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An experimental analysis of laser machining for dental implants

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Abstract

In the recent years, the scientific progress in both technological and medical sectors has led to an evolution of materials and fabrication techniques used for dental prosthetics. This paper proposes laser subtractive process to manufacture dental implants and explores the behavior of a CO_2 laser beam effects on biocompatible materials, namely zirconia and PMMA. The aims of the experiments are the study of CO_2 laser beam effects on biocompatible materials and the creation of a mathematical model to relate the process parameters with groove geometry and surface finish.

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1. Introduction

Dental prosthetic is defined as a manufactured product, realized by a dental technician, used to replace the original teeth lost or compromised for functional or aesthetic reasons. Dental prosthetics must meet several requirements:

- functionality: the prosthesis must re-establish proper chewing and joint functions;
- resistance: the prosthesis must resist to the masticatory load and to the wear of mouth liquids;
- safety: the prosthesis must be made with non-toxic materials and without sharp angles, not to damage mouth tissues;
- aesthetics: the artificial teeth should be as similar as possible to the natural one, so as not to affect the correct patient's facial profile.

The dental sector is characterized by a great propensity towards innovation, in particular as regards materials for dental prostheses. From the original metal implants, in recent years plenty of heterogeneous materials, such as ceramics, glass-ceramics, resins, Polymethylmethacrylate (PMMA), have been introduced in dental prosthesis manufacturing. For obtaining metal implants through the lost wax casting process, also wax prosthesis are used as a transient product.

Among traditional methods, the just mentioned lost wax casting is one of the principal used for manufacturing dental implants. Also milling is used for producing various parts of the prosthesis in different materials. In particular, 4 or 5-axis machines are used in dentistry, to allow the prosthetic machining from all angles. As for welding processes, brazing and laser welding are used in the dental field. Additive manufacturing or rapid prototyping methods include ceramic stereolithography (CSL).

2. Laser machining for orthodontic prosthetic devices

Besides of the above-mentioned techniques for processing materials suitable for dental prosthetics manufacturing, a new method, consisting in the laser subtractive process, can be outlined.

2.1 State of the art

Laser machining on bio-compatible materials is a wide research area and several industrial applications are currently proposed. Despite of the increasing production of customized orthodontic and prosthetic devices, laser machining in implant

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dentistry still deserves much consideration. Laser applications in this area are relegated to the development of systems that modify existing implants, manufacture the infrastructure of fixed partial dentures [1,2] and to improve mechanical properties of cast titanium [3], a widely used material to restore the dental volume and the implant in its entirety.

Çelen and Özden consider the long-term mechanical adaptation of titanium alloy implants to impact the osseointegration process and to prevent stress shielding effect of dental implant surfaces that originate from the mismatch between bone and implant [1]. Watanabe et al. [3] investigate mechanical strength, surface hardness and wear resistance of cast titanium treated with Nd:YAG laser in order to generate residual compressive stresses, deeper than conventional milling, that inhibit the propagation of fatigue cracks. In a pioneering work, Minamizato investigates the modification of cast zirconia by laser micro-drilling for dental root implantation [2]. Initially, zirconia is used in bilayered structures for prostheses, with a framework that gives mechanical resistance and a porcelain layer that provides translucency to the restoration due to a good aesthetic factor. Unfortunately, clinical reports on zirconia-based restorations have indicated a high rate of short-term failures related to cohesive fracture of the porcelain layer [4], which constitutes a weak link from a mechanical point of view, introducing the risk of chipping. Therefore, manufacturers have recently introduced monolithic prostheses, which are fully composed of zirconia, without any veneer porcelain to extinguishing chipping and fracturing of the veneering porcelain [5] and dental restorations of monolithic full-contour crowns or complete arch implant rehabilitation (monolithic restoration) [6]. In addition to the mechanical and optical properties, monolithic zirconia has become an alternative material to pure titanium or titanium alloy for its inexpensive costs due to mass production in commercial solid bulks or disks [7].

2.2 The proposed laser subtractive process for dental implant manufacturing

Typically, laser machining has always been used as an additive process in the sintering phase. In this work, its application as a subtractive process is presented. By generating a high concentration of energy density, the heat focuses on an extremely small superficial portion. The material molecules, thanks to a vibrational motion, overheat till the cutting temperature. Thus, the laser beam serves as a milling cutter, used in the traditional milling process. The two methods are compared in Fig.1, where a milling cutter and a laser beam are represented in removing a depth portion of material *d* with a step between subsequent passes of p_s.

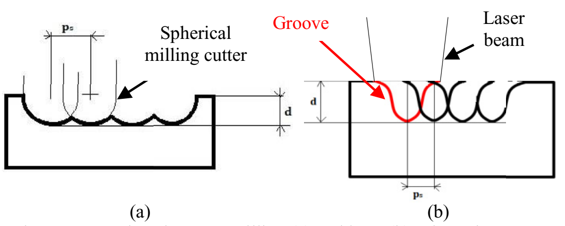

Fig. 1. Comparison between milling (a) and laser (b) subtractive processes.

In general, biomaterials used in monolithic restoration as zirconia and PMMA are particularly suitable for material removal by subtractive processes, whose consist in to machining a bulk to obtain the customized 3D model of single teeth or dental implants. The area to be machined is removed with a number of closely spaced steps of spherical cutting tool or closely spaced parallel grooves of laser beam energy. Subtractive methods overtake transforming methods, as traditional slip casting, hot pressing and injection moulding, because of the customization costs of prosthetic implants. In conventional milling, the mechanical contact of the spherical tool with the sculptured surface of the tooth determinates the process resolution. It depends on process parameters, as feed rates and number of passes, which involves low material removal rate and high tool wear costs.

Among the well-known competitive advantages of laser micromachining, the following are relevant for processing dental implants [8]:

- Non-contact process. The material is directly molted, ablated and vaporized due to the rapid heating produced by high energy density associated with the focused laser spot. Energy transfer from the laser to the material eliminates mechanical force/impingement of abrasive particles, tool wear, machine vibration, industrial effluents typical of subtractive techniques as conventional milling. In addition, the lack of cutting forces allows to quickly position and not to clamp the workpiece for faster operations by not skilled operators like dentists and orthodontists.
- Thermal property. The efficiency of laser machining mainly depends on the thermal and on the optical properties of the material. This makes it suitable for machining hard or brittle materials such as structural ceramics with low thermal diffusivity and conductivity, where milling suffers from excessive tool wear.
- Operation flexibility. In combination with a multi-axis positioning system or robot, lasers can be used without tool changes for different operations and different materials. Both the high speed and the flexibility of the fabrication process make laser systems an effective tool for 3D machining of cavities. As opposed to milling machine, the laser can obtain very small details or radii, including complex shapes and sharp corners.

On the other hand, the choice of such a process involves a cost-benefits analysis, since laser system are expensive and the possible presence of cracks, inclusions or burrs can affect the cutting quality.

2.3 Aim of the present work

On the basis of the previous considerations, the aim of this work is to experimentally analyse the potential of the laser subtractive process as a new method for the creation of dental implants. The motivation is to offer a competitive advantage over conventional materials by means of the increasing efficiency of the applications for groove fabrication on biomaterials. The sector is so promising that, even in the industrial reality, researches in this field are currently being conducted, developing new laser milling machines.