

Research Article

Comparative Analysis of Bone Tissue Temperature during Implant Preparation with Variable Drilling Parameters: *In Vitro* Study

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Purpose. The aim of this work was to compare the temperature fluctuations that occur during the development of the implant bed using three different implant systems and the impact on their value of cooling method and rotational speed of drill. **Material and Methods.** As a model of the human jaw due to the analogy of bone structure and hardness, pig ribs were used. Drills from three different implant systems were used in the study: Straumann® (Straumann GmbH, Basel, Switzerland), AnyRidge® (Megagen Implant Co., Ltd., Daegu, South Korea), and Osstem (OSSTEM IMPLANT CO., LTD., Seoul, South Korea). The sequence of three successive drills was given—from pilot drill to final drill. For each system, a group with two water cooling methods, without cooling, and three different speed ranges, 800, 1200, and 1500 rpm, and their effect on temperature fluctuations was evaluated. The temperature was measured by thermography. **Results.** The highest temperature increases were noted during preparation with pilot drills. The maximum temperature (50.8°C) was noted for the AnyRidge pilot drill at 1500 rpm without cooling. When cooling with physiological saline, none of the applied drills exceeded 28°C. Significant differences between lack of cooling and cooling with saline at 20°C and 3°C have been demonstrated. During preparation with cooling, the difference between the times of the maximum temperature achievement was observed between AnyRidge® and Osstem (2.6 vs. 1.6 s, $p = 0.004$). **Conclusion.** The experiment showed that the drills of the tested implant systems differed in the amount of heat generated during operation. The temperature of the cooling solution and the rotational speed applied have an influence on its amount.

1. Introduction

In implantology, as in every field of interventional medicine, achievement of the optimal therapeutic goal can be ensured by the slightest traumatization of the surrounding tissues. Implant system manufacturers modify the shape of drills to reduce friction on their surface, reducing heat generation while maintaining the ability to accumulate and preserve tissue [1]. This is an important feature, because the tissue recovered during bone preparation can be a valuable augmentation material [2]. An important parameter in bone tissue processing is the optimization of the rotational speed for a given drill. Too low rotational speed contributes to inefficient cutting and the need to apply more pressure on the drill, which in turn increases

friction and causes an increase in tissue temperature. However, if the rotation speed is too high, the increased frequency of drill movements generates excessive heat. In this case, it is recommended to use dedicated speed for a given system, taking into account the variability associated with the diameter of the drill used. Due to the larger contact surface and the resulting greater friction and vibrations at larger drill diameters, the rotational speed should be lower than in the case of initial drills [3]. The generally accepted operating speed range for rotary implant systems is between 600 and 1500 rpm. Bone preparation time is another important parameter when preparing the implant bed. As indicated by the research of Boa et al. [4], shortening of the bone preparation time has a significant impact on reducing the temperature changes in bone tissue. An

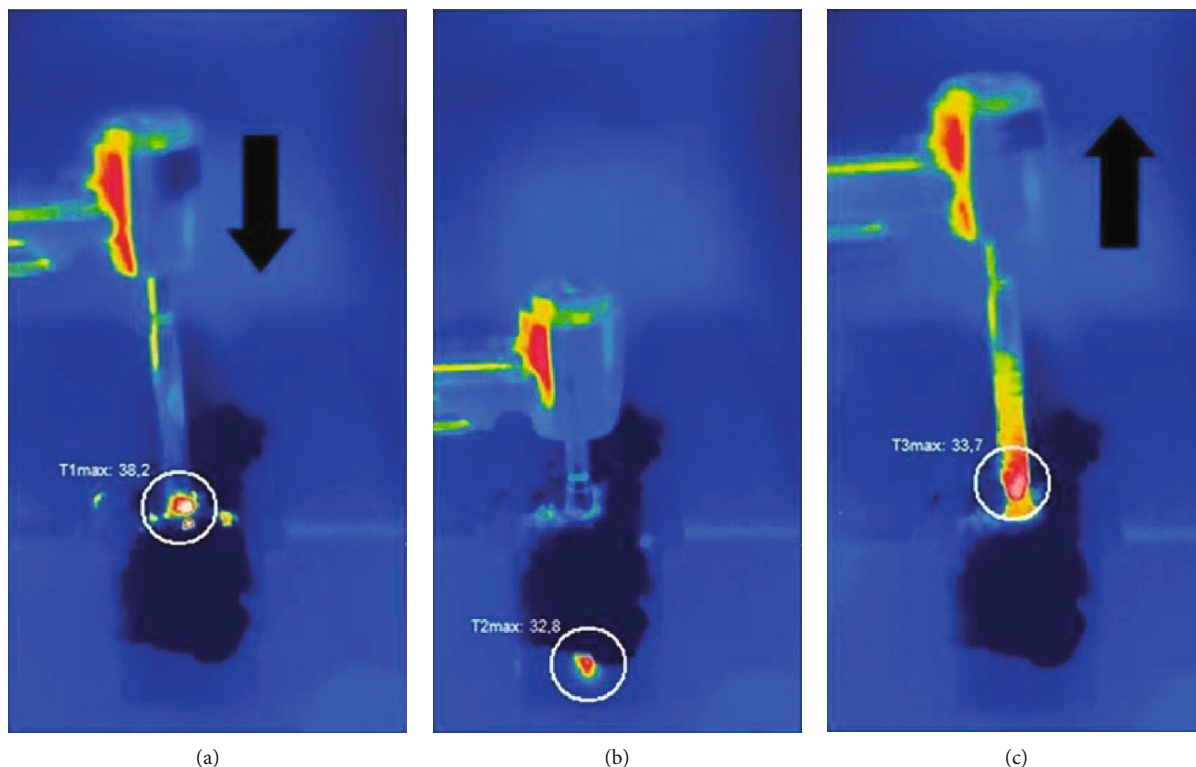


FIGURE 1: Thermograms performed in three phases of the preparation of the bed for the future implant. Osstem system, millØ 3.0 mm, $n = 800$ rpm, and without cooling: (a) hole drilling phase, (b) phase of removing the tool from the bone, and (c) phase of removing the tool from the hole.

important factor limiting temperature changes during preparation is also the use of irrigation with a coolant. For this purpose, physiological saline is used as an inert solution at room temperature or below. According to some researchers, lowering the temperature of the cooling solution helps to reduce bleeding during surgery and further reduce tissue temperature [4]. The use of all the above-mentioned drilling parameters is important for reducing heat emission to bone tissue, because its overheating above 47°C for over 1 minute may be critical and lead to necrosis [5, 6]. This may contribute to complete or partial disturbance of osseointegration, which, as a multistage process, depends to a large extent on the initial parameters and above all on the biological and mechanical qualities of the bones.

The aim of the study was to compare the measurements of temperature changes generated during the bone tissue preparation procedure (in vitro) using infrared thermography.

2. Materials and Methods

Pork ribs from one individual with similar anatomical structure in terms of length, width, and thickness were used for the research. On cross section, all of them on the preparation surface had similar cortical thickness of about 1 mm. Pig ribs were used as a model because of the very high analogy in the macro- and micromorphological structure to the bone of the human jaw. They were marked with consecutive numbers 1-9 for a given drill and implant system. During drilling, they were immobilized using a special vise, which gave the oppor-

tunity to observe temperature changes in the thermal imaging camera. Drills were carried out at a distance of 3 cm from each other, three for each rib to a depth of 13 mm. The study evaluated three implant systems: Straumann® (Straumann GmbH, Basel, Switzerland), AnyRidge® (MegaGen Implant Co., Ltd., Daegu, South Korea), and Osstem (OSSTEM IMPLANT CO., LTD., Seoul, South Korea). Three drills from each system (pilot drill, initial preparation, and final preparation) were analyzed, assessing the temperature rise during preparation under varying cooling conditions, i.e., without cooling, cooling with 0.9% NaCl at temperature 20°C, and cooling with 0.9% NaCl in approx. 3°C, and for different speed ranges: 800, 1200, and 1500 rpm. The bone for the narrowest implant was developed for each implant system. For this purpose, the NeoSurge implant motor (Neobiotech Co., Ltd., Seoul, South Korea) was used with the auto reverse option and 32:1 speed reduction. In the case of preparation with cooling, the same average coolant intensity was used for each drill, which corresponded to a volume of 50 ml/min. Drilling holes in the ribs was performed by one experienced operator, and the press force of bone tools was measured using an electronic scale, on which a vise with bone was placed. The nature of the load measured with the ADVERTI WLC 12/F1/R laboratory scale (maximum load: 12 kg, and reading accuracy: 0.2 g) was similar in all measurements. Press force increased from 0 to 750 g (750 ± 12 g). The entire implant bed development process was recorded at a frequency of 30 Hz with a ThermaCAM P640 thermal imaging camera from FLIR (IRT Consult Ltd., Mullagh, Ireland),

TABLE 1: Maximum temperature within ROI.

System	Drill d (mm)	n (rpm)	Without cooling		Cooling		Cooling with cold saline	
			t (s)	T_{\max} ($^{\circ}\text{C}$)	t (s)	T_{\max} ($^{\circ}\text{C}$)	t (s)	T_{\max} ($^{\circ}\text{C}$)
Osstem	2.2	800	2.39	38.7	2.06	26.2	1.82	24.7
	2.2	1200	2.11	39.6	1.46	26.8	1.92	23.0
	2.2	1500	2.20	40.4	1.19	26.5	1.45	23.2
	3.0	800	2.04	38.2	1.69	26.3	2.49	24.4
	3.0	1200	1.94	38.4	1.33	26.2	2.19	22.7
	3.0	1500	1.83	40.2	1.29	27.5	1.92	23.1
	3.5	800	2.27	36.9	2.16	26.5	2.02	25.2
	3.5	1200	2.04	37.2	2.06	26.3	1.89	24.7
	3.5	1500	1.53	38.7	1.45	23.0	1.46	25.1
	AnyRidge	2.5	800	2.52	40.1	4.54	24.4	3.09
2.5		1200	2.29	48.9	2.82	23.6	2.72	19.7
2.5		1500	2.22	50.8	1.86	23.2	1.43	23.2
2.8		800	1.46	24.4	2.02	25.0	1.86	21.0
2.8		1200	1.26	42.3	1.89	20.7	1.79	22.1
2.8		1500	1.19	44.3	1.99	25.2	1.56	22.8
3.3		800	1.76	29.7	2.92	25.3	1.96	20.7
3.3		1200	1.06	32.2	2.82	24.6	1.59	20.4
3.3		1500	0.99	33.5	2.36	22.8	1.43	20.5
Straumann		2.2	800	2.67	40.8	2.52	25.0	1.86
	2.2	1200	2.42	43.8	2.42	23.6	1.69	21.9
	2.2	1500	2.39	45.9	2.35	23.8	1.56	23.2
	2.8	800	3.96	40.1	2.55	25.9	1.43	21.3
	2.8	1200	4.81	43.4	2.39	26.3	1.33	19.9
	2.8	1500	4.01	45.7	2.15	24.7	1.26	20.1
	3.5	800	3.28	36.2	2.22	27.5	1.95	22.7
	3.5	1200	2.99	39.9	1.65	25.1	1.63	21.2
	3.5	1500	2.95	42.5	2.15	26.0	1.33	23.2

with a 480×320 pixel matrix and a minimum temperature sensitivity of 0.06 K. During measurements, the external temperature (T_{amb}) was constant at 20.0°C and relative humidity was about 65%. Recorded thermogram sequences were analyzed using ThermoCAM Research Pro software (IRT Consult Ltd., Mullagh, Ireland). The maximum temperature was measured on each thermogram in selected milling regions (ROI). Since direct contact access to the surface of the drill during the preparation in the bone due to its penetration in the tissue is difficult to see, differences in the temperature distribution are visible as illustrated in Figures 1(a)–1(c): the top surface of the bone ($T1_{\text{max}}$, Figure 1(a)), at the moment of removing the top of the drill from the bone ($T2_{\text{max}}$, Figure 1(b)), and the temperature of the drill directly after taking it out of the hole ($T3_{\text{max}}$, Figure 1(c)). The implant bed wall temperatures were indirectly estimated by contactless measurement of the temperatures of the cutters at the time they exit the bone hole. In pilot studies using thermocouples, it was found that the temperature inside the bone strongly correlates with the temperature of the cutting (processing) tool. The results of

measuring maximum surface temperatures of milling cutters (T_{max}) and times of reaching the maximum temperature (t) were subjected to statistical analysis. One-way analysis of variance (ANOVA) was used to compare the mean values in three groups (implantological systems). Earlier it was checked whether the examined feature in each of the examined groups had normal distribution and equal variances (Shapiro-Wilk and Levene tests, respectively). If the probability corresponding to the value of Snedecor's F statistics was lower than the assumed level of significance ($p < 0.05$), then in order to determine the average of which group significantly differs from the others, multiple comparison tests (post hoc) were carried out. For this purpose, Tukey's test was used. STATISTICA v.13 program was used for calculations (StatSoft, Inc., Tulsa, OK, USA).

3. Results

Temperature values obtained during the bed preparation in the given period of time at different speeds and with the use of different cooling methods are shown in Table 1.

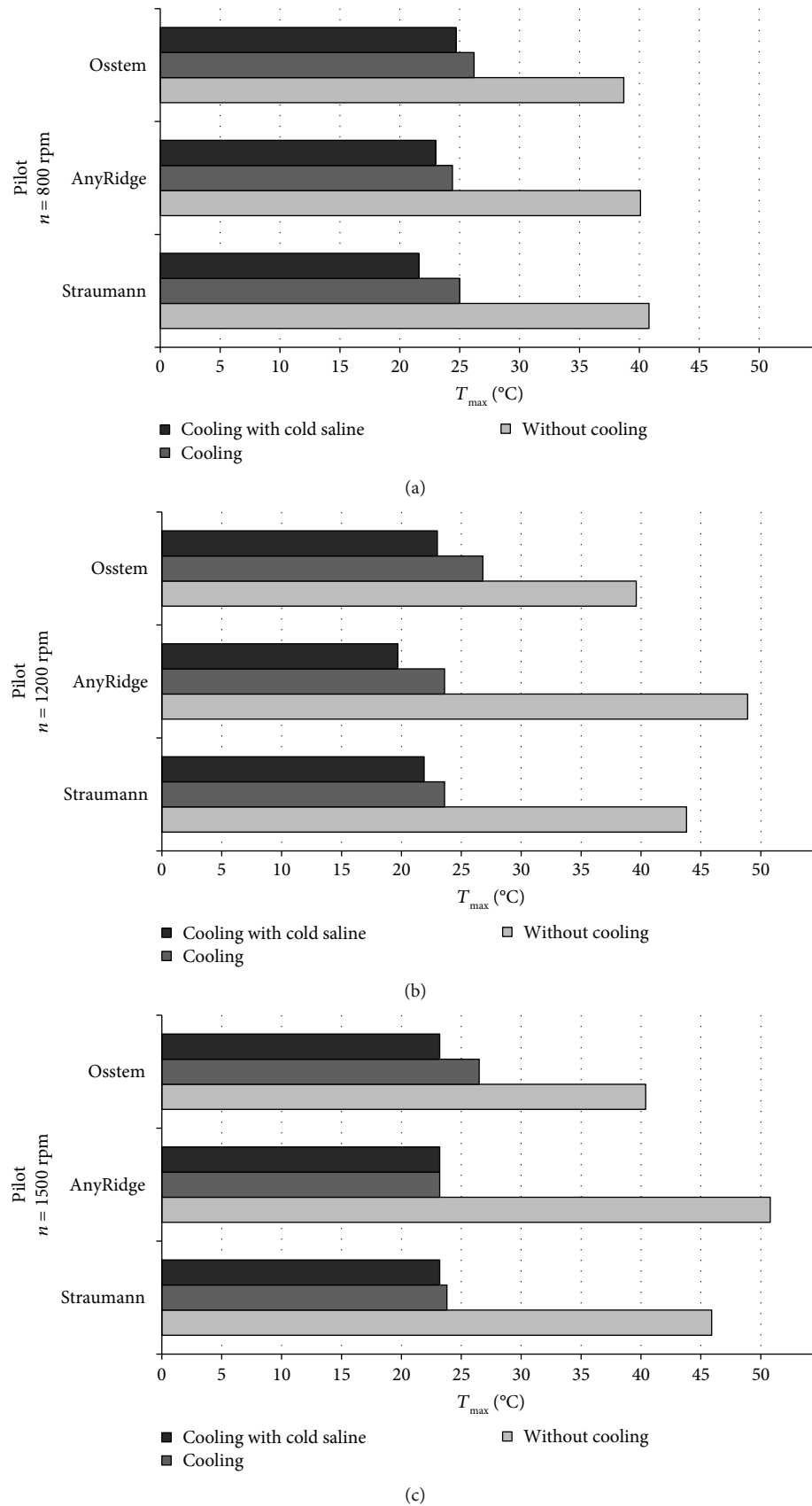


FIGURE 2: Comparison of maximal temperatures recorded during drilling of holes in the bone fragment with the use of pilot drill: (a) $n = 800$ rpm; (b) $n = 1200$ rpm; (c) $n = 1500$ rpm.

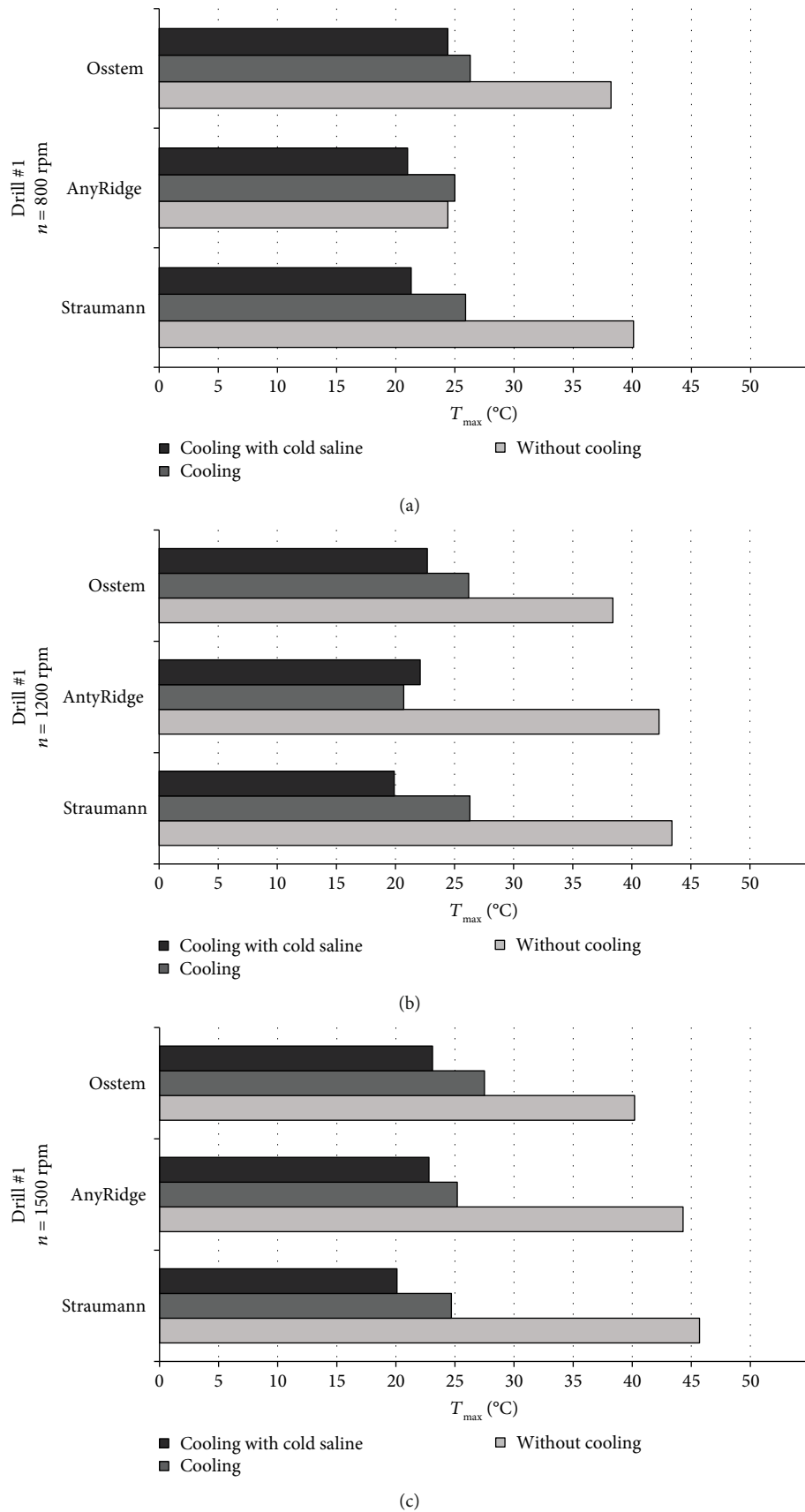


FIGURE 3: Comparison of maximal temperatures recorded during drilling of holes in the bone fragment with the use of drill #1: (a) $n = 800$ rpm; (b) $n = 1200$ rpm; (c) $n = 1500$ rpm.

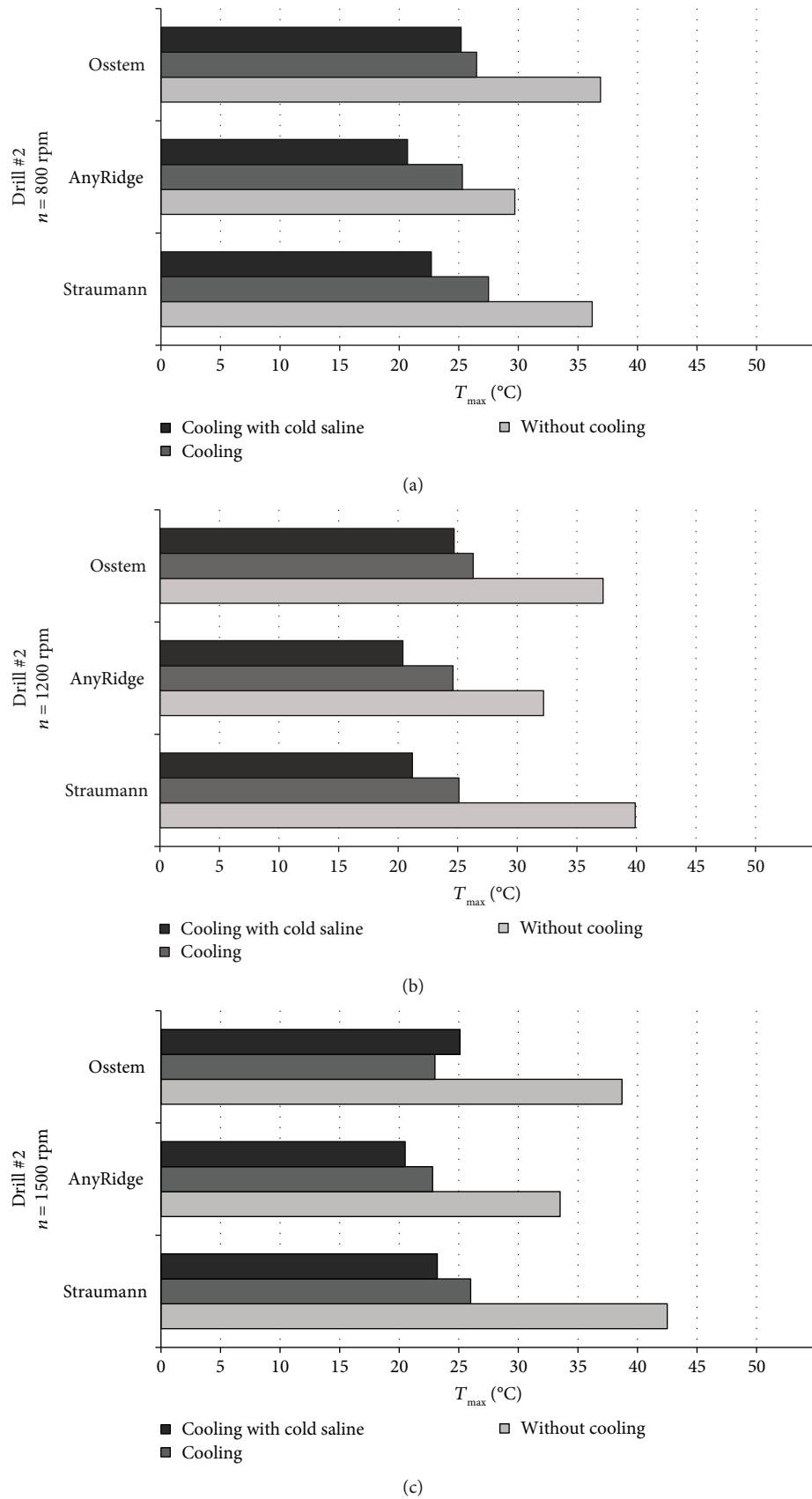


FIGURE 4: Comparison of maximal temperatures recorded during drilling of holes in the bone fragment with the use of drill #2: (a) $n = 800$ rpm; (b) $n = 1200$ rpm; (c) $n = 1500$ rpm.

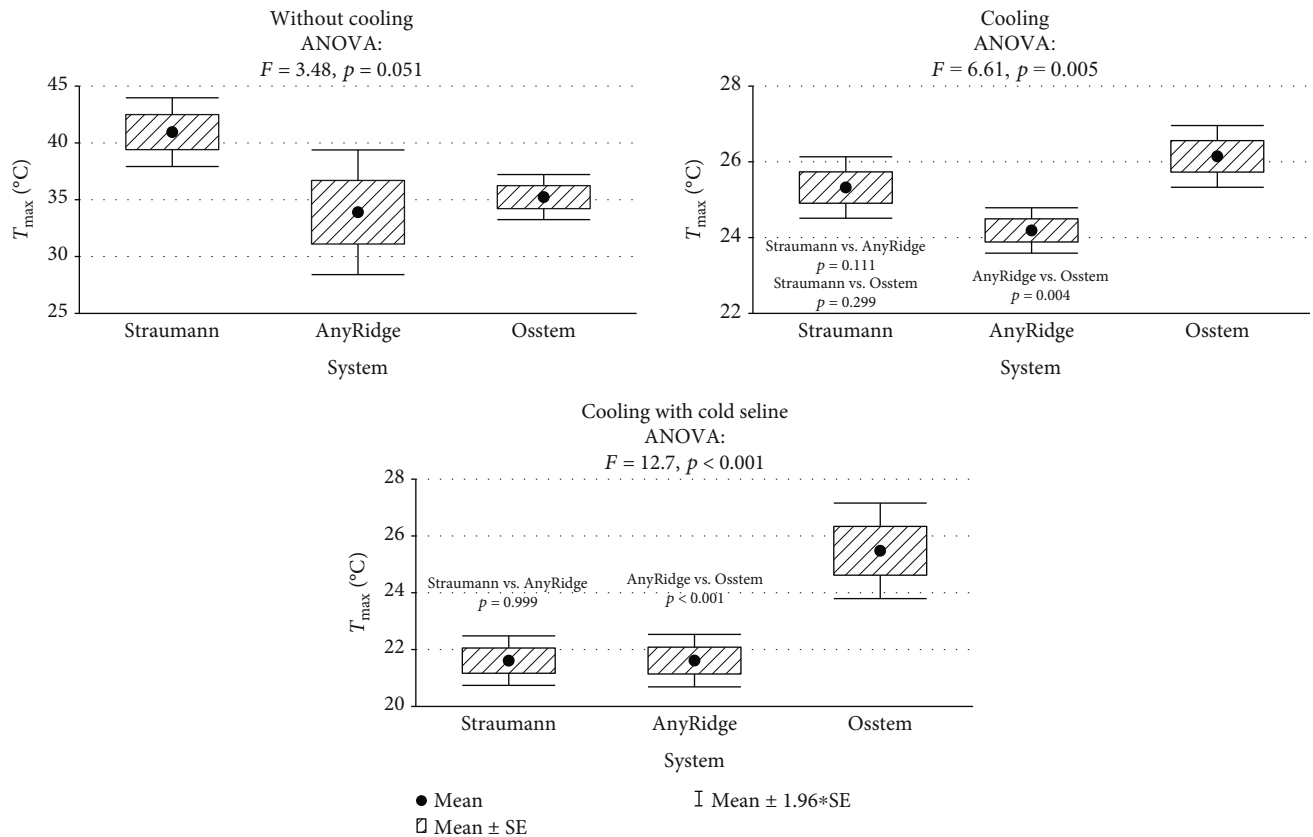


FIGURE 5: Comparison of maximal temperatures recorded during drilling procedure with the use of all three drills and results of the analysis of variance.

Figures 2–4 compare the temperature values read from thermovision with the use of different sizes of drills. Figures 5 and 6 present the results of the statistical analysis of temperature and preparation time of the implant bed. During preparation with cooling, a statistically significant difference in the maximum temperature occurred between the AnyRidge® and Osstem systems (24.2°C vs. 26.1°C, $p = 0.004$). During cooling with cold salt solution, differences occurred between Straumann® and Osstem (21.6°C vs. 25.5°C, $p = 0.001$) and AnyRidge® and Osstem (21.6°C vs. 25.5°C, $p < 0.001$). Drilling time without cooling to reach the maximum temperature with the Straumann® system was longer than AnyRidge® systems (3.3 vs. 1.6 s, $p < 0.001$) and Osstem (3.3 vs. 2.0 s, $p = 0.001$). During preparation with cooling, the difference between the times of the maximum temperature achievement was observed between the AnyRidge® and Osstem systems (2.6 vs. 1.6 s, $p = 0.004$). The maximum temperature (50.8°C) was noted for the AnyRidge pilot drill at 1500 rpm without cooling. The longest preparation time (4.81 s) was measured for a 2.8 mm Straumann® system drill at 1200 rpm.

4. Discussion

The study is aimed at comparing the amount of heat released for three different implant systems and the effect of cooling and drill speed during implant bed prepara-

tion. In addition, it was aimed at showing whether there are significant differences between different drills for the same drilling parameters in bone tissue. Many factors affect this type of bone preparation in the available scientific literature. These include bone structure, drill shape, depth of preparation, drill diameter, and rotational speed [8–12]. Many studies also indicate the essence of bone critical temperature, which is 47°C [13, 14] or, according to other studies, 50°C [15]. If it is exceeded, necrosis areas occur, which significantly reduce the success of osseointegration. The above studies show that the optimal bone preparation time using rotary instruments should be less than a minute.

According to our research, the optimal preparation speed is 1200 rpm. The 800 rpm speed, due to the longer drilling time, generated more friction and associated heat, and at 1500 rpm, increased rotation caused increased friction. It should be noted, however, that the amount of heat generated is also influenced by factors such as the drilling method, drill diameter, bone type, tissue blood circulation, and cooling [16].

Our study showed that lowering the temperature of the cooling solution reduces the amount of heat generated during drilling in bone tissue. Other authors also came to such conclusions in their research [4, 17]. In addition, internal cooling systems through increased irrigation of the drill lead to greater bone loss from the surface of the drill and, as

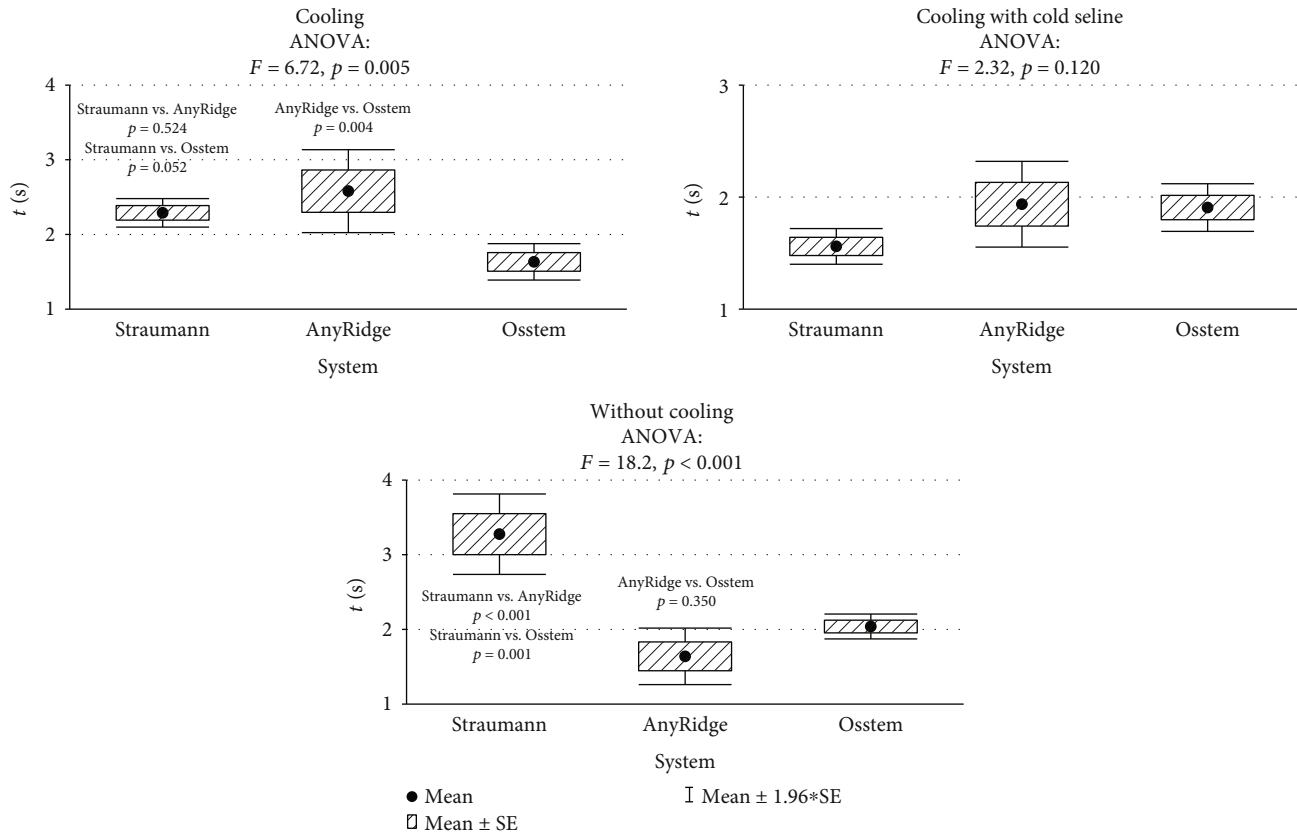


FIGURE 6: Comparison of drilling times for each of the examined dental implant systems and result of the analysis of variance.

shown by studies of other authors, are not more effective than external cooling systems [18].

The preparation depth of 13 mm was supposed to simulate the situation also for long implants, where the problem of drill cooling is particularly important. This is particularly important for such types of implants, e.g., zygomatic or bicortical [19].

The critical temperature for bones referred to in literature [12] was exceeded only when using pilot drills without cooling. This is due to the fact that the first drill in the initial phase must overcome the external resistance of dense bone by creating significant friction. When using water cooling, regardless of its temperature, the bone critical level was not achieved—water cooling turned out to be so effective that the temperature did not exceed 30°C during any of the drilling processes, which indicates the need for water cooling, and at the same time, the time indicates high efficiency of external cooling systems.

The use of pork ribs in the experiment, although not fully reflecting the human bone model, gave the possibility of obtaining very similar results in terms of preparation time in bone, which was proven by comparing different types of bone tissue by Szalma et al. [20]. The thermographic temperature measurement method used in this experiment seems to be the best method due to its noninvasive nature, speed, and simplicity of use that allow it to exceed other methods based on micro sensors located in the channels or preparation tips, which was also confirmed by other studies [3, 6, 7, 21, 22].

5. Conclusions

The properties of the used implant system, diameter of drill, rotational speed, and the method of cooling influence the temperature generated during implant bed preparation. When using the cooling fluid, regardless of its temperature, the level critical for bones was not reached—water cooling was so successful that during none of the drilling processes did the temperature exceed 30°C.

In conclusion, it should be noted that the thermographic temperature measurement method used in this experiment seems to be the best method due to its noninvasive nature, speed, and simplicity of use that allow it to exceed other methods based on micro sensors located in the channels or preparation tips, which was also confirmed by other studies [3, 6, 7, 21, 22].

The conducted research clearly shows that the type and diameter of the drill have an impact on the preparation time of bone tissue.

It should be noted that despite the lack of the possibility of exceeding the critical temperature for bones (confirmed in this study), using the technique of preparation according to the recommendations must be done vigilantly, because the possibility of thermal bone damage may occur at any time.

Further studies should be carried out to determine other factors that may affect temperature changes during osteotomy, such as the optimum ratio of pressure force and rotational speed of the drill, correlation with its shape, and the extent of contact of the drill with the bone.

Data Availability

The data used to support the findings of this study are available from the corresponding author upon request.

Conflicts of Interest

The authors declare that they have no conflicts of interest.

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