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CUSTOM ABUTMENTS FOR DENTAL IMPLANTS, THEIR EVOLUTION AND USES: A NARRATIVE REVIEW

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Custom Abutments for Dental Implants, their Evolution and Uses: a Narrative Review

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Resumo:

Introdução: Recentemente no mundo da dentística o uso de Computer Imaging and Computer Manufacturing (CAD/CAM) para criar pilares de implantes personalizados de Titânio ou Zircônia para atender às demandas funcionais e estéticas de nossos pacientes, está se tornando cada vez mais proeminente com vários métodos, cada um adequado para uma melhor localização e tipo de dente que deve substituir.

Objetivo: Este estudo tem como objetivo a discussão dos pilares personalizados em implantes dentários, seus desenvolvimentos, vantagens e desvantagens, técnicas de fabrico, indicações e contraindicações e por fim sua viabilidade clínica.

Metodologia: Pubmed, B-on (1990-2022) com as palavras-chave: : (“dental implant” OR” dental abutment” OR “custom dental abutment”) AND (“3D Printing” OR “zirconia” OR” titanium” OR “milled abutment” OR “sintering” OR “emergence profile” OR “peri-implant tissue” OR “replacement” OR “materials” OR “ CAD/CAM” OR “Clinical Trial” OR “Esthetic”)

Resultado: Os Abutments Personalizados que atualmente apresentam melhor desempenho são os de Titânio, sendo que os copings de Zircônia sobre Titânio conseguem obter os melhores resultados estéticos e funcionais.

Abstract:

Introduction: Recently in the world of dentistry the use of Computer Imaging and Computer Manufacturing (CAD/CAM) in order to create Titanium or Zirconia custom implant abutments to meet the functional and esthetic demands of our patients is becoming more and more prominent with several methods each suited to a better locale and type of tooth it’s supposed to replace.

Objective: This study has as its objective the discussion of custom-made abutments in dental implants, their development, advantages and disadvantages, manufacturing techniques, indications and contraindications and finally their clinical viability.

Methodology: Pubmed, B-on (1990-2022) with the following keywords: (“dental implant” OR” dental abutment” OR “custom dental abutment”) AND (“3D Printing” OR “zirconia” OR” titanium” OR “milled abutment” OR “sintering” OR “emergence profile” OR “peri-implant tissue” OR “replacement” OR “materials” OR “CAD/CAM” OR “Clinical Trial” OR “Esthetic”)

Result: The Custom Abutments that currently perform the best are Titanium ones, with Zirconia copings on Titanium being able to achieve the best results both esthetically and functionally.

I-Introduction

The theme of this work is Custom Implant Abutments, their benefits, limitations and advantages compared to Stock (Prefabricated) Implant Abutments.

Currently the esthetic demands of implants, especially in the maxillary anterior sector of the mouth, are rising and Stock Abutments, while tried and true in their ability to meet the clinical and functional demands expected of them after over 50 years of fine tuning and research, aren't keeping up with the advantages a more personalized approach can provide to the treatment, namely a carefully designed emergence profile for better soft tissue adaptation and the reduction of cement remnants.

This paper aims to discuss the typologies, advancements and shortcomings of different Custom Implant Abutments when put up against each other and Stock Abutments to better understand their evolution during the years and their current use in modern dentistry while exploring all aspects of their performance: Esthetics, Survivability, Benefits and Disadvantages with a global view of the available materials and techniques coupled with a focus on the two most prominent groups: Zirconia and Titanium.

The method for this research was articles on Pubmed and B-on, limited to the English language and between the years 1990 and 2021, in order to better frame the scope and development of the various methodologies.

II-Development

2.1-What is an Implant Abutment?

Dental Implant Abutments are the portion mounted on the implant connecting the prosthetic Crown with the osseointegrated Implant Body that protrudes through the gingiva, they can be placed with three different approaches [53].

Two-stage, after enough time for the surrounding bone's full recovery, 2 to 3 months for the mandible and 3 to 6 months for the maxilla on average, the soft tissues covering the implant are opened to attach the Abutment and mount the Crown.

One-stage methods instead see the use of a Healing Abutment placed immediately to avoid the cicatrisation of the soft tissues above the implant that would require a 2nd surgery to proceed, after 3 to 6 months the Prosthetic Abutment and the definitive Crown can be placed to restore function.

Immediate Loading is when the Prosthetic Abutment and the Crown are finalized during the first surgery.

Before diving deeper into the argument of Custom Implant Abutments, it's necessary to discuss the Materials, Manufacturing and types of Stock abutments available.

2.2-Materials

2.2.1- Titanium

Titanium has been the most long standing material for constructing implants, both the implant body itself and the abutment, in both stock and custom ones, ever since the concept was first put into practice and it's used either as Commercially Pure Titanium or as an alloy in combination with aluminium, vanadium, iron or other metals, it's currently the most used one out of the mentioned options due to its extensive history while its biocompatibility and corrosion resistance are considered the standard new possible candidates have to match up to. [3]

2.2.2-Zirconia

Zirconia, also known as Zirconium Oxide (ZrO_2), is currently being used mainly for the manufacturing of implant abutment copings in the anterior zone covering a Titanium base, thanks to the hygienic properties similar to Titanium and its colour giving it the ability to mimic dentin without sacrificing strength and durability, while metal-based abutments such as Titanium and Base Metal Alloy can be placed anywhere in the mouth but can wind up performing poorly in the esthetic department. [1]

Zirconia as a material is gaining a lot of traction in both dentistry and general medicine due to the wide variety of uses it lends itself to, but long-term concerns such as crystalline degradation, wear and crack propagation have yet to be completely dispelled by appropriate studies. [2]

2.2.3- Lithium Disilicate

Lithium Disilicate is hybrid ceramic widely used for crowns, inlays and onlays that was only recently an option proposed as an alternative to Zirconia due to the similar overall esthetic properties and mechanical resistance, but long-term studies on its bonding to Titanium and fracture resistance, problems that are still plaguing Zirconia in spite of its widespread use in a much larger timespan, are missing, making it a somewhat risky choice [49].

2.2.4- Precious Metal Alloys

Precious Metal Alloys are showing promise in the restoration of anterior segments with implants due not only to their favourable colorations but also due to an apparent resistance to corrosion and a fit of the implant/abutment gap comparable to that of titanium-based abutments with just as impressive detorque values , however 100% Gold (Au) alloys in particular have shown an higher rate of infiltration of inflammatory immune cells (lymphocytes CD 3, CD 20 and CD 68) compared to titanium, zirconia and other precious metals such as Palladium (Pd) and Silver (Ag) , notably they are used for UCLA-type implants, stock abutments with a Gold/Palladium interface connected to a plastic chimney that are later customized in the lab and as such are regarded by many as custom abutments.[4/5]

2.2.5- Base Metal Alloys

Base Metal Alloys are mostly used for metal-ceramic crowns, at least for now, mainly due to the findings about galvanic corrosion between titanium and such alloys if they're used as abutments which leads to an increase in cytotoxicity that in turn translates into an augmented risk of peri-implant tissue loss due to it impeding cell growth, but they still remain as an option due to their overall lower costs and the new coatings which reduce or eliminate the rate of corrosion, the most used one is Cobalt-Chromium (Co-Cr)[6].

2.2.6- Polyetheretherketone (PEEK)

PEEK is a semi-crystalline linear polycyclic thermoplastic, part of the family of Poly-aryl-ether-ketone, they too are a recent option for custom abutments, but due to the material's short history and the plethora of ways it can be modified, it's still too early for its widespread commercial use [50] ,it's mostly used for healing or temporary abutments, but, due to its reduced cost and time for manufacturing after the initial purchase of an appropriate machine, it has been tested also as a permanent prosthetic abutment , superstructure and even as the full implant body since TiO_2 particles can be added on its surface to promote osseointegration [61].

2.3- Manufacturing Techniques for Custom Abutments.

Each of the discussed materials is then processed in different ways depending on its characteristics and the final type of abutment.

Custom-made abutments can be fabricated with the use of Lost wax technique (LW) and CAD/CAM (Computer aided design/ Computer aided manufacturing) technology that can be further divided into: Milling, Milling and Sintering (MS) and 3D Printing which is either Selective Laser Melting (SLM) or Direct Metal Laser Sintering (DMLS).

The most important factor to consider when choosing the manufacturing process of abutments is the marginal fit between it and the crown, which is in turn affected by the presence or absence of anti-rotational grooves.

2.3.1- Lost Wax Technique

LW technique is the traditional metal casting technique used also for metal crowns, an impression of the base implant and the surrounding tissues is taken with a silicone material which is then turned into a refractory model used to mould the abutment based on which a crown is then constructed.

2.3.2- Computer aided manufacturing/Computer aided design

CAD/CAM uses digitalized images from scanning with Computed Tomography (CT) that are processed by a computer program to analyse the optimal shape, width, angle and position of the implant and abutment, the resulting data can then be used by the following methods:

Milling without sintering, which can be used for metal abutments sculpted by a machine from a block of pre-sintered metal (Dense Co-Cr, Titanium) or pre-sintered Zirconia.

MS is used for Zirconia, that is first milled in a pre-sintering stage with dimensions increased by 20-30%, to account for the compression of the material, and then is sintered in a furnace, or for Agglutinated metal alloys who are milled with a dimensional increase of 10% and then are sintered using either a furnace or other methods (heated Argon gas at 1300C°).

3D Printing uses the processed CT data to plan structures subdivided into individual sections that are then built in sequence with layer-additive manufacturing technologies in the construction of implant abutments:

SLM 3D printing machines to melt powdered metals (Titanium or Base Metal Alloys like Co-Cr) into shape layer by layer by using a laser.

DMLS 3D printing machines to sinter, not melt, layers of powdered metals, binding the individual particles into a solid structure (Titanium or Base Metal Alloys like Co-Cr) by using a laser while following a digital 3D jaw model built from CT data.

Hybrid methods combining more options also exist, these use conventional impressions (silicone material, bone impression or stone model optical scanning) and then digitalizing them into virtual jaw models and then print using a DMLS, SLM or similar machines. [7-9]

2.3.3- Importance of decontamination

All of these previously discussed processes expose the implant abutments to contamination from varied particles, laboratory consumables or generic pollutants, both organic and inorganic, and that additional methods must be employed to eliminate them, like Ultrasonic cleaning [10] in order to avoid inflammatory reactions in peri-implant tissues that may lead to osteoclastogenesis and further down the line periimplantitis and implant loss [21].

Plasma of Argon, for example, was found to be an excellent decontaminating agent for custom abutments, removing as many particles as the previous gold standard, cleaning combined with vacuum sterilization, with a reduced risk of damaging the prothesis, although the use of heterogenic measures to maximize the effectiveness of the procedure is still recommended [57].

2.4- Types of Implant/Abutment Connections

To truly understand the intricacies and reasoning behind the different models of custom abutments, stock abutments must be discussed first.

Stock Abutments are prefabricated and tied to specific implant screws, the connections themselves can be exemplified as:

2.4.1- External connection to External Hexagon

The External butt-joint is one of the earliest types of implant-abutment connections and the first relatively modern one to arise after the understanding that implants didn’t benefit from having tooth-like mobility and flexibility like the truly primitive first models and theories proposed , thorough the 80s and 90s it was widely used in conjunction with hexagonal implants but it had the, in hindsight fatal, flaw of marginal bone loss (1.5mm in the first year) that was so omnipresent it lead to the belief every single implant had to adhere to the same rule and their placement was to account for that reduction, this was exacerbated by the leading theory of the time prohibiting radiographies from being taken close to osteotomy operations in fear that it might end up interfering with osteointegration, this spurred several studies that later confirmed the more apical along the implant axis the connection between the two components is, the more severe bone loss occurs, the importance of a micro gap as small as possible in this joint and the role of bacteria infiltrating such gap plays in the inflammation of the peri-implant tissues (Periimplantitis) and implant loss.

2.4.2- Internal connection to Internal Hexagon

Internal butt-joint connections were one of the first alternatives whose design, while not resolving most of the issues of the External butt-joint, managed to learn from the studies that were started by their predecessors, moving the connection between the implant and the abutment more coronally.

2.4.3- Internal connection to Morse taper

Morse taper abutments utilize a “cone within a cone” connection, a concept first developed by Stephen A. Morse in 1864 for tools and machinery, to increase the stability and the sealing capacity of the components when measured against the hexagonal implants that were developed before them, though most implants are not true Morse tapers because they use a higher percentage of taper compared to the original of 2°50 = 5% mathematical relation.

Some of the advantages of Morse taper connections are that it takes much less force to connect the two pieces than to dislodge them and that the screws aren’t used for the retention of the implant-abutment connection but to guide the connection.

With that said, not all the Morse taper-like implants are same, they use different angles and different lengths of contact with the cone , with measurements set by the individual manufacturers, but, when comparing four of these systems in Ranieri et al.[25], it was found that all of them but one always had some bacterial penetration on the screw and each of them had some sort of microbial invasion, the system with the smallest taper (5.6 degrees) being the least contaminated compared to the ones with 11.5 and 13 degrees respectively, with the author suggesting that the tighter connection caused by the lower degree prevented the infiltration, with the length of the contact also playing a role, this was later confirmed by King et al.[24] where the abutments were welded onto the implants, showing a lesser colonization and less marginal bone loss compared to the non-welded control group. [11]

2.4.4- One-Piece

No interface (One-Piece implants, Tissue Level or One-Body) work on the principle that the gap between the abutment and the implant is the primary site of bacterial colonization and inflammation and that removing it entirely from the marginal bone level could further reduce the bone loss.

This is achieved by using two different surfaces, one for the contact with the bone tissue, presenting the typical grooves and porosity needed to stimulate the connection between the Titanium Dioxide and the bone, and the other for that with the epithelial and connective tissues which is usually smoother to prevent bacterial build-up, making them a valid choice for stock abutments alongside Platform Switch type connections [12-13] but only with appropriate procedures and uneventful healing[14].

The various types of connections have different levels of performance in the micro gap department, with External Hexagons ranking the lowest amongst the Titanium-based models while Morse-taper type joints with platform switching placing far ahead in terms of results in dynamic conditions , as far as Zirconia-based implant abutments go they should be taken into consideration only in anterior restorations because, while they do show a net gain in the esthetics department, they are more prone to microleakage than Ti-based [26].

2.4.5-Other Connections and Variations

In addition to the major players, Hexagonal and Conical type connections, there are other types of Two-piece abutment connections such as Octagonal and Cylindrical, on top of multiple variations due to the presence of different internal geometries which end up affecting the rotational freedom of the connection significantly, with Bone-level Conical and Tapered Internal Hexagon exhibiting the highest stability [76].

2.4.6- In the Anterior Maxilla

The behaviour of each of these connections leads to different results in the anterior Maxilla compared to the rest of the mouth due to the higher esthetic demands that are dependant also on the connection between the abutment and the other two components, it was found that Morse Taper had the best survivability while Internal Hexagon had the best esthetic score when measured with PES/WES (Pink Esthetic Score/White Esthetic Score) and the External Hexagon had the worst PES/WES score but a survivability rate inbetween the other two[47].

2.4.7- Platform-Switching

Platform-Switching is an adjustment to the connection that has as its objective moving the implant-abutment interface horizontally by using an abutment of reduced size compared to the non-switched counterparts, first stemming from a commercial unavailability of appropriately sizes matching components and the use of standard size abutments over wide implants , this allowed for unprecedently low marginal bone loss at the time, 0.34mm for submerged implants and 0.38mm for non-submerged implants compared to the 1.5mm of butt-joint type connections, this is still being debated but studies point towards the connective tissue covering micro gap in the implant-abutment interface reducing the infiltration of bacteria.

2.5- Custom Implant Abutments

Figure 1 (left to right) Hybrid Zirconia Abutment, Straight (Stock) Titanium Abutment, Customized Titanium Abutment

Custom abutments are instead personalized based on the data extrapolated from traditional impressions and/or CAD/CAM, they can be divided into:

One-piece abutments, that follow the same principles of One-piece stock abutments, without a micro gap between the components, they can be fashioned out of Titanium with a separate ceramic crown or fully in Zirconia [15].

Two-piece abutments, where a ceramic esthetic portion is cemented onto a Titanium base for better results while maintaining a tooth colour as natural as possible.

2.5.1-Brief History of CAD/CAM and Milling in Dental Prosthesis

This relatively novel addition in dental implants' over 50 years of history is intimately tied with the advancements in scanning technology of the 1980s, with the first CEREC (chairside economical restoration of esthetic ceramics) machine enabling the translation of CT data into physical models for dental prosthetics made with milled ceramics that were then bonded to the patient's tooth, in 1985, with the limitation of not being able, in this first iteration, of reproducing the occlusal face of the tooth[27].

Another early option was the Celay system, whose specifications allowed for the milling of complete crowns and short-span bridges as it could reproduce all surfaces from the start [28], however it was outpaced by CEREC during the 80s and 90s, that became the predominant system once its 3D version was released in 2002 (CEREC 3D) [29] and basically founded the specialty of prosthetic dentistry focused on chairside use of CAD/CAM technology [30].

2.5.2- Options for Custom Implant Abutment Fabrication

Initially, in the 1980s, the choices for "custom" implant abutments were limited to UCLA, a system employing titanium alloy connectors and a plastic pillar that acted as a scaffold for a wax-up which was then filled with cast gold to form the abutment, to better answer some of the problems that more modern methodologies were also created to face: limited interocclusal space, improper implant angle, the inability to modify stock abutments to fit closely placed screws and the poor esthetics of conventional abutment cylinders[31] .

The first CAD/CAM abutment was a healing abutment developed by Atlantis Components in the year 2000,with the "Atlantis Custom Abutment Technology" , that milled the pieces from commercially pure Titanium, eliminating the need for technician-created wax-up by moving that step into a software that analysed a master cast of the patient's mouth with the implant's position and the surrounding soft tissues as its focus, this was possible due to the presence of a software (VAD ™) with standardized virtual models that the operator could then modify with digital design tools to fit the patient's anatomy and , since the abutments were milled from files and thus repeatable, it allowed for multiple copies and permitted a patient to use a custom healing abutment while the laboratory was working on the ceramic crown much faster than other personalized methods before it[32].

Another early option for this process was the Procera abutment, derived from a 1998 expansion to the original NobelPharma's Procera system for designing ceramic crowns first released in 1990, unlike Atlantis abutments this is a closed system that can be used only alongside Nobel Biocare implant as bases and still uses wax-ups, thus resulting in the fact the contours of the abutment are dictated by the technician, [33] on top of needing a screwed metal interface in the connection between the abutment and the implant that apparently reduces the risk of fracture when employed alongside Zirconia compared to other systems [34].

The third major early CAD/CAM abutment manufacturing program was the 2007 Encode System ™ by Biomet 3i, another closed system this time only usable with 3i implants, it scans a cast made from an intra-oral impression to measure the distance of system specific healing caps engraved with lines that are in turn used to measure the position of the underlying implant screw and, in a combination of technician-created wax-up and software, can program the dimensions of the abutment for milling [35].

The first true prosthetic CAD/CAM abutment was proposed by Dumbrigue et al in 2002 as a way to minimize excess cement while following the gingival contour and simultaneously as a way to deal with angulation of implants that would make a traditional prefabricated abutment either partially exposed or with a much longer prosthetic crown [41].

2.5.3- Generic Custom Abutment advantages

One of the perks of being able to regulate the angle and shape of the abutment is a better adherence to the Emergence Profile, which can be divided into the:

1)Esthetic zone: the 1mm subgingival area, apical to the free gingival margin, which is critical to the final appearance of the restoration and needs to be convex, though implants placed more buccally should instead have it straight or even concave, but that situation should be avoided in the planning phase.

2)Bounded zone: 1-2mm, positioned apically to the Esthetic zone, its greatly affected by the surrounding soft tissue and the position and design of the implant's neck, so either a connective tissue graft or a more convex design should be employed to create the illusion of thickness when necessary.

3)Crestal zone: it's located 1-1.5mm coronally to the implant platform, the design of the abutment in this zone is convex to lessen the pressure on the surrounding tissue, this is the zone with the most variable design, depending on the implant's depth, design and width [40].

The concavity of the abutment's portion in the Crestal zone greatly benefits the soft tissue surrounding it, increasing the blood flow and tissue growth into a thicker and more robust layer, in turn creating a better seal from possible bacterial infiltrations [56] while the ability to regulate the depth of the crown-abutment connection's margin can be leveraged to allow better removal of the remnants from the cement used to bond the two parts by moving it as coronally as possible towards the Esthetic zone[58].

The design of Custom Abutments reduces the loading pressure on the structure compared to Stock in Wu et al (2010) it was calculated that, using Von Mises stress measured in MPa, it was reduced by 30% on the abutment when the pressure was applied along the abutment long axis (86.2 MPa- Custom / 122.6 MPa- Stock) and increased by 5% on the abutment when it was applied along the implant long axis (323.9 MPa- Custom / 308 MPa- Stock) , but still reducing the overall stress by 9% on the implant body compared to prefabricated abutments (360.9 MPa-Custom/ 396.1 MPa- Stock) , and this reduced pressure is thought to significantly boost the survivability by promoting osteointegration[42].

The abutment's width and height can also be modified according to the patient's needs, for example to accommodate a wide implant with limited occlusal space a reduction of the second in combination with an increase of the first can allow implant placement in a location that would normally not have enough room for a standardly sized crown and abutment [54] or, theoretically, the width can also be reduced to place two adjacent implants closer than two stock abutments would normally allow but this choice is severely limited in its possible applications by the horizontal restorative space needed to ensure uneventful bone growth [60].

When cemented in this reduced occlusal space situation while using the later discussed Titanium with Zirconia coping, the height of the Titanium base in relation to the coping should be maintained as much as possible in order to prevent dislodging, as it was found that even a difference of 1mm is statistically significant [59].

2.5.4- Generic Custom Abutment Disadvantages

Recently custom abutments have been linked with an increase in long-term crestal bone loss, but since the study linked with this find is about the follow-up of 10 year old abutments it might be due to antiquated design choices, materials or even cleaning procedures that failed to account for the inherent risk of contamination tied to milling processes [55].

2.6- Custom Titanium Abutments

2.6.1- CTA Advantages

CAD/CAM Custom Titanium Abutments so far have been showing a remarkable resilience to fracture, either of the abutment itself or of the veneering ceramic, while in multiple studies the Custom Zirconia did fail in those departments, hypothesized to be due to the still imperfect process of sintering, but both custom-made groups have shown better soft tissue stability than Stock Titanium and Stock Zirconia [21].

For implant locations where the more esthetically pleasing Zirconia abutments aren't feasible the option of Anodized Titanium is available, this type of Titanium is obtained with the Anodic Spark Deposition Technique which binds particles to the surface of the abutment to change its colour and slightly alter its chemical composition, which was found to have some light antibacterial properties[36] the hue obtained is derived both from the pigmentation bestowed onto the abutment ,the sintering method employed and the type of Zirconia , with Cercon HT showing the highest positive colour variation amongst the ones experimented upon by DeGirmenci et Saridag (2021)[37].

Of the varied choices of colour available, pink and gold have shown the best clinical results for Anodized Titanium abutments regarding peri-implant soft tissue discoloration, but Zirconia remains the most lifelike material for these implants [38].

2.6.2- CTA Disadvantages

As of now, studies have shown that Prefabricated Titanium and UCLA-type abutments still have a better internal fit with the implant compared to fully digital CAD/CAM Custom abutments, in the 3 regions of interest identifiable in the connection between the Abutment and the Implant (superior gap, marginal gap and centre gap) the digital type showed a statistically wider gap in the centre [22].

2.7- Custom Zirconia Abutments

2.7.1- CZA Advantages

Zirconia custom abutments have a much better esthetic value due to their similarity in colour with the dentine when compared to traditional abutments, this can be achieved either by constructing the abutment and crown entirely out of zirconia that, as a material, has demonstrated an elevated biocompatibility and stability both on the bone margin and periodontal levels, [16] or covering a titanium abutment with a layer of Zirconia to preserve the structural strength of the metal on top of attaining the shade of milled zirconia, preventing the greyish effect on the surrounding mucosa, in this style of abutment the first cementation between the Titanium framework and the covering Zirconia occurs extra-orally [17]and is usually done with Resin Composite Cement, though a recent new method is trying to use Glass-ceramic Soldering techniques to bond the two components mechanically instead of chemically to reduce the chance of infiltration that might occur due to the degradation of cement, but this technology, while showing promising results in terms of thermic resistance and mechanical load capacity, is relatively in its infancy, only a handful of studies have been published and the formula for the solder itself still has to be perfected[46].

It should still be noted that the abutment's visibility is all in relation to the soft tissues' thickness as it has been demonstrated that after it exceeds 3mm the human eye can't distinguish the colour of abutments underneath, making Zirconia's esthetic advantage relevant mostly in patients with a thin gingival biotype [45].

Other materials , namely Lithium Disilicate and Resin-based composite, were used for abutments fabricated with similar purpose to Zirconia and bonded with a Titanium base in order to achieve better esthetics but Guilherme et al. [18] concluded that the latter was unequivocally superior in terms of load-bearing resistance during cyclic stress testing and , while still reporting adhesive failures between the Zirconia and the Titanium, the abutment itself doesn't experience brittle failures like with the other two compared materials.

Custom Zirconia abutments don't have a statistically different clinical performance when it comes to the marginal bone level, soft tissue compatibility, fracture strength and loosening compared to Stock Zirconia abutments, but these same studies also confirm them as a viable alternative while making note of the fact that the interdental papilla showed some enhancement after one year compared to Stock metal cast titanium alloy implant [19].

Another perk of Custom Zirconia abutments when put up against other alternatives to Titanium is the path the fracture follows when the load bearing stress is exceeded, in Co-Cr abutments it's the implant itself that gets fractured or deformed while with Zirconia it's the abutment fracturing, thus needing less extensive treatment to substitute [44].

2.7.2- CZA Disadvantages

Still, it's important to acknowledge fully Zirconia abutments exist and their problems, mainly derived from their rigidity which in turn results in a looser and less precise fit in the marginal gap on top of increased wear to the implant itself leading to a vicious cycle each time the piece is re-tightened in the case of screw-supported crowns [20] and, while Zirconia is the best performing dental ceramic right now when it comes to abutments, it's still subject to brittle fractures and microcracks that don't even have the chance of occurring in metals, dictated by the additional elements present, the processing ,the porosity of the structure and the degree of crystalline transformation into monoclinic or tetragonal Zirconia [52].

In one Clinical Report , Mizumoto et al [43], a woman complained about a “loose crown”, the tooth in question was restored with a One Piece Zirconia abutment connected with a Titanium implant by zinc-eugenol cement, at the moment of removal the crown fractured but the abutment remained intact and, upon further analysis, it was found to have been worn out, with discoloration and Titanium particles embedded, while the implant screw itself was in a state of bone resorption so advanced it was deemed unsalvageable, the relationship between the abutment and the implant is thought to be one of the leading causes of the implant loss in this case.

Milled Zirconia has shown a worse marginal fit compared to Titanium when used in abutments, this misfit can be attributed to the difficulty of milling a relatively brittle ceramic material in conjunction with the common practice of milling it in a pre-sintering stage at an enlarged volume (20-30%, to account for the shrinkage during the sintering process), this in turn is likely to become one of the main causes of friction and wear between the components [51].

The pre-treatment of the surfaces, with mechanical and/or chemical means, and the choice of cement are also critical to the successful bonding of the Zirconia and the Titanium interface to guarantee a long lasting and resilient result, with luting cements which are less susceptible to post-polymerization effects of water showing the best performance in laboratory pressure and exposure tests [48].

2.8- Custom Abutments in Implant Restoration

Custom abutments, both Zirconia and Titanium, can be used to reconstruct implants where the crown and/or the abutment were damaged or had unsatisfactory results due to esthetics or implant angulation.

This can be combined, where the gingiva allows it, with peri-implant soft tissue manipulation to better delineate the emergence profile, but, since this ultimately depends on the patient's own characteristics and many implants chosen for this type of restoration are those belonging to individuals with thin soft tissue biotypes, it can't be always relied upon, Kutkut et al performed a Case Series report of 50 of these treatments, in which both Zirconia and Titanium abutments were reviewed, and the results were overall positive:

Clinically, the criteria of stability, absence of radiolucency and absence of periimplantitis or mucositis were met in all the patients.

Radiographically, no significant bone resorption at the various stages of treatment was recorded, with the emergence profile transferring to the new height provided by the custom abutment.

Esthetically, the papillae had reformed around the new abutment and the definitive crowns, with all the patients satisfied with the final outcome [39].

2.9- Biological Width in Custom Abutments

Implant abutments in general are of critical importance in the preservation of an adequate Biological Space so that the gingival mucosa can better act as a barrier between the oral cavity and the implant body, forming a so-called Biological Seal, to prolong the life of the prothesis and avoid the risk of periimplantitis.

The Peri implant Biological Space has several unique characteristics when compared to the one found alongside natural teeth, such as an increased width of Junctional Epithelium (JE) that, however, lacks the basal lamina that would constitute a true JE [64] and the overall health of the surrounding soft tissues prior to the implant's placement along the surgical technique used, implant/abutment connection, the materials used ,proper hygiene and prothesis maintenance are all factors impacting the formation of a competent Biological Seal[66].

Dib-Zaitum et al. [62] confronted 4 types of Titanium abutments (Regular Anodized, Regular Machined, Slim Anodized and Slim Machined) and concluded that the Slim Abutments' concave centre's ability to stimulate the formation of a competent gingival vascular network around the implant combined with the better surface properties of Machined Titanium when it comes to epithelium growth and plaque retention show the best results, this design philosophy is widely used in custom abutments.

The characteristics of the abutment and implant body surfaces in contact with the soft tissues are also vital in the success of the treatment, as machined surfaces show significantly less plaque accumulation than acid or plasma etched ones [63] without sacrificing the ability of human Keratinocytes to grow on the Titanium but instead improving it, but the current studies, both in vitro and clinical, are divided on the matter, showing diametrically opposite results when it comes to the growth patterns of these cells, this doesn't extend to the process of osseointegration which doesn't respond in any significant way to changes to the implant's surface's texture [67].

One of the strategies that can be used to enhance the Biological Seal is to bind collagen or other peptides via Immobilization of those molecules on the Titanium's surface, which are previously "activated" by using an etching medium such as Plasma or Piranha solution (1:1 mixture of sulfuric acid (H_2SO_4) and hydrogen peroxide (H_2O_2)) to reach the required level of roughness in order to grant fibroblasts a better anchor on the abutment and increase the stability of the seal [65], this in accordance to the studies currently claiming that rough surfaces help the proliferation and adhesion of Keratinocytes.

A significant difference can be noted between One-Piece and Two-Piece implants, with the latter having a wider connective tissue attachment leading to a thicker Biological Space [68].

III- Discussion

Custom Abutments in general present treatment opportunities previously impossible with their mass-produced counterparts, with the ability to adapt to the angle of the implant, modify the width and height to place implants in reduced spaces and avoid or mitigate the myriad of complications associated with the presence of cement remnants, with similar results for both Zirconia and Titanium, regardless of the type of cement used [71].

These designs have also enhanced esthetic and physiological properties, greatly reducing gingival discoloration and "Black Triangles", open interproximal spaces, typically associated with mass produced abutments by employing an anatomical design that favours the formation of a healthy interdental papilla by conditioning the soft tissues while creating a better Biological Seal by increasing the blood flow to the surrounding gingiva which significantly increases their number of possible uses beyond simple cosmetic purposes [72].

One of the major functional properties of abutments is resilience to screw loosening and, while Stock Abutments are made with that property in mind so that they can be used at their most efficient alongside Implants of the same brand, Custom Abutments must follow guidelines from each manufacturer about their specifications [69].

Stock Abutments remain as a valid choice, due to the wide array of options that were developed for the international market filling almost all the gaps, the much easier time the implantologist has when putting them to use, since the prefabricated implant body and abutment from the same brand are made to fit together with the tiniest margin of error [73] and don't need the often labour-intensive procedures used to build Custom Abutments, and also the increased costs that these procedures bring with them for the patient and the dentist alike on top of the location of the clinic compared to laboratories able to create these abutments.

When comparing the possible benefits, documented outcomes and available evidence of all the types of Custom Abutments, Titanium-based Custom Abutments are a cut above the rest of the other options in almost every field, not only offering the biocompatibility and stability of Titanium, but also improving the marginal fit compared to the other materials and, when coupled with a Zirconia cap, can match the full Zirconia Abutments in the esthetic department too, other options such as the Anodization procedure to modify the Titanium's colour to gold or pink have been linked to decreased growth of the peri-implant tissues compared to Machined Titanium so they need further evaluation and experimentation before they can become a mainstay of the industry.

To make matters more complicated in regards to Anodized Titanium's use in Custom Abutments, a virtually equal amount of studies claim they have no significant effect on both esthetic and function of peri-implant soft tissues [74] or that they present the optimal surface for the growth of the very same structures due to the rough granular layer formed by the Anodization process and that the change in colour has drastic effects on the final esthetic result [75] making this topic in particular highly divisive in the discipline.

Full Zirconia Abutments manufacturers haven't yet found the right formula to prevent completely uneventful and fully predictable sintering or to address the fragility of the material while milling and the increased risk of fracture, even though there has been a marked improvement compared to the early attempts mainly due to more stable designs [70], in addition to the gap between the abutment and the implant body, which was linked with an increased rate of failure in several studies, is still a weak point that must be resolved.

Alternatives to the more widespread materials, such as PEEK, Co-Cr, Precious Alloys and Lithium Disilicate, have been clinically tested with moderate to good success rates, but as the substances they're mainly competing with, Titanium and Zirconia, have a much more extensive and documented history in dentistry so they're currently lacking the appropriate number of long-term studies to be used on a large scale.

IV- Conclusion

Due to their multiple benefits to both the esthetic and biological aspects of implants Custom Abutments are showing great promise and are poised to become part of the array of standard treatments offered, with additional benefits for the anterior maxilla and angled implants, once their manufacturing and distribution is widespread enough, but Titanium and ceramics have yet to be surpassed by any of the other materials the various production companies have been experimenting on, with Titanium Custom Abutments coupled with a Zirconia coping having the best performance for the foreseeable future.

Bibliography

1) Alshehri M. , Alghamdi M. and Alayad A. S. (2020) . Anatomical Shaping for Zirconia Custom Implant Abutment to Enhance Anterior Esthetic: A Clinical Technique in "International Journal of Dentistry" , 1-5
2) Chen Y.-W., Moussi J., Drury J. L., and Wataha J. C., (2016) *Zir-conia in biomedical applications*, Expert Review of MedicalDevices, vol. 13, no. 10, pp. 945–963
3) Hanawa T. (2020) *Zirconia versus titanium in dentistry: A review* Dental Materials Journal ; 39(1): 24–36
4) Lee, Jee-Ho; Park, Ji-Man; Park, Eun-Jin; Koak, Jai-Young; Kim, Seong-Kyun; Heo, Seong-Joo (2016). *Comparison of Customized Abutments Made from Titanium and a Machinable Precious Alloy*. The International Journal of Oral & Maxillofacial Implants, 31(1), 92–100.
5) P. Serichetaphongse ; W. Chengprapakorn;S. Thongmeearkom;A. Pimkhaokham(2020). *Immunohistochemical assessment of the peri-implant soft tissue around different abutment materials: A human study*. Clinical Implant Dentistry and Related Research, 22(5), 638–646.
6) J.J. Lee; K. Song, S. Ahn; J. Choi; J. Seo; J. Park (2015). *Evaluation of effect of galvanic corrosion between nickel-chromium metal and titanium on ion release and cell toxicity.* The Journal of Advanced Prosthodontics, 7(2), 172–.
7) Aktas G, Guncu MB, Akcin ET, Cakan U, Canay S. (2021) *Effect of Anti-Rotational Abutment Features and Novel Computerized Fabrication Techniques on the Marginal Fit of Implant-Supported Metal Copings.* J Prosthodont.252-256.
8) Markarian, R. A., Galles, D. P., & França, F. (2021). *Dental implant-abutment fracture resistance and wear induced by single-unit screw-retained CAD components fabricated by four CAM methods after mechanical cycling.* The Journal of prosthetic dentistry, S0022-3913(21)00059-7. Advance online publication.
9) Surovas A. (2019). *A digital workflow for modeling of custom dental implants.* 3D printing in medicine, 5(1), 9.
10) Gehrke, P., Abazari, C., Schlichter, K., Fischer, C., Duddeck, D., Romanos, G. E., & Weigl, P. (2020). *Qualitative and Semi-Quantitative Assessment of Processing-Related Surface Contamination of One- and Two-Piece CAD/CAM Abutments before and after Ultrasonic Cleaning.* Materials (Basel, Switzerland), 13(14), 3225.
11) Sasada, Y., & Cochran, D. L. (2017). *Implant-Abutment Connections: A Review of Biologic Consequences and Peri-implantitis Implications*. The International journal of oral & maxillofacial implants, 32(6), 1296–1307.
12) Guglielmotti, M. B., Olmedo, D. G., & Cabrini, R. L. (2019). *Research on implants and osseointegration*. Periodontology 2000, 79(1), 178–189.
13) Caricasulo, R., Malchiodi, L., Ghensi, P., Fantozzi, G., & Cucchi, A. (2018). *The influence of implant-abutment connection to peri-implant bone loss: A systematic review and meta-analysis.* Clinical implant dentistry and related research, 20(4), 653–664.
14) Wagner, G., & Hartung, D. (2021). *One-Piece Titanium Implants: Retrospective Case Series.* Case reports in dentistry, 2021, 6688355.
15) Paolantoni, G., Marenzi, G., Blasi, A., Mignogna, J., & Sammartino, G. (2016). *Findings of a Four-Year Randomized Controlled Clinical Trial Comparing Two-Piece and One-Piece Zirconia Abutments Supporting Single Prosthetic Restorations in Maxillary Anterior Region*. BioMed research international, 2016, 8767845.
16) Xu, J. H., Jiang, J., Shen, C. L., Chen, X. Y., Zhu, L. Q., & Wang, H. M. (2020). *Effect of customized zirconia abutment on peri-implant tissue: a one-year prospective study.* Chinese journal of stomatology, 55(11), 885–890.
17) Valsan, I. M., Pauna, M. R., Petre, A. E., & Oancea, L. (2021). *Biologic and Esthetic Outcome of CAD/CAM Custom Ceramic Implant Abutment: A Clinical Report.* Maedica, 16(1), 145–148.
18) Guilherme, N. M., Chung, K. H., Flinn, B. D., Zheng, C., & Raigrodski, A. J. (2016). Assessment of reliability of CAD-CAM tooth-colored implant custom abutments. The Journal of prosthetic dentistry, 116(2), 206–213.
19) Schepke, U., Meijer, H. J., Kerdijk, W., Raghoebar, G. M., & Cune, M. (2017). *Stock Versus CAD/CAM Customized Zirconia Implant Abutments - Clinical and Patient-Based Outcomes in a Randomized Controlled Clinical Trial*. Clinical implant dentistry and related research, 19(1), 74–84.
20) Barbosa, S. A., Jr, Bacchi, A., Barão, V., Silva-Souza, Y. T., Bruniera, J. F., Caldas, R. A., & Consani, R. (2020). Implant Volume Loss, Misfit, Screw Loosening, and Stress In Custom Titanium and Zirconia Abutments. Brazilian dental journal, 31(4), 374–379.
21) Piattelli, A., Pontes, A. E., Degidi, M., & Iezzi, G. (2011). Histologic studies on osseointegration: soft tissues response to implant surfaces and components. A review. Dental materials : official publication of the Academy of Dental Materials, 27(1), 53–60.
22) Lops, D., Bressan, E., Parpaiola, A., Sbricoli, L., Cecchinato, D., & Romeo, E. (2015). *Soft tissues stability of cad-cam and stock abutments in anterior regions: 2-year prospective multicentric cohort study*. Clinical oral implants research, 26(12), 1436–1442.
23) Ramalho, I., Witek, L., Coelho, P. G., Bergamo, E., Pegoraro, L. F., & Bonfante, E. A. (2020). Influence of Abutment Fabrication Method on 3D Fit at the Implant-Abutment Connection. The International journal of prosthodontics, 33(6), 641–647.
24) King, G. N., Hermann, J. S., Schoolfield, J. D., Buser, D., & Cochran, D. L. (2002). Influence of the size of the microgap on crestal bone levels in non-submerged dental implants: a radiographic study in the canine mandible. Journal of periodontology, 73(10), 1111–1117.

25) Ranieri, R., Ferreira, A., Souza, E., Arcoverde, J., Dametto, F., Gade-Neto, C., Seabra, F., & Sarmento, C. (2015). The bacterial sealing capacity of morse taper implant-abutment systems in vitro. Journal of periodontology, 86(5), 696–702.
26) Mishra, S. K., Chowdhary, R., & Kumari, S. (2017). Microleakage at the Different Implant Abutment Interface: A Systematic Review. Journal of clinical and diagnostic research : JCDR, 11(6), ZE10–ZE15.
27) Calamia J. R. (1994). Advances in computer-aided design and computer-aided manufacture technology. Current opinion in cosmetic dentistry, 67–73.
28) Eidenbenz, S., Lehner, C. R., & Schärer, P. (1994). Copy milling ceramic inlays from resin analogs: a practicable approach with the CELAY system. The International journal of prosthodontics, 7(2), 134–142.
29) Fritzsche G. (2003). Correlation and function in Cerec 3D--what is new?. International journal of computerized dentistry, 6(1), 83–88.
30) Allen, K. L., Schenkel, A. B., & Estafan, D. (2004). An overview of the CEREC 3D CAD/CAM system. General dentistry, 52(3), 234–235.
31) Lewis, S. G., Llamas, D., & Avera, S. (1992). The UCLA abutment: a four-year review. The Journal of prosthetic dentistry, 67(4), 509–515.
32) Kerstein, R. B., Castellucci, F., & Osorio, J. (2000). Ideal gingival form with computer-generated permanent healing abutments. Compendium of continuing education in dentistry (Jamesburg, N.J. : 1995), 21(10), 793–802.
33) Kucey, B. K., & Fraser, D. C. (2000). The Procera abutment--the fifth generation abutment for dental implants. Journal (Canadian Dental Association), 66(8), 445–449.
34) Soo, S. Y., Silikas, N., & Satterthwaite, J. (2019). Measurement of Fracture Strength of Zirconia Dental Implant Abutments with Internal and External Connections Using Acoustic Emission. Materials (Basel, Switzerland), 12(12), 2009.
35) Drago, C. J., & Peterson, T. (2007). Treatment of an edentulous patient with CAD/CAM technology: a clinical report. Journal of prosthodontics : official journal of the American College of Prosthodontists, 16(3), 200–208.
36) Visai, L., Rimondini, L., Giordano, C., Del Curto, B., Sbarra, M. S., Franchini, R., Della Valle, C., & Chiesa, R. (2008). Electrochemical surface modification of titanium for implant abutments can affect oral bacteria contamination. Journal of applied biomaterials & biomechanics : JABB, 6(3), 170–177.
37) DeGirmenci, K., & Saridag, S. (2021). Influence of anodized titanium abutment backgrounds on the color parameters of different zirconia materials. American journal of dentistry, 34(1), 39–43.
38) Wang, T., Wang, L., Lu, Q., & Fan, Z. (2021). Influence of anodized titanium abutments on the esthetics of the peri-implant soft tissue: A clinical study. The Journal of prosthetic dentistry, 125(3), 445–452.
39) Kutkut, A., Abu-Hammad, O., & Mitchell, R. (2015). Esthetic Considerations for Reconstructing Implant Emergence Profile Using Titanium and Zirconia Custom Implant Abutments: Fifty Case Series Report. The Journal of oral implantology, 41(5), 554–561.
40) Gomez-Meda, R., Esquivel, J., & Blatz, M. B. (2021). The esthetic biological contour concept for implant restoration emergence profile design. Journal of esthetic and restorative dentistry : official publication of the American Academy of Esthetic Dentistry ... [et al.], 33(1), 173–184.
41) Dumbrigue, H. B., Abanomi, A. A., & Cheng, L. L. (2002). Techniques to minimize excess luting agent in cement-retained implant restorations. The Journal of prosthetic dentistry, 87(1), 112–114.
42) Wu, T., Liao, W., Dai, N., & Tang, C. (2010). Design of a custom angled abutment for dental implants using computer-aided design and nonlinear finite element analysis. Journal of biomechanics, 43(10), 1941–1946.
43) Mizumoto, R. M., Malamis, D., Mascarenhas, F., Tatakis, D. N., & Lee, D. J. (2020). Titanium implant wear from a zirconia custom abutment: A clinical report. The Journal of prosthetic dentistry, 123(2), 201–205.
44) Markarian, R. A., Galles, D. P., & França, F. (2021). Dental implant-abutment fracture resistance and wear induced by single-unit screw-retained CAD components fabricated by four CAM methods after mechanical cycling. The Journal of prosthetic dentistry, S0022-3913(21)00059-7. Advance online publication.
45) Linkevicius, T., & Vaitelis, J. (2015). The effect of zirconia or titanium as abutment material on soft peri-implant tissues: a systematic review and meta-analysis. Clinical oral implants research, 26 Suppl 11, 139–147.
46) Hey, J., Kasaliyska, M., Kiesow, A., Schweyen, R., & Arnold, C. (2020). Retentive Force of Glass-Ceramic Soldered Customized Zirconia Abutment Copings with Prefabricated Titanium Bases. Materials (Basel, Switzerland), 13(14), 3193.
47) Vetromilla, B. M., Brondani, L. P., Pereira-Cenci, T., & Bergoli, C. D. (2019). Influence of different implant-abutment connection designs on the mechanical and biological behavior of single-tooth implants in the maxillary esthetic zone: A systematic review. The Journal of prosthetic dentistry, 121(3), 398–403.e3.
48) Bankoğlu Güngör, M., & Karakoca Nemli, S. (2018). The Effect of Resin Cement Type and Thermomechanical Aging on the Retentive Strength of Custom Zirconia Abutments Bonded to Titanium Inserts. *The International journal of oral & maxillofacial implants*, *33*(3), 523–529.
49) Pitta, J., Hjerppe, J., Burkhardt, F., Fehmer, V., Mojon, P., & Sailer, I. (2021). Mechanical stability and technical outcomes of monolithic CAD/CAM fabricated abutment-crowns supported by titanium bases: An in vitro study. *Clinical oral implants research*, *32*(2), 222–232.

50) Al-Rabab'ah, M., Hamadneh, W., Alsalem, I., Khraisat, A., & Abu Karaky, A. (2019). Use of High Performance Polymers as Dental Implant Abutments and Frameworks: A Case Series Report. *Journal of prosthodontics : official journal of the American College of Prosthodontists*, *28*(4), 365–372.
51) Abduo, J., & Yin, L. (2019). Fits of Implant Zirconia Custom Abutments and Frameworks: A Systematic Review and Meta-Analyses. *The International journal of oral & maxillofacial implants*, *34*(1), 99–114.
52) Rekow, E. D., Silva, N. R., Coelho, P. G., Zhang, Y., Guess, P., & Thompson, V. P. (2011). Performance of dental ceramics: challenges for improvements. *Journal of dental research*, *90*(8), 937–952.
53) Gupta, R., Gupta, N., & Weber, K. K. (2021). Dental Implants. In *StatPearls*. StatPearls Publishing.
54) Bittner, N., Lal, K., & Neurohr, J. (2008). Fabrication of a custom abutment for a wide-diameter implant in a situation with limited interocclusal space. The Journal of prosthetic dentistry, 100(6), 474–477.
55) Romanos, G. E., Gurbanov, S., Hess, P., Nentwig, G. H., Schwarz, F., & Sader, R. (2022). Crestal bone loss and implant failure of prefabricated versus customized abutments: a 10-year retrospective radiological study. *Clinical oral investigations*, *26*(3), 2879–2886.
56) Otero, N., Scarton, J., Pizzolante, L. L., Inglese, S., Sclar, A. G., & Wong, F. (2018). The Effect of Implant Abutment Design on Long-Term Soft Tissue Stability: A Clinical Case Report. The International journal of periodontics & restorative dentistry, 38(6), 841–847.
57) Canullo, L., Tallarico, M., Penarrocha, M., Corrente, G., Fiorellini, J., & Penarrocha, D. (2017). Plasma of Argon Cleaning Treatment on Implant Abutments in Periodontally Healthy Patients: Six Years Postloading Results of a Randomized Controlled Trial. The International journal of periodontics & restorative dentistry, 37(5), 683–690.
58) Gehrke, P., Bleuel, K., Fischer, C., & Sader, R. (2019). Influence of margin location and luting material on the amount of undetected cement excess on CAD/CAM implant abutments and cement-retained zirconia crowns: an in-vitro study. BMC oral health, 19(1), 111.
59) Abbo, B., Razzoog, M. E., Vivas, J., & Sierraalta, M. (2008). Resistance to dislodgement of zirconia copings cemented onto titanium abutments of different heights. The Journal of prosthetic dentistry, 99(1), 25–29.
60) Carpentieri, J., Greenstein, G., & Cavallaro, J. (2019). Hierarchy of restorative space required for different types of dental implant prostheses. Journal of the American Dental Association (1939), 150(8), 695–706.
61) Rahmitasari, F., Ishida, Y., Kurahashi, K., Matsuda, T., Watanabe, M., & Ichikawa, T. (2017). PEEK with Reinforced Materials and Modifications for Dental Implant Applications. Dentistry journal, 5(4), 35.
62) Dib-Zaitum, I., Guadilla-González, Y., Flores-Fraile, J., Dib-Zakkour, J., Benito-Garzón, L., & Montero, J. (2022). Effect Morphology and Surface Treatment of the Abutments of Dental Implants on the Dimension and Health of Peri-Implant Biological Space. Materials (Basel, Switzerland), 15(13), 4422.
63) Baldi, D., Menini, M., Pera, F., Ravera, G., & Pera, P. (2009). Plaque accumulation on exposed titanium surfaces and peri-implant tissue behavior. A preliminary 1-year clinical study. The International journal of prosthodontics, 22(5), 447–455.
64) DE SANCTIS, M., BALDINI, N., & VIGNOLETTI, F. (2010). Biological width around implants. Journal de Parodontologie & d’Implantologie Orale, 29(4).
65) Marín-Pareja, N., Salvagni, E., Guillem-Marti, J., Aparicio, C., & Ginebra, M. P. (2014). Collagen-functionalised titanium surfaces for biological sealing of dental implants: effect of immobilisation process on fibroblasts response. Colloids and surfaces. B, Biointerfaces, 122, 601–610.
66) Myshin, H. L., & Wiens, J. P. (2005). Factors affecting soft tissue around dental implants: a review of the literature. The Journal of prosthetic dentistry, 94(5), 440–444.
67) Lauer, G., Wiedmann-Al-Ahmad, M., Otten, J. E., Hübner, U., Schmelzeisen, R., & Schilli, W. (2001). The titanium surface texture effects adherence and growth of human gingival keratinocytes and human maxillar osteoblast-like cells in vitro. Biomaterials, 22(20), 2799–2809.
68) Judgar, R., Giro, G., Zenobio, E., Coelho, P. G., Feres, M., Rodrigues, J. A., Mangano, C., Iezzi, G., Piattelli, A., & Shibli, J. A. (2014). Biological width around one- and two-piece implants retrieved from human jaws. BioMed research international, 2014, 850120.
69) Kim, E. S., & Shin, S. Y. (2013). Influence of the implant abutment types and the dynamic loading on initial screw loosening. The journal of advanced prosthodontics, 5(1), 21–28.
70) Yilmaz, B., Salaita, L. G., Seidt, J. D., McGlumphy, E. A., & Clelland, N. L. (2015). Load to failure of different zirconia abutments for an internal hexagon implant. The Journal of prosthetic dentistry, 114(3), 373–377.
71) Hsu, K. W., Liang, C. H., Peng, Y. C., & Hsiao, C. C. (2021). Comparison of the residual cement on custom computer-aided design and computer-aided manufacturing titanium and zirconia abutments: A preliminary cohort study. The Journal of prosthetic dentistry, S0022-3913(21)00323-1. Advance online publication.
72) Urban, I. A., Barootchi, S., Tavelli, L., & Wang, H. L. (2021). Inter-Implant Papilla Reconstruction via a Bone and Soft Tissue Augmentation: A Case Report with a Long-Term Follow-up. The International journal of periodontics & restorative dentistry, 41(2), 169–175.
73) Alonso-Pérez, R., Bartolomé, J. F., Ferreiroa, A., Salido, M. P., & Pradíes, G. (2017). Evaluation of the Mechanical Behavior and Marginal Accuracy of Stock and Laser-Sintered Implant Abutments. The International journal of prosthodontics, 30(2), 136–138.

74) Farrag, K. M., & Khamis, M. M. (2021). Effect of anodized titanium abutment collars on peri-implant soft tissue: A split-mouth clinical study. The Journal of prosthetic dentistry, S0022-3913(21)00518-7. Advance online publication.
75) Mühl, A., Szabó, P., Krafcsik, O., Aigner, Z., Kopniczky, J., Ákos Nagy, Marada, G., & Turzó, K. (2022). Comparison of surface aspects of turned and anodized titanium dental implant, or abutment material for an optimal soft tissue integration. Heliyon, 8(8), e10263.
76) Bédouin, Y., Lefrançois, E., Salomon, J. P., & Auroy, P. (2021). Abutment rotational freedom on five implant systems with different internal connections. The Journal of prosthetic dentistry, S0022-3913(21)00266-3. Advance online publication.

Figure Index

Figure (1) Klongbunjit, D., Aunmeungtong, W., & Khongkhunthian, P. (2021). Implant-abutment screw removal torque values between customized titanium abutment, straight titanium abutment, and hybrid zirconia abutment after a million cyclic loading: an in vitro comparative study.