Implant Restoration Materials: An Overview

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Abstract
Implant success depends not only on successful osseointegration, but also on the harmonious integration of a crown into the dental arch. With many materials being introduced in implant dentistry, it is imperative to acquire knowledge about various materials available and understand the factors which will contribute to the success or failure of the restorations.

Keywords: Implant restorative materials, properties.

INTRODUCTION
Osseointegration and proper loading are two of the most important factors determining long-term implant treatment success. Once successful osseointegration is achieved, occlusal loading of osseointegrated implants through restorative materials is believed to be a determining factor in the long-term success of an implant treatment program.

The restorative materials that can be used in implant dentistry are as follows:

1. Noble metal alloys
   i. Gold-platinum palladium (Au-Pt-Pd) alloys
   ii. Gold-palladium-silver (Au-Pd-Ag) alloys
   iii. Gold-palladium (Au-Pd) alloys
   iv. Palladium-silver (Pd-Ag) alloys
   v. High-palladium alloys.
2. Base metal alloys
   i. Nickel chromium (Ni-Cr) alloys
   ii. Cobalt-chromium (Co-Cr) alloys.
3. Polymers
   i. Acrylic resins
   ii. Composite resins.
4. Ceramics
   i. Feldspathic porcelain
   ii. Alumina based ceramics
   iii. Zirconia based ceramics
   iv. Lithium disilicate ceramics.

Requisites of an ideal implant restorative material
- It should be stable in the oral environment and should not undergo corrosion.
- It should fit passively over the implant abutment.
- It should be esthetic.
- It should not induce undue stresses in the implant or the bone.
- It should be biocompatible and should not induce any allergenic reaction.
- It should be easy to fabricate and handle.
- It should be easy to maintain.
- It should be cost-effective.

The restorative materials used in implant dentistry are explained as follows:

1. Noble-metal alloys
   i. Gold-Platinum-Palladium (Au-Pt-Pd) alloys

   The Au-Pt-Pd alloys were the first to be used successfully for metal-ceramic restorations; however, their use decreased after more economical alloys, were developed with significantly better mechanical properties and sag resistance.* If the alloy contains more palladium than platinum, it is referred to as a gold-platinum-platinum alloy.7

   Alloys in which palladium has been eliminated are referred to as gold-platinum alloys.7

   Limitations
   Ideally, for alloys with solidus temperatures# of 1000ºC or higher, sag deformation should be negligible (<1 mm/min).

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* Sag is the deformation of a metal or alloy which occurs at high temperatures such as during porcelain firing. The resistance to this deformation is called sag resistance.
# Solidus temperature is the temperature at which the last liquid solidified.
Because of their high sag deformation (>1 mm), the use of Au-Pt-Pd alloys should be limited to full coverage metal ceramic crowns and three-unit fixed partial dentures.7

ii. Gold-Palladium-Silver (Au-Pd-Ag) alloys
The Au-Pd-Ag alloys were developed in an attempt to overcome the major disadvantages of the Au-Pt-Pd alloys: high cost, low hardness. The sag deformation of Au-Pd-Ag alloys is 0.9 mm/minute and hardness is 210 to 230 kg/mm² (Diamond pyramid hardness number).7

Disadvantage
The principal disadvantage of these alloys is the potential for their silver content to discolor porcelain surface (greening). This greening effect is thought to be caused by the colloidal dispersion of silver atoms entering body and incisal porcelain or the glazed surface from vapor transport or surface diffusion.7

iii. Gold-Palladium (Au-Pd) alloys
The Au-Pd (silver free) alloys were developed to address the two main problems associated with silver-containing alloys: Porcelain discoloration and a high coefficient of thermal expansion. When used with compatible porcelain, these (silver free) alloys are considered nearly ideal compared with other noble metal alloys. Due to these alloys' low silver content (< 5%), porcelain does not discolor and castability is improved.8 Au-Pd alloys are moderately priced.7

Disadvantage
Their only significant disadvantage is that they have a degree of thermal expansion that is incompatible with some high expansion porcelains. The alloys must possess coefficient of thermal expansion compatible with those of dental porcelains. The coefficient of thermal expansion of porcelain = 13.0 to 14.0 × 10⁻⁶/°C and that of the metals = 13.5 to 14.5 × 10⁻⁶/°C. The difference of 0.5 × 10⁻⁶/°C causes the metal to contract a little more than the ceramic during cooling post-firing. This extracontraction of metal puts the ceramic under slight residual compression, which makes it less sensitive to applied tensile forces.7

iv. Palladium-Silver (Pd-Ag) alloys
In 1974 the first "gold-free" noble metal, metal-ceramic alloys (Pd-Ag alloys) were introduced. These were specifically developed as an economical alternative to the expensive gold-based alloys. Their elastic modulus (95 to 117 GPa) is also the most favorable of all noble metal, metal-ceramic alloys.9

Disadvantage
Due to their high silver content, Pd-Ag alloys produce more porcelain discoloration. Therefore, barring posterior restorations, experience may be necessary in fabrication of fixed partial restorations.7

v. High-Palladium alloys
Several types of high-palladium alloys were introduced in the 1980s.7 These alloys were primarily developed for economic reasons. They also addressed biocompatibility concerns of nickel-based casting alloys and minimized the porcelain discoloration seen with Pd-Ag alloys. The high-palladium alloys have more palladium (>70 wt%) than the Pd-Ag alloys. In time the price volatility of palladium (by 2000) led to the use of other alloys. The most popular types have been Pd-Cu, Pd-Co, and Pd-Ga.10

Palladium-Copper (Pd-Cu) Alloys
Though copper present in gold based metal-ceramic alloys, has been reported to cause porcelain discoloration and bonding problems, the same problem is not seen with high-palladium copper-containing alloys. Addition of copper and indium has been reported to decrease the solid solubility of gallium in palladium, causing the eutectic reaction to occur at lower weight percentages of gallium.10 It is suggested that this provides excellent hardening and strengthening, as the eutectic constituent is formed in greater amounts.10

This can, however, lead to problems during prosthesis fabrication using first-generation Pd-Cu alloys as their high yield strengths (550 to 1100 MPa) and hardnesses (Diamond pyramid hardness number = 350 to 400 kg/mm²) make them difficult to finish and polish.10 Also, some Pd-Cu alloys have low sag resistance (deformation is approximately 1.8 mm/min at a bending stress of 19.6 MPa and 1000°C) due to the alloys' poor creep resistance at high stress levels and temperatures which is close to porcelain's glass transition temperature.11

Palladium-Cobalt (Pd-Co) Alloys
The Pd-Co alloys have had limited use.

Disadvantage
The chief disadvantage of Pd-Co alloys is their tendency to form a dark oxide layer,10 which compromises porcelain esthetics. In addition, it has been reported that Pd-Co alloys have lower porcelain bond strengths than Pd-Cu alloys.12

An adequate bond occurs, when the fracture stress is more
than 25 MPa; however, many metal-ceramic systems have values of 40-60 MPa.\textsuperscript{12}

**Palladium-Gallium (Pd-Ga) Alloys**

The Pd-Ga alloys produce oxide layers that have less capability for ceramic bonding than Pd-Cu alloys.\textsuperscript{7}

One specific type of Pd-Ga alloy, the palladium-gallium-silver (Pd-Ga-Ag) alloy, is a recently introduced noble metal, metal-ceramic alloy. This alloy was formulated to have a lighter-colored oxide layer than the Pd-Cu alloys and is thermally compatible with some lower-expansion porcelains. Compared to other high-palladium alloys, the Pd-Ga-Ag alloys are softer. Though their physical properties appear adequate, more clinical data are necessary to confirm their successful performance.\textsuperscript{7}

Table 1 showing properties of noble metal alloys.

### 2. Base-metal alloys

Use of base metal alloys in implant restorations has not been popular due to the potential for corrosion between dissimilar metals.\textsuperscript{13}

Two main categories of base-metal metal-ceramic alloy systems exist: Nickel based and cobalt based. Alloys in both systems contain chromium as their second largest constituent and depend upon it for corrosion resistance. However, they react more with their environment compared to noble metal alloys.\textsuperscript{7} Base metal alloys have excellent physical properties. For example, they exhibit the highest modulus of any alloy type used for cast restorations.\textsuperscript{14}

For metal-ceramic use, base-metal alloys have been reported to have better castability than noble-metal alloys,\textsuperscript{12} but they tend to form thicker and darker oxide layers that may present esthetic problems.\textsuperscript{14}

#### i. Nickel-Chromium (Ni-Cr) alloys

These alloys are harder than noble alloys, but usually have lower yield strengths (255 to 730 MPa). They also have higher elastic modulii (150 to 210 GPa), and it was hoped that thinner copings and frameworks would result. They have much lower densities (7 to 8 gm/cm\textsuperscript{3}) and generally higher casting temperatures (1300 to 1450°C). Adequate casting compensation is sometimes a problem, as is the fit of the coping.\textsuperscript{7}

#### ii. Cobalt-Chromium (Co-Cr) alloys

Cobalt is the main constituent of cobalt-based metal-ceramic alloys, with chromium added for strength and to provide corrosion resistance via passivation. Cobalt-Chromium alloys are the most common base-metal alternative for patients who are allergic to nickel.\textsuperscript{14} With the exception of titanium alloys, the Co-Cr alloys have the highest melting ranges of casting alloys, which make them difficult to be manipulated in the laboratory.\textsuperscript{14}

Table 2 showing properties of base metal alloys.

### 3. Polymers

Theoretical considerations and \textit{in vitro} experiments suggest that an occlusal material with a low modulus of elasticity such as acrylic resin (elastic modulus = 3.8 GPa) may dampen occlusal impact forces, thereby decreasing its effect

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**Table 1: Properties of noble metal alloys**

<table>
<thead>
<tr>
<th>Type</th>
<th>Ultimate tensile strength (MPa)</th>
<th>0.2% yield strength (MPa)</th>
<th>Elastic modulus (GPa)</th>
<th>Elongation (%)</th>
<th>Diamond pyramid hardness (kg/mm\textsuperscript{2})</th>
<th>Casting temperature (°C)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Au-Pt-Pd</td>
<td>480-500</td>
<td>400-420</td>
<td>81-96</td>
<td>3-10</td>
<td>175-180</td>
<td>1150</td>
</tr>
<tr>
<td>Au-Pd</td>
<td>700-730</td>
<td>550-575</td>
<td>100-117</td>
<td>8-16</td>
<td>210-230</td>
<td>1320-1330</td>
</tr>
<tr>
<td>Au-Pd-Ag</td>
<td>650-680</td>
<td>475-525</td>
<td>100-113</td>
<td>8-18</td>
<td>210-230</td>
<td>1320-1350</td>
</tr>
<tr>
<td>Pd-Ag</td>
<td>550-730</td>
<td>400-525</td>
<td>95-117</td>
<td>10-14</td>
<td>185-235</td>
<td>1310-1350</td>
</tr>
<tr>
<td>Pd-Cu</td>
<td>690-1300</td>
<td>550-1100</td>
<td>94-97</td>
<td>8-15</td>
<td>350-400</td>
<td>1170-1190</td>
</tr>
</tbody>
</table>

**Table 2: Properties of base metal alloys**

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<th>Type</th>
<th>Ultimate tensile strength (MPa)</th>
<th>0.2% yield strength (MPa)</th>
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<th>Elongation (%)</th>
<th>Diamond pyramid hardness (kg/mm\textsuperscript{2})</th>
<th>Casting temperature (°C)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ni-Cr</td>
<td>400-1000</td>
<td>255-730</td>
<td>150-210</td>
<td>8-20</td>
<td>210-380</td>
<td>1300-1450</td>
</tr>
<tr>
<td>Co-Cr</td>
<td>520-820</td>
<td>460-640</td>
<td>145-220</td>
<td>6-15</td>
<td>330-465</td>
<td>1350-1450</td>
</tr>
</tbody>
</table>
on the bone-implant interface. However, the protective role of resin for the bone-implant interface has not been well supported by finite element analysis. More clinical complications have been reported, when acrylic resin or composite is used on occlusal surfaces such as screw loosening, resin fracture and resin wear.\textsuperscript{15}

i. Acrylic resin

Skalak \textsuperscript{6,16} hypothesized that an occlusal material with a low modulus of elasticity might dampen the occlusal impact forces, thereby decreasing its effect on the bone-implant interface. Thus, he suggested use of acrylic resin teeth, and indicated that such a resilient element could be placed elsewhere in the restoration as well. However, the results of an \textit{in vivo} study by Bassit et al.\textsuperscript{17} showed that the resilience of an acrylic resin veneer is insufficient to cause significant change in the force transmission through the prosthesis as compared to a ceramic veneer.

\textbf{Advantages}

Although, acrylic resin has many disadvantages, it has several merits over porcelain fused to metal (PFM) bridges. Although, it cannot dampen shock, it can delay the time of the shock rising to peak force.\textsuperscript{17} Resin material may be better for maxillary long span bridges than the heavier porcelain fused to metal. It also can be easily repaired chairside, if it fractures. This is an advantage considering that porcelain fracture is one of the most frequent complications of conventional and implant fixed partial restorations.\textsuperscript{18}

\textbf{Disadvantages}

They have poor wear resistance. Ceramic and composite wears at roughly 12 to 14 micron/year (height) and 10 to 12 micron\textsuperscript{3}/year (volume). Resin wears at 50 micron/year (height) and 45 micron/year (volume).\textsuperscript{19}

Their excessive thermal expansion ($81 \times 10^{-6}/\text{°C}$) and contraction lead to the development of stresses, when hot and cold beverages and foods are consumed.\textsuperscript{7}

Although, they have good initial esthetics, they discolor over time.

Hence, acrylic resin is used as an implant restorative material only, when the space available is unfavorable for ceramic fused-to-metal or when the patient wants to reduce the cost of treatment. It is also used as an interim prosthesis and in hybrid prosthesis. However, they require frequent relines, tooth replacement (in 20 to 90\% cases), and cause screw loosening and fractures (3 to 8\% in five years).\textsuperscript{20}

ii. Composite resins

Conventional acrylic resin facing materials exhibit poor wear resistance and may not maintain the established occlusal anatomy.\textsuperscript{21}

Fiber reinforced composite (FRC/laboratory processed resin) can be a prospective alternative for implant prosthetic materials due to its higher modulus of elasticity (28.5 GPa) and abrasion resistance compared to conventional composite. Fiber reinforced composite is also called ceromer or polyglass because it has properties of both resin and porcelain. It has greater strength because of the fusion between filler and matrix, which makes its abrasion resistance similar to that of natural teeth. It has superior color stability compared to traditional composites due to low water adsorption. The modulus of elasticity of this material is comparable to dentin (12 to 19 GPa) and hence can be used without metal framework. FRC can be repaired chair side and it exhibits minimal shrinkage as manipulation of the material is completed on the working die, whereas porcelain goes through high temperature sintering on a metal substructure.\textsuperscript{1} Behr \textsuperscript{22} reported the possibility of using FRC for fixed partial restorations on dental implants as an alternative to conventional implant prostheses.

\textbf{Table 3} showing properties of composite resin and acrylic resin.

\textbf{Disadvantages}

Composites absorb water and thus have decreased surface hardness and wear resistance. Hence, there is greater potential for discoloration by water soluble stains. Solubility

<table>
<thead>
<tr>
<th>Property</th>
<th>Laboratory composite</th>
<th>Acrylic resin</th>
<th>Enamel</th>
<th>Dentin</th>
</tr>
</thead>
<tbody>
<tr>
<td>Compressive strength (MPa)</td>
<td>613</td>
<td>427</td>
<td>200-442</td>
<td>232-311</td>
</tr>
<tr>
<td>Flexural strength (MPa)</td>
<td>218</td>
<td>93</td>
<td>80-90</td>
<td>138-270</td>
</tr>
<tr>
<td>Modulus of elasticity (GPa)</td>
<td>28.5</td>
<td>6.1</td>
<td>47-84</td>
<td>12-19</td>
</tr>
<tr>
<td>Vickers hardness (VH)</td>
<td>190</td>
<td>42</td>
<td>270-366</td>
<td>57-76</td>
</tr>
</tbody>
</table>
of resin composites ranges from 1.5 to 2% of the original material weight. Elements from filler particles dissolve in water to varying degrees and are detected in quantities as high as 180 \( \mu \) mol/gm.8

Cermics and metals are characterized by strong bonds between atoms, and the secondary bonds play an insignificant role in their properties. As a result, most ceramics and metals expand relatively little when heated. i.e. their coefficient of thermal expansion is relatively low (4 to 14 \( \times 10^{-6}/\degree C \)). Polymers, however, are characterized by strong bonds within polymer chains and weak bonds between polymer chains. As a result, when a polymer is heated, the chains move farther apart accounting for a high coefficient of thermal expansion (30 \( \times 10^{-6}/\degree C \)).8

Histological studies of the effect of residual monomer molecules on pulp tissue have shown a moderate degree of cytotoxicity, even in low concentrations.8

Thus, in spite of having improved properties as compared to traditional composites, their properties are still inferior to ceramics and metals.

4. **Cermics**

Due to increasing interest in esthetics and concerns about toxic and allergic reactions to certain alloys, patients and dentists have been looking for metal-free tooth-colored restorations. Therefore, the development of high strength dental ceramics, which appear to be less brittle, have less tensile strength, and are less subject to time dependent stress failure, has dominated the latter part of the twentieth century.23-25

A study was conducted to define the fracture rate of implant supported metal-ceramic restorations delivered in private practice, and to identify if a restoration's contact during eccentric mandible movements has any influence on ceramic fracture rates. It was noted that ceramic veneer fracture rate was 6.7%, and a conclusion that a restoration's contact during eccentric excursions may significantly enlarge fracture rates was made.26

Because of their specific mechanical properties, all-ceramic restorations demonstrate a lower fracture resistance than ceramic restorations supported by metal substructures. To avoid these defects, 2 types of industrially prefabricated high-strength all-ceramic abutments with improved optical and mechanical properties are made available for implants: a densely sintered high-purity alumina (Al\(_2\)O\(_3\)) ceramic, and a \( Y_2O_3 \)-partially- stabilized ZrO\(_2\)-ceramic implant abutment. However, the ZrO\(_2\) abutments are more than twice as resistant to fracture as the Al\(_2\)O\(_3\)-abutments.27

Zirconia is widely used to build prosthetic devices because of its good chemical properties, dimensional stability, high mechanical strength, toughness, and a Young's modulus (210 GPa) similar to that of stainless steel alloy (193 GPa). The mechanical properties of zirconia are the highest ever reported for any dental ceramic. The high initial strength and fracture toughness of zirconia results from a physical property of partially stabilized zirconia known as transformation toughening.28,29 In vitro studies of zirconium dioxide specimens demonstrate a flexural strength of 900-1200 MPa and a fracture toughness of 9 to 10 MPa/m\(^2\).7 On the other hand, its ability to transmit light and its white color, similar to the color of natural teeth, makes it useful in esthetic restorations of the oral cavity.30

Zirconia-based fixed partial restorations have a wider application than other ceramics, because they can be used on molar. Although, some manufacturers suggest them for full-arch restorations, five-unit fixed partial restorations are reported to be the maximum possible.31

The success rate of this zirconia framework in the 5-year follow-up was 97.8%.30 The most frequent technical problem in studies of zirconia reconstructions is chipping or cracking of the veneer ceramic. These results were attributed to low or moderate bond strength between zirconia frame works and veneering ceramics. It can be concluded that various veneering ceramics available for zirconia possess insufficient mechanical properties.32

Lithium disilicate is a high strength ceramic material with 360 to 400 MPa of flexural strength. When fabricated to full contour or in a monolithic state, lithium disilicate is extremely durable. Failures in zirconia veneered restorations are the result of a very weak porcelain material (flexural strength of 90 MPa) having masticatory forces exerted upon it. The zirconia substructure with a flexural strength of 1,000 MPa remains in tact but the failure of the layering porcelain ultimately causes a failure of the restoration.33

With monolithic lithium disilicate, the force of mastication is applied on a 360 to 400 MPa material. This strength is homogenous throughout the entire restoration. Several tests have demonstrated that the monolithic lithium disilicate is incredibly durable and that the zirconia veneered restorations fail with less load and fewer chewing cycles.33

However, esthetic outcome of such machinable blocks may be a concern. In a study, regardless of the fabrication method the crowns were esthetically acceptable in all the patients. The mean values for the layering technique and for the machined restorations did not differ significantly.
Thus, it was documented, that machinable blocks could attain esthetically satisfying results.34

CONCLUSION

With newer materials being introduced in implant dentistry, it is imperative to acquire knowledge about various materials available and understand the factors, which will contribute to the success or failure of the restorations. To weigh the advantages and disadvantages of various materials before proceeding with the treatment would be invaluable towards making a prudent decision in rendering the appropriate restoration to the patient in terms of optimal health, esthetics and function.

REFERENCES