Outcomes of Titanium and Zirconia Implant Abutments

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The characteristics of the implant prosthetic abutment are an influential factor which may impact early bone remodeling and soft tissue integration. The abutment material influences the response of both the soft and hard tissues surrounding an implant, making the choice of the prosthetic abutment a crucial phase for the success of implant-supported rehabilitations.

Keywords: dental implants ; abutment ; zirconia

1. Introduction

Dental implants are often used to restore partially and completely edentulous patients due to their reported long-term survival and success [1]. Dental implants are considered survived when they are osseointegrated. The obtainment and maintenance of osseointegration is affected by several factors including the surface properties of titanium implants, which influence molecular interactions at the bone–implant interface, the cellular response and, finally, bone remodeling [2]. Long-term retrospective cohort studies have investigated the relationship between various factors that might influence the implant survival rate [3]. Note that survival means that the implants are still present in the patient's mouth, independent of biologic and/or technical complications, and does not capture a successful treatment [3][4].

Titanium implant surface modifications have been evaluated over the past years and scientific studies have shown that rougher surfaces have a better and more rapid bone formation compared to machined titanium implant surfaces. Modifications of the implant surfaces are made with many different methods such as machining, air-abrasion, acid etching, electrochemical oxidation, and laser treatment. The surface roughness plays an important role for cellular reactions, tissue healing, and implant stability [2]. On the other hand, rough surfaces can accumulate subgingival plaque up to 25 times more than smooth or machined surfaces. This might promote plaque accumulation as well as the subsequent pathology of peri-implant tissues, although a direct correlation with bone resorption has not been demonstrated [5][6][7][8].

A successful osseointegration is defined as a direct bone-to-implant contact without the interposition of any other tissue, and in order to preserve osseointegration it is desirable to have no parafunctional forces, mal-aligned forces, peri-implantitis, an absence of systemic diseases, and to consider the host immune-inflammatory response to bacterial challenges [9]. Besides these, there are also triggering factors that may cause peri-implant bone loss and eventually implant failure that are didactically divided into two main categories: biological factors (for example, the presence of bacterial strains) and biomechanical factors (for example, excessive mechanical stress) [5][10].

It has been well documented in the literature that peri-implant bone supporting two-piece implants undergoes crestal bone loss after the placement of the abutment and delivery of the prosthesis in a single tooth replacement, and in both partially and completely edentulous patients. Among the many factors that cause bone loss, the early stages of bone loss are usually caused by an overload, a micro-gap, a polished implant neck and infection. While the reasons for early crestal bone loss have been extensively studied in the last decade, the stability of the crestal bone over time remains a controversial issue. The micro-gap at the implant–abutment interface [11], has been proven to be a possible triggering factor if placed at the bone level or below. Placing the implant–abutment interface supracrestally can avoid early crestal bone loss, but might represent an esthetic issue [12][13].

It must also be considered that peri-implant soft tissue serves as a protective seal between the oral environment and the underlying peri-implant bone [2][14], and its health is associated with a reduction in the risk of bone resorption [2]. Biological implant-associated complications usually begin in peri-implant soft tissue. Connective tissue and the epithelium of peri-implant soft tissue are in direct contact with the transmucosal implant abutments [15]. Collagen fibers surrounding an implant and a tooth are not the same. For example, natural teeth present perpendicular fibers inserted into the cementum, while collagen fibers around implants are mostly circular and parallel to the implant surface; hence, the peri-implant seal is considered weaker and can be easily invaded by prosthetic cement and contaminated by oral bacteria [16]. The characteristics of the implant prosthetic abutment are considered to be an influential factor which may impact early bone remodeling and soft tissue integration. The abutment material, as surface microtopography [1] has shown, influences the response of both the soft and hard tissues surrounding an implant, making the choice of the prosthetic abutment a crucial phase for the success of implant-supported rehabilitations [17].

Standardized titanium abutments represent the gold standard for implant reconstruction due to the good stability reported in several clinical studies [18]. For many years, the standard stock abutments provided by implant manufacturers were the only option available for clinicians [17]. These prefabricated components may simplify technical procedures; however, they also exhibit several shortcomings, especially in the esthetic aspect. Firstly, the natural emergence profile of a reconstruction cannot be achieved with prefabricated abutments because of the cylindrical cross-section. In order to achieve a natural emergence profile, modifications can be made in the shape of the crown which often leads to over contouring of the reconstruction. Secondly, the predetermined and even height of a crown margin does not follow the natural anatomy of the gingival architecture, making the removal of excess cement difficult in the delivery of cemented prostheses [17][18]. Lastly, the color of titanium abutments may lead to a grayish discoloration of peri-implant soft tissue at the cervical level and cause esthetic concerns [18].

In order to solve these issues, customized abutments of different materials have been developed. Besides the morphological advantages of customization, non-metal materials, such as ceramics, zirconia and polymers are esthetically superior due to their tooth resembling color [18]. Abutment material has shown to be able to affect the stability of peri-implant mucosa and crestal bone as well [19]. When selecting the materials for abutments, clear prerequisites are a proven biological compatibility for assuring long-term stability, together with optimal biomechanical and physical properties [20][21].

Materials such as metals, ceramics (alumina and zirconia), and composites are used for the fabrication of individually customized prosthetic abutments [17].

Cast gold individual customized abutments were considered as a state-of-the-art prosthetic solution for a long time; however, recently, their use has been decreasing due to higher pricing and esthetic and biocompatibility issues. In an animal study by Abrahamsson et al., peri-implant soft tissue did not form a sufficient seal with gold abutments; therefore, soft tissue recession and crestal bone loss can be expected.

Apart from gold, dental porcelain is also not considered to be a proper material to establish a reliable soft tissue attachment. The least favorable outcome was found with the use of feldspathic ceramic, as the soft tissue recession and bone loss had the highest extent along this material. Mechanical resistance is also a big issue when dealing with porcelain. Apart from gold, ceramic might also be considered as an alternative material for customized implant abutments. Nevertheless, there is a lack of evidence to support or refute the use of porcelain (including feldspatic) for this specific purpose, but some researchers report the use of feldspatic ceramic as a valid coating material for veneers, with an acceptable soft tissues margin adaptation [21].

Alumina implant abutments perform well biologically and esthetically, but they present a greater risk of abutment fracture at the implant–abutment connection during clinical use compared to zirconia [19].

Composite resin abutments are considered to be an alternative and have proven to be as strong as zirconia in in vitro tests published by Magne et al. [22][23].

However, the use of composite resin abutments remains limited due to the concerning reaction of the soft peri-implant tissue to the composite.

Zirconia is a biocompatible material that has optimal esthetic and mechanical properties [17]. Zirconia abutments have been routinely preferred as the abutment of choice especially with increasing esthetic demands in patients with a thin, soft tissue biotype [18]. Some advantages of zirconia include its high mechanical strength due to its unique stress induced transformation toughening mechanism, corrosion resistance, and high loading capacity [15]. Compared to titanium, a zirconia abutment enhances the peri-implant health by reducing inflammation and with less bleeding on probing being present [16].

Even though clinical studies have shown that zirconia abutments indicate very good biological and technical outcomes [19], clinicians still often face the dilemma of choosing between titanium or zirconia abutments. There is so much to keep in mind, such as the biological and esthetic outcome and the mechanical strength between these two implant abutment materials.

2. Mechanical Outcomes

There were four main mechanical outcomes that were discussed in the present systematic research reporting a higher incidence of fracture complication in ceramic abutments compared to titanium ones [19]. The inherent properties of ceramic materials, with a lower resistance to fracture and less flexural strength when compared to metals, may explain these findings [19][24]. The risk of abutment fracture may also be affected by the thickness of the material and the position and angulation of the implant with respect to the final prosthetic restoration [19]. To decrease the risk of an abutment fracture, the wall thickness of zirconia abutments must be maintained above 0.5 mm during manufacturing, while titanium has to be preferred when the thickness is less than 0.5 mm [25]. Manufacturers have also restricted the indications for zirconia abutments to limited angulation. Stock abutments provide maximum angulation of 15 to 20 degrees, while CAD-CAM custom abutments are not recommended for an angulation of over 30 degrees [26]. The abutment fracture rate of zirconia varies from 1.08% to 17.86% depending on age, gender, tooth position, abutment systems, implant systems and implant–abutment connections. Abutment fractures are more likely to happen in young male patients, most probably due to higher occlusal forces. In addition, zirconia abutments in the posterior areas seem to be more susceptible to fractures, compared to placement in the anterior areas [25].

Implant–abutment connection design also plays a huge role in the success of zirconia abutments. A one-piece internal connection showed the highest fracture rate, while external and two-piece internal connections reported a lower fracture rate [25]. Most zirconia abutment fractures occurred within 3 years after loading and several occurred during the initial fitting or subsequent tightening under a controlled torque and the primary fracture location can vary depending on the implant–abutment connection design. In one-piece internal connections, fractures mostly happen in the neck of the implant or below the implant shoulder. The region around the abutment screw head experiences the highest torque and stress concentration and is the most critical region for the stability of ceramic abutments, while the zirconia portion below the implant shoulder is the thinnest and, therefore, cannot resist high torque values. In two-piece internal connection and external connection zirconia abutments, fractures are mostly found above the implant shoulder [25].

An abutment screw fracture was mentioned only in one systematic review and, therefore, seems to be a very rare mechanical complication [27]. Irrespective of the abutment material, abutment screw loosening was found mostly in studies using external hex implants for single implant restorations. Although abutment screw loosening may not be considered a failure, repeated screw loosening can affect the success of implant therapy and patient satisfaction [27]. It has been shown that implant screws are submitted to high concentrations of stress during mastication in the posterior area and this is the most critical area for the stability of ceramic abutments. Nothdurft et al. [28] observed that screw loosening on zirconia abutments may occur due to wear induced by the unavoidable micromovements of the prosthetic component at the implant–abutment interface, which is maximized by the difference in the material properties. Ceramic abutments with titanium bases, or a two-piece Y-TZP abutment, have been proposed as an alternative to solve this problematic wear. Moreover, two-piece abutments have a reduced tendency for complications because they have a higher resistance to micromovements due to ductility of the titanium, which allows some deformation when submitted to unfavorable movements [29]. It was observed that failure in the veneer layer on zirconia abutments was considered as the most frequent problem, especially in all-ceramic restorations. Veneer failure, however, may not lead to implant or prosthetic failure, depending on the extension of the fracture, compromised esthetics or function of the prosthesis. This complication may strongly affect patient comfort and satisfaction as it may increase the treatment time, costs and complexity of maintenance. Veneer failure occurs mostly due to weak bonding between the veneering ceramic and the zirconia infrastructure [29]. When comparing zirconia and titanium abutments, apparently the incidence of a veneer failure on single crowns cemented on titanium abutments was relatively higher compared to zirconia abutments, and this may be associated with the inherent and unavoidable differences in the mechanical properties of ceramic and titanium [24][29].

The type of prostheses and the implant connection are other factors that may influence the outcome [30].

Zirconia abutments presented a better performance in the overdenture group compared to titanium abutments; however, only two original studies reported about implants that were restored with implant-supported overdentures [31].

Although according to several studies the success rates of zirconia and titanium abutments were very similar, further studies need to be performed for two-piece abutments, or hybrid zirconia–titanium abutments. In particular, further clinical research about the mechanical outcomes of this implant abutment design is needed, as some published studies were not specific on how the titanium and zirconia were bonded together as a single unit implant abutment.

3. Biological Outcomes

As for the biological outcomes, plenty of outcomes were extracted, mostly regarding the material effect towards peri-implant soft tissue. Although zirconia and titanium have both proven to be biocompatible with the surrounding tissue, biological complications were reported in several studies. Buccal fistulas were involved in both screw and cement-retained restorations. In screw-retained restorations, this was only seen in external hexagon implants, and might have been caused by the gap between an ill-fitting abutment and an implant [32]. Increased leakage was reported for zirconia abutments compared to titanium abutments, possibly due to the lower recommended torque values used to tighten the zirconia abutment [33]. In cement-retained restorations, the fistulas were attributed to uncleaned residual cement [16][32]. The design of the abutment might also affect the amount and incidence of cement remnants in peri-implant sulcus. In fact, when the crown margins are located between 1–1.5 mm submucosally, they prevent the complete removal of cement remnants, even when using customized abutments. Resin cement is the most difficult to remove from abutments; therefore, it may be assumed that this complication is dependent on the abutment design and cementation agent, rather than on the abutment material. Hence, supragingival or epigingival margins of abutments are suggested, especially if the implant restorations are to be cemented with resin luting agents [16].

In a systematic review by Sanz-Martín et al. [1], it was reported that there were cases of suppuration without bone loss with no further explanation mentioning the cause of the complication.

The overall survival rate of the two materials shows no significant difference [1][31], but further study with longer follow-ups might be necessary to determine which of the two materials has a better survival rate.

Peri-implant mucosal recession is also considered a biological complication and was reported in several systematic reviews. This complication was predominantly reported in studies using prefabricated titanium abutments. It may be related to the fact that prefabricated abutments provide less optimal support to gingival tissues compared to customized abutments. Regarding this complication, titanium abutments have been reported in more studies because of their longer period of usage, and recession related to titanium abutments can be easily seen and recorded compared to ceramic abutments [32]. Another systematic review stated that soft tissue recession was not influenced by the selection of the abutment material, but by other important factors such as the 3D position of the implant and the presence or absence of attached mucosa [16]. This result was not in accordance with the systematic review of Cao et al. [31] that revealed that zirconia abutments could better reduce the recession in both the junctional epithelium and alveolar ridge compared to titanium abutments, although the reduction was limited [31].

The implant abutment shape design has shown effects on peri-implant soft tissue. In fact, some outcomes are more dependent on the design rather than the material of the abutment. It was reported that a comparison between concave and convex abutments showed that the soft tissue thickness was greater in the concave group [25]. The use of the concave transmucosal profiles for implant components allowed for more predictable soft tissue stability in esthetic areas. In a study by Rompen et al. [34], concave abutments of both titanium and zirconia material were used for single crown restorations, and their results showed that 87% of the sites showed facial soft tissue stability or a vertical gain, and recession in the remaining 13% was below 0.5 mm [32].

A difference was found for mucosal inflammation or bleeding on probing (BOP) when comparing abutment materials. Some systematic reviews found that mucosal inflammation was greater next to titanium abutments compared to zirconia ones [25][31][35], while the macroscopic design, surface topography or surface manipulation did not have a significant influence on this outcome [25]. Lower BOP values may be caused by less plaque retention in zirconia abutments compared to titanium ones due to the surface properties of the material [24][25][29][32]. It must be added that it is more and more common to treat patients with anticoagulant therapy [36].

This finding is also supported by an in vivo study where the bacterial colonization was compared between zirconia and titanium discs attached to a removable dental prosthesis [16][25]. Ceramic abutments are easier to polish than metal abutments, which can greatly reduce the bacterial colonization and adhesion [24]. They are also resistant to corrosion which allows for the better growth of epithelial cells and inhibits bacterial adhesion. Plaque accumulation can also be affected by several other factors besides implant abutment modifications including a cement excess, and a misfit between the prosthesis and the implant platform caused by screw loosening or ill-fitting prosthetic components [29]. Soft tissue attachment also plays a role in the degree of inflammation. In an in vitro study [27], zirconia exhibited a higher degree of fibroblast proliferation when compared to titanium. This result, however, does not translate to the differential histological outcomes in experimental studies comparing abutments made of zirconia, titanium and gold alloy. A similar soft tissue dimension was reported for titanium and zirconia abutments, while in the gold alloy abutments there was an apical shift of the epithelium barrier followed by a marginal bone loss [25][32]. It was reported that healing at zirconia and titanium abutments allowed the formation of a mucosal attachment that included an epithelial and a connective tissue portion that were about 2 mm and 1–1.5 mm high, respectively, which demonstrates that the abutments made of titanium and zirconia promoted the proper conditions for soft tissue healing [14].

Other than the different materials, the surface properties and in particular the roughness may have effects on soft tissue attachment [37]. Some histological studies on animals and humans have demonstrated that moderately rough surfaces can be beneficial for soft tissue integration, but this conclusion cannot be drawn as there is insufficient investigation on this hypothesis [37]. No significant difference was found for the periodontal probing depth between zirconia and titanium implant abutment material; however, in some studies, the cementation margin was placed subgingivally, which could be a setback in the study design. Clearly, if the restoration margin extended deeper subgingivally, the peri-implant tissues at the gingival parameters would contact the restoration material instead of the abutment material. This would influence the periodontal probing depth, accumulation of plaque and other biological parameters [17].

Titanium and zirconia abutments did not seem to influence marginal bone loss. Although zirconia abutments seem to have less marginal bone loss compared to titanium abutments, there was no significant difference between the two materials [20][24]; however, when changes in the marginal bone loss were assessed over time, a significant loss occurred for both materials except for titanium nitride. The magnitude of this loss, with a mean follow-up of 30 months, has limited clinical significance as it is smaller than the mean error of repeated radiographic measurements [20]. Surface decontamination on implant abutments seems to be an important factor affecting the peri-implant bone levels. A greater amount of bone loss was reported for steamed titanium abutments compared to plasma argon titanium abutments. It is known that the strong affinity of titanium to proteins and amino acids makes the complete cleaning of its surface rather difficult, but plasma argon cleaning has been shown to effectively decontaminate titanium surfaces in vitro. In human histological studies, it has been reported that plasma argon may promote cell adhesion and positively influence collagen fiber orientation [25].

The present systematic research of systematic reviews presents some limitations as some of the systematic reviews that were included faced their own difficulties in collecting data with less heterogeneity and bias in the studies included. The lack of differences for some clinical outcomes analyzed may also be due to the questioned reliability of periodontal parameters to assess peri-implant health. Different studies also use different methods to measure those parameters that may affect the overall results of the investigation. It has been shown that factors such as gender, implant position, or age can influence the peri-implant health parameters. Moreover, excessive probing forces may induce false-positive BOP readings and the insertion of a periodontal probe in cases with overhanging restorations may result in lower periodontal probing depth values, increasing the trauma towards the peri-implant soft tissue and leading to a false-positive BOP [25].

4. Esthetic Outcomes

Another important factor to be considered for the abutment selection is its possible impact on the esthetic outcome of the implant–supported final restoration. The systematic reviews that were included had selected studies with many different esthetic indices used. Studies using spectrophotometry have shown better esthetic results with zirconia abutments compared to titanium abutments, mainly due to the color appearance of peri-implant soft tissue [20]. The blue-grayish shimmering effect of titanium abutments, especially in the case of thin peri-implant mucosal tissues, can compromise the esthetic result [32]. Hu, et al. found no difference in the discoloration of soft tissues with different abutment materials [24]. Peri-implant mucosal thickness is also of importance to achieve satisfactory results, as it has been shown that the abutment material determines minimal color changes in thicker tissue, generally more than 3 mm [17][20][38]. It is recommended to use titanium abutments when the tissue thickness is at least 3 mm, while for zirconia implant abutments, a 2 mm of soft tissue thickness would be enough [38]. Hence, the use of zirconia abutments can be esthetically appreciated only in the case of thin tissue biotype [17]. Additionally, titanium abutments with modified surfaces, such as anodized ones, seem to have more discoloration compared to zirconia [26][38]. Anodized pink titanium abutments present a “grayish” color as they are all-metallic while ceramics present a more “whitish” color [38]. The pink veneering of zirconia seems to be more promising according to spectrophotometric measurement without a significant biological or technical alteration; however, further study is needed [26]. When different abutment materials were compared to natural teeth, both titanium and zirconia abutments induced visible discoloration when assessed using a spectrophotometer in the peri-implant soft tissue [32][38]. It appears that studies using spectrophotometric analysis showed a higher sensitivity to detect peri-implant mucosal discoloration, whereas studies using subjective or objective scoring criteria reported a minimal difference in the esthetic outcomes and patient satisfaction [32]. According to Linkevicius et al. [17], the pink esthetic score (PES) index should be used for the evaluation of the final esthetic outcome because it reflects the soft tissue condition better. The PES was originally proposed by Furhauser et al. [39] and it is composed of five factors, namely, the mesial papilla, distal papilla, curvature of the facial mucosa, level of facial mucosa, and root convexity or soft tissue color and texture at the facial aspect of the implant site. For example, the PES score around zirconia abutments was significantly higher compared to titanium abutments at a 2 year follow-up [17].

There were limitations in the esthetic assessments as well because different systematic reviews included different inclusion and exclusion criteria. In those systematic reviews, different indices were used, hence, the outcome can be greatly influenced when different measurements are taken into consideration.

Additionally, some studies had taken measurements before the cementation of a prosthesis or crown, while others assessed the outcome without prosthesis.

Future research should focus on improving the study methodology in this field of implant dentistry. Although research on implant abutment materials and their modifications have been published for many years, many clinicians still have difficulty in deciding on the abutment material and design. The possible variables in the choice of the implant abutment seems to be limitless, including the material, macroscopic design, surface topography, surface treatment and even the modification of color by veneering in zirconia abutments and anodizing in titanium ones.

Other than that, implant abutment can also be influenced by how a prosthesis is placed, namely, cemented or screw retained. There is a wide variety of factors that play a role in peri-implant soft and hard tissue health.

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