

THE EFFECT OF CEMENT TYPE ON THE RETENTION OF POLYMER
INFILTRATED CERAMIC NETWORK RESTORATIONS TO PREFABRICATED
TITANIUM ALLOY ABUTMENTS

by

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A thesis submitted to the Faculty of the
Comprehensive Dentistry Graduate Program
Naval Postgraduate Dental School
Uniformed Services University of the Health Sciences
in partial fulfillment of the requirements for the degree of
Master of Science
in Oral Biology

June 2019

Distribution Statement

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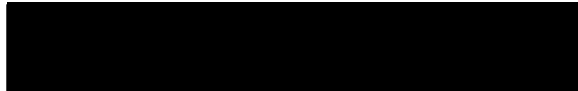
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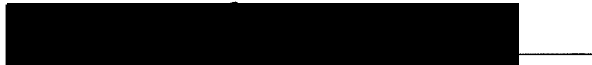

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ABSTRACT

THE EFFECT OF CEMENT TYPE ON THE RETENTION OF POLYMER
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TITANIUM ALLOY ABUTMENTS
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D.D.S., COMPREHENSIVE DENTISTRY, 2019

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Introduction: Polymer-infiltrated ceramic network (PICN) is a recently introduced material that shows promise to overcome some limitations of traditional ceramics, particularly for implant restorations. The attachment of the titanium abutment to the overlying restoration is typically accomplished through the use of an adhesive cement.

Purpose: To examine the tensile bond strength of three cements on the PICN abutment block to an idealized machined prefabricated titanium base abutment.

Methods: 30 unmilled PICN implant abutment blocks were cemented to 30 micro-abraded prefabricated titanium stock implant abutments using 3 resin cements (10 samples for each cement): dual cured self-adhesive cement (Rely-X Unicem 2), dual-cured adhesive cement (Multilink Automix), and self-cured adhesive cement (Panavia 21). After artificial aging with 36,500 thermocycles, the peak failure load was measured using a crown pull-off test. Material fracture patterns and failure modes were examined. Statistical analyses were performed using a Kruskal-Wallis test and Dunn Test.

Results: The median retention values were 358N for Multilink Automix, 547N for Panavia 21, and 738N for Rely-X Unicem. A significant difference of values between Rely-X Unicem and Multilink Automix was found. There were no significant differences

between the other cement types. Failure between Multilink Automix and Panavia 21 occurred primarily at the PICN-cement interface, whereas failure in the Rely-X Unicem group was seen at the titanium-cement interface. For Rely-X Unicem alone, the bond to PICN was greater than that to the micro-abraded titanium alloy.

Conclusions: Rely-X Unicem dual cured self-adhesive resin cement displayed the highest bond strength of the tested cements to the PICN material. However, all 3 tested resin cements displayed acceptable retention values between PICN and titanium alloy abutments required for typical clinical conditions.

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Review of Literature

As patient demands for esthetics, cost-effectiveness, and timeliness increase, ceramic restorations fabricated with in-office Computer-Aided Design/Computer-Aided Manufacturing (CAD/CAM) technology continue to rapidly grow in popularity (Weyhrauch, Igiel, Scheller, Weibrich, & Lehmann, 2016). Millable all-ceramic and hybrid composite ceramic materials have been demonstrated to provide excellent esthetics and cost-effectiveness while satisfying requirements for biocompatibility and mechanical properties, making them an excellent choice for dental restorations (Awada & Nathanson, 2015; Goujat et al., 2017; Thompson & Rekow, 2004). There is well-documented evidence that high levels of accuracy can be achieved with this technology in the fabrication of implant copings, abutments, and restorations (M & TD; Mitrani, Vasilic, & Bruguera, 2005; Parel, 2003). In addition, when compared with restorations fabricated through conventional methods, CAD/CAM restorations have been shown to display similar or better results with respect to marginal fit (Karl, Wichmann, Heckmann, & Krafft, 2008; Takahashi & Gunne, 2003) and clinical performance (Coldea, Swain, & Thiel, 2013a; Jemt, Bäck, & Petersson, 1999; Ortorp, 2005), with survival rates reported to be 97% over 5 years and 90% over 10 years (Fasbinder, 2013).

Vita Enamic is a recently introduced material that shows promise to overcome some limitations of traditional ceramics. It is volumetrically composed of 86% feldspathic ceramic, mostly aluminum oxide (Al_2O_3), and 14% polymer, primarily urethane dimethacrylate (UDMA) and triethylene glycol dimethacrylate (TEGDMA). Vita Enamic is fabricated by penetrating a polymer matrix with pre-sintered ceramic particles, and is therefore classified as a polymer-infiltrated ceramic network (PICN) (Coldea, Swain, & Thiel, 2013b). One advantage of PICN over traditional ceramics

shown in recent studies specifically related to CAD/CAM technology is reduced brittleness, allowing for improved machinability and decreased chipping during the milling process. The result is decreased incidence of micro-fractures in the material and improved milling efficiency. PICN has been further demonstrated to show lower wear loss and less wear damage of opposing enamel than lithium disilicate (Elhomiamy, Aboushady, & El Malakh, 2015).

Certain mechanical properties of Vita Enamic are particularly advantageous as a restorative material for implant restorations. Specifically, the material exhibits hardness and an elastic modulus similar to human enamel and dentin as well as adhesive luting cements (Coldea et al., 2013b). These properties have been shown to improve stress distribution throughout the material and limit the transfer of potentially bone damaging forces to the implant itself during mastication (Menini et al., 2013). In addition, Vita Enamic has the ability to absorb occlusal forces more effectively and distribute them more evenly over a larger area, therefore reducing the likelihood of implant overload (Ramirez, 2017). This makes it a suitable choice for implant-supported restorations (Coldea et al., 2013a; Della Bona, Corazza, & Zhang, 2014; He & Swain, 2011).

Ceramic restorations rely heavily on adhesive bonding for long-term success. This method of cementation has been shown to prevent microleakage, improve retention, and increase fracture resistance of ceramic restorations (Addison, Marquis, & Fleming, 2008; Blatz, Sadan, & Kern, 2003; Peumans, Van Meerbeek, Yoshida, Lambrechts, & Vanherle, 1999; Sorensen, Kang, & Avera, 1991). The conventional surface treatment for predominantly glass ceramics is a hydrofluoric acid (HF) etch to partially dissolve the glass phase and provide a roughened surface for micromechanical interlocking with resin

cement (Della Bona & van Noort, 1998; Venturini, Prochnow, Rambo, Gundel, & Valandro, 2015), followed by the application of a silane coupling agent to facilitate a chemical bond between inorganic glass and organic resin cement (Matinlinna, Lassila, Ozcan, Yli-Urpo, & Vallittu, 2004). In 2016, Schwenter et al demonstrated that silanization of a PICN significantly improves the bond strength to a resin cement. It was noted, however, that this only provides for a chemical bond to the glass component of the material, and that the pre-polymerized resin component participates only minimally in the bond (Schwenter, Schmidli, Weiger, & Fischer, 2016).

Retention of dental restorations to a cast or milled implant abutment is influenced by multiple factors involving the underlying abutment, the restoration, and the cement (Kaufman, Laurence, Schlagel & Coelho, 1966). As opposed to natural teeth, implant abutments have the advantage of extraoral fabrication, and therefore parallelism and height of the opposing walls, the surface area, and the finish of the surface to be bonded can be idealized to improve retention and resistance (Bernal, Okamura, & Muñoz, 2003; Carter, Hunter, & Herbison, 1997; Emms, Tredwin, Setchell, & Moles, 2007). Saber et al demonstrated in 2012 that the minimum heights necessary to provide adequate retention for 3.5 mm diameter implants and 5 mm diameter implants were 3 mm and 4 mm, respectively. Additionally, the study showed abutment height and height-to-width ratio of cement-retained restorations were much more important for retention than abutment total surface area and width alone (Saleh Saber et al., 2012).

Titanium-6aluminum-4vanadium alloy (Ti6Al4V) is a well-accepted material for use in CAD/CAM dental implant abutments, demonstrating adequate machinability coupled with biocompatibility, corrosion resistance, and sufficient strength to survive in

the oral environment (Guilherme, Wadhvani, Zheng, & Chung, 2016). One limitation of Ti6Al4V as a full contour abutment is poor esthetics in the submucosal region due to its grey metallic color (Jung, Sailer, Hämmerle, Attin, & Schmidlin, 2007; Kim, Campbell, Viana, & Knoernschild, 2016). This shortcoming has been addressed with the development of two-piece hybrid abutments which employ a machined Ti6Al4V insert to provide a metal-to-metal interface with the implant, under a tooth-colored translucent superstructure material to cover the alloy (Guilherme et al., 2016). In addition to improving esthetics, this method allows for the restoration to be screw-retained. Two advantages of screw-retained implant restorations over cement-retained restorations are retrievability of the restoration for implant maintenance and prosthesis repair (Priest, 2017) and the elimination of intraoral cementation procedures, which can lead to residual subgingival cement and subsequent peri-implant disease and implant failure (Linkevicius et al., 2013; Linkevicius, Vindasiute, Puisys, & Peciuliene, 2011; Maeyama et al., 2005). Screw-retained crowns allow for extraoral marginal polishing under microscopic control, whereas cemented crowns require the polishing to be performed intraorally, limiting access for both polishing and inspection (Cresti, Itri, Rebaudi, Diaspro, & Salerno, 2015).

The attachment of the Ti6Al4V abutment to the overlying restoration is typically accomplished through the use of an adhesive cement, which involves more than one adhesive interface with the involved materials requiring different surface treatments to maximize their adhesive potential (Abi-Rached, Fonseca, Haneda, de Almeida-Júnior, & Adabo, 2012; Cresti et al., 2015; Wadhvani, Hess, Pineyro, & Chung, 2013). A study by Taira et al found that combining microabrasion with surface treatment of the alloy with 5% hydrofluoric acid and a 10-methacryloyloxydecyl dihydrogen phosphate (MDP)

primer successively may yield slightly greater shear bond strength of composite to the titanium surface (Taira, Odatsu, & Sawase, 2013). Recently however, Guilherme et al demonstrated that treatment of the Ti6Al4V with microabrasion with 50 micron aluminum oxide particles and MDP primer yielded better shear bond strength values to lithium disilicate than etching the alloy with hydrofluoric acid, both 5% and 9.5%, for 30 seconds alone or in combination with microabrasion. A secondary finding of this study was that the type of adhesive cement used did not significantly influence the bond strength (Guilherme et al., 2016).

The effect of thermocycling on the tensile bond strength of resin cements to different substrates is somewhat controversial. In 2013, Guarda et al demonstrated that artificial aging through thermocycling negatively affected the tensile bond strength of resin cements to lithium disilicate ceramic. The study suggested this may be the result of reduction of mechanical properties of the resin cement due to continuous action of water on the interface of the ceramic-resin cement interface (Guarda et al., 2013). However, Mehl et al examined retention of cobalt-chromium crowns to titanium universal abutments, and found that artificial aging through the use of a thermocycler and chewing simulator negatively affected the retentive properties of glass ionomer cement (Ketac Cem), but did not affect that of resin cement (Multilink Implant) (Mehl et al., 2016).

A recent study by Rohr et al examined the influence of cement type and primer on the retention of full contoured PICN restorations to zirconia abutments, and found that most failures occurred at the cement-zirconia interface. It was also noted that at forces above 200 N, fractures occurred within the PICN material itself (Rohr, Brunner, Martin, & Fischer, 2018). A limitation of this study is that the design of the fabricated custom

tensile device used for testing did not closely approximate the PICN-titanium interface, possibly leading to the observed fractures within the material, and failing to examine the bond strength alone. In addition, the PICN blocks were milled before load testing. Depending on the design of the crown, this process has the potential to incorporate microfractures and problematic contours that weaken the material, possibly resulting in intra-material fracture, and fails to limit the test to the bond alone. Finally, thermocycling was not performed which as previously mentioned has been shown to negatively affect the ceramic-resin cement tensile bond strength.

The purpose of the current study is to examine the effect of bonding modalities on the tensile strength of a PICN abutment block to an idealized machined prefabricated titanium base abutment after artificial aging through thermocycling. In addition to artificially aging the cemented restorations, the current study design will use unmilled abutment blocks and alter the jig design to more intimately fit the PICN-titanium interface in an attempt prevent intra-material fracture and more precisely test the strength of the cement interface.

Materials and Methods

Thirty prefabricated Ti6Al4V stock implant abutments (TiBase, Sirona Dentsply) and thirty un-milled polymer-infiltrated ceramic abutment blocks (Vita Enamic Implant Solutions) were used. The bonding surfaces of the prefabricated abutments were microabraded with 50 μ m aluminum oxide according to manufacturer's instructions. The intaglio surface of each abutment block was etched with 5% hydrofluoric acid (Ceramics Etch; Vita Zahnfabrik) for 60 seconds and rinsed. The abutment blocks and the Ti6Al4V abutments were cleaned with a steam cleaner (Hot Shot Professional). Thirty abutment blocks labeled as A, B, or C to correspond to appropriate cement used were cemented on prefabricated stock abutments using 3 different adhesive cements (Table 1) according to the manufacturers' recommendations (n=10). The cements were selected to cover a range of resin cement classifications. An MDP-containing universal primer (Monobond Plus; Ivoclar Vivadent) was applied to the bonding surfaces of all Ti6Al4V abutments and the polymer-infiltrated ceramic blocks of groups A and B, allowed to react for 60 seconds, and then air-dried until all liquid is evaporated. Due to manufacturer's instructions, the bonding surfaces of the abutment blocks in group C were treated with a proprietary ceramic primer (Ceramic Primer; Kuraray).

The abutment blocks were filled with cement, placed on the prefabricated abutments, and excess cement was removed with a microbrush. Each specimen was loaded with finger pressure during photopolymerization for groups A and B. The margins were photopolymerized for 20 seconds per quarter surface with a photopolymerizing unit (Elipsar Freelight 2; 3M ESPE). The specimens of Group C were allowed to self-cure for 60 seconds.

After the cementation process, the specimens were stored in distilled water at 37°C for 24 hours. Thermocycling was performed, subjecting the specimens to 36,500 cycles from 5°C to 55°C with a dwell time of 30 seconds and a drip time of 8 seconds (SD Mechatronik; Julaba). The crown retention testing was performed using a universal testing machine (Crosshead; MTS Insight) at a crosshead speed of 1 mm/min in a Ti6Al4V printed custom specimen holder that was engaged at the implant analog/abutment interface (Figure 1). The peak load required for bond failure was recorded. The surface of each specimen was examined with stereo-microscopy (Stereomicroscope; Leica) and type of failure modes were categorized as follows: (i) cement remained mostly on the surface of the polymer-infiltrated ceramic abutment block and (ii) cement remained mostly on the titanium abutment surface (Figure 5).

Taking into account the small sample size, continuous data were examined for normality using visual inspection. Due to the non-normal distribution of the variable in at least one group, the tensile crown retention force (as measured using a universal testing machine) was summarized for each cement type using medians and 95th confidence interval (CI). To determine the influence of the luting resins on the bond strength among groups a Kruskal-Wallis test was performed followed by a post hoc test (Dunn Test) to evaluate the pairwise comparisons between the different materials.

Results

A total of 10 samples by group were collected. The individual peak retention values, medians, and 95% confidence interval (CI) are summarized in Table 2. The median retention values were 358 N (296 – 447) for Multilink Automix, 738 N (696 – 812) for Rely-X Unicem 2, and 547 N (474 – 701) for Panavia 21. It was determined by the stacked histograms (Figure 2) that the data is not normally distributed. A Kruskal-Wallis test revealed that there was a significant effect of cement type on peak retention levels ($p=.000111$). The null hypothesis that no difference in peak retention among cements was rejected. The post hoc test: Dunn test for multiple comparisons of groups, showed a significant difference in the distributions of values between Rely-X Unicem 2 and Multilink Automix ($p=.000059$). No significant difference was found between Panavia 21 and the other cement types (Figure 3). The highest retention forces for individual measurements of Rely-X Unicem 2 were shown to be highest among the samples tested, however a high variability within all cement groups was found.

All samples in all cement groups experienced a similar pattern of cohesive fracture within the PICN material, leaving small portions of the PICN bonded to the titanium abutment in the cervical region around the base (Figure 4). Cement residue was found on the PICN and the titanium surfaces after failure for all samples. For Multilink Automix and Panavia 21 cements, the bulk of the cement residue remained on the Ti4Al6V abutment while small cement particles were observed on the PICN surface. For Rely-X Unicem 2 cement however, cement was found to adhere mainly to the PICN material, except for small cement remnants that remained on the Ti4Al6V abutment retention grooves (Figure 5).

Discussion

In the present in vitro study, the effect of resin cement type on the retention of a PICN abutment block to a prefabricated titanium base abutment after artificial aging was evaluated. The hypothesis that no difference in retention values exist based on the type of resin cement used is rejected since choice of cement significantly influenced crown retention values to the Ti6Al4V abutments.

Rohr et al examined the influence of cement type and primer on the retention of full contoured PICN restorations to zirconia abutments. In this study, it was noted that separation within the crown was experienced at peak failure loads above 250N (Rohr, Brunner, Martin, & Fischer, 2018). This was not the case in the present study as peak failure forces of up to 1000N were administered without significant PICN material fracture. The fracture pattern, indicating areas of cohesive failure within the PICN material, was similar for all tested specimens. Small fragments of the PICN remained bonded to the titanium abutment in the cervical region around the base beyond peak loads required for adhesive failure. Effort was made in the present study to closely approximate the custom printed Ti6Al4V tensile device to the PICN-abutment interface in order to focus tensile forces on the bond alone. In addition, the PICN blocks were left un-milled before load testing to eliminate the potential for incorporated microfractures and problematic contours that weaken the material, possibly resulting in intra-material fracture. The difference in findings of the present study in relation to PICN fracture patterns are attributed to these modifications.

As there are no current studies examining the tensile bond strength of PICN to Ti6Al4V abutments with or without artificial aging through thermocycling, it cannot be

concluded whether thermocycling had an effect on retention values. However, it should be noted that values recorded in the current study were much higher than those found between PICN and zirconia by Rohr et al (Rohr, Brunner, Martin, & Fischer, 2018), and therefore it did not seem to have a detrimental effect on the bond in the present study.

Although all specimens in the study displayed tensile bond strengths within or above ranges found in similar studies (Guarda et al., 2013; Mehl et al., 2016; Rohr, Brunner, Martin, & Fischer, 2018), it should be noted that Rely-X Unicem 2 exhibited the highest peak failure value of the tested cements. This cement also displayed a different mode of failure from the others, failing at the Ti6Al4V abutment/cement interface rather than the PICN/cement interface. This cement alone exhibited a stronger bond to the PICN material than to the micro-abraded abutment. It is therefore unclear from this study the level of force required to achieve bond failure between the PICN and this cement. A 2016 study by Guilherme et al, found that the type of adhesive cement did not significantly affect the adhesive bond strength between micro-abraded titanium abutments and lithium disilicate ceramic (Guilherme et al., 2016). It is theorized from this study that the demonstrated differences in bond strength and failure mode may be explained by the variation in proprietary resin monomer formulas within the cements used, and their ability to react with the resin matrix of the PICN material.

A wide range of values was noted for all groups in this study. This was likely due to the variation of procedure during preparation of the samples. Although the surface preparations were standardized as much as possible, slight differences may have influenced the extent of the bond. One opportunity for error is the extent of particle abrasion of the Ti6Al4V surfaces. During micro-abrasion, variation in contact time leads

to variation in the degree of surface roughness needed for mechanical retention. In addition, although the etching times of the PICN was standardized, bubbles within the etch may have inhibited complete contact of the etchants with the PICN surface. This may have resulted in areas of incomplete ceramic etching, affecting the mechanic retention to the PICN. To overcome these drawbacks, a considerably larger sample size is recommended in the future.

Conclusion

In conclusion, Rely-X Unicem 2 dual cured self-adhesive resin cement displayed the highest bond strength of the tested cements to the PICN material. For this cement alone, the bond to PICN is greater than that to the micro-abraded titanium alloy. Despite these differences, all tested resin cements displayed acceptable retention values between PICN and titanium alloy abutments required for typical clinical conditions.

Table 1: Cement materials used

Classification	Group	Cement	Manufacturer	Composition
Dual-polymerizing adhesive resin cement	A	Multilink Automix	Ivoclar Vivadent	Dimethacrylate, 2-hydroxyethyl methacrylate (HEMA), barium glass, ytterbium trifluoride, spheroid mixed oxide
Dual-polymerizing self-adhesive resin cement	B	RelyX UniCem 2 Automix	3M ESPE	Phosphoric acid modified methacrylate monomers, bi-functional methacrylate, silanated fillers, initiator components, stabilizers, methacrylate monomers, alkaline fillers, pigments
Chemical polymerizing adhesive resin cement	C	Panavia 21	Kuraray Noritake Dental	MDP, hydrophobic aromatic dimethacrylate, hydrophobic aliphatic dimethacrylate, silanated silica filler, colloidal silica, catalysts, hydrophobic aromatic dimethacrylate, hydrophobic aliphatic dimethacrylate, hydrophilic aliphatic dimethacrylate, silanated titanium oxide, silanated barium glass filler, catalysts, accelerators, pigments

Table 2: Individual Retention Values and Median with 95% CI of PICN abutment blocks to Titanium Inserts Using Different Resin-Based Luting Agents.

Multilink Automix		Rely-X Unicem		Panavia 21	
Sample	Peak Retention (N)	Sample	Peak Retention (N)	Sample	Peak Retention (N)
A1	364.041	B1	637.094	C1	722.931
A2	352.395	B2	763.378	C2	569.983
A3	374.478	B3	713.322	C3	666.376
A4	502.921	B4	732.377	C4	523.409
A5	343.137	B5	1000.391	C5	510.794
A6	494.571	B6	785.638	C6	701.468
A7	297.952	B7	919.842	C7	312.961
A8	249.455	B8	743.006	C8	803.317
A9	447.324	B9	659.489	C9	473.538
A10	364.041	B10	703.692	C10	300.316
Median	358 N (95% CI: 296-447)	Median	738 N (95% CI: 696-812)	Median	547 N (95% CI: 474-701)

Figure 1: Custom tensile device for removing abutment blocks from implant abutment surface.

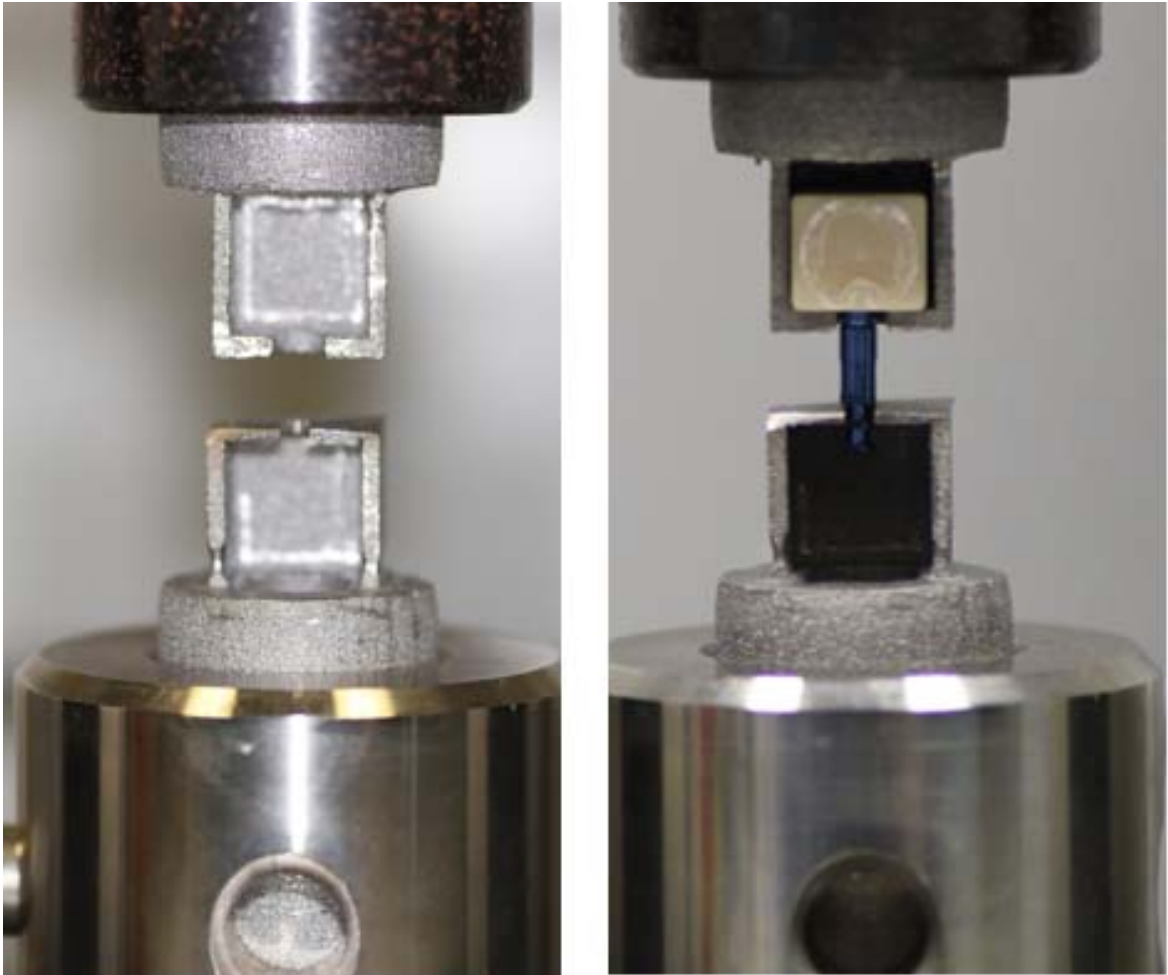


Figure 2: Stacked Histogram of distribution of Peak Load values.

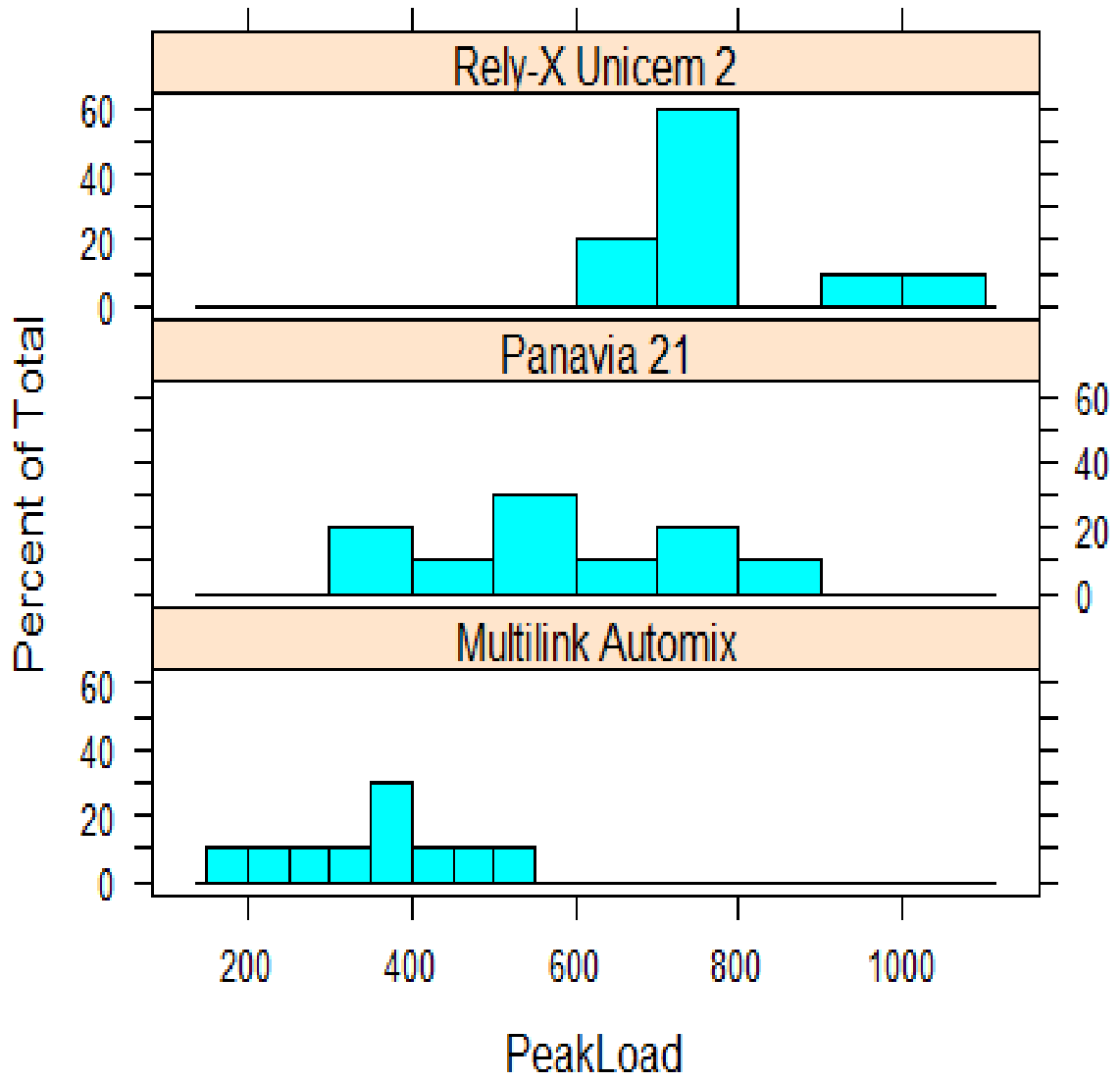


Figure 3: Box-plot diagram of maximum retention strength in N.

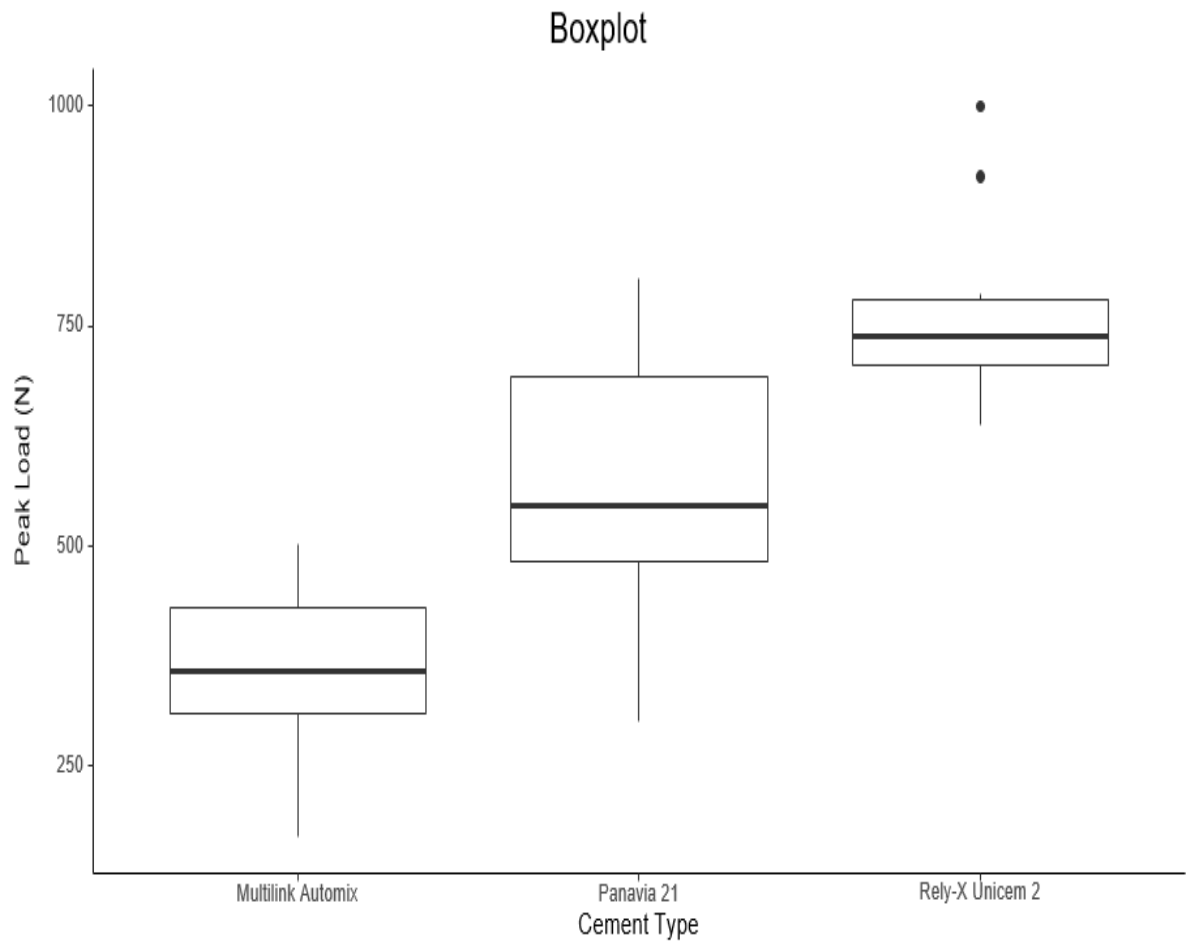
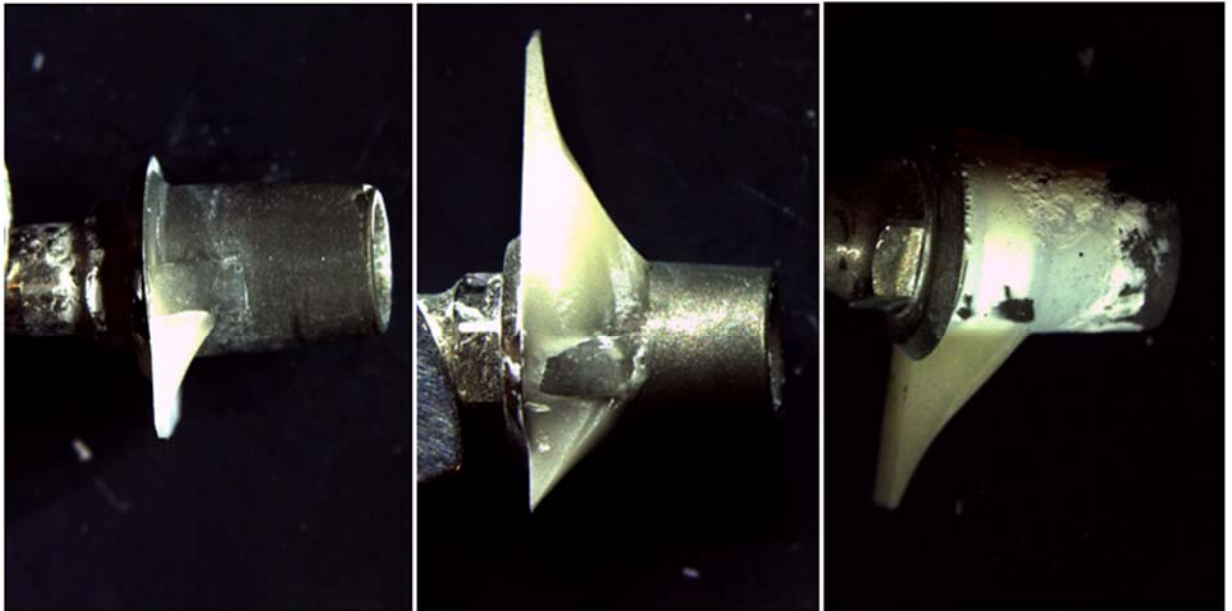


Figure 4: Images of PICN adhesive failure.

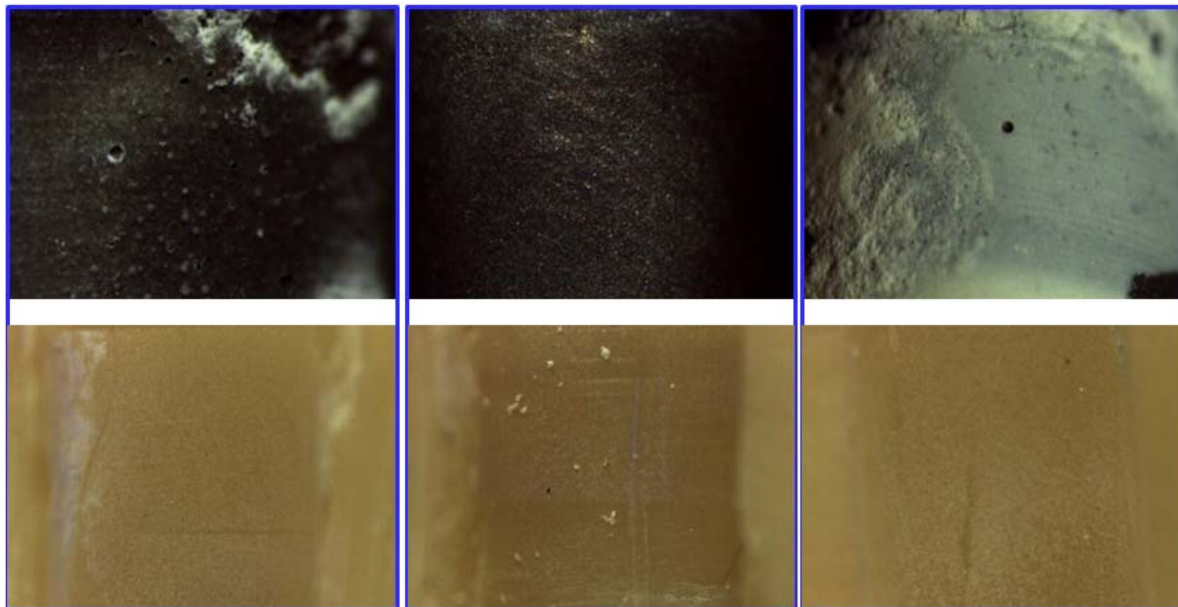


Multilink Automix

Rely-X Unicem

Panavia 21

Figure 5: Stereomicroscopic images of Ti6Al4V and PICN surfaces after bond failure.



Multilink Automix

Rely-X Unicem

Panavia 21

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