

ANALYSIS OF OSSEOUS TISSUE TEMPERATURE DURING PREPARATION OF RECIPIENT BED FOR CYLINDRICAL IMPLANTS

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In the early 21st century, robot-assisted dental implant surgery became a popular alternative to classic implant placement protocols. Postoperative complications are often provoked by poor compliance with surgical guidelines for implant placement, resulting in the overheating of the osteotomy site. The aim of this study was to measure the temperature of osseous tissue at the dental implant site during classic and robot-assisted dental implant placement performed at different cooling modes. Avital skeletonized mandibles of Vietnamese pot-bellied pigs were used as an experimental model. The recipient bed was prepared following the classic surgical protocol. Three cooling modes were tested: no irrigation, irrigation with sterile saline at 25–30 ml/min and standard 75 ml/min irrigation recommended by the standard surgical protocol. The temperature of the isotonic solution was 25 °C. The study showed that both classic and robot-assisted dental implant placement techniques are safe if there is sufficient irrigation and good compliance with the surgical protocol.

Keywords: robot-assisted system, bone heating, dental implant placement

Author contribution: Ivashchenko AV, Postnikov MA collected and analyzed clinical data; Tlustenko VP did organizational work and conducted the experiment; performed systematic analysis; Popov NV performed statistical analysis of the obtained data; Yablokov AE did organizational work and conducted the experiment, collected and analyzed clinical data; Tlustenko VS analyzed clinical data. Tugushev VV, Cherezova NI, Mukhina AA did organizational work and conducted the experiment; Belanov GN — systematic analysis.

Compliance with ethical standards: the study was approved by the Ethics Committee of Samara State Medical University (Protocol 209 dated February 3, 2021).

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ОЦЕНКА ТЕРМОМЕТРИЧЕСКИХ ДАННЫХ КОСТНОЙ ТКАНИ ПРИ ФОРМИРОВАНИИ ВОСПРИНИМАЮЩЕГО МАТЕРИНСКОГО ЛОЖА ПОД ЦИЛИНДРИЧЕСКИЕ ДЕНТАЛЬНЫЕ ИМПЛАНТАТЫ

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Установка дентальных имплантатов с применением механотронных устройств получила широкое применение в начале XXI в., наряду с классическим имплантологическим протоколом. Осложнения нередко обусловлены несоблюдением стандарта хирургического протокола проведения дентальной имплантации и, как следствие, повышением фокуса температуры в месте сверления костной ткани челюстей. Целью работы было оценить фокус температуры костной ткани в области установки дентального имплантата, проводимой по классической методике и с применением механотронной системы с различной степенью охлаждения. В качестве экспериментальной модели использовали авитальную скелетированную нижнюю челюсть поросенка вьетнамской вислобрюхой породы. В соответствии с классическим хирургическим протоколом было сформировано воспринимающее материнское ложе. Исследование проводили в трех режимах: при отсутствии подачи изотонического раствора, при незначительном его объеме (25–30 мл/мин) и при орошении раствором в соответствии с хирургическим протоколом (75 мл/мин). Температура подаваемого изотонического раствора составляла 25 °C. По результатам исследования, и классическая методика установки цилиндрических дентальных имплантатов, и их инсталляция с применением механотронной системы безопасны при условии соблюдения хирургического протокола и с достаточным объемом подаваемого изотонического раствора.

Ключевые слова: механотронная система, нагревание кости, дентальная имплантация

Вклад авторов: А. В. Иващенко — сбор и анализ клинических данных; В. П. Тлустенко — подготовка клинического материала, систематический анализ; М. А. Постников — сбор и анализ клинических данных; Н. В. Попов — обработка и анализ полученного материала; А. Е. Яблоков — подготовка клинического материала, сбор и анализ клинических данных; В. С. Тлустенко — анализ клинических данных; В. В. Тугушев — подготовка клинического материала; Н. И. Черезова — подготовка клинического материала; А. А. Мухина — подготовка клинического материала. Г. Н. Беланов — систематический анализ.

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Robot-assisted dental implant surgery has become a popular alternative to classic implant placement protocols [1, 2]. The key risk factor for postoperative complications is poor compliance with surgical guidelines for implant placement, resulting in the overheating of the osteotomy site [3, 8]. Heating to over 48 °C causes a thermal burn to stromal dental tissue and protein denaturation. This prevents osseointegration between the implant and the bone and eventually leads to implant failure [4, 11].

The primary cause of an osseous burn during drilling is the wrong choice of the bone cutting and cooling modes (drilling speed >1,200 rpm, saline irrigation rate < 70 ml/min) [5, 9, 10]. During robot-assisted implant placement, saline irrigation must be performed at 100 ml/min. Drill manufacturers (Dentium, Israel; MIS, Israel; etc.) recommend that the maximum number of drill uses during surgery should be limited to 40–45 [12–15]. Discrete irrigation of the surgical field during recipient bed preparation is not allowed in both classic or robot-assisted dental implant surgery [6–8].

The aim of this study was to measure the temperature of osseous tissue at the dental implant site during classic and robot-assisted dental implant placement performed at different cooling modes.

METHODS

The study investigated the response of the alveolar bone to osteotomy and was carried out in 15 Vietnamese pot-bellied pigs. Dental implants used in the study were cylindrical. The recipient bed was prepared by drilling using an optic implant handpiece fixed in the robotic arm; the drilling speed was 800 to 1,500 rpm.

In all 3 experimental groups, irrigation of the osteotomy site was performed according to the guidelines for classic dental implant surgery. Implants were inserted at 30–45 Ncm torque. A total of 30 3.6 × 8.0 mm cylindrical dental implants (Dentium®; Israel) were installed.

The animals were divided into 3 groups based on the drilling speed and the type of surgical instrument (Table 1).

The choice of implant placement sites was based on the similarity between jaw bone density in humans and the animals used in our experiment.

Before proceeding to the main part of the study, we computed the maximum optimal temperature during osteotomy for implant placement in ANSYS 19.2 (Cadferm Company; USA) (see Fig.).

The temperature of the bone matrix during osteotomy was modeled at 3 sites: the site of bur tip/bone contact, in the apical alveolar area of the prepared recipient bed and in the recipient bed immediately after removing the bur.

While modeling the temperature during osteotomy, the pressure of the drill on the bone and drilling time were assumed to be constant.

Our assessments of thermodynamic osseous tissue states confirm that an increase in the drilling speed to 1,500 rpm provokes a proportional rise in t °C to the critical threshold of 60.2 °C, given that other drilling parameters remain unchanged. An increase in the drilling speed to 1,500 rpm results in the maximum temperature gradient rising from 37.6 °C to 60.2 °C (i.e., by 22.6 °C).

Three cooling modes were tested: no irrigation, irrigation with sterile saline at 25–30 ml/min and standard 75 ml/min

irrigation recommended by the standard surgical protocol. The temperature of the isotonic solution was 25 °C.

We also studied the response of porcine mandibular bone tissue to robot-assisted osteotomy using the device proposed in [16]. For the “robotic” part of the experiment, similar cylindrical dental implants (Dentium; Korea) were installed using a Surgic XT Plus unit with an optic implant handpiece (Japan). The following cooling modes were tested: 75 ml/min irrigation with sterile saline recommended by the standard surgical protocol, 30 ml/min irrigation and no irrigation. The temperature of the isotonic solution was 25 °C.

The pilot drill was installed in the optic handpiece; the latter was fixed in the robotic arm. Using the joystick control, the surgeon positioned the drill at the drilling site the preoperative road map. Then, the protocol for automated bone drilling was activated. Once the drilling was finished, the robotic arm retrieved the pilot drill from the mouth cavity and the pilot drill was replaced with the bed formation drill.

Temperature was measured using a Testo 104-ir infrared probe thermometer (Testo AG; Germany). Prior to the experiment, the skeletonized porcine mandible was exposed to distilled water ($t = 45$ °C) for 10 min. The temperature of the osteotomy site before drilling was 36.8 °C.

The majority of the installed implants were in quadrants 3 (6 implants, 60%) and 4 (4 implants, 40%) in group 1; quadrants 3 (7 implants, 70%) and 4 (3 implants, 30%) in group 2; quadrants 3 (5 implants, 50%) and 4 (5 implants, 50%) in group 3.

During the experiment on the mandibular bone tissue of pigs, we took temperature measurements of the bone matrix at the osteotomy site. For the cooling mode 3, the peak temperature was as high as 61.5 °C. For the cooling mode 2, the maximum temperature was 52 °C. The optimal temperature (39.1 °C) was achieved in the cooling mode 1.

Prior to the experiment, the animals' body temperature was taken, showing an average of 38.5 to 39.1 °C.

Table 2 shows the drilling speed, the peak temperature during drilling and the duration of drilling at different cooling modes.

The average temperature at the osteotomy site during recipient bed preparation was 39.1 °C. For our experimental animals, this value was close to normal temperature. Bur temperatures over 60 °C during osteotomy resulted in the peak bone temperature well above the physiological norm.

Table 1. Bone cutting modes during recipient bed preparation

Group	Instrument	Drilling speed, rpm	Number of installed dental implants	Implant sites and number (in brackets)
1	Lindemann guide drill	800	10	3.5 – 2
	Lindemann pilot drill	800		4.6 – 3
	Harvest drill	800		3.6 – 2
	Cortical drill	600		3.2 – 1
	Transfer piece	30–45 Ncm		4.1 – 1
2	Lindemann guide drill	1,200	10	3.3 – 1
	Lindemann pilot drill	1,200		3.4 – 2
	Harvest drill	1,200		4.5 – 1
	Cortical drill	1,000		3.3 – 3
	Transfer piece	30–45 Ncm		3.2 – 1
3	Lindemann guide drill	1,500	10	4.2 – 2
	Lindemann	1,500		3.1 –
	pilot drill	1,500		3.6 – 2
	Harvest drill	1,500		4.2 – 1
	Cortical drill	1,200		4.5 – 3
	Transfer piece	30–45 Ncm		4.6 – 1

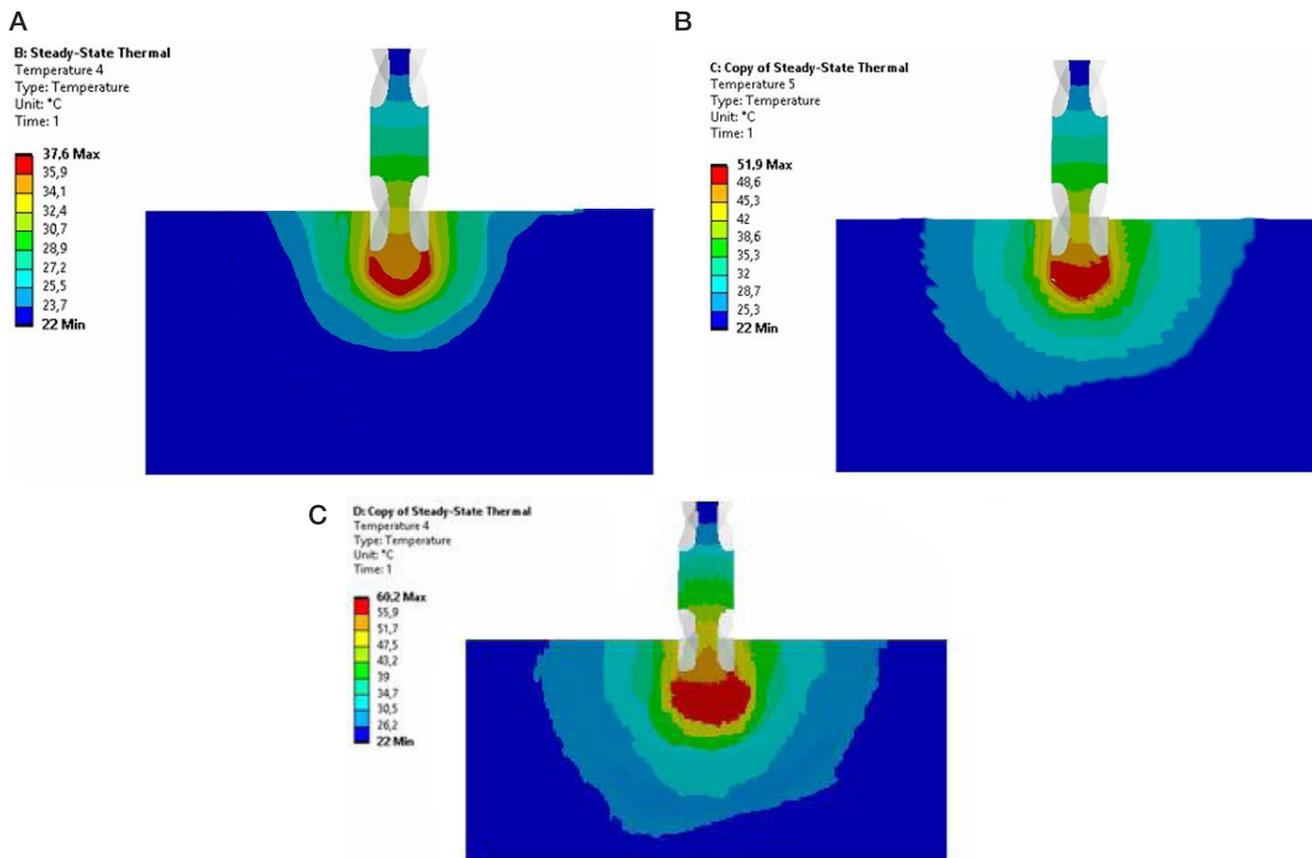


Fig. Modeled temperature during osteotomy for dental implant placement. **A.** Temperature gradient from 22 °C to 37.6 °C (800 rpm). **B.** Temperature gradient from 22 °C to 51.9 °C (1,200 rpm). **C.** Temperature gradient from 22 °C to 60,2 °C (1,500 rpm)

The relative reduction in the rate of negative outcomes in the main vs control groups, i.e relative risk reduction, was 400%. This value, along with the 95% CI, means that the effect is clinically significant (Table 3).

RESULTS

The temperature of the osteotomy site in the mandible rose to 41.3 °C from the initial value of 36.8 °C after 5 seconds of drilling in

Table 2. Peak temperature during osteotomy for dental implant surgery at different cooling modes

Cooling modes	Drilling parameters		
	Drilling speed (rpm)	Bone temperature at the osteotomy site (°C)	Drilling time (s)
Mode 1	800	39.1 ± 0.22	45
Mode 2	1,200	52 ± 0.37	45
Mode 3	1,500	61.5 ± 0.43	45

Table 3. Efficacy of dental implant surgery according to evidence-based medicine criteria

Group	Positive clinical outcome		
	Yes	No	Total
Main	5	0	5
Control	15	0	15
RO	100.00%		
RNO	20.00%		
RR	500.00%		
RRR	400.00%		
CAP	80.00%		
NNT	1.3		
Odds (main group)	-		
Odds (control group)	0.3		
OR	-		

Note: RO — rate of outcomes; RNO — rate of negative outcomes; RR — relative risk; RRR — relative risk reduction; NNT — number of patients that must be treated to prevent 1 negative outcome; OR — odds ratio.

the absence of irrigation during the classic dental implant placement procedure. Irrigation at 30 ml/min during 5 s of drilling resulted in a lower temperature at the recipient bed site (39.4 °C). With irrigation at 75 ml/min, the bone tissue temperature was 36.9 °C.

During recipient bed preparation, which involved bone drilling for 10 s, the bone matrix was heated to 51.5 °C in the absence of irrigation, 43.2 °C at < 30 ml/min irrigation and 39.6 °C at 75 ml/min irrigation recommended by the standard surgical protocol. Heating to over 45 °C causes irreversible changes to bone matrix.

Similar to the classic surgical protocol applied in the first part of the study, the robot-assisted protocol involved placement of cylindrical dental implants in the skeletonized portion of the mandible. The initial temperature of the mandible was close to human body temperature (36.8 °C). In the absence of irrigation, the bone temperature at the osteotomy site rose to 42.4 °C. When irrigation of the osteotomy site was delivered at < 30 ml/min during 5 seconds of bone drilling, the temperature of the osseous tissue at the osteotomy site was 38.2°C. With irrigation at 75 ml/min, the temperature at the osteotomy site was 37.1 °C.

During the preparation of the recipient bed, which involved drilling for 10 s, the bone matrix was heated to 53.9 °C (in the absence of irrigation), 45.7 °C (insufficient irrigation) and 38.9 °C (sufficient irrigation according to the standard surgical protocol).

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DISCUSSION

At present, there is no consensus on the optimal drilling speed. According to early reports, bone temperature rose proportional to the drilling speed [17]. However, later studies revealed that this was true only for the drilling speed of 10,000 rpm [18]. None of the studies revealed any significant changes in the temperature of a human cadaver bone during drilling at 345–2,900 rpm. This means that a temperature rise was dependent on drilling pressure more than on drilling speed. It was demonstrated that low-speed, minimal-pressure drilling of bovine cortical bones caused the same rise in temperature as drilling at higher speed and higher pressure. It is high drilling speed and pressure that allow osteotomy to be performed effectively [19]. At drilling speed below 250 rpm, bone tissue gets fragmented at the edge of the defect.

CONCLUSIONS

The analysis of osseous tissue thermometry data obtained during osteotomy for the subsequent placement of cylindrical dental implants revealed that both classic and robot-assisted dental implant placement techniques can be recommended for clinical use and are safe if there is sufficient irrigation and good compliance with the surgical protocol.

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