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The Biocompatibility of Various Dental Materials

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Abstract

Dentistry is a continuously evolving field with new materials and technologies constantly innovated. The oral cavity presents a harsh environment in which restorative and implant materials must be able to withstand. Aside from meeting the appropriate physical and chemical standards, it is important that dental materials be biocompatible. Biocompatibility relates to the material's ability to function in the body without causing harm to living tissue. It is necessary to analyze the materials being used and determine whether they interact with the body in a detrimental manner. This will enable dental professionals to choose the most beneficial material to utilize for patient safety and overall health.

Introduction

Tooth decay is a prevalent health issue faced by the general population. In fact, according to the National Institute of Dental and Craniofacial Research, 92% of adults between the ages of 20 to 64 have had dental caries in their permanent teeth. Our teeth are comprised of four tissue layers. Enamel, dentin, and cementum, are the three outer layers of hard tissue, which surround the soft pulp tissue layer containing nerves, blood vessels, and connective tissue. Cavities form when bacteria and food debris combine with saliva to create a layer of plaque which sticks to the teeth. Plaque contains acid which begins to dissolve the enamel of our teeth and cause dental caries when the plaque layer is not removed. Tooth decay is an active process that will continue to progress through the multiple layers of tooth structure if left untreated.

There are various restorative treatment options that exist to treat damaged teeth. Choosing the right material is important considering that our teeth are exposed to constant wear and tear. At times, teeth can regress beyond the ability to be repaired. Fortunately, implant replacement has become a viable option, with the use of various metals and synthetic materials. Materials must be durable as well as viable in an aqueous environment.

Amalgam and composite resin fillings are the two most common materials used to fill cavities. Amalgam is composed of liquid mercury combined with an alloy made of silver, tin, and copper solid particles. Dental amalgam is inexpensive and easy to work with, making it a convenient option for dental restorations. Composite resin material is made of a ceramic and plastic compound which makes it a good tooth colored alternative. At present, titanium is the gold standard in implant dentistry. On the other hand, there are other materials being explored in cases where titanium may present issues of biocompatibility.

However, when introducing any foreign substances into the human body there is always the risk of detrimental side effects. Some of the components in these filling materials can be cause for concern. For example, the use of dental amalgam gives rise to mercury vapor exposure. In contrast, composite resin fillings may release bisphenol A (BPA) and other monomers into the blood stream. Both of these restorative materials contain components

that can have toxic effects on the human organ systems and may be hazardous to our health.

This review will explore the biocompatibility of these restorative and replacement materials and analyze the possible long-term side effects that they may have on one's overall health.

Material and Methods

Research was done by studying original research articles and scientific papers found on the Touro College online library. Specific scientific databases such as ProQuest and EBSCO were utilized, and additional information was obtained by analyzing articles found.

Discussion: Amalgam

Amalgam fillings, also known as silver fillings because of their appearance, are one of the oldest used materials in restoring decayed teeth. The low cost, ease of placement, and durability make amalgam a great option for dental fillings. The material is composed of a powdered alloy of silver, tin, copper, zinc, and elemental mercury. Directly prior to placement, the components are mixed together to activate the filling, which makes it soft and pliable for easy placement. It is not necessary for the area receiving the amalgam to be completely dry, which makes it a good choice in locations that are difficult to isolate from saliva.

With a composition of about 50% elemental mercury by weight, there is a concern regarding the toxicity of this material. Interestingly, although it has been in use for over one hundred years, dental amalgam has not undergone the regulatory proof of safety testing required of materials intended to be implanted into the human body. Therefore, the question remains as to whether the components of this material interact with the body in a harmful way.

Inhaled mercury vapor can cause damage to the brain, kidneys, and other major organs. After being inhaled into the lungs, it is transported through the blood to the brain. Liquid mercury is dangerous because it vaporizes at room temperature and can easily be inhaled. Although amalgam fillings harden rapidly and remain in the solid metallic form once placed in the tooth, studies have shown elevated levels of mercury in the blood and urine

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following restorative procedures utilizing amalgam as the material of choice (Nicolae, et. al., 2013). This indicates that there is some inhalation of mercury vapor prior to the material hardening.

Aside for the inhalation upon initial placement of amalgam fillings, low levels of elemental mercury vapor are released when amalgam filled teeth are subject to stress due to chewing, brushing, bruxism, and ingesting hot foods. Measuring urinary mercury concentration is a good method of analyzing the long-term influence due to the presence of such fillings. A comprehensive study utilizing this method of analysis was conducted within the Canadian population (Nicolae et. al., 2013). Factors considered included age, gender, and the number of filled surfaces. Of all groups, 95.42 – 98.23 % of participants had mean urinary mercury levels below 5 ug Hg/L. When compared to a normal range of up to 20 ug Hg/L, these concentrations do not seem to be cause for concern. Overall, less than 5% of participants had mean urinary mercury levels that qualified for possible reevaluation.

Although amalgam seems safe to use in the mouth, there is a potential concern for dental professionals who experience daily exposure (Jamil et. al., 2016). A recent study demonstrated that people working in the dental environment who handle amalgam do have increased levels of mercury concentrations in their blood. Mean concentrations in both dentists and dental assistants were above the normal range of 20 ug/ L, with dentists at a mean concentration of 29.835 ug/L and assistants at 22.798 ug/L. Also, the study demonstrated a correlation between dentists who had more years of experience with greater increases in mercury levels in the blood. This seems to indicate that there is somewhat of a cumulative effect. In addition, working longer shifts was associated with higher concentration of mercury in the blood (Jamil et. al., 2016).

With the phase down of amalgam fillings, this should be less of a concern. Although dental professionals are still utilizing amalgam fillings sporadically, other fillings have become more popular. This would suggest that the occasional use of amalgam for a filling would not contribute significantly to an increase in mercury concentration in the blood. A possible method of preventing increased mercury concentration in the blood of dentists would be to implement appropriate regulatory safety measures, such as wearing protective masks and gloves.

The New Zealand children's amalgam trial (CAT) was a study that explored the impact of exposure to mercury from amalgam fillings on neuropsychological and renal function, focusing specifically on children as the population (Bellinger et. al., 2007). The randomized sample size

was 534 participants, and at baseline there were no amalgam restorations present. Over a five year period, there was an average of 15 tooth surfaces restored per patient. When measured, the group with amalgam as the dental material of choice for restorations had significantly higher mercury levels in the blood. However, this did not translate into impaired neuropsychological and renal function.

A possible explanation can be that this was a study conducted with children as the participants. Increased mercury levels may have a cumulative effect. Perhaps adverse health effects would not appear until later in life. For this reason, it would be appropriate to take precautions with pregnant women and children who are still developing. In fact, studies have shown that mercury easily crosses the placenta as well as the blood brain barrier (Magos, Clarkson, 2006).

Furthermore, with the increase of exposure to electromagnetic fields due to common sources such as Wi Fi routers, laptops, mobile devices, and MRI, there is a new aspect to consider regarding the safety of amalgam fillings. Although fillings have been shown to release mercury vapor even after being placed, countless studies have demonstrated that the release is generally at extremely low dosages which is not a cause for concern. However, the presence of electromagnetic fields increases the release of toxic mercury from amalgam fillings (Mortazavi et. al., 2015). This creates an extra concern specifically for pregnant women who have amalgam fillings. Mercury circulating in the blood easily crosses the blood brain barrier, as well as the placenta (Magos, Clarkson, 2006).

An in vitro study was conducted to examine this new concern regarding amalgam toxicity. The goal was to test the effect of electromagnetic fields on the release of mercury from amalgam fillings. The study included twenty healthy premolar teeth that had been removed for orthodontic treatment. The teeth were all prepared to be filled in an identical way, by the same dentist. They were then restored using amalgam and placed into artificial saliva. The control group was stored in an environment away from any exposure to electromagnetic fields. The experimental group was placed in the vicinity of a Wi-Fi router that was actively exchanging data with a nearby laptop.

Following electromagnetic exposure, the mean concentration of mercury in the artificial saliva was tested. The concentration in the saliva containing teeth that had been exposed was .056 mg/L, in contrast to the unexposed control group that had a mean concentration of .026 mg/L. The results clearly indicate that the radiofrequency radiation given off via Wi-Fi devices can increase mercury release from amalgam fillings (Paknahad et. al., 2016). Being that it is one of the first studies exploring

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this concern, it would be necessary to conduct further studies before stating that it is a concern.

There are people who remain concerned with the presence of amalgam fillings, and even desire to have such fillings removed. However, removing such filling for no other dental related reason may cause more harm than benefit. This is because drilling old fillings would cause the release of additional mercury vapor and would cause the patient to unnecessarily inhale additional mercury vapor.

A study was conducted to determine whether the removal of amalgam fillings alleviated symptoms of health issues attributed to the presence of mercury. The presence of these symptoms had no other medical or psychological explanation. The study consisted of 90 patients between the ages of 20 -50 who reported 10 symptoms of health problems that were suspected to be due to amalgam. There were three groups; a group whose fillings were removed, another group that underwent biological detoxification therapy in addition to filling removal, and a final group that did not remove fillings but participated in a lifestyle improvement regimen.

To begin, baseline mercury levels were taken to be compared to the end results. In addition, all participants were given a 50 item symptom list to complete, ranking each item 0-3, and combining the scores for a weighted sum score. The amalgam fillings were removed and replaced by other materials over a period of time, in the two groups chosen to have fillings removed. The fillings were removed one quadrant at a time with a wait period of one week between treatments. The group undergoing biological detoxification therapy, took vitamin supplements in addition to filling removal.

Mercury levels measured in the blood and urine were significantly lower in the two groups to have their fillings removed as compared to the group that did not have any fillings removed. The 50 item symptom list was completed by all participants at 6, 12, and 18 months following initial treatment. All groups showed a decrease in the main complaint sum score, with a slightly larger decrease for the two groups to have the amalgam removed (Melchart et. al., 2008).

It is difficult to demonstrate a correlation between the amalgam fillings and attributed symptoms of health issues. The results of this study indicate that although the presence of amalgam fillings increase levels of mercury in the blood, they are not the source of any known adverse health effects. Therefore, it would be unwise to have such fillings removed if not deemed necessary for improved oral health.

Amalgam continues to be used as a great option in restorative dentistry. Research thus far has demonstrated

that amalgam remains a biocompatible material that does not cause harm to the human body. Although it does increase mercury levels, the concentration is too slight to be considered significant. Specifically in the case of posterior teeth where aesthetics are not as much of a concern, it may actually be a preferable option. This is because it can withstand stronger chewing forces.

On the other hand, being that it is not the only source of environmental exposure to mercury, there is a movement to utilize other available materials in cases where it will not compromise treatment outcomes. In addition, appropriate protective safety measures should be taken to protect dental personnel who are more frequently exposed. Thus far the use of amalgam has not been linked with adverse health effects. Further studies are necessary to determine the association between electromagnetic fields and the release of mercury from amalgam fillings.

Resin-Based Composite

Resin-based composites (RBC) are a more recent innovation in restorative dentistry. These fillings are made up of a mixture of ceramics and plastics. RBC are often preferred, as they match the color of teeth and have a nicer esthetic appearance. However, these fillings may contain Bisphenol A (BPA), and other components that are toxic when released as monomers. BPA is used to synthesize various monomers that make up RBC, such as BPA-glycidyl methacrylate (BisGMA). Often, residues of BPA remain in the process of synthesizing RBC material (Luo, et. al., 2016).

BPA is in the class of xenoestrogens. Xenoestrogens are chemicals that are known to be endocrine disrupters, and they inhibit normal hormone function (Zimmerman-Downs, et. al., 2010). BPA is thought to be related to various diseases including diabetes, heart disease, obesity, as well as immune and reproductive disorders. The European Food Safety Authority has established a tolerable daily intake of no more than 4 ug/ kg of body weight per day.

Most of the BPA that humans are exposed to comes from people's diet. Upon entering the body and passing through the digestive tract, BPA passes through the liver and is detoxified. The liver converts most of the BPA from its free unconjugated form to a non-estrogenic conjugated form. This prevents it from interacting with the body in a harmful way. However, research has shown that even after fasting, the concentration of unconjugated BPA is higher than predicted (Stalhut, et. al., 2009). This demonstrates that it is not metabolized immediately, but remains in the body for some time.

In addition, BPA entering the body via the skin, as well

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as oral or respiratory mucosa, bypasses initial liver metabolism and circulates in the blood for a longer period of time in its unconjugated form. This presents a concern specifically when dealing with dental treatment. Materials that contain BPA or precursor molecules may leech these harmful chemicals into saliva and enter the blood stream. Various studies have been conducted both in vitro and clinically to determine if the use of these materials in dental fillings negatively impacts overall health.

A study was done to test whether the presence of composite fillings was related to increased levels of BPA in saliva. The study consisted of 40 volunteer participants between the ages of 20 -35 who were patients of dental clinics in Bergen, Norway. All of the participants underwent a comprehensive dental evaluation and were given a score between 1 and 3 based on the number of existing composite restorations. The experimental group consisted of twenty individuals with at least 6 tooth surfaces restored with RBC. The control group was made up of twenty people without any composite fillings. Five ml. of saliva was collected from all participants and stored in BPA free test tubes.

The collected saliva samples were then tested using a liquid chromatography technique. Both the unconjugated, as well as total BPA concentrations were measured. In the experimental group, eight out of the twenty were found to have saliva BPA concentrations above the detectable limit of .1 ng/mL. Within the control group there were 3 participants with concentrations above the detectable limit. However, in both cases the concentration was still very low (Berge et.al. 2017). This study seems to indicate that the presence of RBC alone is not the cause of BPA related health concerns. However, there are factors that limit this study (i.e. sample size), and further studies are necessary to explore this issue.

An in vitro study was done to test cytotoxicity of resin based composite fillings. The harmful effects of these materials are decreased once placed in dentin, but not completely eliminated. The release of toxic materials from composite materials was previously thought to be a concern only within the first 24 hours following placement. Therefore, many studies were designed focusing on the potential harm caused only following initial placement. This study aimed to test whether or not there is a long-term release of toxic materials into our body systems.

Various common composite materials used were prepared in lab dishes and light cured. The specimens were then split into three groups; a control group stored as is, a second group aged in lab simulated artificial saliva for seven days, and a final group also in saliva for 14 days. High- pressure liquid chromatography was used to test

the components of the artificial saliva for presence of harmful substances. The results indicated that although the release of these substances decreased after 24 hours, a cytotoxic effect on cell activity remained even after a two week wait period. This study suggests that further clinical testing should be designed with a focus over more than a 24 hour release period (Al-Hiyasat, et. al., 2005).

Composite fillings require a bonding agent, which assists the material in adhering to a prepared tooth structure. 2-hydroxyethyl methacrylate (HEMA) and BPA are components contained in bonding agents that can be cytotoxic to human gingival fibroblast (HGF). In a recent study, cell cultures were grown using healthy human gingival tissue to test various bonding agents. It demonstrated that both HEMA and BPA negatively impact cell viability of HGF although they exhibit different patterns of cytotoxicity. Although the cytotoxic effect was reduced after 24 hours, this is a matter of concern that requires further study being that all of the bonding agents displayed some level of cytotoxic activity on HGF (Reddy, 2017). The study was important as it displayed that different bonding systems had varying effects, with some being more harmful to HGF cells than others. Until an improved method is developed it is necessary to evaluate and choose a low risk bonding agent.

When using RBC, the technique for placing them varies. Composite fillings are soft and pliable for placement, and then cured with a blue light to harden the material into a strong durable filling. These fillings are available in flowable, paste like, and bulk consistencies. Interestingly, studies have demonstrated that the method used for placement is related to the degree of release of toxic monomers and BPA into circulation (Pongprueksa et. al, 2015). They are generally placed in 2 mm increments to ensure adequate polymerization and reduce polymerization shrinkage stress. For deep fillings, a bulk fill composite has been developed that can be cured in 4 mm increments. Fillings that are not cured completely can result in monomers leeching into the oral cavity and reaching pulp tissue.

The efficiency of polymerization is important, as composites with low degree of polymerization release more monomers. The degree of conversion (DC) can be measured by means of spectroscopy. A study was conducted with the objective of determining how the DC varied based on the consistency of RBC used, and how it related to monomer elution. It also analyzed the change in release of monomers over time. Cylindrical samples were prepared using three types of RBC. They were filled in two 2 mm thick layers or one 4 mm bulk layer, and light cured to polymerize.

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For all of the composites, there was a mean DC between 60 and 70%. There was a significant difference in total monomer release depending on the composite type. The paste-like composite showed the lowest monomer elution. This can be attributed to the fact that it has a lower resin content to begin with. In addition, it is administered in layers allowing for better curing. Four mm bulk placement resulted in a lower DC and higher monomer release. Evidently, curing through a thicker layer of composite material is not as effective in complete polymerization of the material. This results in greater release of toxic monomers. In addition, fillings that are not fully cured can lead to gaps forming between the filling and the tooth structure. This can lead to secondary caries.

The study demonstrated that monomer release is dependent on both the composite type and the method of application. Therefore, the usage of paste-like composite and a layered placement technique seem to be the preferable method of treatment. This would limit the unnecessary release of monomers and BPA. In addition, it was found that rinsing and scrubbing fillings following placement further reduces the escape of harmful monomers. This extra step should be implemented for a safer procedure.

During the placement of RBC, composite dust particles are released into the surrounding environment. These nano sized particles become airborne and upon inhalation can travel deep into the lungs. This may present a concern for patients, and for dental personnel who perform multiple such procedures daily. RBC are composed of methacrylate monomers, which have been shown to provoke allergic reactions. It is important to investigate whether the composite dust that escapes into the atmosphere releases methacrylate monomers.

A recent study analyzed the dust particles released from four common composites used in dentistry. Samples of composite were light cured and polished in an enclosed chamber using a diamond bur. The dust was collected by means of a cyclone vacuum for analysis. The particles collected underwent various examinations by means of microscopy and spectroscopy. They were shown to release unpolymerized methacrylate monomers (Cokic, et al., 2017). This poses a respiratory risk to those in the surrounding environment. Interestingly, dental workers are prone to developing asthma and other respiratory issues, although the cause has not been verified. Composite dust particles released in the air may be the culprit of this observed phenomenon. Further measures should be taken to reduce the inhalation of composite dust. Perhaps better safety masks should be implemented to reduce the inhalation of unhealthy composite dust.

Amalgam vs. Composite: Which to Choose?

The biocompatibility of materials used in restorative dentistry relates to how well it can interact with living tissue. According to the above data both amalgam and composite fillings contain components that can create issues of biocompatibility. However, although studies indicate the presence of toxic materials circulating in the body following dental procedures, the concentrations generally remain below levels that are harmful. Therefore, the question remains as to which material is preferred for treatment.

With the increased focus on esthetics, many patients opt for composite fillings. Particularly when dealing with anterior teeth, it definitely seems to be a better option. However, when considering which material to use for posterior teeth, amalgam does have some advantages. This is because the back molars bear a lot of stress from chewing forces. Amalgam has been shown to withstand more strain and is less prone to cracking or needing to be replaced. In addition, composite fillings are sensitive to temperature, and shrink upon exposure to heat, which can cause increased tooth sensitivity. Furthermore, shrinkage of composite material creates a gap between the tooth and the filling. This is known as leakage, and is a big cause of secondary caries formation. However, with proper oral hygiene much of this can be avoided.

Implants

Prosthetic implant devices are an evolving field in dentistry, and choosing the right materials are key to a successful procedure. Implants provide an excellent replacement option for teeth that are no longer restorable and need to be removed. Titanium is often the material of choice, as its osteophilic nature makes it highly biocompatible. Titanium is very reactive, and will rapidly form a layer of titanium oxide when exposed to an aqueous environment (such as the mouth) or air. This forms a boundary at the interface between the implant material and biological environment, which protects the material from corrosion. Therefore, the metal ion release into the body is limited and generally unreactive (Kumar et. al, 2016).

Although less prevalent than other metal allergies, titanium allergies do exist (Lahori et. al., 2015). An allergic reaction can create a rift in this oxide layer formation and may impair the biocompatible function. Allergic reaction to titanium is caused by the release of ions interacting with native proteins in the nearby environment. This may cause a hypersensitive reaction and rejection of the implant. Determining the presence of titanium allergies and working with alternative materials is an area of continued research. Titanium allergies may be the culprit to otherwise unexplainable implant failures.

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Another potential issue of this otherwise successful material is its elasticity. Young's modulus is a mechanical property which measures the stiffness of a solid material. It is a measurement determined by the slope of the stress-strain curve of a material. At 113.8 GPa, the elastic modulus of titanium is significantly higher than bone (18.6 GPa). This makes it less flexible than bone and can result in strain upon implant insertion and subsequent implant failure (El Hajje et. al., 2014). The implant material will act to shield the bone from stress, which eventually can lead to loosening and losing contact with the surrounding tissue.

Zirconium has been introduced as a possible alternative implant material. Clinically, it has demonstrated success similar to traditional titanium implants. Studies have shown little difference in osseointegration between the two materials. In addition, zirconium implants actually display reduced microbial growth as compared to titanium. This decreases plaque formation on the implant and surrounding tissue, which is important for the long-term success of an implant.

Peri-implantitis is the inflammation of the gum and bone structure in the area of a dental implant. It is caused by the buildup of trapped bacteria and can lead to bone loss. An in-vitro study was conducted to explore the adhesion of oral bacteria to different implant materials. It included both titanium and zirconium, as well as a combination of both. The results displayed that oral bacteria have less of an affinity for zirconia (Al-Radha et. al., 2012). This suggests that zirconia implants can lead to better implant results and more successfully prevent the development of peri-implantitis.

Over time, recession of soft tissue surrounding implants can occur. This can lead to exposure of implant parts and is a particular concern when dealing with anterior teeth. Also, titanium implants can result in discoloration of gingival tissue. In patients with a thin gingival biotype or high smile line, such discoloration is readily apparent. Zirconium implants may provide a solution to this issue as they result in a more esthetic appearance (Bhasin, et. al., 2015).

Polyetheretherketone, or PEEK, is a new material being explored as a possible alternative implant material. This may be an effective way to circumvent the titanium allergy, as well as provide a more esthetic option. In addition, with a low elastic modulus it can prevent issues of stress-strain distribution. This is in contrast to both titanium and zirconium, which possess higher elastic modulus (El Hajje et. al., 2014). However, being that its elastic modulus is actually lower than that of bone it is necessary to reinforce the material in order to use it successfully (Schwitalla et. al., 2015).

A finite element analysis technique, which is commonly

used to test dental materials in vitro, was used to study the stress distribution on the jaw following implant placement. It focused on titanium vs PEEK as the materials to be analyzed. A 3D model of the left mandibular jawbone was produced and an implant screw and abutment was inserted. Three different implant materials were used in the study to be compared, including titanium, and two different forms of commercial PEEK.

Circular contact areas were used for the purpose of testing the degree of stress caused to the different implant materials. Force was applied to the occlusion areas of the simulated implant via a specialized device, and the stress, deformations, and contact pressure were measured. The results of the study indicated that PEEK reinforced with 60% vertical carbon fibers was similar in stress distribution as titanium. Pure PEEK displayed higher stress damage. Perhaps this can be attributed to the fact that the elastic modulus of pure PEEK is lower than that of cortical bone. Reinforcing it with vertical carbon fibers makes it strong enough to withstand more stress, yet still maintain a lower elastic modulus than titanium (Schwitalla et. al., 2015).

The characteristics of PEEK suggests that it possesses the potential to be a good alternative to titanium. However, long term studies regarding clinical success are lacking. Further research is necessary before implementing the use of this synthetic material as a final abutment for implants.

For the most part, titanium implants have a track record of success and continue to be used as an excellent replacement option. It is a highly biocompatible material that generally integrates into the bone well. In the case of allergies or hypersensitivity, there are other options being explored. Zirconia is a good alternative as it has shown similar clinical success and may even have higher antimicrobial properties. In addition, it seems to be a preferred option in the case of anterior teeth and thin gingival biotypes.

Conclusion

The above studies indicate that the field of biomaterial compatibility requires further attention. It is necessary to take a closer look, even though they are already being utilized in the dental field. Amalgam as an older material is less of a concern. However, in regard to composites, future studies focusing on the long term and cumulative effect should be designed. This information is important in being able to further improve the biocompatibility of dental materials. On the other hand, with both of these materials, the release of toxic components is shown to be below baseline levels of what is harmful to the body.

Therefore, in terms of clinical applications the decision of which material to utilize can be made by practicing dentists. The choice can be made based on the individual needs of each patient and situation.

When dealing with implants, titanium remains an excellent option. Although it is a small percentage, there are some people who experience hypersensitivity or allergies to this material. There are other materials being explored with similar success rates. Some of these materials have shown good potential experimentally, yet clinical case studies are lacking. Further studies are necessary before implementing the widespread use of such materials.

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