Root-Analogue Implants

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It is estimated that 10% of the world's population will need a dental implant in their lifetime. Despite all the advances in the comprehension of dental implant designs, materials and techniques, traditional implants still have many limitations. Customized root-analogue implants are, therefore, gaining increased interest in dental rehabilitation and are expected to not only preserve more hard and soft tissues but also avoid a second surgery and improve patient overall satisfaction.

root-analogue implants | custom-made | CAD/CAM technology | zirconia | titanium | clinical trial

1. Introduction

Dental implants are an attractive option for replacing missing teeth, providing many advantages, reliability and comfort for improving quality of life [1]. There is a variety of different implants systems on the market [2][3] and some companies are already offering an implant selection system for their customers. However, the approaches aiming at implementation of completely customized dental implants are still uncommon [4]. Osseointegration has been defined as a direct and functional connection between bone and an artificial implant [5]. Traditional implants have a cylindrical or tapered geometry with threads along the screw length and over the placed abutment, followed by the crown (for a single tooth). Due to the geometry and design, they may only provide limited options for available implant length, diameter, and thread parameters, and, therefore, cannot completely meet the personalized requirements of every patient [4][6]. This lack of proper congruency between the implant and the socket bone can eventually lead to implant failure due to stability loss and osseointegration [7][8]. To overcome this problem, novel approaches are being evaluated to manufacture customized root implants which are explicitly tailored to each patient's condition. This is expected to reduce the bone and soft-tissue trauma and promote a better primary stability, being thus a promising alternative for dental rehabilitation [6][7]. Additionally, the placement of such root-analogue implants (RAI) is a minimally invasive procedure, since they do not usually require bone drilling, sinus lifting, bone augmentation or other traumatic procedures [9]. Root-analogue implants were first described by Hodosh et al. back in 1969 [10]. A polymethacrylate implant was developed and clinically tested at that time, but outcomes were not satisfactory. Some years later, Lundgren D. et al. [11] reintroduced the topic by developing a titanium RAI and testing it in beagle dogs. Results revealed that the use of titanium instead of a polymeric material led to a success rate of 88% (28 of the 32 implants were successfully osseointegrated).

Titanium remains still as “the gold standard” metallic material for dental implants. However, an increased concern with aesthetical issues has led to an increased interest in ceramic materials, namely zirconia, for such applications [12]. Apart from its tooth-like colour, its high corrosion resistance, biocompatibility and high wear resistance make zirconia a promising material for dental implants [13]. This is being already deployed in dental practice with zirconia abutments [14][15]. Despite the recent developments in the design and implementation of totally customized root-analogue implants, reliable data on the long-term use of RAI in humans are still scarce.

2. Research Progress

wo materials-titanium alloys) and zirconia-were the only materials found in RAI used in these studies. The excellent mechanical properties of titanium, its biocompatibility, high corrosion resistance and low weight, are well known for this material as a solution for dental implants [16]. However, its colour together with the possible long-term corrosion and release of ions to the body environment has led to an increase in the interest in zirconia as an alternative to this metallic material [17].

Zirconia is characterized by its biocompatibility, sufficiently low bacterial affinity (yet higher than treated titanium), high mechanical flexural and compressive strengths, excellent wear resistance, and adjustable white colour, being a promising solution to overcome the aesthetic issues caused by metallic dental implants [18]. The implants’ surface finishing, namely their roughness has been proved to have a huge influence on the implant osseointegration. Some published studies indicate that rough surfaces promote a faster osseointegration comparing to smooth ones [19][20][21], and many techniques have been applied for the creation of the desired implant roughness. The most common found in literature, and also in the clinical studies of this review are sandblasting and acid etching [22][23]. Sandblasting followed by an acid etching treatment might be considered as the gold standard surface modification in the dental implants market world [24]. On the other hand, it has been shown [25][26][27] that using simple roughness value as a single parameter is a significant oversimplification, as other factors together with porosity, hydrophilicity, nano- and macrotopology are important for implant success (at least, for metallic titanium materials).

One of the biggest differences found in the evaluated literature was the implant designing technique. Some authors opted to scan the original tooth by laser, others designed the implant before tooth extraction, using the patient radiographic (CT) images, followed by 3D image manipulation, and posterior implant milling. This approach, known as computer-aided design/computer-aided manufacturing (CAD/CAM) technology, has become increasingly popular in the dentistry field over the past years [28]. In fact, many dental offices worldwide have been trying to implement modern IT solutions in their daily practice in order to reduce costs, work more efficiently, and increase patient satisfaction [29]. Modern CAD/CAM solutions seem to be the future of the dentistry field, namely for the customization of dental implants.

The success of an implant is known to be directly dependent on its osseointegration process. This process requires an initial interlocking between the alveolar bone and the implant (primary stability) and later, biological fixation through continuous bone remodelling toward the implant (secondary stability) [30]. There are key factors that influence implant stability: surface roughness (as previously mentioned), the congruity between the implant and bone, the period of time between tooth extraction and implant placement, bacterial adhesion, among others [31]. The majority of the studies that are being analysed reported ideal primary stability, where a perfect correspondence between the implant and the post-extraction socket was observed. However, in one study [32] some implants could not be inserted to the intended depth leading to implant exposures. Nevertheless, none of those implants was lost.

For the latency time (between tooth extraction and implant placement), a healing period of 6–9 months was previously recommended (a late implant placement). Later, insertion of implants after 2–3 months was suggested (a delayed implant placement), and more recently, immediate implantation has been clinically tested too [7]. Despite new interest in immediate implant insertion, the literature reports it encompassing two main problems: (a) maintaining the implant primary stability and (b) preventing soft tissue ingrowth during the healing period [7]. Additionally, it is might to higher infection risks, flap dehiscence over the extraction site, and incongruity between the socket wall and the implant [3][14][33]. The articles evaluated in the scope of this review performed the implant placement immediately after tooth extraction or a few days later. However, and contrarily to what was reported in the literature, it seems that this strategy did not trigger any specific side effects nor biological complications. In fact, primary stability was achieved in most of the tested implants.

Another aspect that is worth discussing is the incorporation of macro-retentions on the implants' surface. Some authors mention the incorporation of these protrusions on the implant surface aiming to promote an improved attachment to the bone and consequently improved mechanical stability. Pirker et al. [34] have even compared the performance of RAI with and without macro-retentions, and results were clearly conclusive: RAI without the macro-retentions (n = 5) were suddenly lost, without prior pain or infection, in the first 128 days. On the other hand, among the RAI with macro-retentions (n = 12), only one was lost. These results were later corroborated in one study performed by Moin D. et al. [35] that analysed, by means of FEA (Finite Element Analysis), the influence of 5 custom root-analogue implant designs on the stress distribution of peri-implant bone.

The results of this study revealed that the addition of macro-retentions to an RAI standard design would have a positive effect on the stress distribution, reduce the concentration of bone stress, and provide a better primary stability. Despite being a promising alternative, the authors believe that the macro-retentions alone may not be enough to ensure implant mechanical stability. Since the RAI geometry is characterized by its conical shape, there is a risk that the implants may tend to be expelled and hence other strategies to avoid this risk should be further explored and developed. It is also notable, that FEA analysis conventionally used in dentistry usually suffers from an oversimplification of tissue properties, which are not well known (especially for soft tissues), and where anisotropy is seldom considered [36][37]. The advantage of the linear elastic models is of course in the provision of simple and direct prediction of the tissues properties for the sake of the computational efficiency but the usefulness of such data is very questionable (e.g., "elastic modulus of mucosa" ranging from 0.1 to 680 MPa [38]). FEA outcomes should be considered as a complement to the clinical studies, aiming to better understand the influence of some variables on the implants' clinical performance.

Together with the aforementioned mechanical features, there are also some mechanobiological aspects expected to improve the implants' osseointegration. Some reported techniques are being developed and evaluated aiming to promote the infiltration and supply of nutrients and fluids around dental implants, consequently inducing vascularization at the implant’s surface [39]. However, in this review not much information regarding these biological stimuli has been found: only one article referred that small perforations were created in the palatal tissue of the socket to stimulate bleeding [40]. Other techniques, such as the creation of hydrophilic surfaces or the incorporation of micro-channels on the implant’s surface would also have a positive impact on the implant’s vascularization [41], and eventually needed to be further explored to reveal their potential clinical benefits.

Despite the satisfactory clinical results observed in the selected articles, none of these solutions is widely available on the market—the manufacturing companies and dentists tend to prefer standard products with lower associated costs; most of the dental clinics do not have the necessary equipment (CBCT) for the design of such customized solution; despite its weaknesses, conventional dental implants have been reported with success rates of 90–95% for 10 years follow up periods [42] based on current definitions of success, which are questionable in the opinion of the authors of this paper. Authors believe that these factors may be hindering the worldwide practice of such dental treatment and studies should proceed, focusing on the implementation of RAI in the global dental market.

The main findings of this review show that:

- Titanium and zirconia are the selected materials for the manufacturing of RAI.
- CAD/CAM technology followed by surface treatments such as sandblasting has been the preferred manufacturing technique for such applications.
- The clinical outcomes of the analysed studies suggest that further investigations should be performed aiming to evaluate whether RAI may be considered a promising solution for the replacement of missing teeth or not.

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