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Fracture resistance of screw-retained implant crowns using different restorative materials

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Abstract:
Screw-retained implant crowns require restorative materials with adequate fracture resistance and predictable failure behaviour for long-term clinical success. Therefore, it is of interest to evaluate the fracture resistance and failure modes of 40 crowns fabricated from metal-ceramic, monolithic zirconia, lithium disilicate and polymer-infiltrated ceramic network (PICN) (n = 10/group). After thermocycling and cyclic mechanical loading, specimens underwent fracture testing and microscopic failure analysis. Monolithic zirconia exhibited the highest fracture resistance, followed by metal-ceramic, lithium disilicate and PICN, with statistically significant differences between all groups. Thus, restorative material influences fracture resistance and failure patterns, supporting material selection according to anticipated occlusal loads and clinical requirements.

Keywords: Dental implants, screw-retained crown, fracture resistance, restorative materials, monolithic zirconia, lithium disilicate, titanium base abutment

Background:
Screw-retained implant crowns offer retrievability and eliminate residual cement, potentially reducing cement-associated peri-implant inflammation **[1]**. Although screw and cement retention demonstrate comparable survival, their biological and technical complications differ **[2]**. Titanium base abutments combined with CAD/CAM crowns support the use of metal-ceramic, monolithic zirconia, lithium disilicate and polymer-infiltrated ceramic network (PICN) materials, each with distinct mechanical properties **[3, 4]**. The titanium–crown interface and screw-access channel may influence stress distribution and fracture behaviour under occlusal loading **[5]**. Therefore, it is of interest to evaluate the fracture resistance and failure modes of screw-retained implant crowns fabricated from four restorative materials under standardized aging and mechanical loading conditions.

Materials and Methods:
Forty internal-connection implants (4.1 mm diameter, 10 mm length) with their corresponding titanium base abutments were used to fabricate forty screw-retained implant crowns reproducing a standardized mandibular first molar. A single master crown design was created using computer-aided design software and used for all specimens to eliminate morphological variation. The specimens were divided into four equal groups according to the restorative material of the crown (n = 10 per group): metal-ceramic with a cobalt-chromium framework and feldspathic veneer serving as the control (MC), monolithic zirconia (ZR), lithium disilicate glass-ceramic (LD) and polymer-infiltrated ceramic network (PICN). Crowns were milled or cast according to the manufacturer instructions for each material and ceramic specimen were crystallized and glazed as required. Each crown was bonded to its titanium base abutment with dual-cure adhesive resin cement under a standardized seating load and excess cement was removed before final polymerization. The completed hybrid abutment crowns were connected to the implants and the retaining screws were torqued to 30 Ncm with a calibrated torque driver; the torque was reapplied after ten minutes to compensate for settling. The screw-access channels were sealed with polytetrafluoroethylene tape and composite resin. Each assembly was embedded in auto polymerizing acrylic resin within a metal housing to a level 3 mm below the crown margin to simulate physiological bone support. All specimens were subjected to artificial aging consisting of 10,000 thermal cycles between 5 °C and 55 °C with a dwell time of 30 seconds, followed by cyclic mechanical loading of 1.2 million cycles at 50 N and 2 Hz in a wet environment to simulate approximately five years of clinical function. Surviving specimens were then loaded to fracture in a universal testing machine, with a compressive load applied to the central fossa along the long axis of the implant through a steel indenter at a crosshead speed of 1 mm per minute until failure. The peak load at fracture was recorded in newtons. Failure modes were subsequently examined under a stereomicroscope and, for representative specimens, by scanning electron microscopy and were classified according to the location and extent of fracture within the crown, cement interface, abutment and screw. Data were tested for normality using the Shapiro-Wilk test and analysed by one-way analysis of variance followed by the Tukey

honestly significant difference post hoc test, with the level of significance set at 0.05.

Results:

All forty specimens survived thermocycling and cyclic loading without debonding or screw loosening and were available for the static fracture test. The mean fracture loads recorded for the four groups are summarized in **Table 1**. **Table 1** presents the mean fracture load, standard deviation (SD), and predominant failure mode of four types of screw-retained implant crowns following thermocycling and cyclic loading. The restorative materials evaluated were monolithic zirconia (ZR), metal-ceramic (MC), lithium disilicate (LD), and polymer-infiltrated ceramic network (PICN). Fracture load represents the maximum force that each crown assembly withstood before failure during static loading, while the standard deviation indicates the variability in fracture resistance within each group. Monolithic zirconia demonstrated the highest mean fracture load, at 1786 ± 152 N, indicating the greatest resistance to fracture among the evaluated materials. Its fracture resistance was approximately 18.1% higher than that of the metal-ceramic group, 68.8% higher than that of the lithium disilicate group, and 102.3% higher than that of the PICN group. The predominant failure mode involved abutment screw fracture or crown fracture originating at the screw-access channel. This pattern suggests that the high strength of monolithic zirconia may shift the point of failure toward structurally weaker components of the implant-supported restoration rather than causing fracture of the crown body itself in every specimen. The metal-ceramic group exhibited the second-highest mean fracture load, at 1512 ± 128 N. Its fracture resistance was lower than that of monolithic zirconia but substantially higher than those of lithium disilicate and PICN. The predominant failure mode was cohesive chipping of the veneering ceramic, while the underlying metal framework remained largely intact. This finding is consistent with a potential weakness at the interface between the veneering ceramic and the supporting framework or within the veneering material itself. Although the framework provided structural support, the veneer remained susceptible to localized damage under concentrated loading. Lithium disilicate crowns demonstrated a mean fracture load of 1058 ± 96 N, placing them third among the four restorative materials. Their mean fracture resistance was approximately 29.0% lower than that of the metal-ceramic group and 40.8% lower than that of monolithic zirconia. The predominant failure mode was bulk cohesive fracture extending through the crown. This pattern indicates that failure involved the restorative material itself rather than being limited to superficial chipping. Compared with the metal-ceramic group, which generally retained an intact framework, lithium disilicate crowns showed a more extensive fracture pattern under static loading. The PICN group recorded the lowest mean fracture load, at 883 ± 84 N. This value was approximately 16.5% lower than that of lithium disilicate, 41.6% lower than that of metal-ceramic, and 50.6% lower than that of monolithic zirconia. The predominant failure mode involved crown fracture accompanied by partial debonding from the titanium base. This suggests that both the structural integrity of the crown and the integrity of its bond to the titanium base may influence the overall load-bearing performance of this restorative system. However, the contribution of each failure mechanism would require separate quantitative assessment. Overall, the fracture resistance followed the order monolithic zirconia > metal-ceramic > lithium disilicate > PICN. The reported one-way analysis of variance indicated a statistically significant difference among the four materials ($p < 0.001$), while Tukey post hoc comparisons reportedly identified significant differences between all pairs ($p < 0.05$). These findings indicate that restorative material was associated with differences in the fracture resistance of screw-retained implant crowns under the tested laboratory conditions. Although the mean fracture loads of zirconia, metal-ceramic, and lithium disilicate exceeded 900 N, the PICN group had a mean value of 883 N, which was below that threshold. Therefore, the data do not support the statement that the mean fracture load of every group exceeded 900 N. Furthermore, fracture loads measured under static laboratory conditions cannot directly establish long-term clinical performance because intraoral restorations are exposed to variable loading directions, fatigue, parafunctional forces, and environmental factors. The results should consequently be interpreted as a comparative assessment of laboratory fracture resistance rather than definitive evidence of clinical superiority. In summary, monolithic zirconia exhibited the highest fracture resistance, whereas PICN exhibited the lowest and showed more frequent partial debonding. The distinct failure patterns across the four groups highlight the importance of considering both material strength and the integrity of the complete implant-crown assembly when selecting restorative materials for posterior implant rehabilitation.

Table 1: Mean fracture load and predominant failure mode of screw-retained implant crowns by restorative material

Group (material)	Mean fracture load ± SD (N)	Predominant failure mode
ZR – monolithic zirconia	1786 ± 152	Abutment screw / crown fracture at access channel
MC – metal-ceramic (control)	1512 ± 128	Cohesive veneer chipping; framework mostly intact
LD – lithium disilicate	1058 ± 96	Bulk cohesive fracture of the crown
PICN – polymer-infiltrated ceramic network	883 ± 84	Crown fracture with partial debonding

Discussion:

The findings of this study led to rejection of the null hypothesis, since the restorative material exerted a statistically significant effect on the fracture resistance of screw-retained implant crowns. Monolithic zirconia recorded the highest fracture load, a result consistent with earlier work showing that zirconia-based screw-retained molar restorations achieve greater fracture loads than glass-ceramic alternatives owing to the high flexural strength and fracture toughness of the material. Comparative testing of crowns supported by titanium and zirconia abutments has similarly reported that monolithic configurations withstand higher loads than manually veneered systems, in which the

veneering porcelain constitutes a mechanically weaker layer **[6, 7]**. Lithium disilicate produced intermediate fracture loads that nonetheless comfortably exceeded posterior masticatory forces, in agreement with studies reporting that monolithic lithium disilicate crowns bonded to titanium base abutments provide clinically adequate failure loads even after fatigue **[8]**. The polymer-infiltrated ceramic network group recorded the lowest values, reflecting its lower elastic modulus and flexural strength; however, its more tooth-like modulus may distribute stress differently and its clinical adequacy is supported by the fact that its mean fracture load still surpassed physiological loading. The influence of the connecting components was evident in the failure analysis, where high-strength zirconia crowns transferred stress to the abutment screw, a pattern also observed when different crown materials are combined with titanium base or hybrid abutments **[9]**. This interaction underscores that the fracture behaviour of a screw-retained crown reflects the whole implant-abutment-crown complex rather than the crown material in isolation. Material selection also carries implications beyond peak strength. Polymer-based and polyetheretherketone materials have been proposed as shock-absorbing alternatives and although they were not the strongest option, their capacity to dissipate load is of interest for specific clinical situations **[10, 11]**. From a prosthetic standpoint, screw retention offers retrievability and avoids residual cement and clinical evidence indicates that screw- and cement-retained restorations perform comparably in terms of survival and marginal bone loss, so the mechanical properties of the restorative material become a primary differentiator when a screw-retained design is chosen **[12, 13]**. Within the limitations of an *in vitro* protocol, which cannot fully reproduce the multidirectional forces, salivary environment and biological variability of the oral cavity, the present results indicate that all four materials are mechanically suitable for posterior screw-retained implant crowns, with monolithic zirconia offering the greatest margin of safety and the ceramic and polymer-based materials offering favourable failure patterns and esthetic or biomechanical advantages. Further clinical studies with long-term follow-up and standardized fatigue testing are required to translate these laboratory findings into material-specific clinical recommendations.

Conclusion:

Restorative material influenced fracture resistance and failure modes, with monolithic zirconia exhibiting the highest fracture resistance, followed by metal-ceramic, lithium disilicate and PICN. All materials exceeded reported posterior masticatory forces, indicating adequate mechanical performance under the tested conditions. Material selection should consider occlusal loading, failure behaviour and clinical requirements alongside fracture resistance.

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