INTRODUCING CUTTING-EDGE ADVANCEMENTS IN 3D PRINTED CUSTOMIZED PROSTHESES FOR VERTEBRAL REPLACEMENT: INNOVATIVE ANTIBACTERIAL, BIOMIMETIC, AND NANOSTRUCTURED COATINGS

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INTRODUCTION

In spine surgery the vertebral body replacement represent one of the most highly challenging, complicate and invasive procedure which carries a significant complications rate. Among these complications, surgical site infections pose a particularly critical and arduous challenge to treat. Additionally, issues such as poor bone regeneration and mechanical instability are closely linked to infections. To address these concerns, a personalized vertebral prostheses was implemented through the optimization of implant architecture by means 3D modeling and additive manufacturing technologies. This prostheses will also incorporate a nanostructured antibacterial coatings made of silver to prevent infections, and bone apatite to improve bone regeneration.

METHODS

Significant efforts were invested in the development of a personalized 3D-printed vertebra prosthesis, focusing on optimizing its design and manufacturing process. Additionally, the application of nanostructured and biomimetic coatings, possessing antibacterial and osteointegrative properties, was pursued using Ionized Jet Deposition technique. Comprehensive in vitro and in vivo studies were conducted using representative preclinical models, encompassing cytotoxicity, bioactivity and microbiological investigations. As a concluding phase, a study on large animal models was designed to evaluate the feasibility of device realization, the maintenance of all the features optimized and developed during the Project, the safety and the actual performance in a preclinical model which was closer to patient dimension. For these reasons in four adult crossbred sheep, prostehsis properly customized were implanted at the cervical level (C4) after authorization obtained from the Italian Ministry of Health (No. 932/2021-PR). Comprehensive investigations, including histological analysis, histomorphometric assessments, and microtomographic examinations, were conducted after 4 months to explore the biocompatibility of the prosthesis and its capability to regenerate bone in the specific in vivo model. These investigations aimed to evaluate the compatibility of the newly developed approach with the living tissue, as well as to determine its effectiveness in promoting bone regeneration.

RESULTS

The optimization of the device led to the selection of a gyroid-deformed structure (porosity of 90% and principal pore size of 1.3 x 2.6 mm) and the results obtained from the physico-chemical investigations demonstrated that the realized coatings possessed a nanostructured surface morphology and a homogeneous distribution of the main elements. The coatings demonstrated excellent biocompatibility, as evidenced by their non-cytotoxic properties and positive effects on the viability, proliferation, adhesion, and differentiation of primary human osteoblasts. Macroscopic, microtomographic, and microscopic analyses conducted on the final device revealed the presence of newly formed bone tissue, associated with endochondral ossification, even within the porosities of the prosthesis. The peripheral area of the coated samples exhibited complete osseointegration, including the silver component. Remarkably, the innermost porosity of the prosthesis was also colonized by bone tissue, despite the short experimental timeframe. Within the vertebra, the presence of newly formed bone tissue was detected, characterized by the presence of osteoid matrix and osteoblasts, indicating active deposition activity stimulated by the biogenic apatite component of the coating.

DISCUSSION

The *in vivo* model of the vertebral implant incorporated various elements developed throughout the project. These included the meticulous study and design of a device with optimized geometric and structural characteristics. The device was further enhanced by the application of a combined coating, which exhibited remarkable osseointegration and bone regenerative capabilities, along with promising antibacterial properties.

SIGNIFICANCE/CLINICAL RELEVANCE: These achievements represent a significant advancement in the field and offer a viable approach to broaden the range of surgical options available to patients.

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