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Implant Abutment Materials

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INTRODUCTION

A wide variety of abutment materials are available on the dental implant market. A major challenge for clinicians today is understanding the biologic response to each material, as well as the best indication for using each of the different types.

To complicate this problem, there are no well defined and comprehensive sources reviewing the properties associated with abutment materials. This chapter provides relevant information on abutment materials and their soft tissue response.

MUCOSAL SEAL

The mucosal seal surrounding a dental implant abutment is an essential factor in preventing bacterial penetration into the crestal bone and around the implant neck. In order to understand the soft tissue response, it is important to be familiar with the anatomy of the mucosal seal.

Natural Dentition

The periodontal soft tissue is an important factor in a person's natural protection against periodontal disease. The biologic width is the depth of soft tissue below the sulcus in the natural dentition. It consists of a junctional epithelium and connective tissue layer. The junctional epithelium ranges from 1 to 2 mm wide followed apically by a 1 mm layer of connective tissue. The alveolar bone lies just below this connective tissue.

In the natural dentition, this zone has been proven to be essential for protecting the periodontium from plaque and bacteria penetration into the oral cavity. The junctional epithelium attaches to the teeth with a hemidesmisomal attachment, providing a shield against bacteria. The connective tissue layer contains collagen fibers that insert into the teeth and cementum perpendicularly to the tooth. These fibers provide additional reinforcement against an apically migrating junctional epithelium caused by periodontal disease.

Peri-implant Mucosal Seal

A mucosal seal surrounding dental implants is also essential in avoiding peri-implantitis. The biologic width surrounding dental implants also contains a junctional epithelium, followed apically by a connective tissue layer. As in the natural dentition, the coronal portion of the biologic width contains the junctional epithelium. In 1984, Gould and colleagues demonstrated that this junctional epithelium attaches to the titanium surface in a similar manner to the natural dentition, with hemidesmosomes. A connective tissue attachment can be found further apically. Buser et al. (1992) described this attachment as being rich in collagen fibers but sparse in cells or resembling scar tissue.

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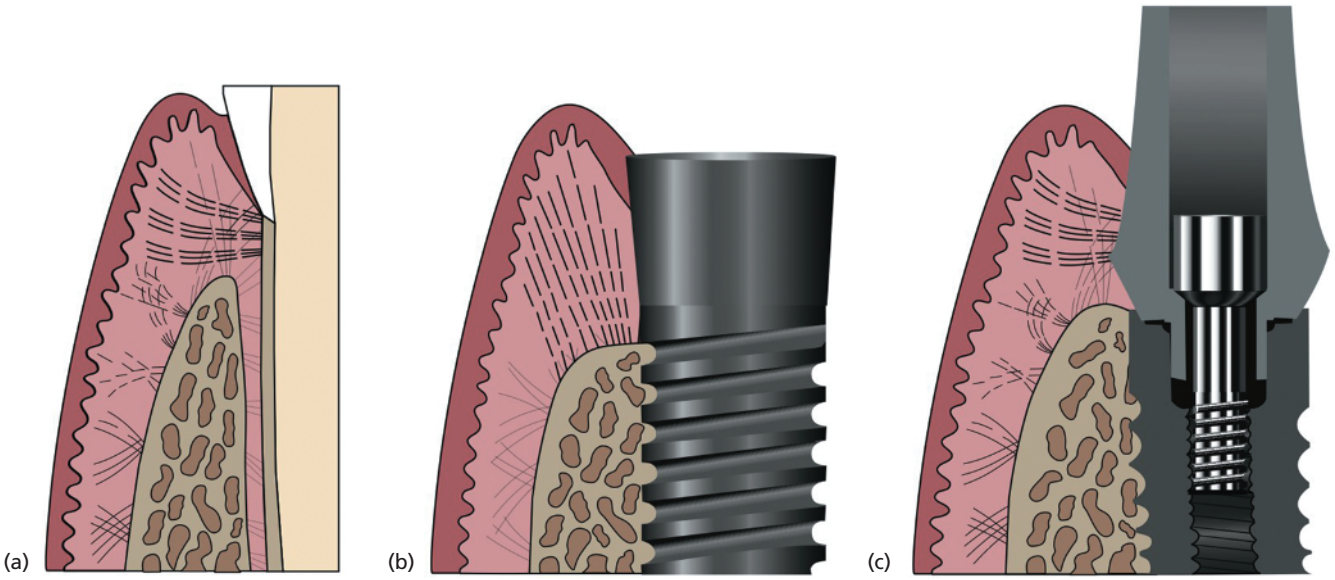

Figure 1.1 Note the perpendicular collagen fibers in the natural dentition (a) and Laser-Lok abutments (c) in comparison to the parallel collagen fibers with other implant abutments (b).

Unlike the natural dentition, in implant abutments the apical connective tissue fibers do not have the same quality of attachments. The natural dentition has dentogingival fibers running perpendicular to the tooth from the bone to the cementum. The connective tissue layer surrounding a dental implant abutment has fibers running in a parallel fashion (Figure 1.1). The only exception to this histology is with Laser-Lok™ abutments which are discussed later in this chapter.

Due to the weakened connective tissue support around implant abutments, the junctional epithelium is believed to be more susceptible to apical migration. In other words, a dental implant is more susceptible to peri-implantitis than a natural tooth is to periodontitis.

It is important to note that this biologic width or "peri-implant seal" protects the implant against peri-implantitis and provides an esthetic result. When considering which abutment type to use one should consider how well the abutment *forms* and *maintains* this mucosal seal.

PELLICLE, BIOFILM, AND PERIODONTAL DISEASE

One of the key factors in selecting an abutment material is its hygienic property. To review the importance of hygiene it is important to understand pellicle formation, subsequent biofilm production, and the pathway of peri-implantitis development.

Pellicle

The process of plaque formation begins with glycoproteins attaching to the surface of the enamel or an abutment, creating a thin layer called the pellicle. Although this layer by itself is harmless, it provides a framework for bacteria to adhere to.

Biofilm

A biofilm is an aggregation of multiple organisms coexisting together. Initially, Gram-positive aerobic cocci adhere to this thin glycoprotein layer or pellicle. As these bacteria multiply, the bacterial colonies multiply creating a more anaerobic environment. This anaerobic environment then permits more harmful Gram-negative rods to collect within the biofilm. The biofilm creates an acidic environment that contributes to dental caries but, more relevant to the topic at hand, the biofilm also contributes to periodontal disease.

Periodontal Disease in the Natural Dentition

Periodontal disease is caused by the biofilm, which destroys the periodontium and causes loss of the alveolar bone and inflammation of the periodontal tissues. This is not a novel development – the landmark paper by Page and Schroeder outlined this process of periodontal disease back in 1976.

Peri-implantitis

As in the natural dentition, development of the pellicle and biofilm and subsequent inflammation also occurs with dental implants. This process can cause the potential for apical migration of the peri-implant seal and bone loss. The process of peri-implantitis is more common with dental implants than periodontal disease is with natural dentition. This is because the peri-implant mucosal seal is not as effective (except in the case of Laser-Lok abutments) as the mucosal seal surrounding the natural dentition.

As will be discussed, some abutments have enhanced capabilities for resisting bacterial colonization. Other abutments have improved capabilities for forming a more resistant mucosal seal with a strengthened connective tissue attachment.

IMPLANT ABUTMENT MATERIAL RELATED RESEARCH

The remainder of this chapter focuses on the variety of abutments available on the market. Different abutment materials will be compared in terms of their ability to *form* and *maintain* the "peri-implant seal." Carefully chosen research has been selected to demonstrate how the varieties of abutments specifically affect soft tissue.

The most commonly used implant abutment materials (Figure 1.2, Table 1.1) to be discussed are:

- Titanium:
  - machined
  - polished
  - Laser-Lok.
- Surgical grade stainless steel.
- Cast gold.
- Zirconia.
- Polyether ether ketone (PEEK).

Titanium

Physical properties

Titanium is the only element that offers the unique combination of strength, light weight, and biocompatibility, as well as being extremely durable and strong. Titanium has high corrosion resistant and the highest strength to weight ratio of any known element (Figure 1.3).

Titanium abutments are either made of commercially pure titanium or titanium alloy.

Commercially pure titanium Commercially pure (CP) titanium is widely utilized for medical applications because of its corrosion resistant, high strength, and biocompatible applications. The mechanical properties of CP titanium are influenced by small additions of oxygen and iron. By careful control of these additions, the various grades of CP titanium are produced to give properties suited to different applications. CP titanium with the lowest oxygen and iron levels makes the most formable grade of material; while progressively higher oxygen content results in higher strength levels.

Figure 1.2 Different types of abutments made of different materials by Dentsply Implants.

Table 1.1 Abutment materials and soft tissue response

Abutment material	Forming the peri-implant seal	Maintaining the peri-implant seal
Titanium (machined or polished)	Long-term studies supporting favorable soft tissue results with machined or polished titanium. Most validated abutment material in the literature	Long-term studies supporting favorable soft tissue maintenance with machined or polished titanium. Most validated abutment material in the literature
Titanium abutments with a Laser-Lok transmucosal collar	Greatest ability to form a connective tissue attachment compared with all other abutment materials on the market	Strongest peri-implant seal permitting improved long-term soft tissue maintenance (comparable mucosal seal to the natural dentition)
Gold	Conflicting studies in the literature concerning the ability to form an adequate peri-implant seal	Conflicting studies concerning the long-term maintenance of the peri-implant seal
PEEK (polyether ether ketone)	Comparable soft tissue results to titanium	Comparable hygienic properties to titanium
Zirconia	Comparable ability to form a peri-implant seal to that of machined or polished titanium	Most hygienic abutment on the market allowing improved long-term maintenance of the peri-implant seal

Commercially pure titanium grades

- CP titanium grade 1 (*softest*)
- CP titanium grade 2
- CP titanium grade 3
- CP titanium grade 4 (*hardest*)

Color Titanium abutments come either with a silver gold color coating (Figure 1.4).

The gold color coating over the surface of the abutment is called titanium nitride. The titanium nitride (TiN; sometimes known as "Tinite," "TiNite," or "TiN") coating is created by a plasma coating process in which titanium and nitrogen ions are combined with TiN, and then molecularly bonded with the titanium substrate of the abutment. TiN was first used in the medical device industry in the 1980s. Biocompatibility testing has been conducted on TiN over many years and this testing, as well as subsequent clinical applications, has demonstrated that TiN is biocompatible and appropriate for use in implantable medical devices that come in contact with bone, skin, tissues, or blood (Figure 1.5).

Titanium nitride is an extremely hard ceramic material, often used as a coating over the titanium component to not only improve the substrate's surface properties but also to achieve a warm, esthetic tone under the gingiva because of its gold shaded hue. Generally, the TiN coating covers the entire abutment except for the contact area between the abutment/implant and screw/abutment. This type of titanium abutment is ideal for esthetically challenging cases with thin soft tissue or when using an all-ceramic crown. In most applications the TiN coating is less than 5 micrometers (0.00020 inches) thick. This coating is only meaningful with CAD/CAM milled abutments where the abutment is not adjusted. Prefabricated abutments are adjusted and generally will lose any strength added by the nitrates following the abutment adjustment.

Titanium alloy (Ti-6Al-4V, Ti6Al4V, or Ti-6-4)

Titanium alloy is also called grade 5 titanium. Titanium alloy contains 6% aluminum, 4% vanadium, 0.25% (maximum) iron, 0.2% (maximum) oxygen, and the remainder titanium. Ti-6Al-4V alloy is significantly stronger than commercially pure titanium and offers better tensile strength and fracture resistance (Figure 1.6).

Because of titanium's unique physical properties, titanium abutments are the first choice for posterior implants. These abutments are available as prefabricated stock or CAD/CAM milled customized abutments.

There is an extensive literature validating the favorable soft tissue response with titanium abutments. Because the majority of the research about peri-implant tissue and abutment materials is based on titanium abutment, this material has become a reference point in describing the properties of other abutment materials.

Machined versus polished titanium and soft tissue responses

Surface roughness is the key difference between machined and polished titanium. This section evaluates whether there is a clinically significant difference between the soft tissue response to polished and machined titanium.

The break down of the peri-implant seal is brought on by the development of a pellicle, biofilm, and inflammation followed by alveolar bone loss. It is well established that the initial glycoproteins and biofilm are more likely to attach to a rough surface than a smooth one. With this logic it could be wrongly assumed that abutments with a smoother surface have less inflammatory response, thus less bone resorption. However, multiple clinical studies have failed to show a clinically significant relationship between an inflammatory response and a roughened abutment surface.

To provide one of many examples, Zitzmann's study concluded that there was no relation between inflammatory response and the abutment surface roughness (Abrahamsson et al. 2002).

Zitzmann's study on the differences in soft tissue response with smooth and rough abutments

- This study used four implants into the premolar regions of five separate beagle dogs
- After 3 months abutments roughened with acid etching and smoother abutments with a turned surface characteristic were placed
- Six months later biopsies of the implants and the surrounding soft and hard tissues were obtained
- No significant differences were noted between the soft tissue attachments near the rough and smooth abutments

In conclusion, although it has been shown that bacteria are more likely to aggregate on a roughened surface, clinical studies between titanium abutments on the market fail to show this relationship. There is no clinically significant different soft tissue response to machined and polished titanium.

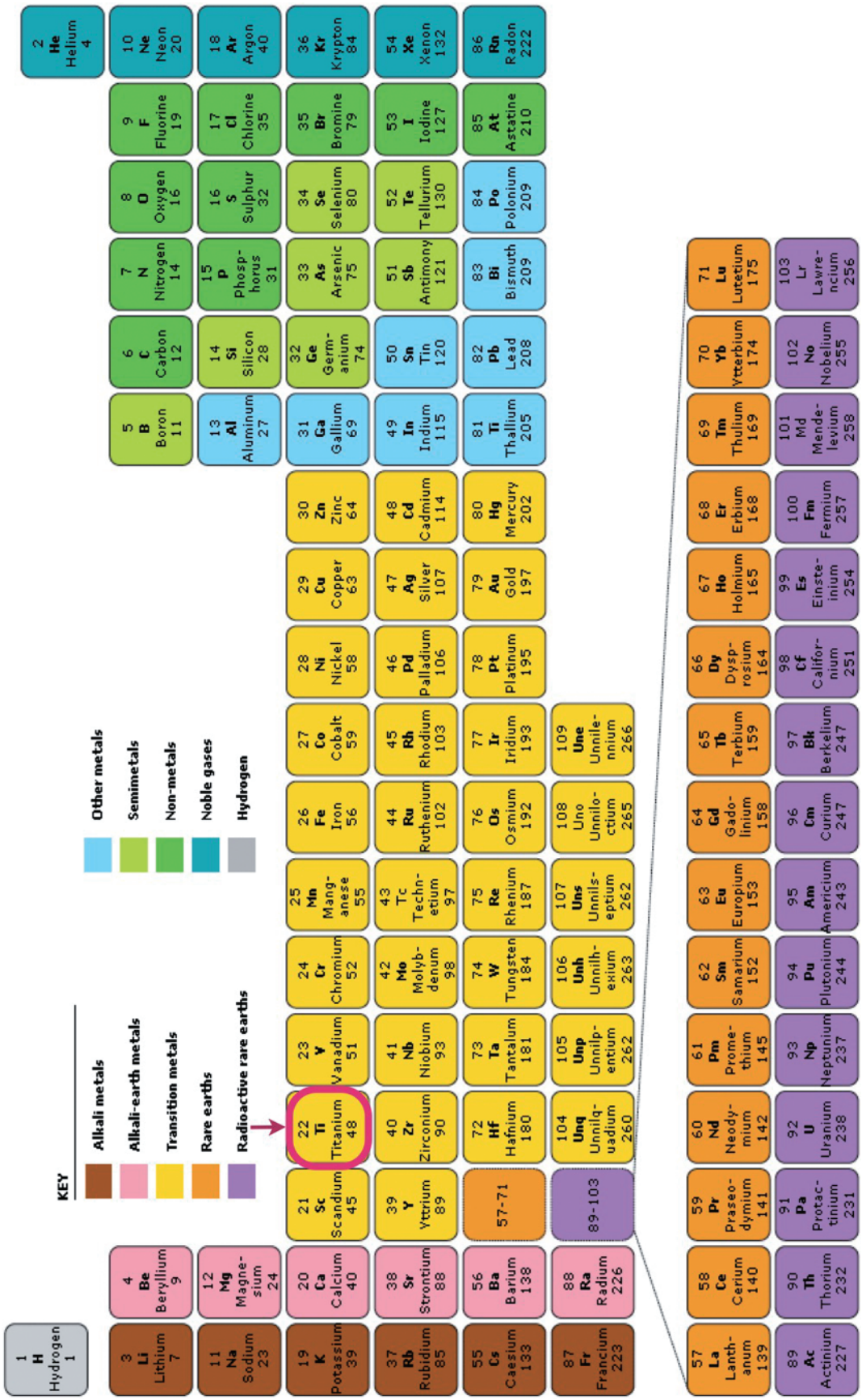

Figure 1.3 The location of titanium on the periodic table.

Prefabricated abutments with a Laser-Lok surface characteristic are a new innovative product (Figure 1.7). The Laser-Lok consists of 8–12 micron titanium micro-channels. These micro-channels provide the following advantages:

- They enhance the establishment of a connective tissue attachment.
- They inhibit the apical migration of the junctional epithelium.
- They preserve the crestal bone.

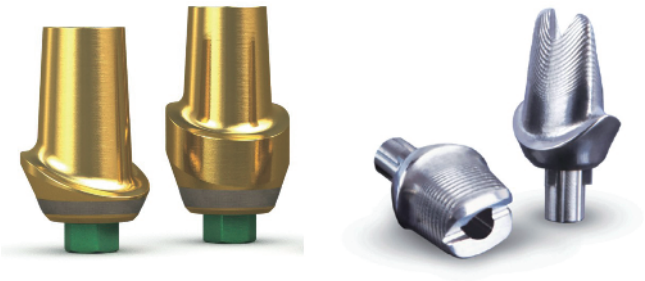

Figure 1.4 Gold (left) and silver (right) color titanium abutments.

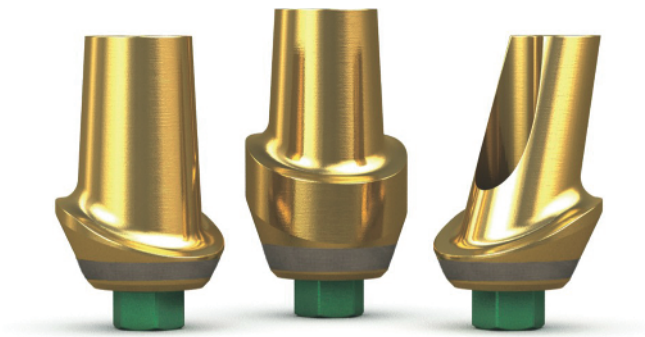

Figure 1.5 Titanium nitride abutments.

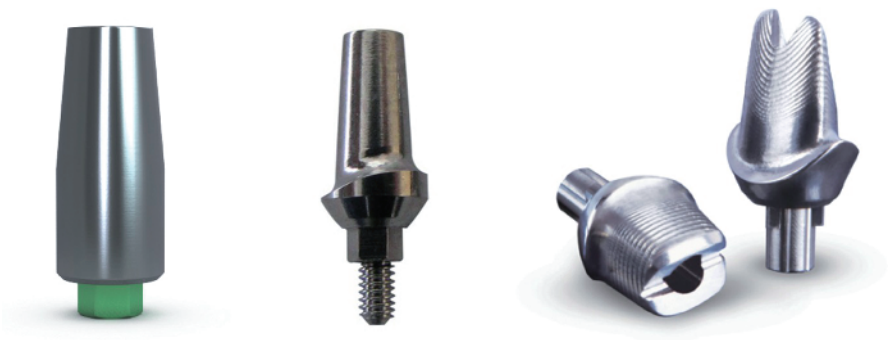

Figure 1.6 Silver titanium alloy abutments.

Nevins et al.'s study on soft tissue healing using Laser-Lok

- A prospective preclinical trial using a canine model to compare Laser-Lok abutments to machined titanium abutment surfaces
- The study confirmed that the Laser-Lok abutments inhibited the apical migration of the junctional epithelium, prevented coronal resorption, and provided a connective tissue attachment
- On histologic examination the Laser-Lok design provided healing in a similar fashion to the natural dentition. The connective tissue fibers healed perpendicular to the abutment surface demonstrating the rationale behind Laser-Lok's favorable soft tissue maintenance

With all other implant abutments on the market, connective tissue forms in a weakened parallel fashion to the abutment. The Laser-Lok technology enables the formation of an improved mucosal seal similar to the natural dentition, thus giving it a bright future.

Surgical Grade Stainless Steel

Surgical stainless steel is a specific type of stainless steel used in medical applications, and includes alloying elements of chromium, nickel, and molybdenum. The chromium gives the metal its scratch resistance and corrosion resistance. The nickel provides a smooth and polished finish. The molybdenum gives greater hardness and helps maintain a cutting edge.

Stainless steel is easy to clean and sterilize, strong, and corrosion resistant. Nickel/chrome/molybdenum alloys are sometimes used for implant abutments, but immune system reaction to nickel is a potential complication. Surgical grade stainless steel can be used for temporary implant abutments but is not an ideal material of choice for permanent implant abutment.

Cast Gold

Implant manufacturers recognized the limitations of early "stock abutments" and developed a castable abutment called a UCLA abutment. This abutment is comprised of a machined-fit gold alloy base that fits to the corresponding implant head, combined with a plastic sleeve which can be cut, modified, and added to with wax prior to casting into gold (Figure 1.8).

Cast gold abutments were used to fabricate implant-level, custom-cast restorations that provided subgingival margins for esthetics, reduced height for vertical occlusal clearance, and/or custom angles. Cast gold abutments were popular during 1980s and 1990s but with the introduction of more sophisticated stock abutments and CAD/CAM milled abutments they have lost popularity.

- *Gold specs:* 60–65% gold, 20–25% palladium, 19% platinum, and 1% iridium (not a ceramic alloy).
- *Melting range:* Solid, 1400°C; liquid, 1490°C.
- *Recommended casting alloys:* High palladium or high noble porcelain fusing alloys or type III or type IV high noble dental alloys.

Generally, a plastic UCLA abutment is waxed up and customized to an ideal geometry and shape. After investing, the wax and plastic UCLA are burned out of the pattern following the lost wax process. When molten alloy is cast into the investment mold, the gold base component of the UCLA abutment is incorporated into the casting and provides a machined interface that precisely fits the implant. The gold base is fabricated from a non-oxidizing alloy that promotes chemical adhesion of the cast alloy, but does not permit the adhesion of porcelain.

Figure 1.7 Laser-Lok abutment. Courtesy of BioHorizons.

Relevant Studies Comparing Gold, Porcelain, Titanium, and Aluminum

Since the late 1990s there has been a consensus that gold and porcelain have a worse soft tissue response

Figure 1.8 Cast gold abutment.

in comparison with aluminum oxide (an outdated ceramic material) and titanium. Much of this thought process comes from Abrahamsson et al.'s 1998 animal study. As a result of this study many clinicians have avoided gold and porcelain abutments altogether.

Abrahamsson et al.'s study comparing the use of titanium and aluminum with gold and porcelain

- Five beagle dogs were used for dental implantation
- Each dog had two commercially pure titanium abutments, two aluminum oxide abutments, one short titanium abutment with attached porcelain fused to gold, and one gold abutment placed
- After 6 months the titanium and aluminum oxide abutments had formed a junctional epithelium of 2 mm and a connective tissue portion of 1–1.5 mm in height
- After 6 months the gold and porcelain abutments had no attachment formed at the abutment level. The soft tissue margin had receded and the bone resorbed
- It was concluded that titanium and aluminum oxide abutments have a favorable soft tissue response over gold or porcelain

Rompen's 2006 literature review agreed with Abrahamsson's findings. Rompen concluded that titanium, aluminum, and zirconia were found to have favorable long-term biocompatibility with soft tissue where gold and porcelain were shown to be less biocompatible.

Abrahamsson and Rompen's conclusions have faced challenges by other studies. The most notable conflicting study is a human study by Vigolo et al. in 2006. They concluded that there was not a significant difference in peri-implant marginal bone and soft tissue response when titanium or gold alloy abutments are used.

Vigolo et al.'s study on soft tissue response to gold and titanium

- 20 single-tooth bilateral edentulous patients (utilizing 40 implants) were used in the trial
- One side of the arch was restored using a gold abutment while the contralateral side was restored using a titanium abutment
- Four years after prosthetic restoration the bilateral sites were examined for supragingival plaque, gingival inflammation, bleeding on probing, the amount of keratinized gingiva, and probing depth
- No significant differences were found in the peri-implant marginal bone levels or soft tissue responses

Vigolo determined that if only the soft tissue response is considered, the choice between using a gold or titanium abutment is merely up to clinician preference. The gold and the titanium were shown to form and maintain an appropriate soft tissue response within this human study.

In addition, Abrahamsson's work with Cardaropoli in 2007 contradicted his earlier findings. In this study Abrahamsson utilized one-piece implants in beagle dogs where the transmucosal portion of the implants were made of gold or titanium. No significant soft tissue differences were found while utilizing titanium or gold at the transmucosal tissue level. However, Abrahamson's work with Welander the next year (Welander et al. 2008) established again that titanium and zirconia had a superior soft tissue result in comparison to gold.

Studies concerning gold abutments have been conflicting. It is difficult to assess where the inconsistencies stem from. However, a few significant disadvantages with gold should be mentioned.

First, titanium and zirconia have the benefit of utilizing CAD/CAM milled technology. With CAD/CAM every abutment is consistent because the CAD/CAM milling machine removes the human element from creating an abutment. Gold abutments are cast in a lab by a technician. One possible explanation for the variable soft tissue response found in studies may be attributed to the expertise of the lab technician. Another issue that arises with gold abutments is sterility. Titanium and zirconia abutments are consistently sterile prior to placement. Gold abutments, after fabrication in a lab, may have inconsistencies with sterility prior to placement.

Zirconia

Zirconium dioxide (ZrO_2), also known as *zirconia* (not to be confused with zircon), is a white crystalline oxide of zirconium. Its most naturally occurring form, with a monoclinic crystalline structure, is the mineral baddeleyite.

Baddeleyite is a rare zirconium oxide mineral (ZrO_2 or zirconia), occurring in a variety of monoclinic prismatic crystal forms. It is transparent to translucent, has high indices of refraction, and ranges from colorless to yellow, green, and dark brown (Figure 1.9). Baddeleyite is a refractory mineral, with a melting point of 2700°C.

Advances in biomaterial science and ceramic manufacturing technology have allowed the production of high strength and biocompatible zirconia that can be used in biomedical devices and implant abutments. The introduction of yettria partially stabilized tetragonal zirconia polycrystals (Y-TZP), powder injection molding (PIM), and hot isostatic pressing (HIP) tech-

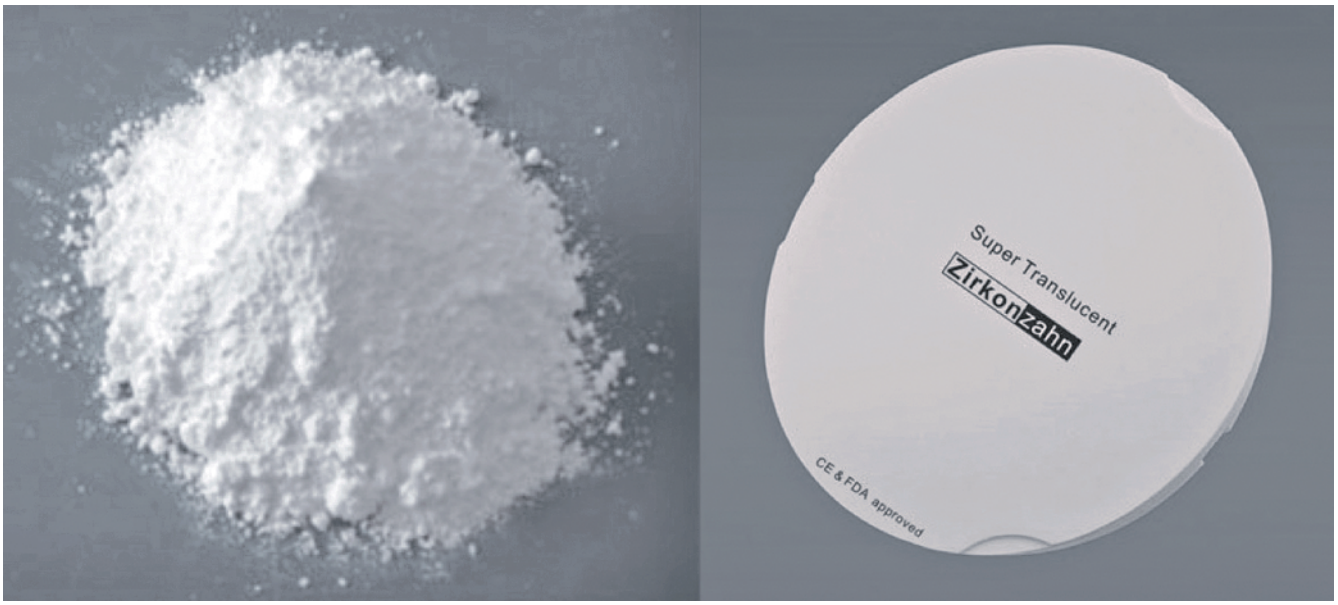

Figure 1.9 Zirconia powder (left) and blank (right).

niques were the hallmarks of this development. Other developments such as the use of zirconia-toughened alumina and ceria-doped zirconia to minimize the incidence and halt the progression of zirconia aging are also considered as key steps in the growing popularity of zirconia as a bioceramic.

Because of its material properties and strength, zirconia is utilized whenever esthetic considerations are important and high loads are expected (e.g. esthetic zone cases, posterior fixed prosthesis frameworks, implant abutments, and multi-unit implant restorations). Zirconia has a high bending strength and fracture toughness, and a Young's modulus comparable to that of steel. In addition to its strength, the greatest advantage of ZrO_2 is its excellent tissue integration. Various studies have demonstrated the successful application of zirconia abutments in terms of stability of soft tissue and marginal bone. Results indicate that the type of material used affects both the amount and quality of the surrounding tissues (when comparing zirconia with cast gold alloys). Also, ziconia abutments minimize bacterial and plaque adhesion and prevent soft tissue inflammation.

Because of its physical properties, adjustment and grinding can be challenging for dentists and dental technicians. Post-sintering adjustment of zirconia components significantly increases the risk of microcracks that could result in subsequent failure under clinical function.

Physical properties

ZrO_2 adopts a monoclinic crystal structure at room temperature and transitions to tetrgonal and cubic structures at higher temperatures. The volume expansion caused by the cubic to tetragonal to monoclinic transformation induces large stresses, and these stresses cause ZrO_2 to crack upon cooling from high temperatures. When the ziconia is blended with some other oxides such as yttrium oxide (Y_2O_3, yttria), the tetragonal and/or cubic phases are stabilized (Figure 1.10).

Even though different brands of zirconia can be chemically similar they are not necessarily the same. Different brands of zirconia ceramic are chemically similar, but once processed it can exhibit different mechanical and optical characteristics. When working with zirconia there are differences in machinability (e.g. wet milling and dry milling) and in sintering (e.g. sintering temperature for Vita™ YZ-Cube is 1530°C; for Lava™ frameworks is 1500°C; for Cercon™ is 1350°C).

What is different? In principle, there is pre-sintered zirconia and HIP zirconia available on the market. The pre-sintered zirconia is milled and the material still has a soft, chalk-like consistency (Figure 1.11). For full density, it is sintered again after milling. HIP material is milled in the fully sintered state (Figure 1.12). Note that the processing parameters for pre-sintered zirconia affect its performance attributes.

Pre-sintered zirconia is prepared by three main steps (Figure 1.13). The zirconia powder is pressed and pre-sintered. This is usually done by the manufacturer. The dental lab mills the pre-sintered blank and then sinters the coping or framework to achieve full density. Preparation of the pre-sintered blanks by the manufacturer differs depending on the zirconia powder source and both the pressing and the pre-sintering conditions selected.

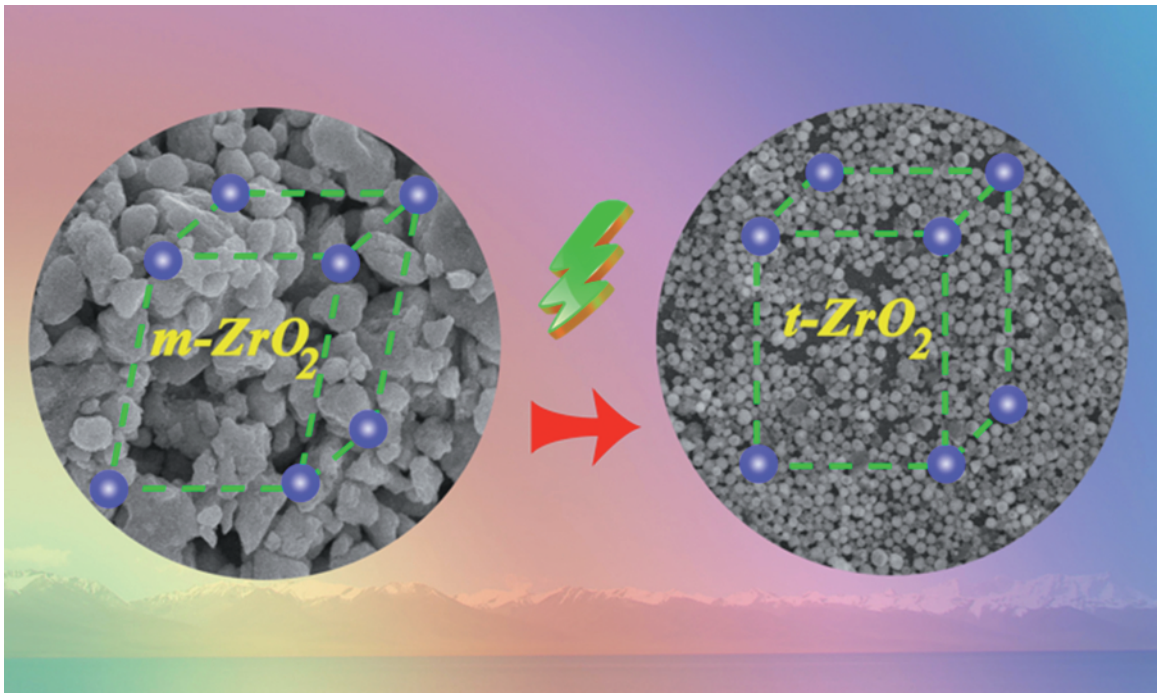

Figure 1.10 Structural differences between monocline and tetragonal zirconia. Courtesy of Professor Naoto Koshizaki, reproduced with permission.

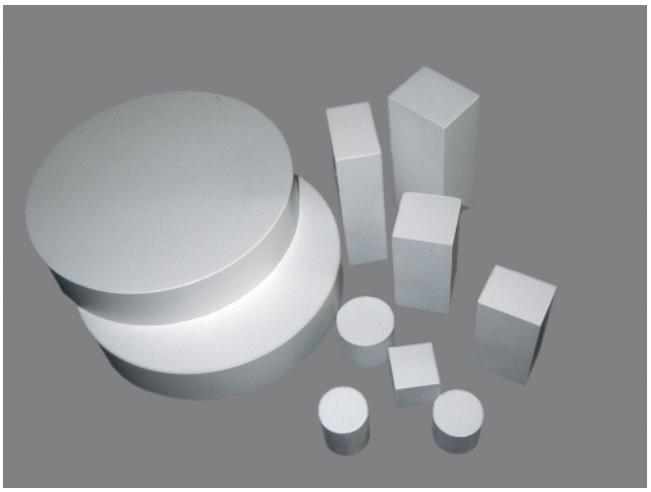

Figure 1.11 Pre-sintered zirconia blank.

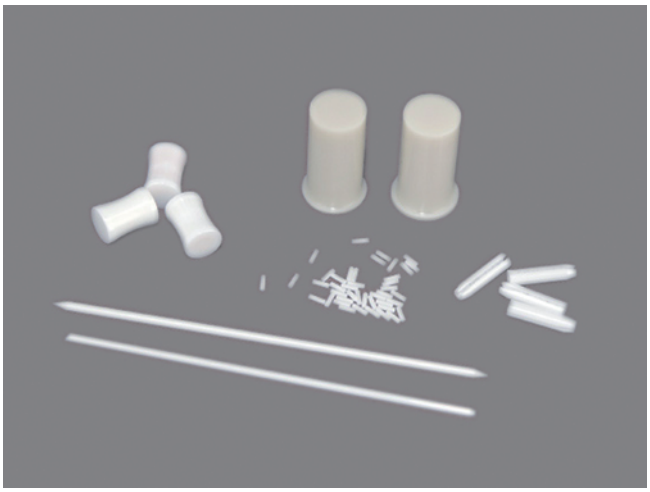

Figure 1.12 HIP-sintered blanks.

1. *Powder.* The available zirconia powders can have different grain sizes, different distributions of the various grain sizes, and different additives (e.g. binder for the pressing step). The additives yttrium oxide and alumina can be distributed within the material in a variety of ways, such as a homogeneous distribution throughout the whole material, higher concentration at grain borders, etc. The grain size has an effect on strength and transformation toughening – a special and key mechanical characteristic of zirconia. Variations in grain size distribution affect the resulting porosity and hence

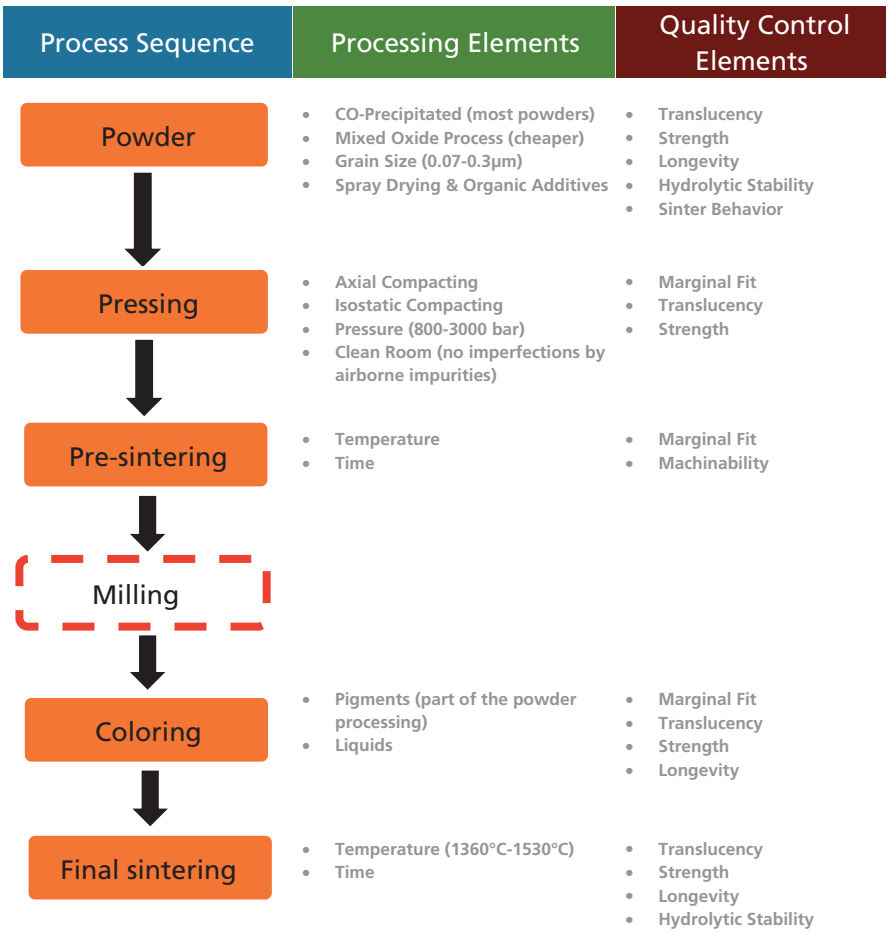

Figure 1.13 Main steps in the production of pre-sintered and sintered zirconia.

the translucency of the material. The distribution of additives can affect the hydrothermal stability of the sintered material.

Note: Differences in the zirconia powder affect the strength/long-term stability and translucency of the abutment.

2. *Pressing conditions.* The powder is first pressed, which can be accomplished by different procedures (e.g. isostatically or axially). The pressing conditions are adjusted to get an optimized blank for the pre-sintering step. The pressing methodology influences the homogeneity and the density distribution of the material and hence the marginal fit. The pressing conditions can lead to differences in strength and translucency and affect the final sintering temperature of the zirconia.

Note: The pressing condition and pressing method affect the marginal fit, strength, and translucency of the restoration.

3. *Pre-sintering.* The pressed zirconia powder is then pre-sintered in a furnace with an optimized temperature profile to generate a blank with suitable strength and millability.

Note: Pre-sintering conditions affect the strength of the pre-sintered material and its millability.

4. *Coloring.* Some zirconia materials can be colored in the pre-sintered state by immersing the copings, abutments, and frameworks in a dyeing liquid. This enables the absorption of coloring agents in the zirconia material. Coloring can be achieved either by pigments (grains) or non-pigmented (ions) agents. It is important to control the effect of the dyeing liquid on the mechanical characteristics of the zirconia material (Figure 1.14).

Note: Coloring of the zirconia can affect the marginal fit, strength, and translucency of the material.

In summary, the zirconia used in dentistry is chemically similar but not necessarily alike.

Figure 1.14 Process of making zirconia abutment from pre-sintered zirconia.

Table 1.2 Comparison of the physical properties of different dental implant materials

	Titanium alloy grade 5	CPT4	Zirconia	Bone
Tensile strength (MPA)	993	662	1000	104–121
Compressive strength (MPA)	970	328	2000	170
Modules of elasticity (GPA)	113.8	103	200	10–15

CPT4, commercially pure titanium grade 4.

Table 1.2 provides a comparative analysis of zirconia's physical properties to bone, commercially pure titanium, and titanium alloy.

These physical properties present adjustment and grinding challenges to dentists and dental technicians. Post-sintering adjustment of zirconia components significantly increases the risk of micro-cracks that could result in subsequent failure during clinical use.

In addition to its strength, the greatest advantage of ZrO_2 is its excellent tissue integration. Various studies have demonstrated the successful application of zirconia abutments in terms of soft tissue and crestal bone stability. Zirconia abutments provide a less plaque-retentive environment around a final prosthesis compared with any other type of abutment material. This improves a patient's ability to maintain a higher level of oral hygiene around the final prosthesis.

Sample studies on the hygenic properties of zirconia

Studies have demonstrated that zirconia has a lower bacterial count and inflammatory infiltrate compared with titanium. Because of zirconia's hygienic properties it has natural benefits in maintaining esthetic soft tissue and preserving crestal bone.

Rimondini et al. performed in vitro and in vivo tests comparing bacteria accumulation on zirconia and titanium. They concluded that zirconia accumulated fewer bacteria than titanium.

Rimondini et al.'s study on the hygienic properties of zirconia compared with titanium

In vitro test
- Disks of titanium and zirconia were used and tested for bacteria accumulation
- Cultures were incubated for 4 days and the bacterial counts were measured
- Zirconia showed significantly less bacterial growth

In vivo test
- Zirconia and titanium were placed onto silicone stents and attached to orthodontic wires intraorally
- The stents were worn for 24 hours and removed
- Bacterial counts were measured on the zirconia and titanium
- Zirconia was found to have a lower bacterial count than the titanium

Scarano et al.'s 2004 work also aimed at comparing the hygienic properties of titanium and zirconia. Their results were similar to Rimondini's results – that zirconia is a more hygienic material.

Poortinga et al.'s 1999 research demonstrated that zirconia's resistance to bacterial adhesion is likely due to the electron conductivity of this material. They demonstrated that the charge transfer occurs during bacterial adhesion. Bacteria that donate electrons adhere to the substrate more strongly than bacteria that accept electrons.

Inflammatory response with zirconia use

A natural response to the presence of bacteria is the release of inflammatory mediators which leads to bone loss. Rather than evaluating the biofilm, another method of evaluating hygienic properties is to evaluate inflammatory factors such as vascular endothial growth factor (VEGF), nitric oxide synthase expression, inflammatory infiltrate, and microvessel density in the peri-implant soft tissues. An increased level of these factors indicates the presence of inflammation due to bacteria accumulation.

In 2006, Degidi et al. used these inflammatory markers to evaluate the hygienic properties of zirconia compared with titanium.

Degidi et al.'s study on inflammatory infiltrate levels with zirconia and titanium

- Implants were placed into human patients
- Half of the abutments were made of zirconia, while the other half were titanium abutments
- After 6 months biopsies were taken and analyzed for inflammatory mediators
- Significantly less inflammatory infiltrate was noted around the zirconia abutments compared with the titanium abutments

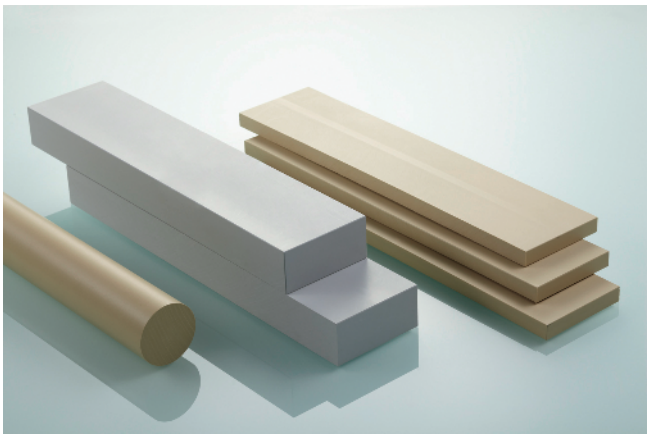

Figure 1.15 PEEK blanks.

As a side note, regardless of the material used, if there is a micro-gap between the implant and abutment, inflammation and crestal bone loss may occur. As a result, platform switching has been proposed as a solution to reduce the gap and limit crestal bone loss.

Polyether Ether Ketone (PEEK)

PEEK has become the most popular material for fabricating temporary abutment. It is a beige or white colored organic polymer and a semicrystalline thermoplastic with excellent mechanical and chemical resistance properties. The Young's modulus is 3.6 GPa and its tensile strength 90–100 MPa. PEEK has a glass transition temperatures at around 143°C and melts at around 343°C (662°F). It is highly resistant to thermal degradation as well as attack by both organic elements and moist environments. These robust properties have made PEEK an ideal material for temporary abutment (Figure 1.15).

Technical advantages

- Ability to be sterilized without degradation in mechanical properties or biocompatibility.
- Compatibility with X-ray, magnetic resonance imaging (MRI), and computed tomography (CT) imaging without producing artifacts.
- Excellent mechanical properties such as stiffness and durability.
- High compressive strength.
- Proven hard and soft tissue biocompatibility.
- Natural color for excellent aesthetics (Figure 1.16).
- Metal-free solution eliminates ions exchange in the mouth.
- Ease of chairside preparation and modification by dentists.

As early as 1987, Williams et al. provided an animal study demonstrating that PEEK was biocompatible.

Figure 1.16 PEEK abutment.

Hunter and colleagues, in 1995, compared PEEK with titanium and cobalt chromium (CoCr) for orthopedic uses. They did not note any difference between fibroblastic or osteoblastic attachments with PEEK and those with titanium or CoCr.

Within dentistry, PEEK polymers are used to manufacture restorative and healing abutments. Unlike the orthopedic literature, dental implant research concerning PEEK polymers is limited but what is available is promising.

Koutouzis et al., in 2011, provided a human prospective study comparing titanium and PEEK healing abutments. It was concluded that after 3 months there was not a significant difference between the two materials in terms of soft and hard tissue response. The response was measured in terms of plaque, bleeding on probing, and gingival and crestal bone height.

Another study by Volpe et al., in 2008, compared PEEK with titanium healing abutments using real-time polymerase chain reaction (PCR) in terms of bacterial colonization. After 2 weeks following second stage surgery, no statistical differences were noted between titanium and PEEK abutments in terms of bacterial colonization.

For provisional restorative abutments or healing abutments, PEEK abutments are the first-line option.

CONCLUSIONS

- *Titanium abutments:* There is an extensive literature showing there should be no reservations concerning the use of titanium abutments. Due to the strength of titanium implants they should be considered as the first choice for posterior implants.
- *Machined versus polished titanium abutments:* The commercially available titanium abutments are not significantly different enough from one another to have a clinical impact. Clinically, the surface roughness of the dental abutments on the market is a non-issue.
- *Laser-Lok titanium abutments:* Laser-Lok titanium abutments are superior to titanium abutments without a Laser-Lok transmucosal portion in all clinical scenarios. They are highly recommended in anterior esthetic cases or with patients who have a thin gingival biotype.
- *Stainless steel abutments:* Since the immune systems reacts to the nickel in stainless steel there is a potential complication if it used as a permanent abutment. Surgical grade stainless steel can be used for temporary implant abutments in the short term only.
- *Gold abutments:* Due to contradictory research, clinically it would be prudent to use gold abutments cautiously. In anterior esthetic cases, patients with thin gingiva, or other clinically sensitive cases one should consider another abutment option until more definitive research is available.
- *Zirconia abutments:* Zirconia is the most hygienic abutment on the market and maintains the mucosal seal better than titanium. It is highly recommend for anterior esthetic cases, for patients with thin gingiva, and for any patient with questionable oral hygiene (e.g. with an overdenture where an elderly patient may lack dexterity).
- *PEEK abutments:* When used as a temporary restorative abutment, a clinician should expect a similar soft tissue response as seen with the use of titanium. PEEK abutments are the first line choice for temporary abutments.

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