

CLINICAL RESULTS OF BONE TISSUE INTEGRATION INTO ADDITIVELY MANUFACTURED DENTAL IMPLANT SAMPLES

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Annotation :

Additive manufacturing technologies for metal structures using laser sintering are an accessible and advanced method for producing high-resolution products with a variety of three-dimensional forms. This advantage is widely used in medicine, particularly in dentistry. In this study, we used samples of the trabecular implant walls (Cell), manufactured from titanium powder (Grade 4), which were implanted in experimental animals and explanted for histological examination at 30, 60, and 90 days.

The surface of the samples, in addition to macroporosity, was treated using the SLA technique, which additionally created large-scale micro- and nano-roughness that enhances the process of osseointegration. Osteoblasts (MG63 cells) demonstrated high activity in interaction with the implant samples, which subsequently resulted in bone tissue ingrowth and full integration into the thickness of the experimental sample wall.

Keywords:

Osseointegration, morphological aspects of the implant–bone interface, implant, osseointegration, morphological aspects of the implant-bone interface
implant

Purpose:

To investigate the features of the biological interaction of bone structures with additively manufactured three-dimensional titanium structures under clinical conditions.

Objectives:

1. To determine the aspects of biological compatibility of bone structures with additively manufactured three-dimensional titanium structures.
2. To investigate the possibilities and quality of bone tissue integration into the thickness of three-dimensional titanium samples.
3. To determine the timelines of proliferation and maturation of bone structures on the surface of the experimental samples..

Materials and Methods:

For the experiment, 8 sexually mature laboratory rabbits of the California breed were selected. Under aseptic clinical conditions and general anesthesia with Telazol (100 mg diluted in 10 ml of 0.9% NaCl solution), one implant sample was placed into the tibia of each hind leg of every experimental animal. Additionally, local infiltration anesthesia with 4% articaine hydrochloride solution was used. The study was conducted in accordance with the necessary regulatory acts (the 2000 Helsinki Declaration on the humane treatment of animals and the “Rules for Conducting Work with Experimental Animals”).

The experiment used fragments of dental implant bodies, totaling 16 units, made from Grade 4 titanium. The surface of the samples featured a micro- and nano-relief topography obtained through sandblasting with aluminum oxide (creating pores 20–40 microns in size) followed by a double acid-etching process at different temperatures (resulting in micropores 1–5 microns in size) at the manufacturer’s facility (Fig. 1).

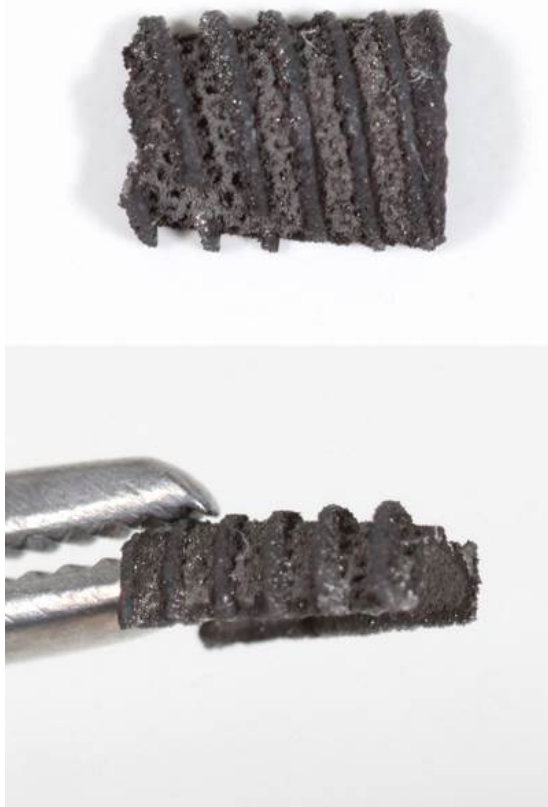


Fig. 1. Fragment of a titanium implant.

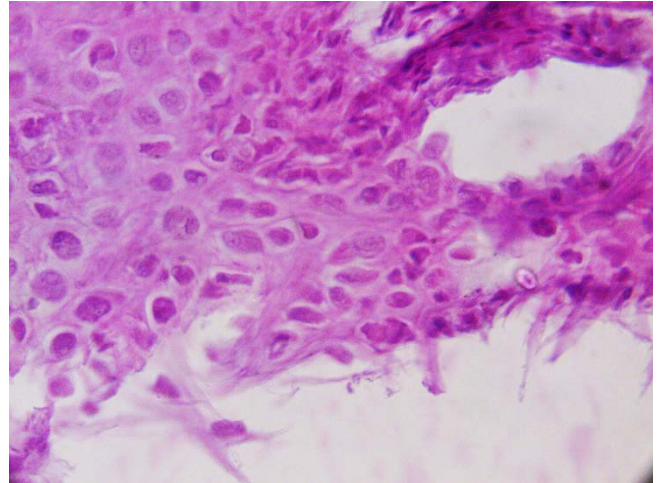
The results of osseointegration were evaluated using morphological studies. Macroscopic specimens were examined after sawing the bone into blocks on the 30th, 60th, and 90th day after implantation. After appropriate fixation in 12% neutral formalin, the bone specimens were treated with 0.4% hydrofluoric acid to dissolve the titanium, followed by decalcification with orthophosphoric acid. Sections were prepared and stained with hematoxylin and eosin, as well as with picrofuchsin according to Van Gieson's method.

Results of the Study:

Histological studies conducted one month after implantation show the formation of a fibrous capsule around the implant, combined with the development of new bone trabeculae. The dense fibrous capsule is lined with a thin epithelial layer. The connective tissue layer between the implant and the bone is of medium width, containing a moderate number of cellular elements, mainly fibroblasts with well-developed fibrillar structures. The protein substrate is primarily

represented by cells exhibiting morphological features of mesenchymal stem cells and osteoblasts (Fig. 2).

Fig. 2. Histological specimen of bone tissue on the 30th day after implantation. Hematoxylin and eosin staining.



In all samples from this observation period, collagen fibers forming bundles with areas of loosening were present, with numerous contact points to the implant surface. A thin fibrous capsule separated the implant from the spongy native bone. Microscopy of the samples during this period revealed individual osteogenic stromal progenitor cells on the metal surface, with ectoplasmic projections.

On the 60th day of the study, the histological picture was characterized by the remodeling of structures around the implant. Cellular structures were observed to be “spread out” on the metal surface, with ectoplasmic projections of osteogenic stromal progenitor cells of the bone marrow anchored to existing irregularities within the channels and openings of the spongy structure of the titanium implants. The presence of osteogenic differentiating cells on the surface of the implants was noted (Fig. 3).

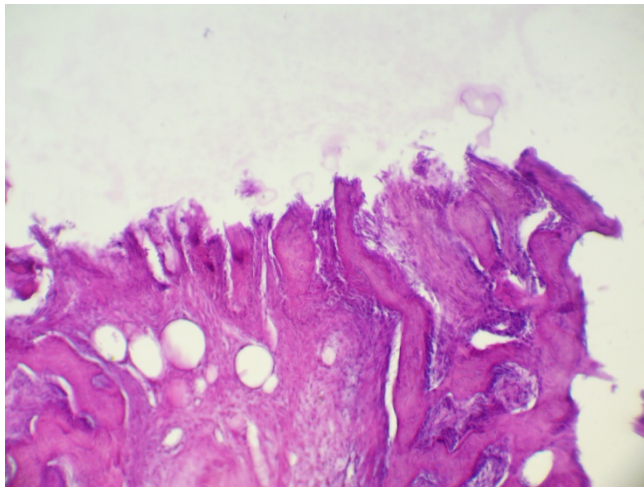


Fig. 3. Histological specimen of bone tissue on the 60th day after implantation. Hematoxylin and eosin staining.

This period is characterized by the presence of bone “bridges” between the main native bone and the connective tissue located in the implant openings, indicating bone growth into the thickness of the titanium structure and the presence of a chemical bond between the titanium and the structures of the newly formed tissue. A gradual replacement of connective tissue elements with bone tissue was observed (Fig. 4).

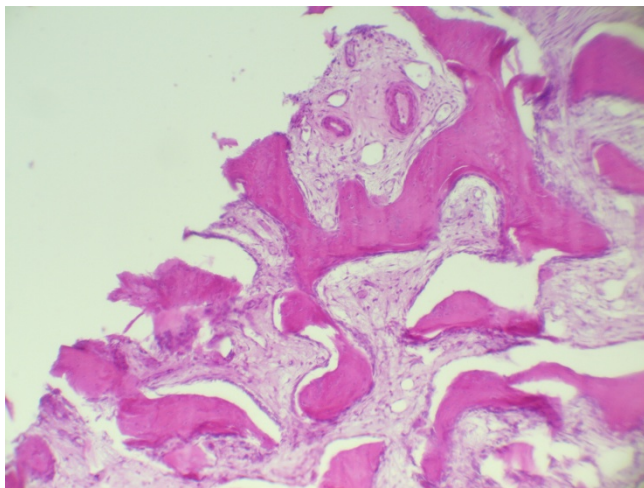


Fig. 4. Histological specimen of bone tissue on the 60th day after implantation. Hematoxylin and eosin staining.

Three months after implant placement, histological specimens showed no connective tissue layer between the implant and the bone. Fully developed bone osteons located within the implant body exhibited complete blood supply through a finely branched vascular network. The metal was in close contact with mature compact bone tissue. A distinct “bonding” line between the structures was observed. The number of immature

bone trabeculae had significantly decreased. Numerous bonding lines indicated the gradual layering of newly formed bone tissue. The bone tissue was mature and compact. There was clear evidence of the reliable integration of lamellar native bone tissue with the implant surface (Fig. 5).

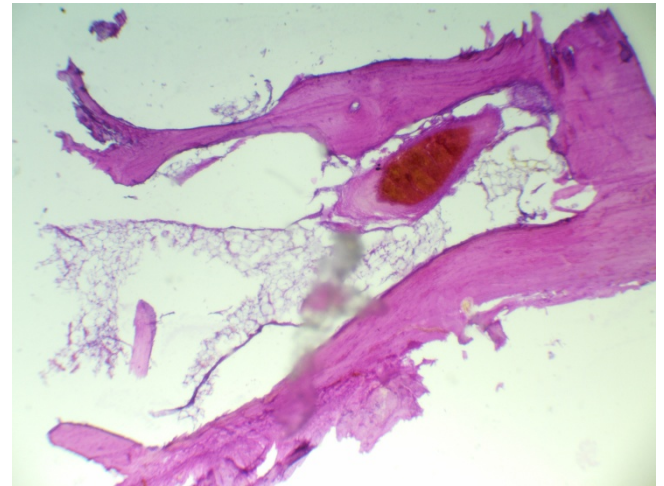


Fig. 5. Histological specimen of bone tissue on the 90th day after implantation. Hematoxylin and eosin staining.

Conclusions:

1. The study demonstrates that additively manufactured three-dimensional titanium structures exhibit a high level of biological compatibility, which creates prospects for the broader implementation of additive implants in medical practice.
2. The in vivo experiment demonstrated the possibility of complete organic integration with the subsequent stable presence of bone structures not only on the surface but also within the micro-openings and grooves of the body of the printed titanium implant, indicating a significant increase in bone-to-implant contact.
3. Based on the histological data, the hypothesis was substantiated that the period of osseointegration during the stages of surgical treatment can be reduced due to the penetration of bone structures into the thickness of the implant.

Summary:

Additive manufacturing technology is rapidly gaining popularity among dental implant developers due to its design flexibility, which allows for the creation of both customized implant structures for each patient and previously inaccessible shapes and micro-architecture of implants. In this article, the biological properties and features of osseointegration into three-dimensional titanium fragments of dental implants *in vivo* are thoroughly examined and presented in detail, with a description of the morphological picture of the reparative process in living tissues, providing a foundation for further research into the potential applications of titanium implants manufactured using additive technology.

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