Use of infrared thermography to control osteoreparative and integrative processes during implantation in animals

A V Krasnikov and E S Krasnikova

FSBEI HE "Michurinsk State Agrarian University", 101 Internationalnaya Street, Michurinsk, Tambov region, Russia

E-mail: krasnikovaes77@yandex.ru

Abstract. Thermography is an integral indicator which is formed by means such factors as the vasculature and the level of tissue metabolism. Infrared thermal imaging can be a tool for assessing the safety and effectiveness of implantation in bone tissue using various materials. The aim of the study was a comprehensive assessment of osteoreparative and integrative processes using thermography when implantation in dogs. The research objects were clinically healthy outbred dogs (n=16) at the age of 1 year and a live weight of 10-12 kg. Experimental implants coated with titanium dioxide had on their surface a polymer film of polyazolidinammonium modified with halogen hydrate ions with nanoaggregates of flavonoids according to the original author's technique (Patent No. 2535067). Similar implants without coating were used as a control. According to the results of x-ray studies in the early and long-term after surgery, there were no foci of bone resorption in the peri-implant zone. Thermography showed a difference in temperature values in the peri-implant zone of experimental and control samples reaching 2°C during 1-4 weeks after implantation. On day 32, the temperature indicators for control and experimental samples were stabilized. Consequently, osteoreparative and integrative processes when using implants with author's coating are accompanied by significantly less metabolic stress for the animal's body, which was established using infrared thermography.

1. Introduction

Thermography is based on the use of special devices for detection and measurement of thermal infrared (IR) radiation. IR radiation is visualized in the form of a thermogram that reflects distribution of the thermal radiation on the surface of the controlled object. Since thermogram not only relays the object temperature, but also is an integral indicator which is formed by means such factors as the vasculature and the level of tissue metabolism, in recent years, IR thermography or thermal imaging has been widely used in biology. Infrared thermal imaging enables to perform a comparative physiological assessment of various processes, including thermogenesis, peripheral blood flow adjustments, evaporative cooling, and to respiratory physiology [1]. Measuring thermal imagers (IR radiometers) make it possible to measure the temperature remotely and quickly at many points of the analyzed object, while the number of points can exceed a million. Thermography is a non-invasive express method for the diagnosis of inflammatory processes, including in animals [2], techniques for measuring respiration in biomedical research and in clinical settings [3], a tool for assessing the safety and effectiveness of implantation in bone tissue using various materials [4].
In veterinary medicine, implantation in bone tissue is widely used in osteosynthesis. And recently the problem of dental implants has become urgent, especially in dogs [5]. Methods of experimental and clinical assessment of the dynamics of osteoreparative and integrative processes during implantation have a number of disadvantages. They are either quite invasive (cytological, histological), or do not give an opportunity to judge about the intensity of metabolic processes (computer capillaroscopy), or are indirect and mediated by many other factors (hematological, biochemical and cytokine status). Currently, radiography is a non-invasive method for monitoring of bone tissue microarchitectonics [5]. At the same time, local hemodynamic changes at the microvasculature level, leading to the mucous membranes temperature variances, is an important integral indicator of the local metabolism status. Thermal imaging renders it possible to judge objectively hemodynamics and the tissue metabolism status without invasive interventions [1]. This type of diagnosis not only makes it possible to analyze functional changes in dynamics, but also allows us to specify the localization and nature of functional changes, the activity of the process and its prevalence.

The aim of our study was a comprehensive assessment of osteoreparative and integrative processes using thermography when implantation in dogs.

2. Materials and methods
The research objects were clinically healthy outbred dogs (n=16) at the age of 1 year and a live weight of 10-12 kg. Comparative dynamics of reparative osteogenesis was studied when experimental cylindrical implants with a diameter of 3.5 mm and a length of 10 mm with a screw groove were installed in the jaws of dogs. Induction-heat treatment of implants surface was conducted by heating with high frequency currents at the temperature of 800 ± 10°C for 2 min. Then the implant surface was cooled to form a titanium dioxide bioceramic coating and apply a polymer film (polyazolidinammonium modified with hydrate ions of halogens with flavonoid nanoaggregates) according to the original author's method (Patent no.2535067). Similar implants with a bioceramic coating were used as a control, but without the polymer film developed by the author, which has antiseptic, adaptogenic and regenerating properties. Premolars were removed in experimental dogs with neuroleptanalgesia, and then control and experimental implants were installed simultaneously using a dynamometer key, without covering the extra-osteal part with a mucous membrane. Post-surgical therapy consisted of a standard veterinary procedure. All experimental studies were performed in accordance with GOST ISO 10993-1-2011.

Radiographic control of the ostointegration process in dogs' jaws peri-implantant tissues was performed on a digital x-ray machine "Vatel 1" with an x-ray tube Toshiba D-124. To avoid layering of underlying tissues, x-rays were directed at an angle of 45° to the studding object, in addition to standard positions. The visualized thermal field was studied using the Flir SC3000 Quantum Well Infrared Photodetector (USA). Processing of the mucosal surface infrared radiation was carried out through the ThermoCAM Researcher HS software package at a frame rate of up to 750 Hz for the PAL standard and up to 900 Hz for the NTSC standard, which provide analysis of dynamic objects and processes.

3. Results
According to the results of x-ray studies in the early - 1, 3, 7, 21, 28 day and long-term - 2, 6, 12, 19 months after surgery, there were no foci of bone resorption in the peri-implant zone (figure 1).

As it shown in figure 1, radiography allowed us to track the dynamics of bone architectonics, visually expressed in a gradual increase in its density and the absence of resorption foci in the implantation zone, which is a marker of successful ostointegration of both control and experimental implants. However, these data do not allow us to judge about the character of biological processes in the tissue and do not give an opportunity to make a comparative assessment of osteoreparative and integrative processes for control and experimental samples. Thermal imaging, as a method of
visualization of thermal radiation, can be successfully used for an objective assessment of reparative processes.

Before the implants were installed, the temperature difference between the surrounding tissues of the proposed implant sites was 0.2°C at absolute values of 30.6°C and 30.8°C. The results of thermal imaging diagnostics of the implantation zone of the control and experimental samples at 1 day after surgery showed that the difference in temperature values of the gingival areas near the control and experimental samples was insignificant and amounted to 0.1°C with absolute values of 31.5°C near the experimental and 31.6°C near the control samples. During the first week of the experiment, the temperature difference increased. The peak temperature difference was registered on the 9th day of the experiment, it amounted to 2.0°C with absolute values of 33.4°C near the experimental and 35.4°C near the control samples. From 9 to 18 days of the experiment, the temperature values decreased in the peri-implantant zone of control and experimental samples, and then, from 18 to 25 days, the temperature values increased. However, the difference between them remained within 0.7°C (figure 2).

A gradual decrease in the temperature difference between the control and experimental zones occurred from 25 to 32 days and at the end of the experiment was 0.1°C with absolute values of 33.3°C near the experimental and 33.4°C near the control samples (figure 3).
Figure 3. The dynamics of the temperature values.

As it follows from the presented in figure 3 thermography data, observed in the first week local increase of mucosal surface temperature in the peri-implantant zones, may be a marker of the inflammatory process due to mechanical trauma and penetration of heterogeneous material into the tissues. Moreover, in the area where the experimental implants were installed, the temperature curve was smooth and less expressed compared to the control, where it had the form of a peak. In addition, the obtained using thermography data showed a difference in temperature values in the peri-implantant zone of experimental and control samples reaching 2°C, which allows us to judge about implants biocompatibility. A gradual decrease in temperature of the peri-implantant zone indicates a weakening of the inflammatory response and stabilization of local homeostasis. Then, the temperature curve again relays an increase in metabolic processes in the peri-implantation zone tissues, which can be a marker of active biointegrative processes. On day 32, the temperature indicators for control and experimental samples were stabilized. Consequently, osteoreparative and integrative processes when using implants containing of polyazolidinammonium modified with hydrate ions of halogens with flavonoid nanoaggregates on their surface are accompanied by significantly less metabolic stress for the animal's body, which was established using infrared thermography.

4. Conclusion
Thus, our data indicate that, despite the high biocompatibility both of experimental and control samples, qualitative and quantitative differences in thermograms, corresponding to the characteristics of implant coatings, were established. Therefore, the thermal imaging method is effective for studying the response of tissues to implantation materials, which makes it possible to recommend thermography as a non-invasive method for dynamic and comparative analysis of osteoreparative and integrative processes during implantation in animals.

References
[1] Tattersall G J 2016 Infrared thermography: A non-invasive window into thermal physiology Comp Biochem Physiol A Mol Integr Physiol 202 78-98
[2] Shecaira C L, Seino C H, Bombardelli J A, Reis G A, Fusada E J, Azedo M R and Benesi F J 2018 Using thermography as a diagnostic tool for omphalitis on newborn calves J Therm Biol 71 209-11
[3] Mutlu K, Rabell J E, Martin Del Olmo P and Haesler S 2018 IR thermography-based
monitoring of respiration phase without image segmentation J Neurosci Methods 301 1-8

[4] Scarano A, Lorusso F and Noumbissi S 2020 Infrared Thermographic Evaluation of Temperature Modifications Induced during Implant Site Preparation with Steel vs. Zirconia Implant Drill J Clin Med 9(1) pii: E148

[5] Krasnikov A V, Annikov V V, Fomin A A, Zajarskiy D A, Kapustin R F and Morozova D D 2014 Morfofunction justification implants from titanium dioxide modified flavonoids nanounits Annals of Anatomy (Anatomischer Anzeiger) Beijing 196(1) 270

[6] Morozova D D, Krasnikov A V, Annikov V V and Krasnikova E S 2019 Osteodensimetric indicators of dogs’ mandible during deciduous teeth change period IOP Conf. Series: Earth and Environmental Science 315 042030