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Effect of osteotomy strategy on primary stability and intraosseous temperature rise: an ex-vivo study

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Abstract

Background Primary stability is a perquisite for achieving successful osseointegration. Additionally thermal effect of implant bed preparation plays an important role in success of a dental implant. This ex vivo study was conducted to compare one step implant specific osteotomy and conventional osteotomy in terms of primary stability and thermal changes during surgery.

Methods Forty eight implants were inserted into the sheep iliac crest bones each with a safe distance to each other and divided into six groups. In two of the groups implant specific osteotomy and in the remaining 4 groups conventional osteotomy was performed. In the groups, the primary stability of the trioval implants designed for the implant specific osteotomy were compared with the oval active threaded implants. The two osteotomy methods were also compared. Additionally the thermal changes during the two osteotomy methods were compared using a double-channel temperature monitoring device.

Results Statistically significant differences ($P<.05$) were observed between the stability groups and the thermal evaluation groups ($P<.05$). Implant specific osteotomy revealed significantly higher stability than the conventional osteotomy ($P<.001$). Osteotomy without irrigation caused significantly higher thermal changes than the conventional osteotomy wit irrigation ($P<.001$).

Conclusion Although the implant specific osteotomy reveals better primary stability, it causes higher temperature during drilling. However, since this increase is within the limits and doesn't cause a risk in terms of osseointegration, it may be used safely in clinical practice.

Keywords Dental implant, Osteotomy technique, Primary stability, Drill design, Drilling speed

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Introduction

Primary stability can be defined as the absence of clinical mobility at the time of surgery. It depends on factors related to the local bone quality and quantity, the geometry of the implant, the placement and surgical technique used, and the precise fit in the bone [1, 2].

Several techniques have been proposed to determine implant stability including destructive ones such as push-out/pull-out or removal torque tests or the non-destructive ones such as insertion torque, electronic percussive testing, and resonance frequency analysis (RFA). A simple, reliable and non-destructive method should be selected for the measurement of implant stability. RFA is a frequently used method for the clinical measurement of stability which has been publicized many times to ensure these features. Additionally, since insertion torque can only be measured at the implant surgery, RFA has been recommended both to measure primary stability and to collect longitudinal data to evaluate the changes in implant stability changes after implant placement [3]. RFA is measured using resonance frequency analyzers. Initially, these devices were designed cabled with L-shaped transducers screwed into the implants. The difficulties in using a cabled device especially during surgery forced the manufacturers designing more user friendly magnetic devices (Ostell Mentor, Sweden) that measures the RFA via magnetic smartpegs in values called implant stability quotient (ISQ) values ranging from 1 to 100 [4]. Higher the ISQ indicates the higher stability of an implant. This method has been used to determine the loading time of the implants and the possible stability changes during the healing time in order to take precautions to prevent failures and the value of ISQ 70 is considered the threshold value for loading the implants [3, 5–7]. Since these smartpegs are disposable and this presents an additional cost for the patients, recently a new magnetic RFA device (Penguin, Integration Diagnostics, Sweden) was introduced using multipegs that can be sterilized [7].

Thermal trauma inflicted on the bone during the preparation of implant osteotomy poses a significant risk factor for early dental implant failure. The heat generated during this process can impede regenerative processes and induce tissue osteonecrosis. It has been shown that to maintain bone viability, the maximum temperature during implant site preparation should not exceed 47 °C, with drilling time kept under 1 min to prevent adverse effects [6]. Therefore, it is mandatory to cool the osteotomy site with irrigation fluids during high speed preparation.

Recently, creating the osteotomy with drills at low speed without cooling has been proposed as an alternative to the traditional high speed procedures. Moreover, low-speed osteotomy has several advantages such as the ability to collect bone grafts with burs without contaminating with saliva [8] and increased vision of the operation area via excluding the irrigation solutions. However, since no cooling solution is used in this technique, bone tissue temperature might rise which may adversely affect osseointegration [9, 10]. Therefore a novel site preparation instrument (OsseoShaper, Nobel Biocare, Sweden) was developed featuring a design consisting of a tapered body with an outer thread profile, a cutting flute, and an unconventional site preparation protocol. Following the pilot drill in irrigation, the osteotomy is prepared with an implant-specific single-use drill, OsseoShaper (OS), without irrigation at low speed (25–100 rpm) using a motorized drill unit with a maximum torque setting of 40 Ncm [10].

Many studies have focused on investigating the effect of drilling techniques on the primary stability of dental implants and the intraosseous temperature rise; however, to our knowledge, no study has compared implant-specific drilling techniques with conventional drilling techniques on these matters, leaving a dearth of understanding regarding whether the primary stability value and intraosseous temperature control provided by this novel system is superior to that of other active implant systems.

Therefore this ex-vivo study was conducted to measure the primary stability and intraosseous temperature changes of dental implants (N1, Nobel Biocare, Sweden) placed with the implant-specific osteotomy and compare them with the implants inserted with the conventional osteotomy (NobelActive, Nobel Biocare). The null hypothesis was "there would be no difference between the primary stability values and the intraosseous temperature changes of the two osteotomy methods".

Materials and methods

Study design

Fresh sheep iliac crest bones were obtained from the butcher shop and used for the present ex-vivo study. The bones were not frozen and directly used at the same day after collecting. Bone densities were determined with the Morita One Volume Viewer Manager (Kyoto, Japan) program (Fig. 1). The mean value of Houndsfield Unit values was determined as 749 HU (highest 848 HU, lowest 650 HU), and it was observed that the bones were of D3 density [11].

Implant site Preparation and assessment of the ISQ values and temperature changes

Eight iliac crest samples were chosen and the soft tissues covering the bones were completely dissected by using lancets and periost elevators to expose the bones. All the osteotomies were made by an experienced oral surgeon. The experimental groups containing 8 implants each in the study to assess ISQ values were as follows;

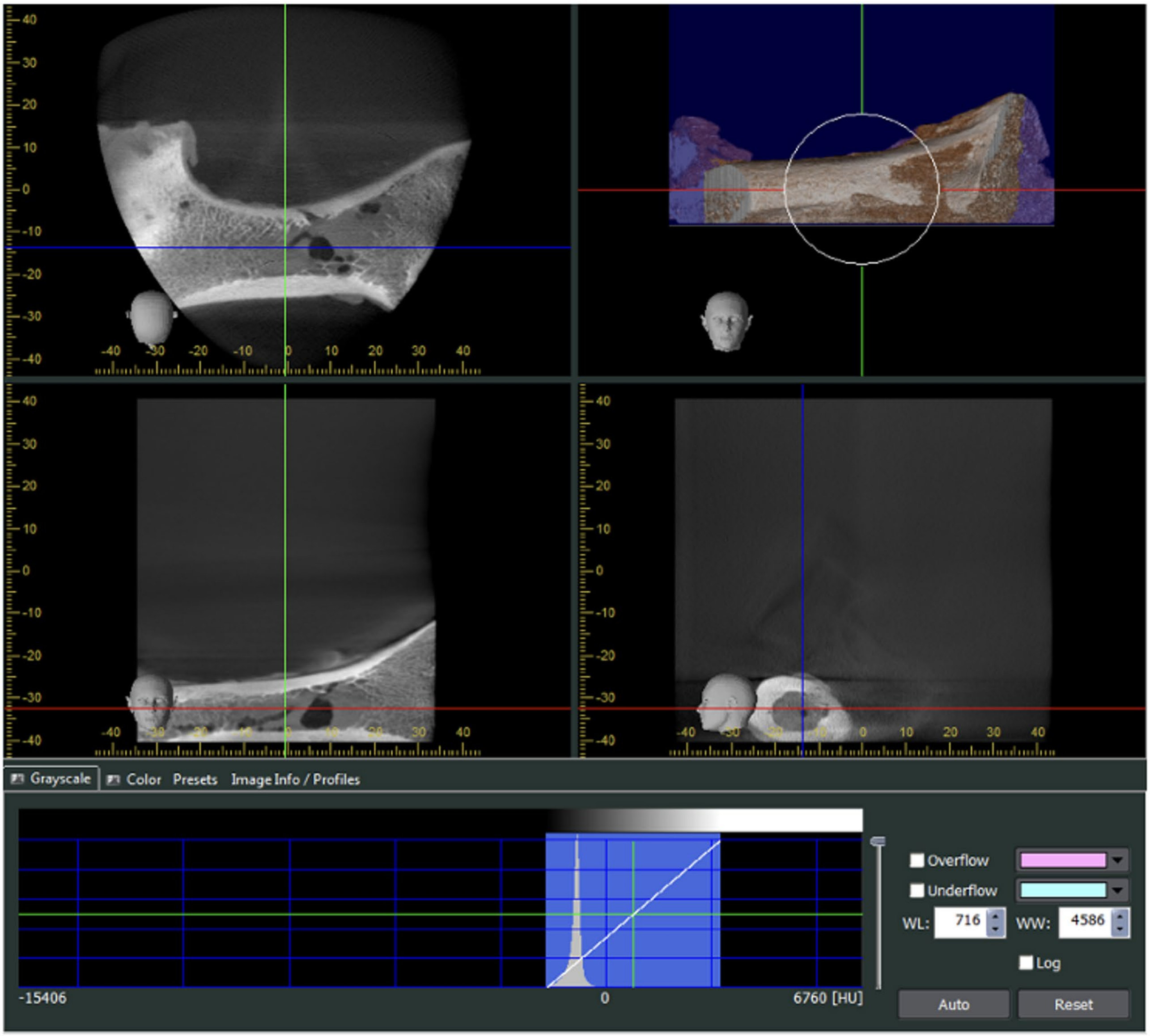


Fig. 1 Determination of bone densities with CBCT imaging

Group 1 Implant-specific osteotomy was performed at low speed without irrigation to create 3.5 mm wide and 11 mm long implant sockets using the Osseoshaper implant set (OsseoShaper, Nobel Biocare, Goteborg, Sweden). Implants with trioval necks (N1, Nobel Biocare) were placed into the prepared sockets.

Group 2 Implant-specific osteotomy was performed at low speed without irrigation to create 3.5 mm wide and 11 mm long implant sockets using the tapered OS drill (Nobel Biocare) after 15 repetitions and the implants with trioval necks were inserted into the prepared sockets (N1 Nobel Biocare).

Group 3 Conventional osteotomy was performed at low speed without irrigation to create 3.5 mm x 11 mm implant sockets and the same implants were inserted (N1, Nobel Biocare).

Group 4 Conventional osteotomy was performed at low speed without irrigation to create 3.5 mm x 11 mm implant sockets and implants with aggressive threads and oval necks belonging to the same manufacturer were inserted (NobelActive, Nobel Biocare).

Group 5 Conventional osteotomy was performed at high speed with irrigation was performed to create 3.5 mm wide and 11 mm long implant sockets and implants with trioval necks were inserted (N1, Nobel Biocare).

Group 6 Conventional osteotomy was performed at high speed with irrigation was performed to create 3.5 mm x 11 mm implant sockets and implants with aggressive threads were inserted (NobelActive, Nobel Biocare) (Fig. 2).

Six implant osteotomies were performed on each sample, one from each group, and the dental implants determined in the relevant group were placed with a safe distance to each other. Following hand-tightening the corresponding multipegs, to the dental implants after insertion, the ISQs of the implants were measured with the magnetic analyzer and recorded (Penguin RFA, Penguin Instruments, Sweden).

Group 1 and Group 4 were compared the active implant systems applied with the implant-specific osteotomy method and conventional osteotomy, whereas Group 1 and Group 3 were compared to see the effect of OS on primary stability by inserting the same implants. The comparison between Group 1, Group 3, Group 5 and Group 6 evaluated the impact of the drilling speed on primary stability. Group 2 was created and compared with Group 1 to determine any disadvantage in the multiple use of implant-specific burs that were recommended for single use by the manufacturer.

Three experimental groups were additionally created to assess temperature changes were determined as follows:

Group A Implant-specific osteotomy was performed at low speed without irrigation to create 3.5 mm x 11 mm implant sockets ($n = 8$). Temperature changes occurring in the cortical and cancellous layers were recorded.

Group B Conventional osteotomy was performed at low speed without irrigation to create 3.5 mm x 11 mm implant sockets ($n = 8$). Temperature changes occurring in the cortical and cancellous layers were recorded.

Group C Conventional osteotomy with irrigation was performed at high speed to create 3.5 mm x 11 mm implant sockets ($n = 8$). Temperature changes occurring in the cortical and cancellous layers were recorded.

Temperature changes were carried out in room temperature control set to 24 °C. In order to maintain the same beginning temperature throughout the experimental procedures, the bone specimens were stored in a saline solution at a temperature of 24 °C. The changes in temperature levels during the process of preparing the implant site were observed by utilizing a double-channel temperature monitoring device (Redbox TCS 01, Turkiye) with a sampling rate of 100 milliseconds and a K-type thermocouple (Ser Resistans, Turkiye) with a diameter of 2 millimeters. A polyvinyl siloxane impression (Elite HD+, Zhermack, Italy) material is included with the thermocouple isolation to avoid room temperature detection. In order to insert thermocouples into the bone, pilot drills with a 2 mm diameter were used to prepare sockets of the length 2 mm for the cortical and 10 mm for the cancellous layer. The sockets were situated 1 mm away from the implant osteotomy areas (Fig. 3).

Specimens were fixed to the table with two vices for stabilization. The surgical unit provided continuous external cooling for Group 5, 6 and C, and flow was kept constant at 100 ml/min. In Groups 1, 2, 3, 4, A and B, external cooling was not provided based on the manufacturer's recommendation to work at low speed and without irrigation to provide the advantages of controlled procedure and autograft collection. Following the manufacturer's instructions, implant sites were prepared in Groups 1, 2, 3, 4, A and B at 50 rpm and, Groups 5, 6 and C at 800 rpm by applying up-down movement and pulling back the bur at half the length. The Osseoshaper bur was used following the pilot bur in Groups 1, 2 and A. In Groups 1 and A, each bur was only used once, following the manufacturer's instructions. For Groups 3, 4, 5, 6, B and C, each set of burs was only used for five osteotomies to prevent drill wear. Special attention was paid to ensure that the specimens were anatomically similar in structure.

Statistical analysis

Analyzing ISQ values

Data were analyzed with SPSS IBM v23 program. Normal distribution of data was examined with Shapiro-Wilk test. Kruskal Wallis H test was used for comparison of three or more groups for data that did not show normal distribution and Dunn Test was used for multiple comparisons. Mean ± standard deviation and Median (minimum-maximum) were used to display quantitative data.

Analyzing temperature changes

Data were analyzed with IBM SPSS V23 and JAMOVI v2.3.21 programs. Compliance with normal distribution was examined with the Shapiro-Wilk test. Kruskal Wallis test was used to compare ISQ values that were not normally distributed according to groups and multiple comparisons were examined with Dunn test. Robust ANOVA was used to compare temperature change values that were not normally distributed according to groups and distances and multiple comparisons were examined with Bonferroni test. Analysis results were presented as mean ± s. deviation and median (minimum-maximum).

All the results were assessed at 95% confidence interval, at a significance level of 0.05.

Results

The number of subjects was 8 in each group, according to Power analysis using the G*Power V3.1.9.6 (Heinrich Heine University, Dusseldorf) program, which

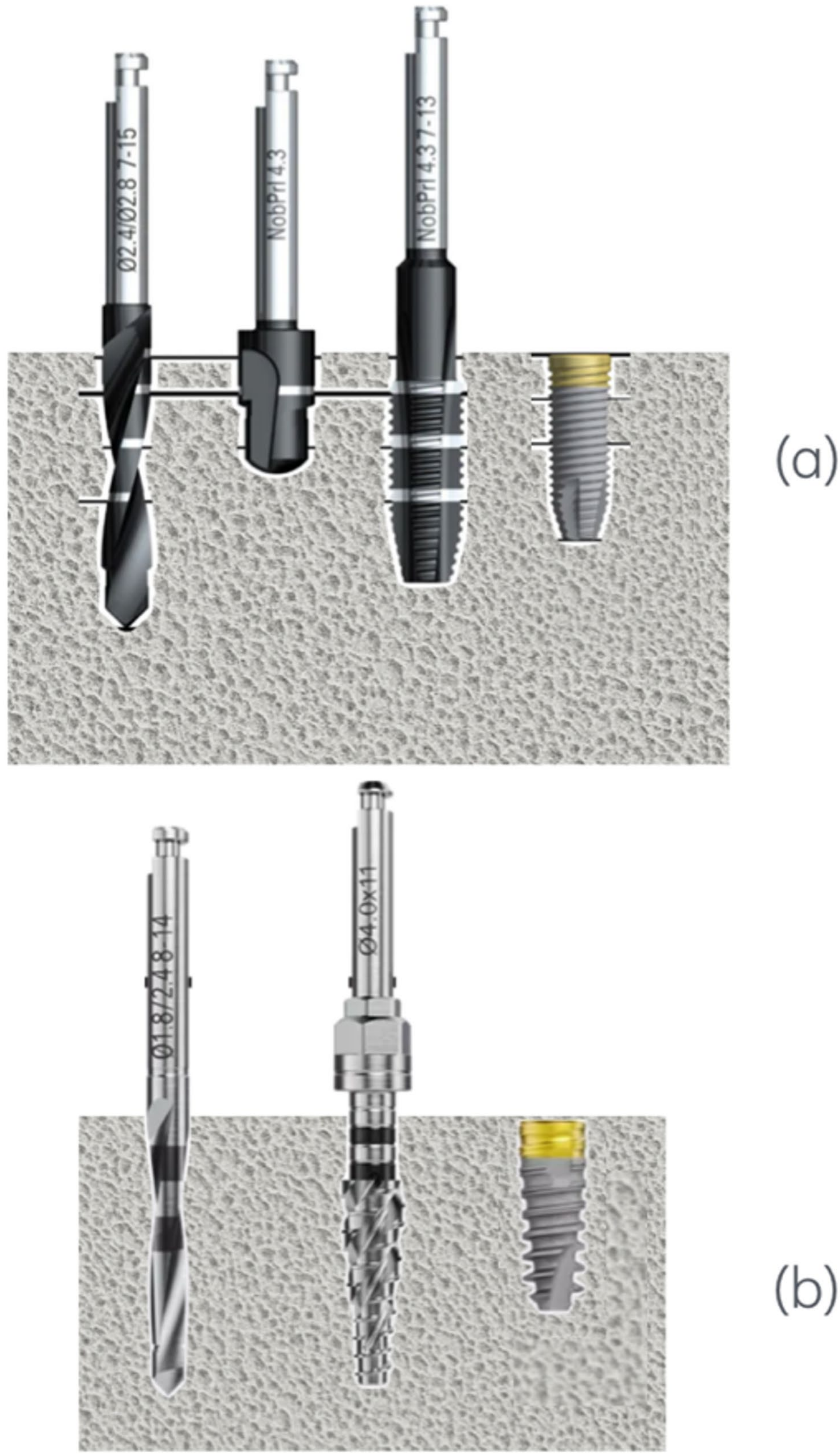


Fig. 2 Graphics showing drill and implant geometry for conventional osteotomy and implants with aggressive threads (**a**) and, implant-specific osteotomy and implants with trioval necks (**b**)

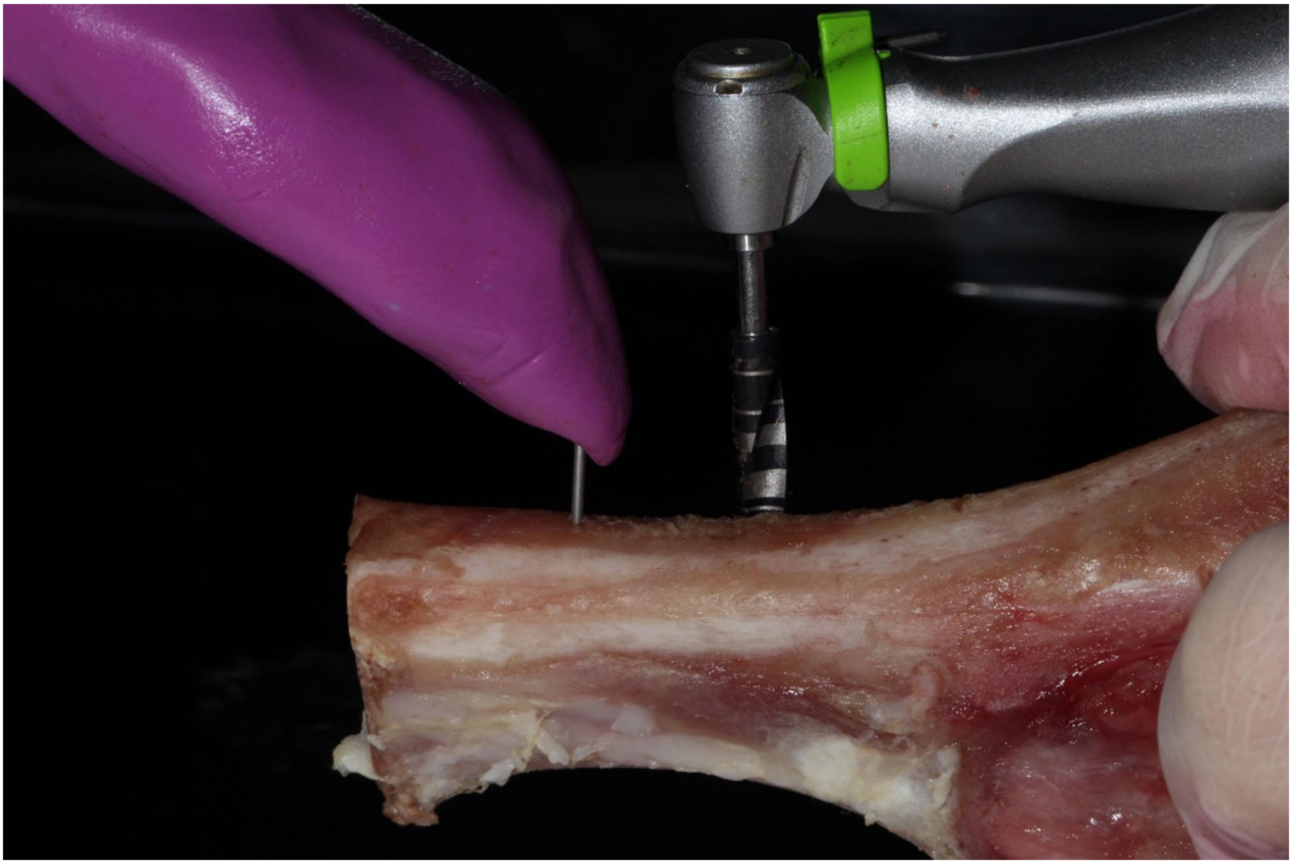


Fig. 3 Implant site preparation and assessment of the temperature changes

Table 1 Comparison of ISQ values according to groups

	mean value ± standart deviation	median (min. - max.)	Test statistics	*p*
Group 1	78,25 ± 3,65	79,50 (70,00–82,00)a	24,12	< 0,001
Group 2	77,25 ± 2,55	77,50 (74,00–80,00)a		
Group 3	72,63 ± 1,41	72,50 (71,00–75,00)ab		
Group 4	71,88 ± 1,64	72,00 (70,00–75,00)b		
Group 5	72,38 ± 1,51	72,50 (70,00–75,00)ab		
Group 6	71,63 ± 2,00	71,50 (69,00–75,00)b		

*Kruskal Wallis test, a-b: There is no difference between groups with the same letter

determined that each group had 8 subjects. The study needed 40 samples, with a 95% confidence interval (1-α), 95% test power (1-β), and an effect size of f = 1.376.

Evaluation of ISQ values

The mean, median ISQ values of the groups are presented in Tables 1 and 2. Statistically significant difference was observed between the ISQ values according to the groups (p <.001).

Evaluation of temperature changes

Statistically significant difference was observed between the temperature change values of the groups without making a distinction between depths (p <.001). The median of Group A was 6.00 °C, the median of Group B was 6.00 °C, and the median of Group C was 2.50 °C. Group C differed from the other groups (Table 3).

The median temperature change values differed according to the depth without making a distinction between groups (p <.001). While the median value at 2 mm depth was 7.00 °C, the median of change at 10 mm depth was 4.00 °C (Table 4).

Discussion

The aim of this study was to investigate the possible positive effect of implant-specific osteotomy in increasing the primary stability of active implant systems frequently used for immediate loading and whether this method could cause an increase in intraosseous temperature that might lead to thermal damage to the bone negatively

Table 2 Box plot of ISQ values by groups

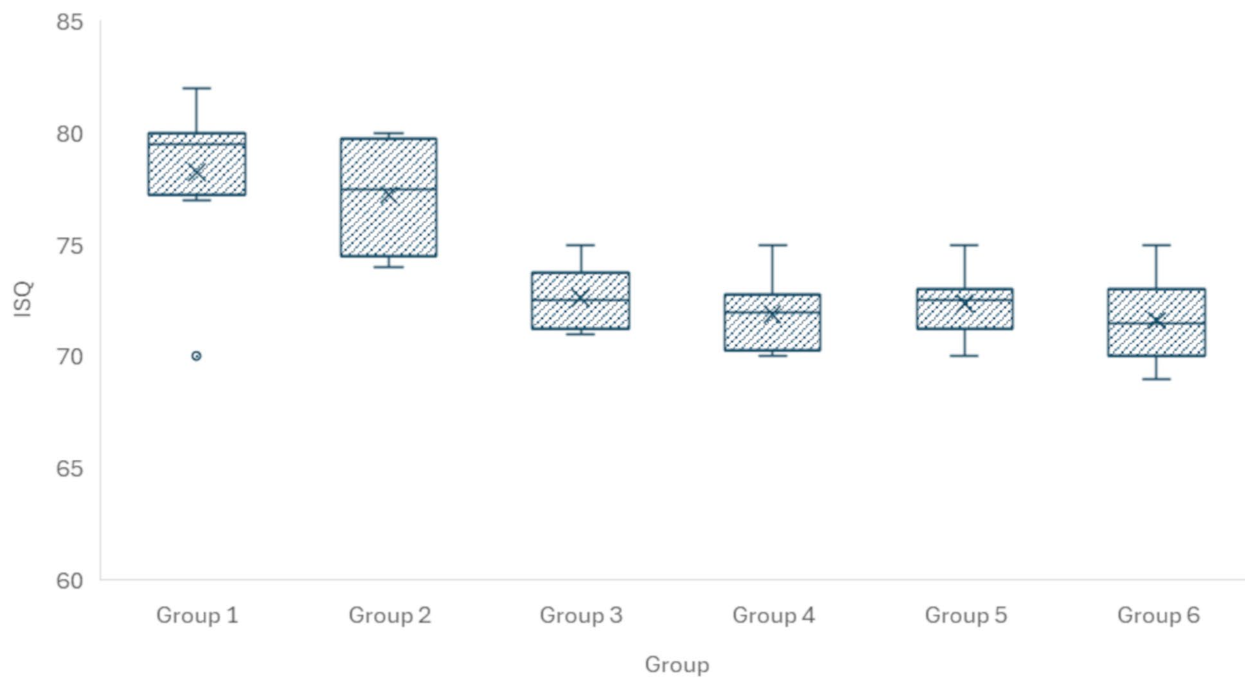
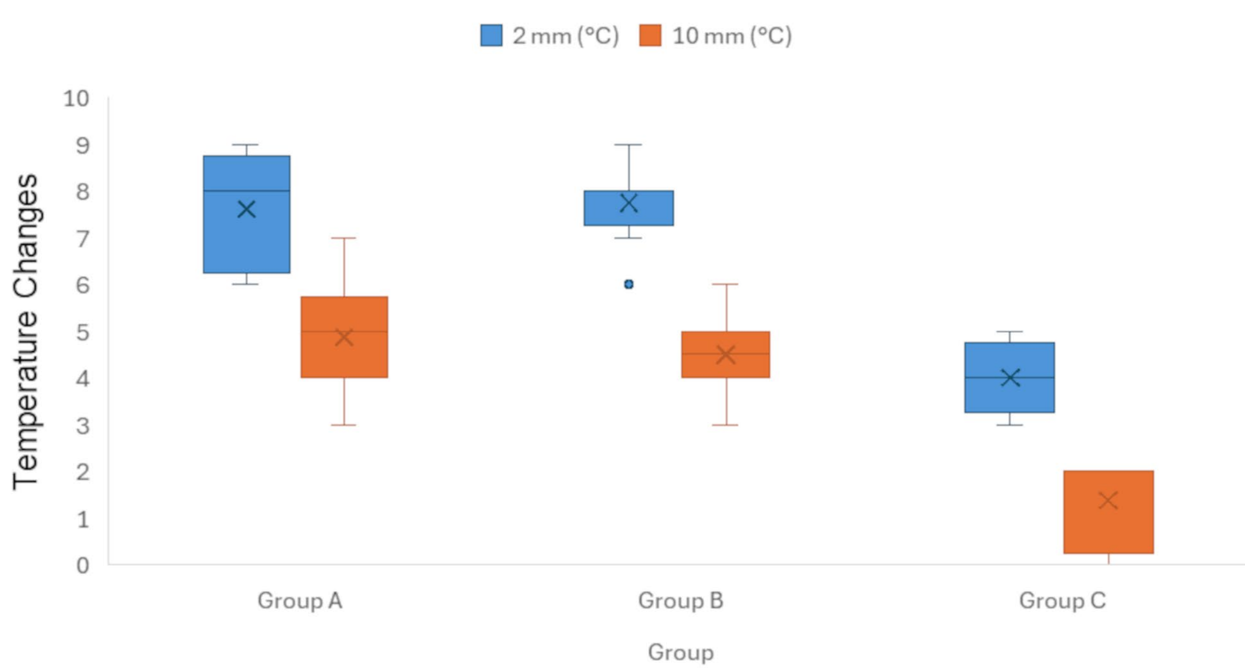


Table 3 Box plot of ISQ values by groups



affecting the osseointegration process. Implant specific osteotomy both showed higher implant stability and higher intraosseous temperature leading to the rejection of the null hypothesis that there would be no difference between the primary stability values and the intraosseous temperature changes of the two osteotomy methods.

Primary implant stability, generally defined as implant stability at the time of implant placement, has been clinically recognized as having a positive effect on successful

Table 4 Descriptive statistics of temperature change values according to groups and depths

	2 mm		10 mm		Total	
	Mean value ± standard deviation	**Median (min. - max.)**	**Mean value ± standard deviation**	**Median (min. - max.)**	**Mean value ± standard deviation**	**Median (min. - max.)**
Group A	7,63 ± 1,19	8,00 (6,00–9,00)	4,88 ± 1,25	5,00 (3,00–7,00)	6,25 ± 1,84	6,00 (3,00–9,00)[a]
Group B	7,75 ± 0,89	8,00 (6,00–9,00)	4,50 ± 0,93	4,50 (3,00–6,00)	6,13 ± 1,89	6,00 (3,00–9,00)[a]
Group C	4,00 ± 0,76	4,00 (3,00–5,00)	1,38 ± 0,92	2,00 (0,00–2,00)	2,69 ± 1,58	2,50 (0,00–5,00)[b]
Total	6,46 ± 2,00	7,00 (3,00–9,00)	3,58 ± 1,89	4,00 (0,00–7,00)		

a-b: There is no difference between groups with the same letter

osseointegration. Many studies have previously examined the effect of osteotomy technique on primary stability [12]. The results of the studies indicated that the primary stability values obtained when techniques such as piezosurgery, under dimension drilling or osseodensification were higher than those obtained with the traditional osteotomy techniques [13–15]. Conventional surgical osteotomy uses successively increasing-diameter drills at high speed and requires abundant irrigation [16]. In contrast, recently introduced implant-specific osteotomy burs operate at low speed without irrigation. Several biological benefits of this new site preparation concept has been shown such as increased cell viability at the site by eliminating high temperatures during site preparation and preserving the granulated bone generated in situ [17].

In the present study, to evaluate the success of implant-specific osteotomy method in increasing primary stability, Osseoshaper (Nobel Biocare, Sweden) burs, which allow working at low speed without cooling and provide the preparation of a specific socket for the implant in the length and diameter of the implant to be placed directly after the use of the pilot burs were used for the placement of trioval implants that were designed for this system (N1, Nobel Biocare) and were compared with the implants with aggressive threads designed in a similar form belonging to the same company (NobelActive, Nobel Biocare) inserted with conventional osteotomy method. Our results showed that although the ISQ values of the implants applied with the conventional osteotomy revealed ISQs higher than 70 which is the threshold value for immediate loading and meeting the expectation of successful osseointegration; higher ISQs were detected in the implants with trioval necks inserted with osseoshaper. Two similar implant designs were used in the present study. Both designs had aggressive threads but one had trioval necks. In order to understand the reason of the raise in the ISQs in trioval implants inserted with osseoshaper, these implants were additionally inserted using high speed conventional osteotomy with irrigation (Group 5) and also low speed conventional osteotomy without irrigation (Group 3) but both groups showed lower ISQs indicating that the reason of the raise in the ISQs was the implant-specific osteotomy technique. When the studies in the literature are inspected, it is obvious that although the success rates of short implants applied especially to low-density bone regions are high, failing implants are generally reported to have low ISQ values [18, 19]. In line with the findings of our study, it is possible to report that the high primary stability values obtained with the implant-specific osteotomy method are of significant importance in providing the long-term success of implant systems.

The present results showed no advantages of high-speed drilling with irrigation over low-speed drilling without irrigation which are consistent with other studies investigating the effect of drilling speed on primary stability [20–22].

Since the osseoshaper burs used in the implant-specific osteotomy are produced in a particular thread structure, length, and diameter to allow a socket preparation that mimics the morphology of the implant to be placed, it is recommended by the manufacturer to be used for single-use to ensure maximum socket quality and stability. In the present study, also the effect of multiple use of these burs on maintaining implant stability was investigated. When the results of Group 1 and Group 2 are compared, a slight decrease was observed between the average of the stability values obtained in the first use and the 15th use, but no statistically significant difference was found, and it is possible to report that repeated uses of the burs do not create a significant difference in the primary stability. However, since osteotomy procedures are performed at low speed and without saline cooling, we can make a clinical note that bone debris accumulates between the aggressive threads of the burs, and this debris may affect osseointegration by causing a more extended time spent in implant socket preparation in repeated uses and indirectly increasing the intraosseous temperature. This result should be confirmed in clinical situations to draw more reliable conclusion.

Various factors can influence the temperature rise in bone during implant osteotomy preparation, including drilling speed and use of external irrigation [22]. These factors have been reported to affect the early bone healing response and subsequent osseointegration process [20]. Classically, it has been considered that the temperatures reached per minute should not exceed 47 °C [18]. The precise threshold temperature has not been clearly defined, though it appears to fall within the range of 47–55 °C per minute [23].

Drilling at low speed without irrigation has been analyzed several times [22]. Kim et al. found low-speed drilling without irrigation using three different drilling system brands to be safe from the thermal perspective [24]. Despite the dissimilar results among the different studies, none of the publications evidenced increments above the critical threshold temperature associated with thermal osteonecrosis [22]. Drilling at low speed without irrigation seems to be a thermally safe technique [22].

Our results revealed that the temperature increase in implant sockets prepared with the implant-specific osteotomy did not cause a significant difference compared to the conventional osteotomy when the operation was performed without irrigation and at low speed, but it was significantly higher than the implant sockets prepared at high speed under irrigation. When the temperature increases occurring in the cortical and cancellous bone layers were examined, it was determined that the temperature increases occurring in the cortical layer were significantly higher than the cancellous layer in all study groups. However, considering the 10 °C difference between the body basal temperature of 37 °C and the critical temperature threshold for bone vitality of 47 °C, since the temperature increase did not exceed 10 °C in any study group, it is possible to state that using this method during implant osteotomy does not pose a risk in terms of osseointegration within the limits of this study. Additionally, one-drill protocol of this system offers a simplified surgical workflow which may have a beneficial effect both for the patient and the clinician [25]. This result is in consistent with the results of the systematic review conducted to compare low-speed and high speed drilling methods [22].

Our study is subject to some limitations since it is ex-vivo. The specimens were not living or had circulating blood, there may have been a change in the bone density between the slaughtering of the animals and the conduct of the study, and the room temperature differed from the human body basal temperature; which may have affected the outcome. To reduce the diversity of the samples, the specimens were selected to have the closest possible anatomical features to human mandible, and the bone densities of the specimens were examined by CBCT, and all were chosen from D3 density bones. However, the inability to standardize the specimens' cortical and cancellous bone ratios and the natural differences between sheep and human bone morphology might lead to variability in the recorded ISQ values. Moreover, although the points of thermocouples to be placed were determined by measuring precisely, human error may have occurred. Therefore, further research on this subject is needed to conclude precisely, and these research should focus on in vivo methods. A more thorough investigation into the cumulative effects of repeated osteotomy procedures on intraosseous temperature could provide additional insights, especially in cases of repeated drilling or longer procedures.

It should be kept in mind that the present study should be followed by in vivo trials to confirm the clinical applicability of the findings. Animal studies with a more human-like bone structure would be valuable to bridge the gap between ex-vivo findings and real clinical scenarios. Additionally, further studies should evaluate the long-term impact of using implant-specific osteotomy drills in vivo, particularly focusing on osseointegration rates, implant survival, and patient outcomes.

Conclusion

Within the limitations of the present study, it is possible to report that preparing the implant socket with burs that creates a socket suitable for the morphology of the implant to be placed in a single step with the implant-specific osteotomy method provides better primary stability, but working at high or low speeds does not offer a significant advantage to obtain better primary stability in implant sockets prepared with the traditional osteotomy method. Although the use of the implant-specific osteotomy method at low speed and without cooling with irrigation solution causes a greater increase in intraosseous temperature than the traditional method, the increase is not high enough to affect bone vitality, and this method can be considered safe. In conclusion, advantages such as providing higher primary stability, performing a more controlled procedure, and completing the osteotomy in fewer steps can be publicized as the superior properties of the placement of trioval implants using implant-specific osteotomy.

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Author contributions
O.G. and S.S. formalized the groups and prepared the workflow. G.G.U. and S.S. made the ex-vivo experiments, measurements and tables. M.Ç made the statistical analysis and wrote the main manuscript. O.G. did final review of it.

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Data availability
The datasets used and/or analysed during the current study are available from the corresponding author on reasonable request.

Declarations

Ethics approval and consent to participate
Not applicable. (Because iliac crest bones were obtained from dead animals and the animals were not sacrificed for use in the study, this study is not subject to ethics committee approval.)

Consent for publication
Not applicable.

Competing interests
The authors declare no competing interests.

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