Review Article

Effect of surface treatments on bond strength of resin cements to titanium: A Literature review

Abstract:

Objectives: The aims of this literature review are to provide answers to questions on how to improve bonding between titanium and resin cement and how to further implement, in clinical practice, titanium-resin as an alternative to conventional metal–resin systems.

Material and methods: A literature search of PubMed was conducted and eight fulfilled the search criteria, namely mentions of titanium, resin cement, bond strength, surface treatments, and luting agents. These papers were compiled for comparison and evaluated regarding the bond strength achieved with different methods.

Results: The results strongly indicate that there are possibilities to improve the adhesion methods for titanium–luting agents.

Conclusions: The combination of micromechanical and chemical surface treatments enhanced the adhesion between different resin cements and titanium. It is important to select the appropriate surface treatments of titanium regarding the type of resin cement that will be used. Utilizing titanium with resin cements for crowns and fixed partial dentures can be recommended for routine clinical use.

Keywords: Bond strength, cement, titanium, surface treatments

Introduction

In recent years, titanium has become a material of great interest in prosthetic dentistry (1, 2). It has been used in metal-ceramic restorations because of its several advantages, such as good corrosion resistance, excellent biocompatibility, low density, low thermal conductivity, and reasonable price (3). Low density allows a routine dental radiograph to pass through titanium crowns or frameworks thereby identifying defects, thus, preventing clinical failures and future costs of replacement restorations (4).

Titanium and its alloys present with an oxide layer at ambient temperatures. The surface properties will differ fundamentally from the metallic substrate due to this oxide layer. Consequently, oxidation factors such as temperature, type of oxidizing elements, and contamination affect the physicochemical properties (5). Effective surface preparation for titanium requires the elimination of weak layers that are incompatible with the adhesive and consequently the formation of stable adherend layers that are compatible with the adhesive (6).

Proper cementation of titanium and its alloys using effective luting materials is crucial in the various dental application (7). Successful adhesion of luting materials to a substrate depends on both micromechanical interlocking and physicochemical bonding (8). Using titanium as a prosthetic superstructure requires a strong bond of cement to titanium. (6)

Previous studies evaluated the influence of different surface treatment methods on the bond strength of titanium to dental cements including acidic and alkaline/heat treatments, metal primers, phosphate monomer, titanium nitride coating, fluoride gel, hydrogen peroxide (H_2O_2), and silanization to silica-coated titanium (5, 7, 9-14).

In these studies, the titanium surface chemistry and topography were reported as significant variables affecting the strength and durability of the titanium-cement joint. Although such methods can successfully enhance the adhesion of dental cements to titanium, some of them are relatively complicated and time-consuming, so they have not been accepted for use in practice (7, 15). Consequently, the aim of this literature review was to provide answers to questions on how to improve the bonding mechanism between titanium and resin cement and how to further implement the concept in clinical practice for indirect restorations.

Material and methods

A PubMed literature search was conducted using the search terms ’titanium ‘AND ’resin cements ‘AND ’luting agents ‘AND ’surface treatment ‘AND ’bond strength‘. The search was restricted to studies published between 1 January 2010 and 31 January 2022.

Results

A total of 31 papers were found as a result of the PubMed search. Eight papers were found that dealt with the effect of different surface treatments on the bond strength of titanium–luting agent according to the selected criteria (Figure 1). These studies are summarized in Table 1.

The studies presented have different test designs. In some cases, are designed to investigate the behavior of different brands of material, while other studies are comparisons of the same brand of material with variations in the method of treatment. It was documented that the bond strength was significantly affected by both the type of surface treatment and the type of resin cement used (6, 16, 17), as well as by different storage conditions (16, 18, 19).

It was also documented that there was an improvement in bond strength by using different metal primers (9, 18, 20, 21), use of different bonding agents (9, 21), roughing the titanium surface using grit blasting (20), polydimethylsiloxane silicon with different thermal treatment (19), chemical etching (6, 16), air abrasion (9, 17, 21). Other studies also showed that there was a high bond strength with the treatment of the titanium surface with Rocatec (9, 21).

Discussion

The findings from this study were to provide answers to questions on how to improve the bonding mechanism between titanium and resin cement and how to further implement the concept in clinical practice for indirect restorations.

It was shown that the surface roughness of titanium increased after acid etching. Grit blasting followed by alkaline/heat treatment (GB/AH) not only forms micropores but also forms nanoscale pores on the surface. The largest bonding strength was obtained by using alloy primer (ALP). After the GB/AH treatment, a dense and uniform net structure is formed on the surface of the machined CP-Ti and provides a great adhesive microstructure The concentration of the acidic monomer on the surface of the machined CP-Ti is enhanced by increasing the use of MDP, which forms more hydrogen bonds that further improve the chemical bonding strength. The combination of these treatments makes the most robust bond between machined CP-Ti and the resin adhesives (20).

It was reported that the surface treatment of titanium by a polydimethylsiloxane coating with a thermal treatment changed both the physical and chemical characteristics of the titanium surface. Silane coupling agents were used for increasing the bonding between resins and silica-coated metals, consequently; chemical bonding is formed between resin cement and titanium. The bond strength was improved by the treatment using a polydimethylsiloxane coating at elevated temperatures when compared to sandblasted group (19).

In another study, it was shown that the use of metal conditioners and sandblasting increased the bond strength in comparison to the values obtained on polished surfaces. It was suggested that the use of chemical bonding systems combined with mechanical retention improved the bonding between a resin composite and cpTi. This evidence implies that clinicians may consider the use of techniques that combine chemical bond and mechanical retention when reliable bonding is required between a metal surface and resin composite (18).

It was reported that reliable bonds between Ti and resin-based luting agents could be achieved by using surface pretreatment with a hot etching solution. The surface roughness of the Ti surface provides mechanical interlocking with resin cement and is considered to be a significant factor influencing bond strength. Surface roughness is considered to increase surface area and, consequently, may enhance the Ti-resin cement bond. Interfacial bond strength was influenced by the choice of luting material. Dual-polymerizing, resin-based cements are preferred as luting materials for metallic prostheses. This treatment could be considered as an alternative to airborne-particle abrasion to avoid the contamination of prostheses by alumina particles (16).

The creation of micromechanical retention through airborne-particle abrasion remains necessary for adequate bond strength. It was shown that the use of smaller particles (50 µm) promoted lower bond strength than abrasion with 120 µm and 250 µm Al_2O_3 particles. The use of silane did not significantly increase the bond strength, regardless of the particle size used for abrasion. Neither the mechanical action nor the chemical effects of silane were observed (17).

The achievement of effective bond between titanium and cement depends on two factors: (1) titanium surface properties and (2) composition, properties, and adhesive ability of the cement employed. The acidic monomers containing phosphoric groups and carboxylic acid derivative monomers are capable of bonding chemically with the superficial oxide layer of base metals via Bolger‘s acid-base interaction. Treatments with 30% H_2O_2 for 5 or 10 min significantly improved the cp Ti/resin bond strength compared to the control group. The use of 9% HF, CH_2Cl_2, or 30% H_2O_2 solutions as chemical treatments for cp Ti may effectively enhance the adhesion between resin cements and cp Ti by the formation of a surface with different elemental composition to that presented by unmodified cp Ti surface (6).

It was reported that the abrasion with silica-modified Al_2O_3 particles enhanced the adhesion between titanium and resin cement. Surface treatment with silane only, resulting in both bonding mechanisms (micromechanical retention and chemical bonding). Abrasion with 250 µm Al_2O_3, adhesive, and silane presented the highest bond strengths, demonstrating the influence of the particle size on bond strength (larger size results in higher strength) and indicating that surface treatment differing from those recommended by the manufacturer may yield better bond strength results (9).

It was reported that in all the situations in which there was only micromechanical retention (no silane coupling agent), there was no significant difference between airborne-particle abrasion with 50 µm Al_2O_3 particles. Surface roughness with 110 µm promoted significantly higher mean bond strength than Cojet Sand (30 µm). The superiority of silane compared to no post airborne-particle abrasion treatment and adhesive; this behavior could be justified by the chemical bonding this material promotes. This is an additional bonding mechanism, as the airborne-particle abrasion already promotes micromechanical retention. Silanes establish a chemical bond between the resin matrix and the metal surface due to their bifunctional characteristics. The evidence of the superiority of some of the combinations to others, with decisive factors in determining the bond strength being the particle size under certain conditions and the chemical composition of the particles in others (21).

Conclusion

The combination of micromechanical and chemical surface treatments enhanced the adhesion between different resin cements and titanium. It is important to select the appropriate surface treatments of titanium regarding the type of resin cement that will be used. Utilizing titanium with resin cements for crowns and fixed partial dentures can be recommended for routine clinical use.

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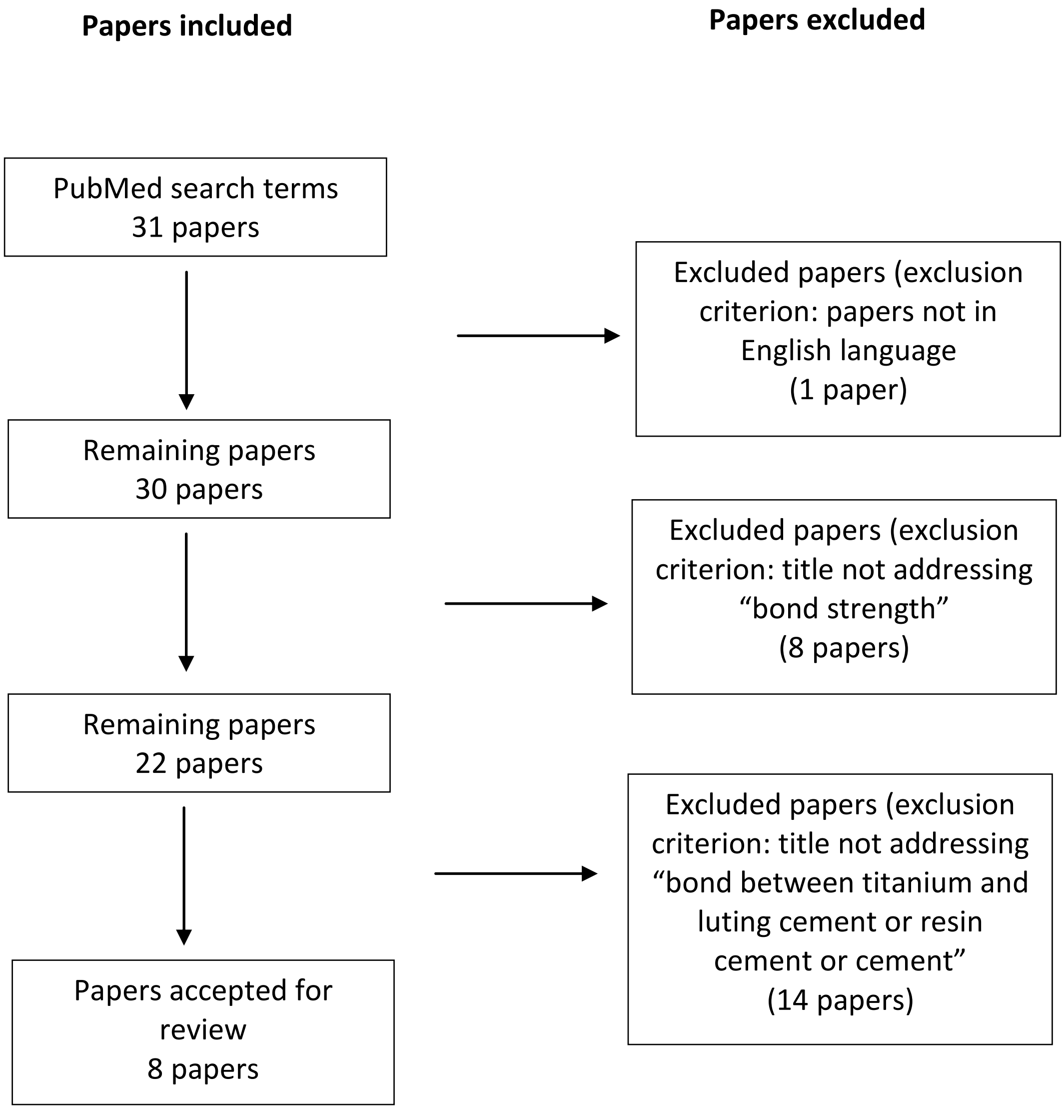

Figure 1. PubMed search process.

Table 1. Comparison of different surface treatments on bond strength of titanium and resin cement

Reference	Test criteria	Results	Conclusion
20	Investigated the effects of grit blasting, acidic or alkaline/heat treatments, and metal primer application on the shear bond strength (SBS) of resin cement to machined commercially pure titanium (cp Ti).	The surface roughness, in descending order, was grit-blasting (GB), grit blasting followed by either acidic treatment (GB/AC), or alkaline/heat treatment (GB/AH). The (GB/AH) group showed the highest shear bond strength (SBS) among all the treatments. As for primers, the alloy primer (ALP) group showed the highest (SBS), while the Rely X Ceramic Primer (RCP) group showed the lowest. Using grit-blasting GB followed by alloy primer (ALP) presented the highest (SBS).	The grit blasting followed by alkaline/heat treatment group (GB/AH) treatment significantly improved the bonding strength relative to the grit-blasting followed by acid etching group (GB/AC) treatment. The alloy primer (ALP) treatment facilitated the formation of hydrogen bonds, which further improved the chemical bond strength. The combination of the previous surface treatments resulted in the most robust bond between machined commercially pure titanium (cp Ti) and the resin adhesives.

19	Evaluated the effect of titanium surface treatment by a polydimethylsiloxane coating on the shear bond strength of a resin composite cement to titanium.	The results showed that there was a significant difference between different surface treatments ($p > 0.001$) and different storage conditions ($p > 0.01$) on the mean shear bond strengths.	Surface treatment of titanium with a polydimethylsiloxane coating at 1000 °C and 1100 °C curing provides sufficient resin bonding for clinical services.
18	Evaluated the effect of three metal conditioners on the shear bond strength (SBS) of prosthetic composite material to commercially pure titanium (cp Ti) grade.	On 50 SB surfaces, opaque primer (OP) groups showed higher shear bond strength (SBS) means than metal photo primer (MPP) ($p < 0.05$). Among opaque primer (OP), one surface modification system siloc (S), and targis link (TL) groups. On 250SB surfaces, (OP) and (TL) groups exhibited higher SBS than MPP and S ($p < 0.05$). No significant difference in (SBS) was found between (OP) and (TL) groups nor between (MPP) and (S) groups.	Sandblasting associated with the use of metal conditioners improves the SBS of resin composites to commercially pure titanium (cp Ti).

16	Evaluated the effect of treating surfaces with chemical etching solution on the adhesion of titanium-resin cement systems as determined by strain energy release rate (G-value, J/m^2).	Strain energy release rate values were significantly affected by the type of cement, surface treatment, and thermocycling ($p < 0.05$). After thermocycling, the cp Ti/i CEM groups showed the highest G-values among the groups. Atomic force microscope (AFM) and Scanning electron microscope (SEM) analyses showed that the surface topography of commercially pure titanium (cp Ti) was modified after treatments.	The strain energy release rate (G-value, J/m^2) between resin cement and commercially pure titanium (cp Ti) can be improved by the use of an experimental hot etching solution before cement application.
17	Evaluated the effect of surface treatments on the shear bond strength (SBS) of resin-modified glass ionomer and resin cement to commercially pure titanium (cp Ti).	The surface treatments, cement, and their interaction significantly affected the SBS ($p < 0.001$). Rocatec + silane promoted the highest SBS for RelyX ARC. RelyX U100 presented the highest SBS mean values ($p < 0.001$). All groups showed a predominance of adhesive failure mode.	The adhesive capability of RelyX Luting 2 and RelyX U100 on the SBS was decisive, while for RelyX ARC, mechanical and chemical factors were more influential.

6	Evaluated the effect of different chemical surface treatments on the adhesion of self-adhesive resin cement to commercially pure titanium (cp Ti) using strain energy release rate (G-value, J/m^2).	The cp Ti/G-CEM and cp Ti/Rely X Unicem (9% HF for 5 or 10 min) groups showed the highest G-values among their groups. The sandblasted group showed the highest surface roughness value when compared with other treated groups.	Adhesion between resin cement and commercially pure titanium (cp Ti) can be improved by the use of certain chemical baths as surface treatments of titanium before cementation as alternative techniques to sandblasting treatment.
9	Evaluated the effect of surface treatments on the shear bond strength (SBS) of resin cement to commercially pure titanium (cp Ti).	The results revealed that the air-abrasion technique ($p < 0.001$), additional surface treatment ($p < 0.001$) and their interaction were significant ($p < 0.001$). The two combinations that promoted the highest shear bond strength (SBS) were 250-µm Al_2O_3 + adhesive and Rocatec Plus + silane. All groups showed 100% adhesive failure.	The selection of the best additional surface treatment varied according to the air-abrasion technique. Particle size was the decisive factor in determining the bond strength when micromechanical retention was the only bonding mechanism. When both mechanisms were present, in addition to particle size, the material applied as the additional surface treatment also contributed to determining the bond strength.

21	Evaluated the effect of surface treatments on the shear bond strength (SBS) of resin cement to commercially pure titanium (cp Ti).	The results revealed that airborne-particle abrasion, post-airborne-particle abrasion, and their interaction were significant ($p < 0.001$).	The best association was Rocatec plus silane. All groups showed 100% adhesive failure. There were combinations that promote higher shear bond strength (SBS) than the protocol recommended by the manufacturer of RelyX ARC.