bovine bone blocks.

Material and methods

In this *in vitro* study, a total of 320 osteotomies, each 3 mm deep and 10 mm length, were performed using two different piezosurgical devices (OE-F15, Osada Inc., test group A/Fig. 1a and Surgybone, Silfradent Inc., test group B/Fig. 1b), by a calibrated examiner and based on the manufacturers guidelines for bone osteotomies. Each was paired with a serrated tip, ST94 and P0700, respectively, which have a similar shape and geometry (Fig. 2). The cuts were made in artificial bone blocks (BoneSim, Newaygo, MI, USA) that resembled type I (dense) and type IV (soft) bone qualities, with and without copious saline irrigation.

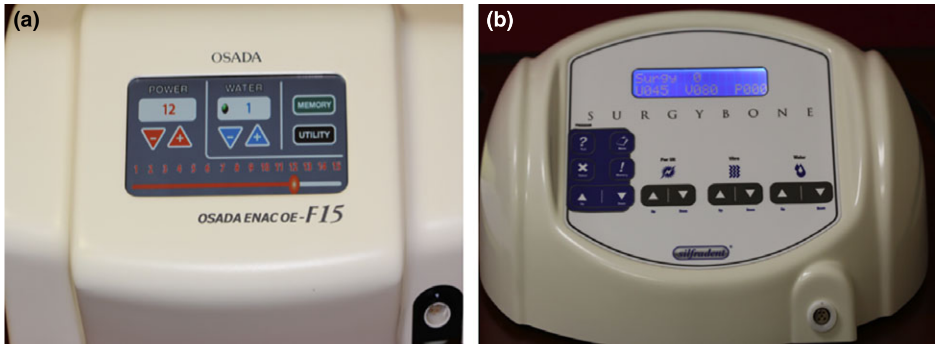

Fig. 1. Devices used in this experiment. (a) Osada unit (Test A), (b) Surgybone unit (Test B).

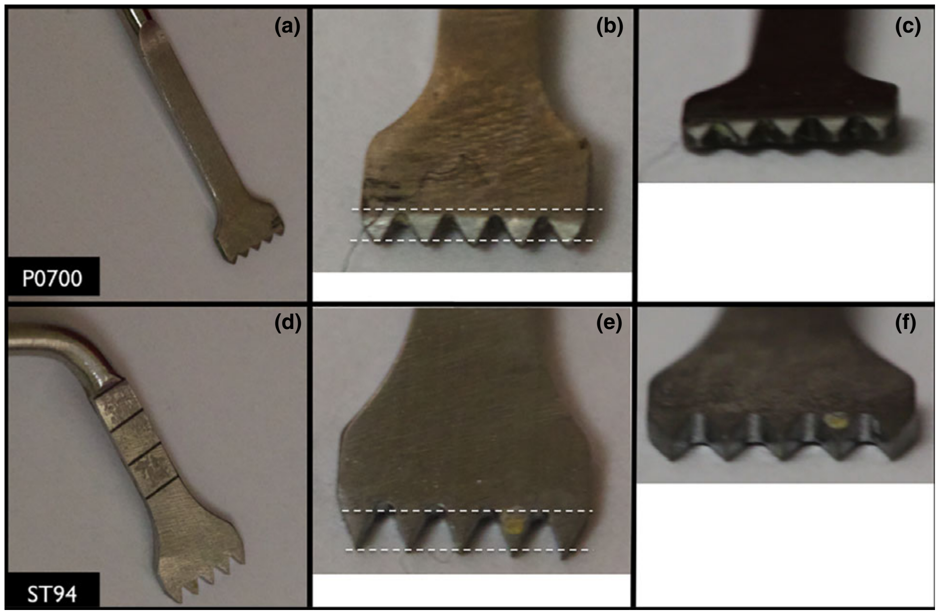

Fig. 2. Inserts used for each device. (a) is showing the insert used for the Test A unit, (b) is showing a close view of the five points of the serrated tip of the insert used with the Test A, (c) is showing a close view of the serrated edge of the insert used for Test A, (d) is showing the insert used for the Test B, (e) is showing a close view of the serrated edge of the insert used for Test B, and (f) is showing the edge of the insert used for Test B.

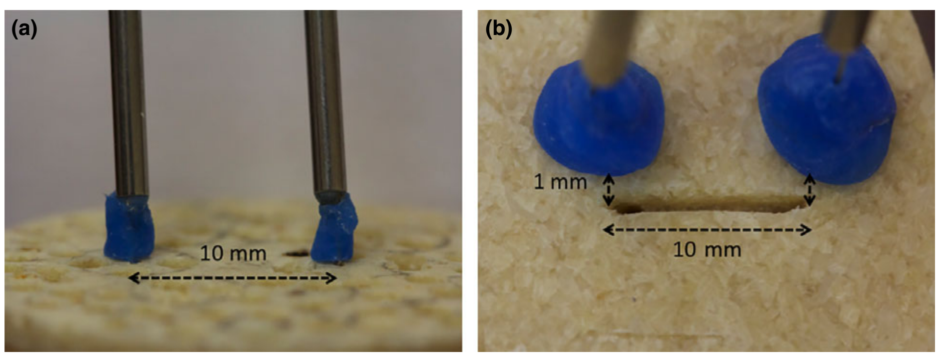

Fig. 3. Thermocouples setting. Thermocouples were inserted in previous drilled holes of 1 mm diameter. The thermocouples were supported by blue wax. (a) shows the thermocouples, which have a diameter of 0.7 mm and length of 3 mm, and the thermocouples have a separation of 10 mm; (b) shows the distance from the osteotomy to the thermocouple micro-needles.

First, a grid was drawn on the artificial bone blocks, containing boxes with 10 mm length dimensions, and this assured that the cuts were 10 mm long. Then, small holes (1 × 1 mm) were drilled into the artificial bone blocks, into both type II and type IV bone densities. Two T-Type MLT 1406 thermocouple (AD Instruments Inc., Colorado Springs, CO, USA) micro-needles with a length of 3 mm and a diameter of 0.7 mm were placed inside both holes which previously were filled with a heat transfer compound (HTCP20S 20 ml, Electrolube®, Leicestershire, UK) to ensure temperature transfer from the bone to the sensors during the piezosurgery osteotomy at the beginning and at the end of the planned cuts. The external portion of the thermocouple needles were isolated with wax to avoid the thermal dissipation and to hold it in place to avoid any movement during the osteotomy procedure (Abboud et al. 2014) (Fig. 3).

An osteotomy was performed approximately 1 mm away from the thermocouple to avoid damage of the thermocouple tip and to accurately detect the temperatures changes that occurred during each procedure. The thermocouples were connected to two ML312, T-Type Pod conditioners (ADInstruments, Inc.) connected to a bridge amplifier, FE221 (ADInstruments, Inc.), which in turn was connected to a Power Lab 4/35-channel recorder (ADInstruments, Inc.) (Fig. 4). This enabled the continuous reading of the temperature changes that occurred during the osteotomies.

In total, 160 osteotomies were performed using test group A piezosurgical machine (frequency = 30 kHz, power = 10, irrigation = 50 ml/min) coupled with an ST94-insert. Forty cuts were made in bone type II with saline irrigation and 40 in bone type II without irrigation. In a similar way, 40 osteotomies were made in bone type IV (Fig1 5). Similarly, 160 osteotomies were performed using test group B piezosurgical device (frequency=30 kHz, power=46, irrigation=50 ml/min) coupled with a P0700-insert (Figs 4 and 6). Thermal changes that occurred during each osteotomy were recorded, in degrees Celsius, by real-time thermography by paired thermocouples via LabChart computer software (ADinstruments Inc., Colorado Springs, CO, USA). Real-time (in seconds) necessary to complete the osteotomies, with and without irrigation, was recorded, via LabChart software as well.

Statistical analysis

Kolmogorov–Smirnov test was used for the confirmation of the normal distribution of the samples. Statistical analysis was performed by two-way analysis of variance (ANOVA) followed by Tukey's post hoc test for multiple comparisons of the temperature and time changes. Descriptive statistics,

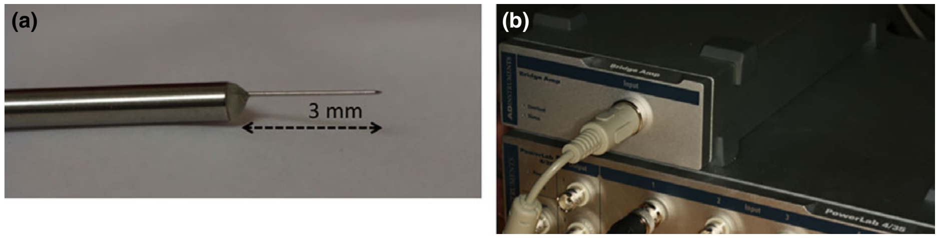

Fig. 4. Details of the thermocouple and the setting of the recording devices. (a) is showing the thermocouples, which have a diameter of 0.7 mm and length of 3 mm. (b) is showing the amplifier at the top and the recording system at the bottom. The signal was transmitted through the thermocouples to a T-Type Pod signal conditioner, this signal was sent to a bridge amplifier, and the amplifier sent the information to the Power Lab 4/35 channel recording system controlled by a software for thermal analysis.

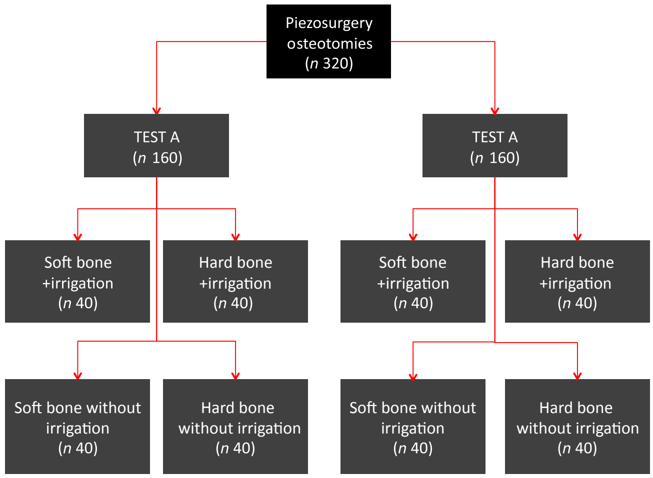

Fig. 5. Sample distribution. Three hundred and twenty osteotomies were performed. One hundred and sixty osteotomies were performed by device, 40 osteotomies for each experimental group.

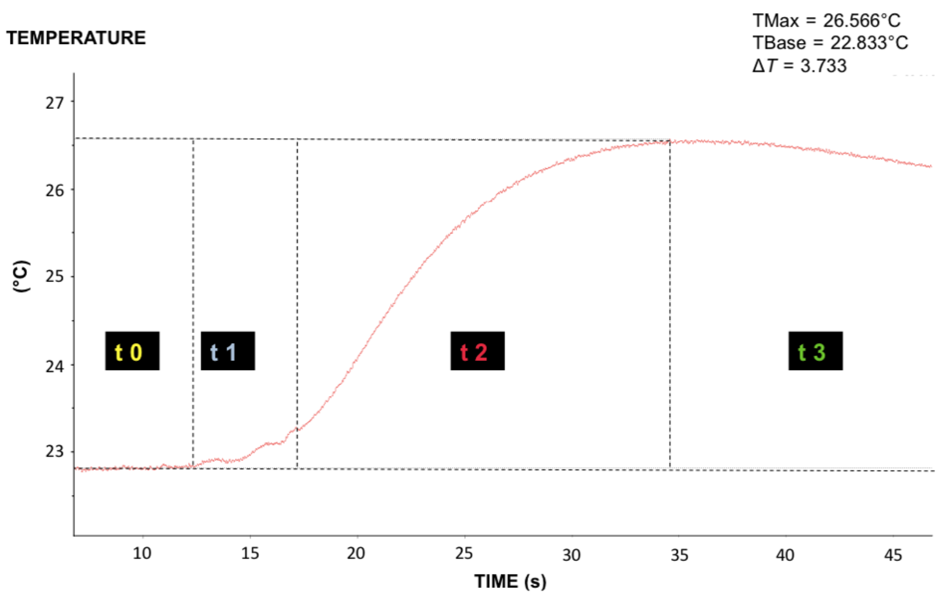

Fig. 6. Example of temperature and time curve when drilling in soft bone with irrigation. TMax (Maximum temperature), TBase (Base temperature), ΔT (Differential temperature), t0 (Time elapsed from the beginning of the recording to the first thermal change), t1 (Time elapsed from the first thermal change to the point of continued temperature increase), t2 (Time elapsed from the end of the peaks and valleys period to the peak temperature), t3 (Time elapsed after the peak temperature for the reduction of 1°C).

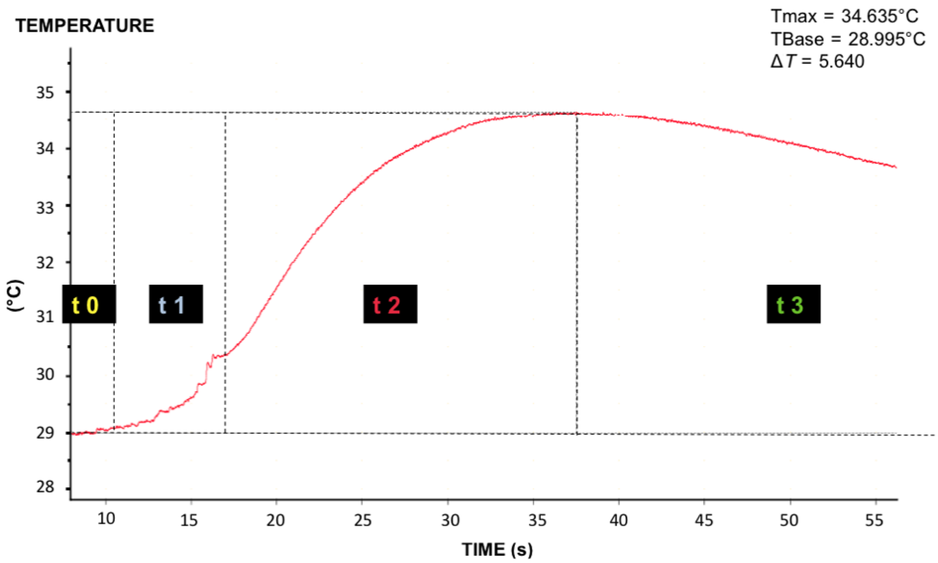

Fig. 7. Curve of the temperature and time when drilling in soft bone without irrigation TMax (Maximum temperature), TBase (Base temperature), ΔT (Differential temperature), t0 (Time elapsed from the beginning of the recording to the first thermal change), t1 (Time elapsed from the first thermal change to the point of continued temperature increase), t2 (Time elapsed from the end of the peaks and valleys period to the peak temperature), t3 (Time elapsed after the peak temperature for the reduction of 1°C).

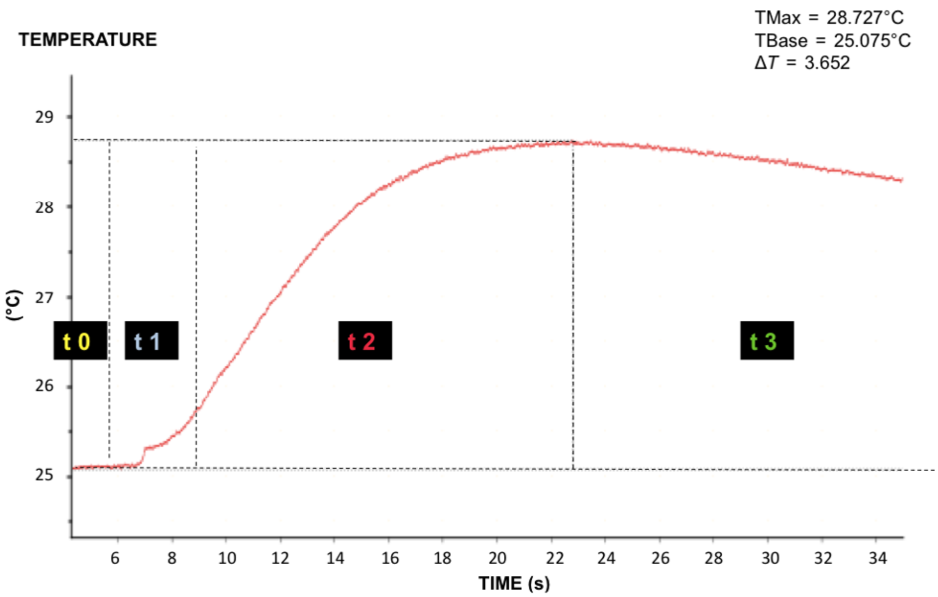

Fig. 8. Curve of the temperature and time when drilling in hard bone with irrigation TMax (Maximum temperature), TBase (Base temperature), ΔT (Differential temperature), t0 (Time elapsed from the beginning of the recording to the first thermal change), t1 (Time elapsed from the first thermal change to the point of continued temperature increase), t2 (Time elapsed from the end of the peaks and valleys period to the peak temperature), t3 (Time elapsed after the peak temperature for the reduction of 1°C).

mean, standard deviation, median, and quartile values were used. The level of significance was set as $P < 0.05$.

Results

The temperature in dense bone with irrigation for group A was 29.52(±0.98)/26.2 (±0.85)°C and for group B was 28.26(±0.79)/26.52(±0.91). The temperature in dense bone without irrigation for group A was 35.29 (±0.94)/27.48(±0.84)°C and for group B was 35.52 ± 0.90/27.51 ± 0.75°C. (Table 1a,b).

The temperature (T-max/T-min ± SD) observed in soft bone with irrigation for group A was 27.05(±0.99)/24.68(±0.99)°C and for group B was 28.19(±0.94)/25.52(±0.95)°C. The temperature observed in soft bone without irrigation for group A was 33.0 (±0.97)/28.54(±0.34)°C and for group B was 33.82(±0.43)/28.62(±0.39)°C. (Table 1a,b).

The values of the temperature changes that elapsed during the osteotomies in each bone type, with both devices, with and without irrigation are recorded in Table 1a,b. Thermal analysis demonstrated higher temperatures in osteotomies performed without irrigation as compared to those with irrigation. In addition, significantly higher temperatures were observed in hard bone as compared to soft bone (Table 2).

The time needed for the accomplishment of the osteotomy in type II bone using the test A device showed a mean time for the osteotomy of 33.53 ± (1.25) seconds meanwhile using the test B device, it took an average of 28.75 ± (4.53) without differences between groups (*P* value: 0.071).

The time needed for the accomplishment of the osteotomy in type IV using the test A device showed a mean time of 31.43(±1.97) seconds meanwhile using the test B device a mean of 25.0(±3.57) seconds without differences between groups (*P* value: 0.068).

The time comparison showed significant shorter time for osteotomies performed with piezosurgical devices in soft bone compared to hard bone was observed (*P* value: 0.041).

The values for the mean times that elapsed during the osteotomies in each bone type with both devices are recorded in Table 3. The mean time values necessary to perform the osteotomies were shorter in soft bone (type IV), as compared to dense bone (type II).

Although numerical differences were observed, the type of piezosurgical device did not significantly (*P* value 0.057) influenced the thermal variations, only the bone density influenced the observed differences (Table 3).

Temperature variations related to the time during piezosurgery osteotomies were observed for all the bone densities and for both piezosurgical devices with and without irrigation, and four periods were registered as follows (Table 4):

- t0: Time elapsed from the beginning of the recording to the first thermal change. The duration was within 5 ± 4 s.
- t1: Time elapsed from the first thermal change characterized by a brief period of peaks and valleys in the temperature/time graphic to the point of continued temperature increase related to the beginning of the cutting of the cortical bone. The duration was short within 4 ± 1.5 s.

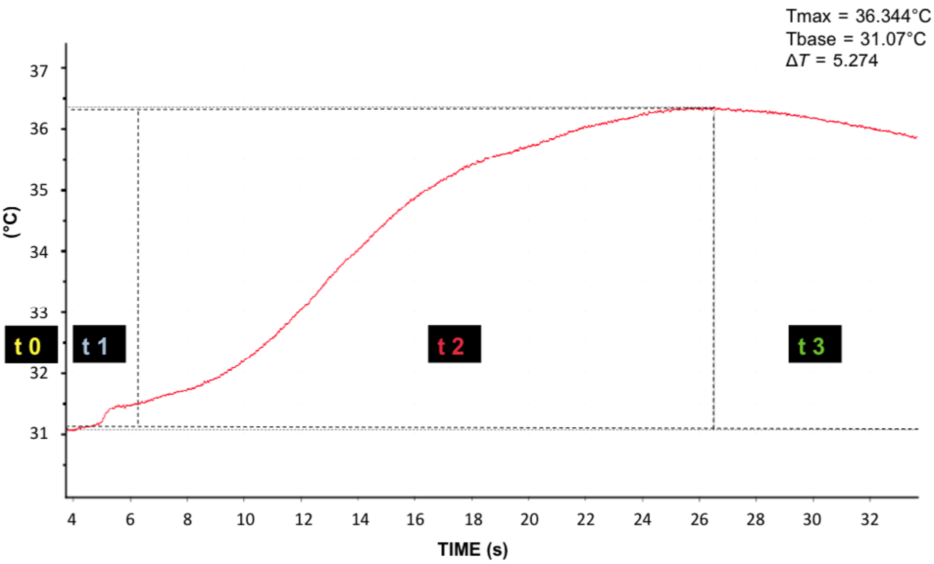

Fig. 9. Curve of the temperature and time when drilling in hard bone without irrigation TMax (Maximum temperature), TBase (Base temperature), ΔT (Differential temperature), t0 (Time elapsed from the beginning of the recording to the first thermal change), t1 (Time elapsed from the first thermal change to the point of continued temperature increase), t2 (Time elapsed from the end of the peaks and valleys period to the peak temperature), t3 (Time elapsed after the peak temperature for the reduction of 1°C).

- t2: Time elapsed from the end of the peaks and valleys period to the peak temperature, which results in an ascending curve in the temperature/time graphic. The duration is long within 18 ± 3 s.
- t3: Time elapsed from the peak temperature to the decrease of the temperature in 1°C, which appears as a declining curve in the temperature/time graphic. The duration is within 8 ± 2 s (Figs 6–9).

Discussion

In the present study, osteotomies were performed by a calibrated clinician using two different piezosurgery devices coupled with cutting insert tips with similar design. We did not use another method of osteotomy in an attempt to reduce the number of variables. Thus, we investigated whether the device influenced the temperature and the time differences that occurred during piezosurgery linear osteotomies.

For the experimental setting, standardized bovine bone disks with a density comparable with the human bone and same thermal conductivity were used (Abboud et al. 2014; Strbac et al. 2014). Specifically, the study by Abboud et al. 2014 used the same bovine disk in dry conditions (without immersion or pre-wetting of the bone disks in saline or other solutions) for recording the temperature variations induced by simplified drilling procedures with stepped drills.

The rationale behind the use of dry samples for the evaluation of thermal changes during simulated osteotomies is not new; indeed, Gehrke et al. 2014 used synthetic dry blocks for the comparison of temperatures during the use of trephine drills with internal and external irrigation, and they found that the combination of internal and external irrigation was the most efficient in the control of the temperature. Moreover, in the presence of a wet sample (immersed in saline solution at 37°C), some of the heat generated during the osteotomy might be partially dissipated

***Table 1.* (a) Temperature changes induced by piezosurgical device group A during osteotomies in bone types II and IV, with and without irrigation. (b) Temperature changes induced by the piezosurgical device group B during osteotomies in bone types II and IV, with and without irrigation**

(a)

	Group											
	Test A Soft bone + Irrigation[a]			Test A Soft bone no irrigation[b]			Test A Hard bone + Irrigation[c]			Test A Hard bone no irrigation[d]		
Statistics	TMax °C	TBase °C	ΔT °C	TMax °C	TBase °C	ΔT °C	TMax °C	TBase °C	ΔT °C	TMax °C	TBase °C	ΔT °C
Mean±SD	27.059 ± 0.991	24.685 ± 0.99	2.6734 ± 0.885	33.008 ± 0.976	28.546 ± 0.343	5.432 ± 0.643	29.526 ± 0.98	26.202 ± 0.858	3.3245 ± 0.637	35.293 ± 0.9462*[a,b,c]	27.486 ± 0.843	8.4295 ± 0.952*[a,b,c]
Minimum	25.198	22.811	1.3246	31.062	24.541	2.8720	27.158	24.853	3.1152	34.521	26.561	6.534
Median	27.466	24.684	2.8162	33.041	28.128	4.7580	29.471	25.945	3.6723	36.182	27.862	9.123
Maximum	28.564	26.400	3.5606	35.778	29.668	8.2130	30.698	27.821	4.0263	39.822	28.564	11.235

(b)

	Group Test B Soft bone + Irrigation[e]			Test B Soft bone no irrigation[f]			Test B Hard bone + Irrigation[g]			Test B Hard bone no irrigation[h]		
Statistics	TMax °C	TBase °C	ΔT °C	TMax °C	TBase °C	ΔT °C	TMax °C	TBase °C	ΔT °C	TMax °C	TBase °C	ΔT °C
Mean ± SD	28.193 ± 0.9462	25.523 ± 0.953	2.1272 ± 0.445	33.821 ± 0.4351	28.628 ± 0.395	5.192 ± 0.568	28.264 ± 0.79	26.524 ± 0.91	3.457 ± 0.571	35.526 ± 0.902*[e,f,g]	27.518 ± 0.750	8.2295 ± 0.783*[e,f,g]
Minimum	24.541	23.137	1.2120	31.553	22.769	2.7740	25.872	25.198	2.0650	33.368	24.541	6.2443
Median	28.128	25.304	2.345	33.427	27.686	4.7535	28.688	27.466	3.2595	36.007	27.978	8.756
Maximum	29.668	26.483	3.728	36.386	37.934	10.370	30.378	28.564	4.8440	39.507	29.156	9.357

*$P < 0.05$ for significance. The highest temperatures were observed in dense bone without irrigation for both piezosurgery devices. Superscripts letters were used for the identification of the groups compared with the Tukey test. The superscripts a, b, c, d were assigned for Test A group and indicates soft bone with irrigation; superscript b indicates soft bone without irrigation; superscript c indicates hard bone with irrigation and superscript d indicates hard bone without irrigation. The superscripts e, f, g, h were assigned to the Test B group. Superscript e indicated soft bone with irrigation; superscript f indicates soft bone without irrigation; superscript g indicates hard bone with irrigation and superscript h indicates hard bone without irrigation.

Table 2. **Exact *P* values after Tukey's multiple comparison test. The variables bone density, piezosurgery group, and presence of irrigation were compared. Group d (Test A hard bone without irrigation) and group h (Test B hard bone without irrigation) showed significant higher temperatures compared to a, b, c, e, and f groups. There were no temperature differences between the piezosurgical devices ($P > 0.05$). The absence of irrigation resulted in higher temperatures (*$P < 0.05$), and bone type II showed higher temperatures compared to bone type IV (*$P < 0.05$)**

Group	Comparison	*P* value
Test A Soft bone + Irrigation[a] vs. Test A Soft bone + No irrigation[b]	b>a	0.045*
Test A Soft bone + Irrigation[a] vs. Test A Hard bone + Irrigation[c]	No difference	0.063
Test A Soft bone + Irrigation[a] vs. Test A Hard bone + No Irrigation[d]	d>a	0.039*
Test A Soft bone + Irrigation[a] vs. Test B Soft bone + Irrigation[e]	No difference	0.058
Test A Soft bone + Irrigation[a] vs. Test B Soft bone + No Irrigation[f]	f>a	0.041*
Test A Soft bone + Irrigation[a] vs. Test B Hard bone + Irrigation[g]	No difference	0.062
Test A Soft bone + Irrigation[a] vs. Test B Hard bone + No Irrigation[h]	h>a	0.037*
Test A Soft bone + No irrigation[b] vs. Test A Hard bone + Irrigation[c]	No difference	0.053
Test A Soft bone + No irrigation[b] vs. Test A Hard bone + No Irrigation[d]	d>b	0.048*
Test A Soft bone + No irrigation[b] vs. Test B Soft bone + Irrigation[e]	b>e	0.044*
Test A Soft bone + No irrigation[b] vs. Test B Soft bone + No Irrigation[f]	No difference	0.052
Test A Soft bone + No irrigation[b] vs. Test B Hard bone + Irrigation[g]	b>g	0.043*
Test A Soft bone + No irrigation[b] vs. Test B Hard bone + No Irrigation[h]	h>b	0.039*
Test A Hard bone + Irrigation[c] vs. Test A Hard bone + No Irrigation[d]	d>c	0.033*
Test A Hard bone + Irrigation[c] vs. Test B Soft bone + Irrigation[e]	No difference	0.062
Test A Hard bone + Irrigation[c] vs. Test B Soft bone + No Irrigation[f]	f>c	0.045*
Test A Hard bone + Irrigation[c] vs. Test B Hard bone + Irrigation[g]	No difference	0.061
Test A Hard bone + Irrigation[c] vs. Test B Hard bone + No Irrigation[h]	h>c	0.036*
Test A Hard bone + No Irrigation[d] vs. Test B Soft bone + Irrigation[e]	d>e	0.030*
Test A Hard bone + No Irrigation[d] vs. Test B Soft bone + No Irrigation[f]	d>f	0.045*
Test A Hard bone + No Irrigation[d] vs. Test B Hard bone + Irrigation[g]	d>g	0.039*
Test A Hard bone + No Irrigation[d] vs. Test B Hard bone + No Irrigation[h]	No difference	0.066
Test B Soft bone + Irrigation[e] vs. Test B Soft bone + No Irrigation[f]	f>e	0.042*
Test B Soft bone + Irrigation[e] vs. Test B Hard bone + Irrigation[g]	No difference	0.064
Test B Soft bone + Irrigation[e] vs. Test B Hard bone + No Irrigation[h]	h>e	0.038*
Test B Soft bone + No Irrigation[f] vs. Test B Hard bone + Irrigation[g]	f>g	0.041*
Test B Soft bone + No Irrigation[f] vs. Test B Hard bone + No Irrigation[h]	h>f	0.047*
Test B Hard bone + Irrigation[g] vs. Test B Hard bone + No Irrigation[h]	h>g	0.031*

Superscripts letters were used for the identification of the groups compared with the Tukey test. The superscripts a, b, c, d were assigned for Test A group and indicates soft bone with irrigation; superscript b indicates soft bone without irrigation; superscript c indicates hard bone with irrigation and superscript d indicates hard bone without irrigation. The superscripts e, f, g, h were assigned to the Test B group. Superscript e indicated soft bone with irrigation; superscript f indicates soft bone without irrigation; superscript g indicates hard bone with irrigation and superscript h indicates hard bone without irrigation.

Table 3. **Mean times of osteotomies in bone types II and IV**

Time for osteotomy (sec.)	Bone type II Test A[a]	Bone type II Test B[b]	Bone type IV Test A[c]	Bone type IV Test B[d]
Mean	33.5348	28.756375	31.43364	25.0046
Standard Deviation (SD)	1.2517	4.5355	1.9712	3.5710
P-value	0.068	0.073	0.047*[a,b]	0.041*[a,b]

*$P < 0.05$ for significance. Statistically significant shorter times for the piezosurgery osteotomy were observed in bone type IV compared to bone type II for both groups. Superscripts letters were used for the identification of the groups compared with the Tukey test. The superscripts a, b, c, d were assigned for Test A group and indicates soft bone with irrigation; superscript b indicates soft bone without irrigation; superscript c indicates hard bone with irrigation and superscript d indicates hard bone without irrigation.

by the presence of the fluids and may be carried away by the chips formed (Hillery & Shuaib 1999).

While previous studies have shown that there is a maximum temperature that should not be exceeded when performing osteotomies (Eriksson & Albrektsson 1983), the factors involved in the temperature changes and the threshold of temperature rise to avoid causing bone necrosis still need to be elucidated (Augustin et al. 2012).

The results of the present work showed that the bone density was one of the factors responsible for the temperature and time differences as dense bone resulted in significantly higher temperature changes and elapsed time than piezosurgery osteotomies in soft bone. This is in agreement with the results of Rashad et al. (2011), who evaluated the time required for preparation and the heat production in cortical and cancellous bone using ultrasonic as compared to conventional drilling preparation of the implant bed. They found higher temperatures and more time-consuming in piezosurgery osteotomies than in conventional drilling. Apparently, the higher frictional forces developed during cutting the cortical bone are responsible for the temperature and time increase (Abouzgia & Symington 1996).

The other factor, which affected the temperature generation, was the presence or absence of irrigation. Our results showed that the temperatures were substantially lower for dense and soft bone when the irrigation was used. However, the type of the device seems not to play a significant role in either temperature changes or operation time.

In the present study, there were no differences in the temperature and time obtained during the osteotomies performed with similar inserts, and this might indicate that the bone density and the irrigation are the major factors responsible for the thermal changes for the osteotomies and not the piezosurgical device.

Table 4. **Descriptive time-related temperature changes in hard and soft bone with and without irrigation using different piezosurgical devices. Four periods of time were recorded: t0 (time elapsed from the beginning of the recording to the first thermal change), t1 (time elapsed from the first thermal change to the point of constant temperature increase), t2 (time elapsed from the constant temperature increase to the peak temperature), t3 (time elapsed from the peak temperature to the point of a reduction of 1°C), time periods expressed in seconds. Peak temperatures were registered for each period of time expressed as °C. Values expressed as mean ± standard deviations**

		Temperature in bone (°C) Type IV – Test A		Temperature in bone (°C) Type IV – Test B		Temperature in bone (°C) Type II – Test A		Temperature in bone (°C) Type II – Test B	
Time/Temperature		Irrigation	No irrigation	Irrigation	No irrigation	Irrigation	No irrigation	Irrigation	No irrigation
Time Periods (s)	**t0** (5 ± 4 s)	22.024 ± 1.13	29.074 ± 1.09	22.553 ± 1.16	28.136 ± 1.14	25.023 ± 1.12	31.033 ± 1.09	25.051 ± 1.07	31.052 ± 1.15
	t1 (4 ± 1.2 s)	23.351 ± 0.62	30.719 ± 0.78	23.242 ± 0.80	30.593 ± 0.74	25.834 ± 0.71	31.623 ± 0.84	25.682 ± 0.68	31.466 ± 0.79
	t2 (18 ± 3 s)	26.566 ± 0.27	34.627 ± 0.33	26.844 ± 0.25	34.741 ± 0.32	28.727 ± 0.35	36.344 ± 0.41	28.842 ± 0.38	36.218 ± 0.39
	t3 (8 ± 2 s)	25.013 ± 0.43	33.542 ± 0.42	25.035 ± 0.36	33.684 ± 0.38	28.231 ± 0.32	35.662 ± 0.30	28.163 ± 0.33	35.819 ± 0.32

This is in agreement with the study of Lamazza et al. 2015 who evaluated different factors influencing temperature elevation during implant site preparation with piezoelectric technique, and they found that working load, working movements, and bone features (density) were the main factors influencing temperature raise during piezoelectric implant site preparation.

On the other hand, the results of the present work are in disagreement with the study performed by Schütz et al. (2012), who stated that the thickness of the cortical bone and the coolant did not influenced the temperature increase. The differences may be related to the method used for the determination of the cortical bone thickness used in their study (evaluation of tomography images).

There is no doubt that more comparative studies should be performed using various piezosurgical devices to evaluate the temperature rise in the bone under calibrated parameters as the quality of the osteotomy depends on the piezosurgical unit as previous morphological studies have confirmed (Bauer & Romanos 2014).

This information may improve the quality in the development of the new piezosurgical devices and provide further information for better clinical care.

Conclusions

Within the limitations of this *in vitro* study, it may be concluded that the temperature increases more in piezosurgery osteotomies in dense bone without irrigation, the time to perform the piezosurgery osteotomy is shorter in soft bone compared to hard bone, and the piezosurgical device has a minimal influence in the temperature and time variations when a similar tip design is used during piezosurgery osteotomies.

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