DENTAL MEDICINE **ORIGINAL PAPERS**

THE VALUE OF IMAGING INVESTIGATION IN DESIGNING OF AN EXPERIMENTAL STUDY OF BONE TISSUE DYNAMICS IN ORTHODONTIC MINI-IMPLANTS

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A SHORT HISTORY OF THE HISTOLOGICAL PROCESSING TECHNIQUES FOR TOOTH AND SUPPORTING HARD TISSUES (Abstract): **Background and aim**: Mini-implants play an important role in orthodontic treatment. However, the mechanism of bone remodeling associated with these orthodontic devices is not yet fully elucidated. The research focusing on the dynamics of biological changes at the implant site frequently involves experimental animal models. Our study aims to evaluate, by imaging methods, the success rate of implantation process of orthodontic mini-implants, using an original experimental model for the study of tissue biological responses present at the bone – mini-implant interface. **Materials and methods**: The study was conducted on adult male Sprague Dawley rats divided into 9 groups of 6 rats (G1 – G9) in which two mini-implants were surgically implanted in the right tibia. Two rats in each group also acted as controls by inserting a mini-implant in the left tibia without force. After implantation, traction forces were applied between the two mini-implants with closed NiTi helical orthodontic springs. Springs were extended at 2.2 cm, generating a force of 100 gf (G1, G4, G7); at 1.4 cm, the force generated was 75 gf (G2, G5, G8); at 1.2 cm, the force generated was 50 gf (G3, G6, G9). Animals were sacrificed at 7 days (G1, G2, G3), 21 days (G4, G5, G6), and 42 days (G7, G8, G9) from implantation. On the day of harvesting, each rat was examined radiologically by Spectral AMI HTX, Spectral Instruments. **Results**: The overall mini-implant success rate was 94.1%. In 5.9% of the subjects, either distal implant fracture with spring detensioning or distal implant detachment was observed. In control mini-implants, without spring, the overall success rate was 100%. **Conclusions:** Imaging exams are valuable tools for analyzing bone remodeling, density, and in vivo structure of bone tissue. Our study confirms the effectiveness of imaging examination in verifying the stability of the implantation stage, as a mandatory step in the subsequent evaluation of morphological changes in peri-implant bone tissue.
Keywords: MINI-IMPLANT, EXPERIMENTAL STUDY, BONE TUSSUE, RADIOLOGIC EXAM, SUCCES RATE.

INTRODUCTION

Advances in orthodontic practice are directly related to basic and clinical research focused on oral tissue morphology and craniofacial biomechanics (1-3). The basic principle of orthodontic treatment consists in the application of directed orthodontic forces to the teeth, resulting in concomitant remodeling of periodontal ligament and alveolar bone. The review of the literature underwrites several aspects of tissue transformation in the presence of force application (4). Another line of orthodontic research concerns the relationship between bone resorption associated with orthodontic movement and systemic medication (5).

Mini-implants play an important role in orthodontic treatment. The use of mini-implants is based on the development of implantation techniques because of the optimization of dental procedures, imaging studies of the oro-dental region and implant characteristics (design, biocompatibility). Mini-implants are an increasingly used treatment option, mainly motivated by the significant potential to shorten treatment (6). Through their action, they provide skeletal anchorage and prevent unwanted tooth movement. A major advantage is that no healing period is required after implantation, allowing immediate loading (7).

Although their use is on an upward trend and the clinical benefits are evident, the mechanism of bone remodeling associated with these orthodontic devices is not yet fully elucidated (4). This is mainly due to the difficulty in assessing the dynamics of positive and negative biological changes at the implant site. Consequently, translating the analysis of changes in the anatomical structures involved from the clinical, macroscopic level to the cellular and molecular level is a challenge for orthodontic research (8). For this purpose, specialist groups in the field are constantly using in vitro models and systems.

However, there are also opinions advocating the use of experimental animal models, which are superior as a possibility to test the efficacy and safety of application procedures - although the difficulties of extrapolating results to humans must be considered (9). In experimental studies, to complete the overall picture of bone tissue dynamics at the implant site, advanced imaging techniques can provide important information about the bone remodeling and evolution of treatment process. Nevertheless, the bone response is individualized, depending on several specific factors. Therefore, the design of an experimental study gains, in the relationship between methodology complexity and results consistency, by including an imaging assessment step.

Within this general context of knowledge, our study aims to evaluate, by imaging methods, the success rate of implantation process of orthodontic mini-implants, using an original experimental model for the study of tissue biological responses present at the bone – mini-implant interface.

MATERIALS AND METHODS

The study was conducted on 28-week-old adult male Sprague Dawley rats weighing between 340 g and 450 g, provided by the National Institute for Medical and Military Research and Development “Cantacuzino” (Bucharest, Romania). The ethical aspects of the research were strictly respected in accordance with the European Directive 2010/63/EU on the Protection of Animals used for Scientific Purposes, the European Convention for the Protection of Vertebrate Animals used for Experimental and Scientific Purposes (Council of Europe No. 123, Strasbourg, 1985), and the guidelines established by the National Animal Welfare Authority (approval no. 64/12.09.2023). The study protocol was approved by the University's Research Ethics Committee (approval no. 59/ 23.03.2021).

The experiment was conducted over a period of 6 weeks. The experimental animals were divided into 9 groups of 6 rats (G1 – G9) in which two mini-implants were surgically implanted in the right tibia. Two rats in each group also acted as controls by inserting a mini-implant in the left tibia without force.

The type of mini-implant used was Dual Top Anchor System screws, diameter 1.3 mm, and length 5 mm, made of titanium alloy. After implantation, traction forces were applied between the two mini-implants with closed NiTi helical orthodontic springs, size: 0.008 x 6 mm, this type of springs generating continuous forces.

The forces were determined using the Sauter Digital Force Gauge FH 10, and the resulting distances were 1.2 cm, 1.4 cm, 2.2 cm. Thus, the spring extended to a distance of 1.2 cm generated a force of 50 gf on the mini-implant; at a distance of 1.4 cm, the force generated was 75 gf; at a distance of 2.2 cm, the force generated was 100 gf. Groups G1, G4, G7 were loaded with 100 gf, groups G2, G5, G8 with 75 gf, and groups G3, G6, G9 with 50 gf.

The animals were sacrificed as follows: after 7 days from implantation for groups G1, G2, G3, at 21 days - for groups G4, G5, G6, and after 42 days - groups G7, G8, G9.

On the day of harvesting, each rat was examined radiologically. Radiological exam was performed using Spectral AMI HTX, Spectral Instruments, with the animals in lateral or dorsal recumbence. A medio-lateral or cranio-caudal radiograph of the hind limb was taken for each subject, focusing on the tibial region.

RESULTS

In G1, two subjects showed a misalignment between the two implants, with a normal position of the spring. All subjects had stable implants and no bone lesions were visible.

In G2 only one subject showed misalignment of the two implants, with a straight position of the spring. None of the subjects showed dislodgement of the implant or visible bone lesions.

In G3, only one subject revealed misalignment of between the two implants, with a normal position of the spring. There were no displacement or bone lesions visible in any of the subjects.

In G4 all subjects revealed stable implants with normal position of the springs. No bone lesions were detected in any subject.

In G5, only one subject showed misalignment of the two implants (fig. 1A), with a normal position of the spring. The implants were stable in all subjects and no bone lesions were detected on radiography.

In G6, all implants were stable except one subject. In one subject the distal implant was dislodged, and the spring was unstressed and curved (fig. 1B).

In G7, all subjects except one subject had a correct position of the implant without visible bone lesions (fig. 1C). The affected subject revealed a tibial fracture with displacement at the insertion point of the distal implant (fig. 1D).

In G8, in one subject the implants were not aligned in the same plane however, but the spring was not rotated, and the implants were stable. There were no abnormalities found in the rest of the subjects.

In G9, a mild misalignment between the implants was detected by radiography, with a normal position of the spring in two subjects. In one patient, a tibial fracture with displacement at the point of insertion of the distal implant was visible.

The overall mini-implant success rate was 94.1%. In 5.9% of subjects, either distal implant fracture with spring detensioning or distal implant detachment was observed. In control mini-implants, without spring, the overall success rate was 100%.

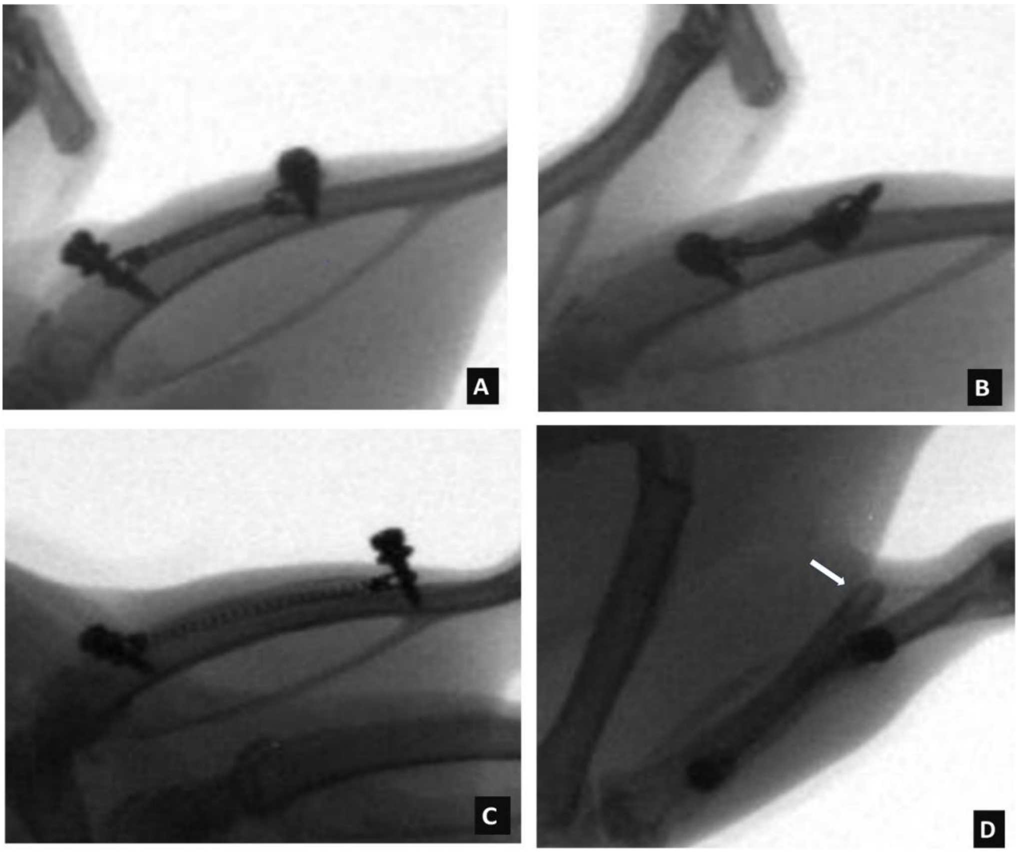

Fig. 1. Radiological images of the hind limb in medio-lateral view in subjects with implants: A. Incorrect alignment of the two implants, but with normal arch position;
B. Distal implant dislocation and arch de;
C. Tibia with implants in normal position and arch under tension;
D. Tibia fracture with displacement, at the distal implant focus;

DISCUSSION

In experimental studies aimed at evaluating orthodontic mini-implants, the use of radiological investigations is relevant both to provide complementary information to other types of examinations (e.g. histological or histomorphometric examinations) and as a single method of analysis (10).

An eloquent example of the value of radiographic examination is the study conducted by the team coordinated by Dhaliwal, which aimed to investigate the osseointegration of mini-implants using histomorphometric analysis. However, after mini-implant placement and suturing, the authors performed radiographs to confirm proper placement of the mini-implants and to observe any bone fractures in the rabbit tibia (10).

Micro-computed tomography (micro-CT) is indicated for further experimental research on the efficacy of mini-implants, as the information on the morphology, structure and density of peri-implant bone tissue is superior to other types of radiological investigations. An experimental study aimed at identifying mini-implant movements in bone and observing the bone remodeling pattern proposes a new experimental animal model, in which mini-implants are inserted into vertebrae, in rats (11). Using micro-CT, the authors recorded volumetric images from the same animal at different times, thus accumulating information on the movements of the mini-implants under the action of orthodontic forces and the changes occurring in the bone structure (11). The results revealed that the mini-implant movements are accompanied by a thickening of the bone, especially in the direction of force loading, which led to a decrease in the mini-implant movement during the experiment (11).

Imaging assessment can also be performed using cone beam computed tomography (CBCT). Recent research in an experimental canine model investigated the role of orthodontic mini-implant placement at different times after lateral incisor extraction (12). The study examined the development of alveolar ridge height, width, and density of the maxillary bone by histological, histomorphometric and imaging analysis. CBCT results showed that mini-implants placed immediately after extraction retained greater alveolar ridge height than mini-implants placed at 6 weeks or in the absence of implant placement (12). Bone density was higher with implants, regardless of when they were placed, compared to bone density in the post-extraction zone without implants (12). Insertion of mini-implants had a positive outcome, preserving post-extraction socket height, increasing bone density and stimulating new bone formation compared to the control area (12).

Not only bone remodeling, bone density or verification of the position of the mini-implant in the bone has been analyzed with radiological studies. Another line of research aimed to assess stability according to the insertion angle of the mini-implant (13). Micro-CT examination of the bone-implant contact area and correlation with the pull-out test showed that stability is influenced by the amount of bone tissue around the mini-implant (13). The obtained data indicated that a maximum amount of bone, i.e. increased stability, can be achieved by inserting the mini-implant at angles between 50° and 70° (1).

The analysis of our results suggests that post-implant fractures, as well as implant dislocation and arch stress relief, occurred because of external factors – namely manipulation or trauma. This assumption is supported by the fact that in most animals the implants remained stable throughout the experiment, without inducing bone damage or dislocation of the implanted system. In addition, all subjects with complications showed a fracture focus at the distal point of implant insertion, an area where the tibial bone diameter is smaller – which may be explained by reduced bone strength rather than secondary to post-implant osteolysis-type injuries.

CONCLUSIONS

Experimental orthodontic research has the major objective of optimizing orthodontic treatments and increasing the success rate. Imaging exams are valuable tools for analyzing bone remodeling, density, and in vivo structure of bone tissue. Their use, in parallel with histological examination, allows a reduction in the number of animals that will ultimately be sacrificed. Our study confirms the effectiveness of imaging examination in verifying the stability of the implantation stage, as a mandatory step in the subsequent evaluation of morphological changes in peri-implant bone tissue.

CONFLICT OF INTEREST AND FUNDING

The authors declare that there is no conflict of interest, and they received no specific funding regarding this scientific research.

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