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Application of a hybrid additive manufacturing methodology to produce a metal/polymer customized dental implant

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Abstract

In this paper an integrated methodology for implants personalized manufacturing is presented. This methodology materializes the hybrid material implants manufacturing through the integration of two or more advanced Additive Manufacturing (AM) technologies. Furthermore, high strength biomechanical implants with optimized geometry and mass can be manufactured by biomimetic concepts application. The combination of polymers and ceramics or polymers and metal materials (or metal alloys) allows a significant leap in the development and production of a great diversity of components and applications. The combination of advanced additive manufacturing processes, e.g. the Selective Laser Melting (SLM) or Selective Laser Sintering (SLS) and the StereoLithography (SL), make possible the production of parts with almost unlimited geometric freedom and custom multimaterial. The manufacturing flexibility and the processing capacity of the different combinations of materials - metal/polymer - obtained from hybrid additive manufacturing systems - SLM/SL - are demonstrated here by the manufacture of a dental bridge implant.

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1. Introduction

The prevalence of edentulism is considered an index that, although coarse, indicates the quality of oral health of a significant segment of the population [1]. Fixed prosthesis has been a commonly adopted solution to solve this problem. However, the oral rehabilitation of edentulous patients, through the use of fixed total prostheses, involves previous reconstructive procedures, which may include soft tissue problems, instability of the removable prosthesis, papillary hyperplasia - "denture callus", poor tissue tolerance and functional, aesthetic and psychological problems [2]. These limitations have led to a growing demand for alternative approaches such as implant prostheses or the placement of bone integrated implants, which has made dental implantation a widely accepted and widespread therapeutic approach in dentistry. However, a significant number of patients, whether due to single or multiple tooth loss, a process of osteolysis, or genetic factors, presents mandibular or maxillary bone atrophy, that is, it does not present a sufficient bone thickness for implant placement [3].

The combination of additive manufacturing technologies and new designs inspired in algorithms that mimic patterns, e.g. Voronoi patterns, provides new ways of thinking about form, material behavior, structure performance, geometry optimization, etc [4-7]. Furthermore, new hybrid material components, e.g. metal/polymer, besides size and mass component decrease, allow for enhanced mechanical properties, improved application reliability and multifunctional features. Due to their high performance, hybrid material parts are increasingly sought in several markets such as electronics, aeronautics, automotive, among others. However, the current supply of these types of components is low since a hybrid additive manufacturing approach is required.

Concerning the health area, bone replacement customized implants is a very important application, where hybrid material manufacturing parts have had a high demand growth, in particular, permanent and/or temporary medical implants with mechanical properties identical to bone. The development of both new hybrid materials and hybrid manufacturing processes, which lead to implants that satisfy biocompatibility, mechanical, and structural behaviors, customized geometry, comfort and aesthetic needs, appears as an innovation. This integrated strategy will contribute to reduce recovery times, reduce symptoms and improve functional capacity, which translates into a significant impact on the quality of life of medical interventions. With these purposes and in order to find an alternative solution for edentulism problems, a procedure to develop and manufacture customized, less costly and suitable dental implants, avoiding an initial surgery and allowing immediate intervention, is presented in this paper. This procedure, apart from 3D direct digital design modelling of customized implant [7], uses a combination between the two advanced additive manufacturing technologies, the SLM and the SL [4,5]. This combination enables the photopolymerization of a polymer in the voids of a 3D core metal mesh previously produced by SLM. This biocompatible metal mesh, which has the required mechanical strength, was optimized based on Voronoi patterns to promote rigid and soft tissue regeneration and growth [6]. The core mesh is then placed on the SL platform and the additive process starts with the first daylight resin layer polymerization until the complete manufacture of the crown teeth.

2. Application of a AM hybrid strategy to the manufacturing of customized dental implants

Recent developments in CAD/CAM tools, where machining is done from a block of material, have allowed the replacement of conventional orthoses, prosthesis and implant techniques [8]. However, these subtractive techniques present serious limitations in the manufacture of structures with complex geometric shapes, which limits the range of products that can be manufactured by this technology. The use of the SL technique, for example, eliminates the molding process to obtain the positive mold, allowing its production directly from the CAD file. It has been demonstrated that, by SL, orthoses can be produced with variable thickness, with better fit, greater comfort and dimensional accuracy [9]. Faustini et al. And Pallari et al. [11, 12] have demonstrated the feasibility of SLS in the manufacture of custom orthotics in particular with respect to the development of a mass customization system that, with the exploitation of the freedom of design offered by the SLS, offers a holistic approach with significant clinical potential. Using the combination of two or more AM techniques, e.g. SLM / SL or SLM / SLS, it is possible to produce biomechanical devices with high mechanical strength and optimized mass/volume ratios of material thanks to the use of two or more kinds of materials. However, the manufacturing of parts with functional gradients - multimaterial components - is a huge challenge due to the different processing parameters associated with each type

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