Porcelain Fracture Resistance of Screw-Retained, Cement-Retained, and Screw-Cement-Retained Implant-Supported Metal Ceramic Posterior Crowns

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Abstract

Purpose: The purpose of this *in vitro* study was to compare the porcelain fracture resistance between screw-retained, cement-retained, and combined screw- and cement-retained metal–ceramic (MC) implant-supported posterior single crowns; and to investigate the effect of offsetting the occlusal screw-access opening on porcelain fracture resistance of screw-retained and cement-retained MC implant-supported posterior single crowns.

Materials and Methods: Forty standardized MC molar-shaped restorations were fabricated. The 40 restorations were divided into four groups (SRC, SRO, CRP, and CSC) of 10 specimens each. Group SRC: screw-retained, screw-access hole placed in the center of the occlusal surface; Group SRO: screw-retained, screw access hole placed 1 mm offset from the center of the occlusal surface toward the buccal cusp; Group CRP: cement-retained, zinc phosphate cement was used; Group CSC: cement-retained with a screw-access hole in the center of the occlusal surface. The screw-retained restorations and abutments were directly attached to 3i implant fixtures embedded in acrylic resin blocks. Subsequently, all test specimens were thermocycled and vertically loaded in a universal testing machine at a crosshead speed of 2 mm/min until fracture. Mean values of load at fracture (in N) were calculated in each group and compared with a one-way ANOVA and Tukey's Studentized test ($\alpha = 0.05$).

Results: Mean values of loads required to fracture the restorations were as follows (N): Group SRC: 1721 ± 593; Group SRO: 1885 ± 491; Group CRP: 3707 ± 1086; Group CSC: 1700 ± 526. Groups SRC, SRO, and CSC required a significantly lower force to fracture the porcelain than did the CRP group ($p < 0.05$).

Conclusion: The cement-retained restorations showed significantly higher mean fracture loads than the restorations having screw-access openings in their occlusal surface. The position of the screw-access hole within the occlusal surface did not significantly affect the porcelain fracture resistance.

The long history of osseointegrated implant use in restoring missing teeth has yielded a huge array of treatment options based on an expanding number of dental implants. Implant-supported prosthetic treatments have shown predictable success for the treatment of completely[1,2] and partially edentulous patients,[3,4] and for single tooth replacement.[5-8] A longer review period extending to 5 years has shown higher success for single-implant restorations compared to the other treatment option, which replaces single missing teeth using fixed partial dentures.[9]

Metal–ceramic (MC) restorations are commonly used in prosthetic treatments supported by dental implants.[10] When comparing single implant-supported restoration materials, MC crowns had a survival rate significantly higher than the survival rate of all-ceramic crowns. Problems arising in these restorations ranged from screw or abutment loosening, screw or abutment fracture, and superstructure-related complications of ceramic or veneer fractures.[8]

Implant-retained crowns can be either screw-retained[11,12] or cement-retained;[13,14] however, controversial recommendations have been made over the best retention type for implant-supported restorations.[15-18] Porcelain fracture was reported to be among the most common causes of MC restoration failure.[19,20] Although porcelain fracture incidence was reported in clinical studies on implant-supported MC restorations,[12,13,21] the results were not adequately conclusive to make a valid comparison of the porcelain fracture incidence between screw- and cement-retained restorations.

Screw-retained prostheses offer the major advantage of retrievability,[16,18] in addition to accessibility for replacement and maintenance; however, screw-retained restorations usually necessitate more complex and expensive lab procedures and suffer from inherent mechanical complications such as screw loosening and fractures.[22,23] Removal and replacement of fractured screws are usually expensive and labor intensive.[16] Moreover, the presence of a screw access opening may interfere with natural occlusal morphology,[15] disrupt the porcelain continuity, and result in unstable occlusal contacts.[24,25]

Cement-retained restorations offer several advantages, including the absence of a screw opening that could interfere with esthetics and occlusion,[15] and the reduction of cost due to reduced number of components.[14] Cement-retained restorations also offer the possibility of more passive fit compared to screw-retained restorations,[14,26] although it is possible that nonpassive fit does not necessarily cause clinical or biomechanical complications with implant restorations.[27-29] Moreover, the fabrication of cement-retained restorations is simpler as it follows conventional tooth-retained restorations, does not require technical training, and is easier for restoring severely divergent implants;[14,16] however, the main drawbacks of cement-retained restorations are the difficulty of retrievability, difficulty in removing excess cement around the crown, and cement loss, which may result in periimplant inflammation.[16,18,30,31]

The presence of a screw-access opening in screw-retained restorations leaves a thin collar of porcelain and disrupts the structural integrity of MC restorations; however, scarce data are available on the porcelain fracture of implant-supported MC restorations. In recent *in vitro* studies, cement-retained, implant-supported single MC crowns showed values of fracture resistance higher than screw-retained restorations.[24,25,32] Moreover, neither the location of the screw access hole nor narrowing of the occlusal table had any effect on the porcelain fracture resistance.[24]

The aims of this *in vitro* study were to compare the porcelain fracture resistance between screw-retained, cement-retained, and combined screw- and cement-retained MC implant-supported posterior single crowns and to assess whether offsetting the screw-access opening would affect the porcelain fracture resistance of screw-retained MC implant-supported posterior single crowns. The combined screw and cement-implant-retained crowns offer the advantage of easier repair and maintenance. In case of a need for replacement of the crown, the same screwed abutment could be used and will not need to be replaced as in the case of screw-retained-only crowns, which may reduce the cost of crown replacement. The null hypotheses of the study to be tested is that there is no difference in porcelain fracture resistance between screw-retained, cement-retained, and the combined screw- and cement-retained MC implant-supported posterior single crowns and there is also no relation between the location of occlusal screw access opening and the fracture resistance of implant-supported MC single crowns.

Materials and methods

Ten 3i LTX external hexagon implants (3i Implant Innovations, West Palm Beach, FL) with a diameter of 5.0 mm and length of 10.0 mm were embedded in a special stainless steel specimen holder in a clear autopolymerizing poly(methyl methacrylate) acrylic resin (Acrylic Meliodent, Heraeus Kulzer, Hanau, Germany). The implants were aligned at 90° to the horizontal plane in the center of the holder with the aid of a surveyor (Degussa, Geschaftsbereich Dental, Frankfurt, Germany). The resin covered the implant bodies up to the first thread (Fig 1). The implants supported 40 MC crowns divided into four groups ($N = 10$) as follows (Figs 2 and 3):

Group 1 (SRC): screw-retained, with the screw access hole placed in the center of the occlusal surface.

Group 2 (SRO): screw-retained, with the screw-access hole placed 1 mm offset from the center of the occlusal surface toward the buccal cusp.

Group 3 (CRP): cement-retained using zinc phosphate cement.

Group 4 (CSC): cement-retained with a screw-access hole in the center of the occlusal surface (the combined screw- and cement-retained restoration).

Group 1 (SRC)

A resin block of 2.2-cm diameter with an implant analogue (ILAW5, 3i Implant Innovations) was used to perform the laboratory work. Then, a UCLA plastic cylinder (WPC51C, 3i Implant Innovations) was fixed on the implant analogue with a try-in screw (UNITS, 3i Implant Innovations). A coping was fabricated by constructing a wax pattern reproducing the anatomy and dimension of the mandibular molar[33] with a buccolingual width of 10 mm, and mesiodistal width of 11 mm (wax-up No. 1) on a straight UCLA abutment, connected to a 5.0-mm diameter, 10.0-mm long 3i implant analogue (ILAW5). A 4-mm perforation representing the diameter of the UCLA plastic cylinder was made in the center of the occlusal surface of the wax pattern with a stainless steel drill attached to the milling machine (Paraskop M, Bego Bremen, Germany). The wax mold with the 4-mm hole was seated on the plastic cylinder, acting collectively as a "waxed UCLA."

An addition cure silicone impression (Elite, Zhermack S.p.A., Badia Polesine, Rovigo, Italy) was made of wax-up 1 (index No. 1). The silicone index was then sectioned in half to facilitate retrieval of the wax pattern (Fig 4).

Subsequently, the wax pattern was cut back for a thickness of 1.7 mm to allow for adequate uniform porcelain thickness (Fig 5). A second silicone index (index No. 2) was made for the cut-back wax pattern (Fig 6). The cut wax mold was retrieved from the UCLA plastic cylinder. Afterward, ten wax patterns were made on UCLA plastic cylinders with the aid of index No. 2. This was achieved by injecting molten wax between the UCLA plastic cylinder and index No. 2. After the wax cooled, index No. 2 was removed, and the try-in screw was

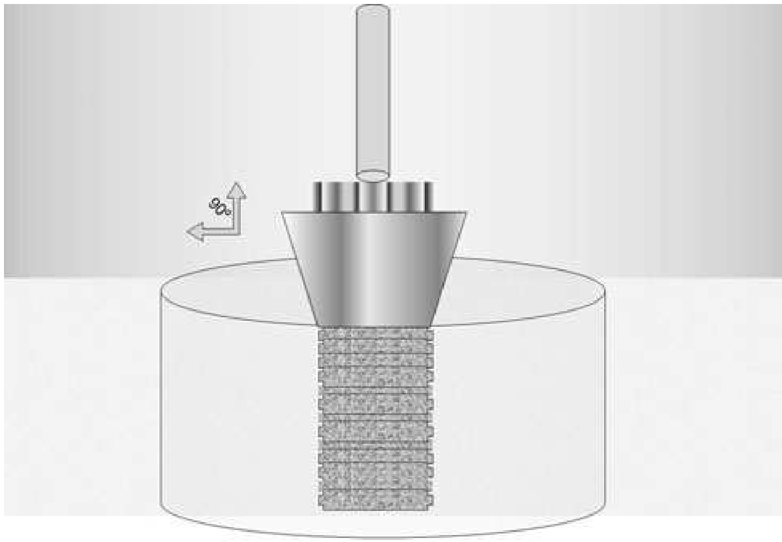

Figure 1 The implant mounted in clear acrylic resin block.

unthreaded. Subsequently, the "waxed UCLAs" (the wax patterns attached to the plastic cylinders) were sprued, invested with phosphate-bonded investment (Bellavest® SH, Bego), and cast in a Co–Cr alloy (Remanium® 2000+, Dentaurum J. P., Ispringen, Germany; Co 61%, Cr 25%, Mo 7%, W 5%, Si 1.5%, Mn, N < 1%).

After casting, specimens were allowed to bench cool, then divested, sandblasted with 125 μm pure aluminum oxide particles, finished to ensure that all line angles were rounded, and sandblasted again with 125 μm pure aluminum oxide particles at 2 to 3 bar pressure, strictly following the manufacturer's instructions. The seating bases of the castings

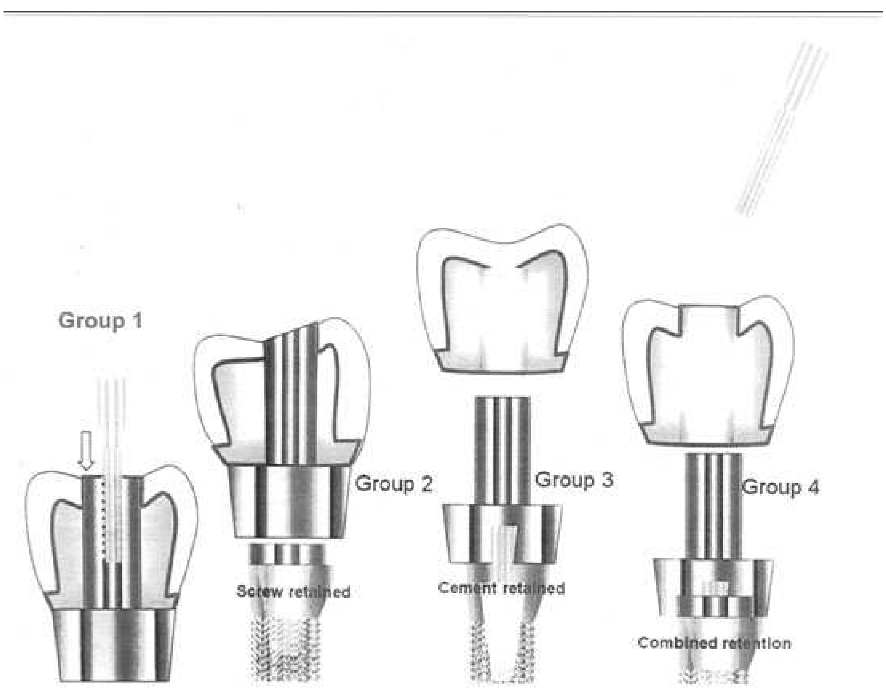

Figure 2 Methods of retention in various groups. *Group 1*: Screw-retained with screw hole-access in the center of the crown (SRC); *Group 2*: Screw-retained with screw-access hole placed 1 mm offset from the center of the crown (SRO); *Group 3*: Cement-retained (CRP); *Group 4*: combined screw- and cement-retained with screw-access hole in the center of the crown (CSC).

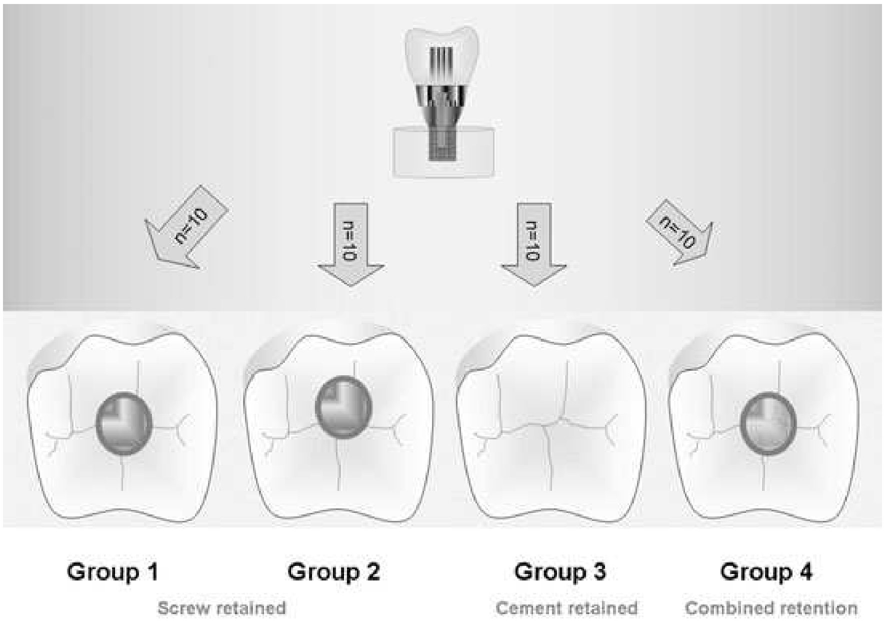

Figure 3 The occlusal view of crowns produced from the indices and assigned to groups 1 to 4.

were blasted with 50 μm glass beads at 2 to 3 bar pressure, and the screw-access holes were finished with the aid of a special reamer (RH600, 3i Implant Innovations) according to the manufacturer's guidelines. Finally, all castings were cleaned in an ultrasonic bath in distilled water. Before porcelain was applied, the castings were seated onto implant fixtures to inspect the marginal adaptation visually, with a sharp probe, and with the use of a fit checker (Contactspray, Shera Werkstoff-Technologie GmbH & Co. KG, Lemforde, Germany).

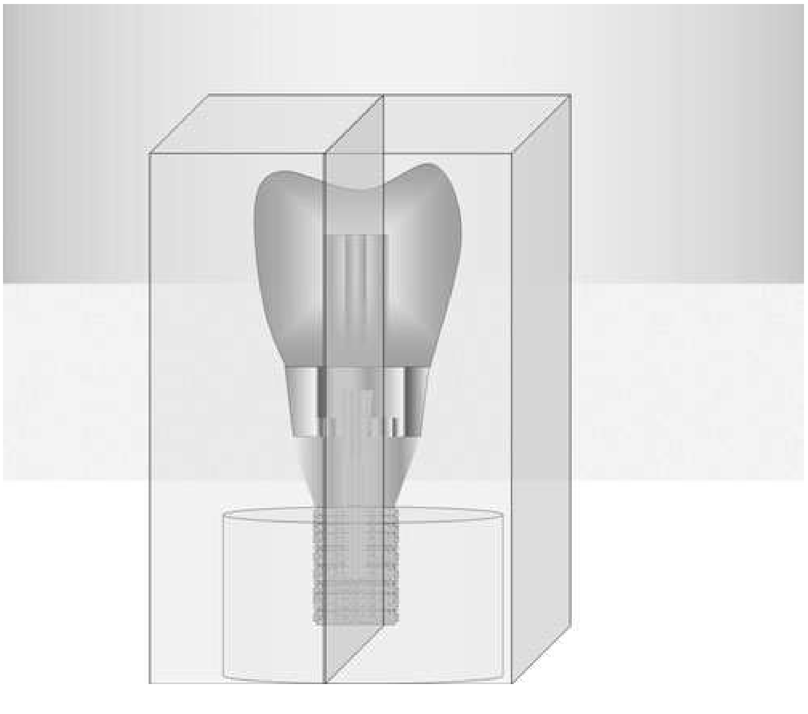

Figure 4 Production of index number 1. Rubber impression material is molded around the assembly of a lower first molar wax pattern.

Figure 5 Wax pattern number 2. Wax pattern number one is cut back to allow for uniform thickness of porcelain (arrows).

Porcelain application was standardized with the aid of silicone index No. 1, which was related accurately to the casting and confirmed by measuring the final dimensions of the final crowns, which were found to coincide with the dimensions of the mandibular first molar. Veneering porcelain (VITA VM® 13, Vident, Bad Säckingen, Germany) was applied, condensed, fired, and glazed according to the manufacturer's recommendations.

After porcelain application, the finished screw-retained restorations were seated onto implant fixtures to check again the precision of fit with the same previously mentioned methods. In addition, the finished restorations were tested

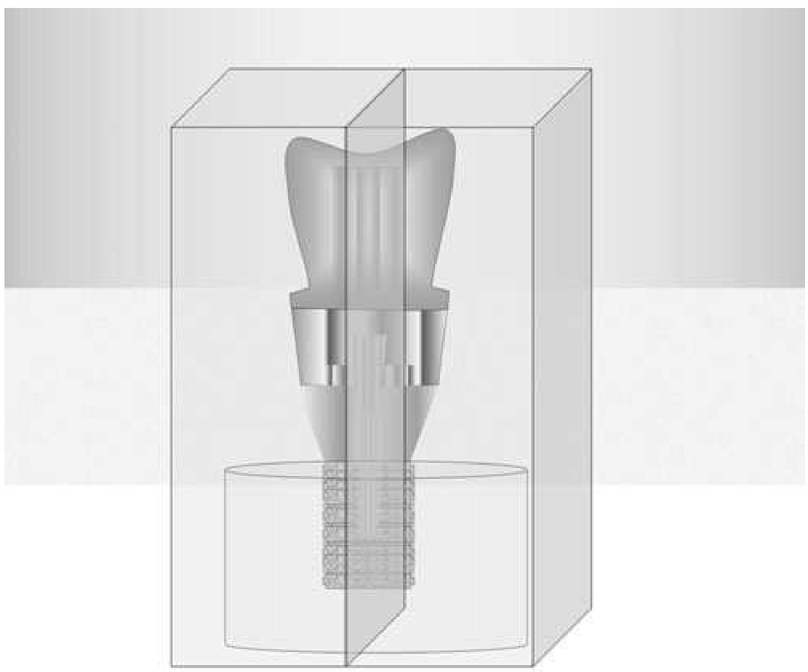

Figure 6 Index number 2. Rubber impression material is molded around the assembly of metal wax pattern number 2.

under a standard 4× magnifying lens and under a florescent light box to ensure that the veneering porcelain was crack free.

The screw-retained restorations were fixed on the implant fixtures with Gold-Tite™ Square abutment screws (UNISG, 3i Implant Innovations). All abutment screws were torqued to 35 N-cm, as recommended by the manufacturer, using torque indicator (Restorative Torque Indicator, RTI2035, 3i Implant Innovations). After 5 minutes, the occlusal screws were retightened using the above-mentioned procedure. The occlusal screws were retightened after 5 minutes to counteract the effect of screw settling phenomenon and therefore, prevent screw loosening under compressive load.[34]

Group 2 (SRO)

For group 2 (screw-retained, with the screw-access hole placed 1 mm offset from the center of the occlusal surface toward the buccal cusp), the same procedure for group 1 was followed, except that the screw access hole was placed 1 mm offset from the center of the occlusal surface toward the buccal cusp with the aid of the milling machine. The restorations-abutments assembly was torqued at 35 N-cm to the implant as for group 1.

Groups 3 (CRP)

With the aid of silicone index No. 1, a UCLA plastic cylinder attached to an implant analogue was waxed-up to the approximate shape and average dimensions of the lower first molar. Then, a uniform total taper of 6° was achieved using a conical wax scaler attached to a milling machine (Fig 7). A silicone index (index No. 3) of the milled "waxed UCLA" was made (Fig 8). Ten abutments were made for the "waxed UCLAs" by injecting molten wax between the UCLA plastic cylinder and index No. 3. The resultant wax patterns were sprued, invested with a phosphate-bonded investment, and cast in a Co–Cr alloy (Remanium® 2000+). Finishing and polishing of the castings were the same procedure followed for group 1. The resultant castings represented prepared abutments with a 6° total convergence angle, a 90°, 0.5-mm thickness shoulder finish line, and a 5-mm height (measured from finish line to the occlusal surface). Then, two layers of die spacer (Noritake Cement Spacer; Terra Dent, Surcursala Plevnei, Bucharest, Romania) were painted to within 1 mm of the finish line, as recommended by the manufacturer, to allow room for the cement. The wax-ups of metal copings were fabricated directly on the abutments for cement retention to provide a more accurate fit of the cast copings.[35] To ensure standardized thickness of porcelain for all groups, silicone index No. 2 was used. These wax patterns were then sprued, invested, cast in Co–Cr alloy as the abutments, and finished to a minimum 0.4 mm thickness following the manufacturer's instructions.

Porcelain build-up was performed as for group 1 using index No. 2. Abutments were torqued to the implant as in group 1. The inner surfaces of the crowns and the surfaces of the abutments were burnished with 50 μm aluminum oxide high-luster blasting beads according to manufacturer's recommendations. After the abutments were secured to the implants with Gold-Tite screws, a cotton pellet was used to close the screw-access channel of each of the abutments. The screw-access holes of the screw-retained and the combined screw- and cement-retained restorations were left unfilled because so far, no uniform guidelines exist as to which material should be used. In addition, the screw-access holes were left unfilled to facilitate removal of

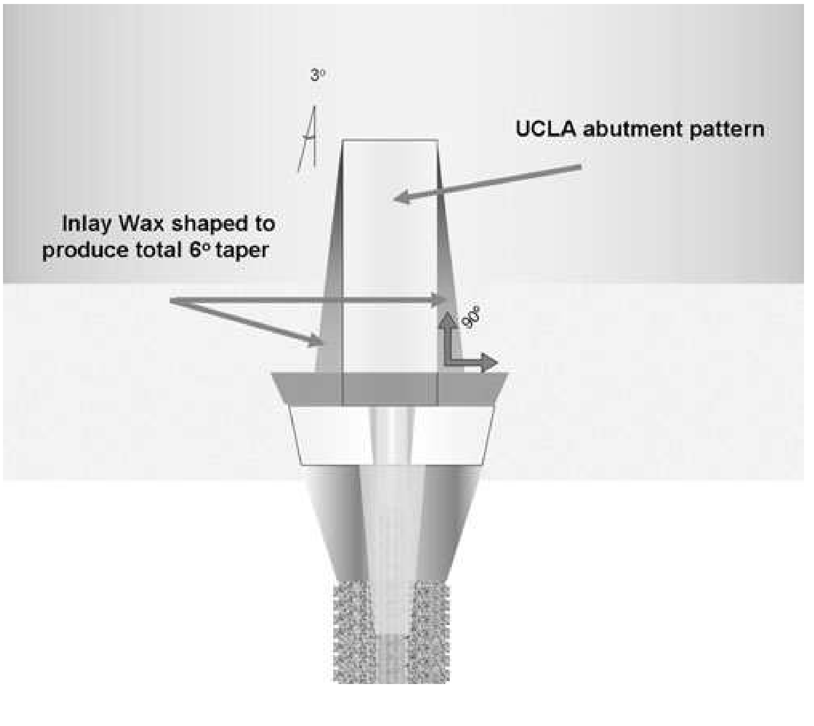

Figure 7 Wax pattern number 3 with 6° taper prepared to produce abutments for cement-retained crowns.

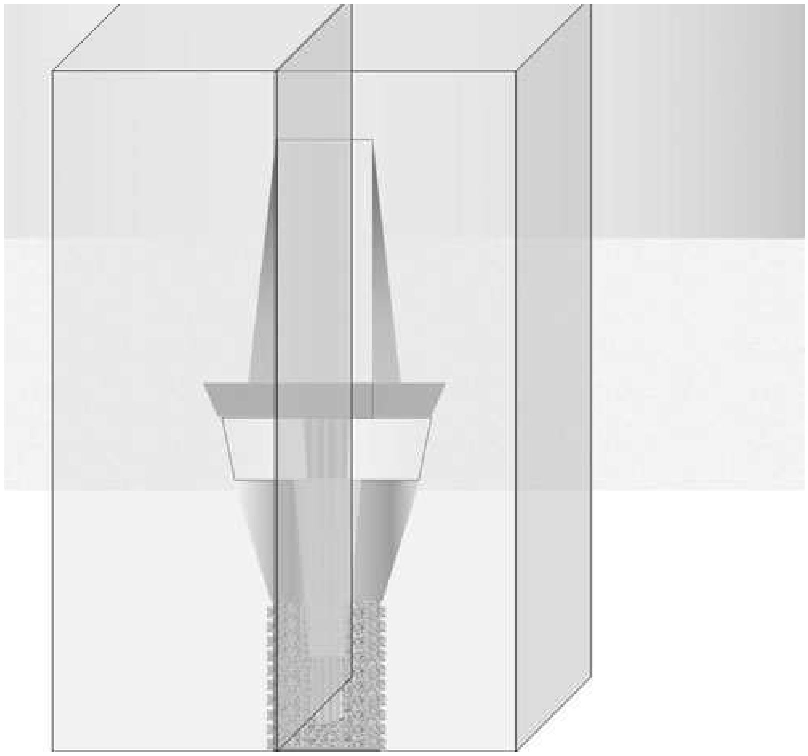

Figure 8 Index number 3 prepared by rubber impression material molded around wax pattern number 3.

restorations from implants after testing of one group to be attached to the next group of restorations. Moreover, leaving the access hole unfilled produced more standardized specimens for comparison purposes, as the placement of composite and cotton pellet is subjected to variations due to variations in the size of pellet placed and also placement and packing of composite in the hole.

Zinc phosphate cement (Adhesor® Fine, Spofa Dental, Cernokostelecka 84, Prague, Czechoslovakia) was mixed according to the manufacturer's recommendations and applied to the intaglio surfaces of the restorations. Each restoration was seated immediately on the corresponding abutment and held in place with constant finger pressure until the cement was set (6 to 8 minutes). Excess cement was removed with an explorer.

After completing the testing for group 3, a hole was made in the occlusal surface of the fractured crowns until the cotton pellet covering the screw head was located. Then, the screw was unthreaded by torque indicator and accordingly, the crown cemented to the abutment was removed in one unit without causing any damage to the implant or implant-abutment joint. A new abutment with new gold screw was used for every crown.

Group 4 (CSC)

In group 4, restorations were cement-retained but with a screw-access hole in their occlusal surface. The same procedure for group 3 was followed, except that during waxing up of metal copings, a screwdriver tip was placed in position to maintain the screw-access channel, and the screw-access channel was also kept patent during ceramic veneering with the same screwdriver tip. Accordingly, silicone indices No. 2 and No. 1 were altered to secure the screwdriver tip position during wax-up and during porcelain condensation, respectively.

Fracture resistance testing

All specimens were subjected to thermal cycling between 5 and 65°C for 30 seconds each, with an intermediate pause of 12 seconds for 500 cycles prior to fracture-resistance testing to render the findings more clinically relevant.[36,37] The temperature extremes (5°C and 65°C) were selected to mimic variations in temperature in the oral cavity during fluid intake as reported by Longman and Pearson,[36] and to thermally stress the crown/luting agent interface. Although the transient thermal changes are of greater significance intraorally,[37] the dwell times at each extreme of temperature in this study were extended to 30 seconds per each temperature to allow equilibrium to be attained. The number of cycles employed was the same as used in a previous study.[38]

Each specimen was subjected to vertical-compression load with a universal testing machine (Model 1195, Instron, Buckinghamshire, England). The specimen was held in a custom-made round stainless steel holder, which was fixed in position by horizontal screws. A hardened steel bar with a 6-mm diameter ball was mounted on the crosshead of the testing machine (Fig 9).[39] The same ball was also used in previous studies as an antagonist in a molar restoration.[40,41] The ball was used to apply a static compressive load along the long axis of the restoration at a crosshead speed of 2 mm/min[42-44] and 10,000 N load cell. This rate was selected to allow time for distribution of applied forces throughout the porcelain. If the crosshead speed is too great, the resultant data may overestimate the strength of

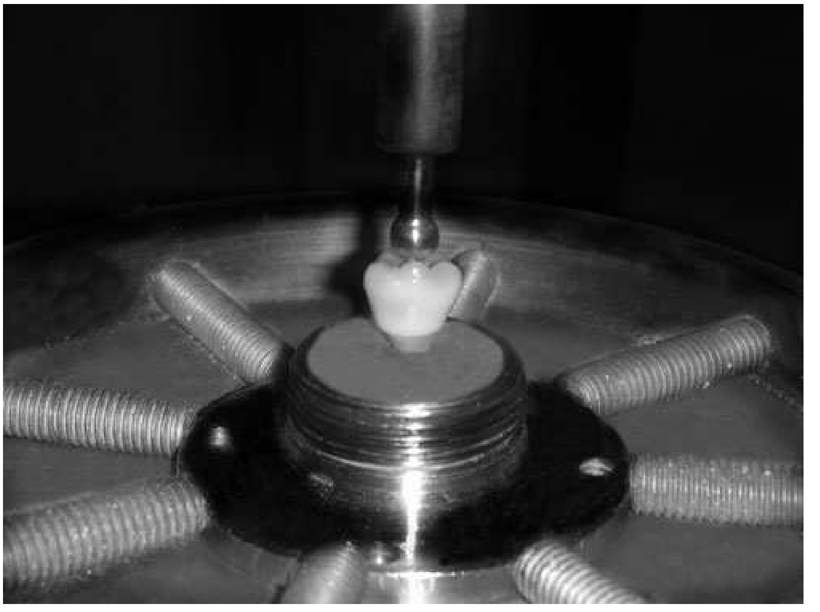

Figure 9 Frontal close-up view of loading apparatus.

the restorations. And even during clenching or bruxing, forces might be applied at a rate much closer to the actual testing conditions described in this study.[35]

The compressive load (N) was applied perpendicular to and at the central part of the restoration, so the force would be applied to the triangular ridges of both facial and palatal cusps simulating the contact established by an opposing tooth. To consistently align the loading ball to the restorations during testing, the stainless steel specimen holder containing the specimen could be moved in the horizontal plane.

The specimens were loaded to failure, and the load values were recorded at the moment of failure or when any fracture occurred within the porcelain or at the metal/porcelain interface regardless of location. The applied force was also graphically recorded on a load–deflection curve, with failure defined as a deviation from graphic linearity.

Mean values for all groups were calculated and compared using one-way ANOVA and Tukey's studentized *post hoc* test to identify differences in fracture resistance values between all groups. Statistical significance was set at $\alpha = 0.05$.

Results

The highest mean fracture resistance value occurred in group 3, CRP (3707 ± 1086 N), followed by group 2, SRO (1885 ± 491 N), group 1, SRC (1721 ± 593 N), and group 4, CSC (1700 ± 526 N). One-way ANOVA revealed a significant difference between the experimental groups ($p = 0.000$); however, Tukey's studentized test showed that the only significant difference was between CRP and the other groups. Group 3 (CRP) required significantly higher force at failure compared to other groups. No differences were found between the other three groups.

Discussion

Several factors are associated with crack initiation and propagation within dental ceramic and therefore affect its strength. These include the shape and thickness of the ceramic veneer, microstructural inhomogeneities, size and distribution of surface flaws, residual stresses induced by processing, the magnitude, direction, and frequency of the applied load,[44] size and location of occlusal contact areas, the elastic modulus of the supporting substrate material, and environmental effects.[45]

Despite the meticulous protocol followed in the current investigation to standardize the fabrication of the specimens, it was difficult to control 3D slumping of porcelain during the firing cycle. In addition, minor inaccuracies could have been introduced during the execution of the numerous technical steps performed to construct the experimental crowns, such as usage of the silicone indices, wax-ups, investing, finishing and polishing, and die spacer application. These potentially introduced inaccuracies might have been responsible for the large standard deviation reported in this study. Therefore, every effort should be exercised to produce accurately standardized experimental specimens.

Many authors[15,16,24,26,32,46] believe that the screw-access hole in screw-retained restorations can weaken the porcelain around the opening and at the cusp tip, resulting in porcelain fracture, while cement-retained restorations can overcome this problem. This study supported this assumption and found that the presence of screw-access opening in the occlusal surface of the crowns significantly decreased porcelain fracture strength. Thus, the null hypothesis that there would be no significant difference in porcelain fracture resistance between screw-retained, cement-retained, and the combined screw- and cement-retained MC implant-supported posterior single crowns was rejected.

Several factors might contribute to the reduction in fracture strength of the crowns having a screw-access hole in their occlusal surface. The centric contact of the screw-access hole, which had an average diameter of 3 mm, occupied nearly 50% of the intercuspal occlusal table, which averaged 6 mm buccolingually for molar teeth. A minimum width of porcelain collar varying between 1.25 and 1.75 mm remained around the screw-access openings and thus became more susceptible to fracture.[24]

In addition, it has been shown that the screw-access hole of the screw-retained restoration disrupts the structural continuity of porcelain, thereby modifying the position of the center of mass of the ceramic bulk toward which the ceramic shrinks during the sintering process.[25] This will affect the behavior of porcelain in these restorations compared with their cemented counterparts.[25]

Furthermore, it has been demonstrated that the MC bond strength is significantly affected by the shape and geometry of the metal framework. This framework was disturbed by the presence of the occlusal screw-access hole in the restorations, thereby affecting the MC bond strength; however, this bond was more efficient in cement-retained restorations, because it was not affected by geometrical variations of the metal framework.[25]

The decrease in fracture strength found with the screw-retained restorations compared with that of the cement-retained ones was consistent with the findings of studies by Torrado et al,[24] Zarone et al,[25] and Karl et al;[32] however, caution is advised for a direct comparison, as different test methods, implant systems, loading conditions, cementation material, restoration designs, type of abutment, and metal alloy were used.

Torrado et al[24] used premolar-shaped single crowns, perforated crowns with no actual screws, and a palladium gallium alloy, while in this investigation actual screw-retained molar restorations were used where one-unit, screw-retained restorations directly attached to implant fixtures by screws were employed. This resulted in a greater core/veneer thickness ratio, which may have increased the fracture resistance of porcelain.[47] Moreover, the Co–Cr alloy metal alloy has a greater elastic modulus than palladium gallium alloy.[48] Tensile stresses in the porcelain were found to be inversely proportional to the elastic modulus of the metal core, because alloys with an elevated elastic modulus resist deformation to a greater extent.[38,49] This resistance translates to smaller strains, which, in turn result in smaller stresses in the restored system and better resistance to fracture.[50] In addition, concerning cement-retained restorations, petroleum jelly was used to act as a cement medium in the previous study[24] instead of the actual cement used in our study.

Although a different test method was applied, the results of the study at hand supported the findings of Karl et al[32] who investigated the number of chipping fractures that occurred during dynamic loading on the occlusal surface of screw-retained and cement-retained MC implant-supported fixed partial dentures (FPDs), and reported more chipping fractures in screw-retained FPDs than in cement-retained ones; however, the specimens were subjected to thermal cycling in this study, which renders the findings more clinically relevant. It has been shown that glass-containing dental restorations accumulate damage during thermal cycling, which weakens the restorations and can cause clinical failures and slow flaw propagation.[51]

Having the screw-access opening placed 1 mm offset from the center of the occlusal surface did not significantly influence the porcelain fracture resistance of screw-retained MC restorations. This finding was also in agreement with a previous study.[24] No comparison data is available in the literature regarding the performance of the combined screw- and cement-retained implant-supported restorations.

It has been reported that functional chewing forces range between 2 and 150 N,[52,53] while the maximum bite force in the posterior area has been reported to vary from 300 to 880 N for the first molar.[54,55] The physiologic maximal biting forces of 807 N for men and 650 N for women in the molar region have been reported by Kiliaridis et al.[55]

Although the results of this study cannot be directly compared with the *in vivo* situation, all test groups showed minimum fracture resistance levels greater than the clinically anticipated loads. Thus, all test specimens exceeded the maximum limits of the fracture resistance for posterior restorations.

The primary limitation of this study is that the specimens were loaded to failure in a single cycle, even though restorations may fail clinically through slow crack growth caused by fatigue loading.[56] Also, a single compressive load-to-failure does not replicate all the clinical loads to which the restoration is exposed.[57] Indeed, the nature of a single compressive load-to-failure test in a dry environment may well cause different fracture dynamics than the noncritical, wet, cyclic loading conditions that occur intraorally.[58,59] Therefore, instead of using monotonic static loading, it is more clinically relevant to test the specimens under physiological fatigue loading where vertical lateral forces are applied.

Subjecting the restorations to an accelerated degradation in one contact area deviates from normal masticatory patterns, which are distributed over all the dentition in most clinical situations, thereby decreasing the load on the restoration.[60,61] This might possibly lead to fatigue failures at lower levels than were recorded in this study.[60]

Also, leaving the screw-access openings unfilled may be considered a further limitation decreasing the clinical comparability of this study. In addition to the above-mentioned limitations, since this study investigated the porcelain fracture resistance of MC restorations fabricated with one alloy only (Co–Cr), the outcomes observed herein cannot be generalized to other types of ceramic alloys.

Conclusions

This study compared the porcelain fracture resistance of screw-retained, cement-retained, and combined screw- and cement-retained MC implant-supported posterior single crowns, and also investigated the effect of offsetting the occlusal screw-access opening on porcelain fracture resistance.

Within the limitations of this study, the following conclusions can be drawn:

1. The cement-retained restorations showed significantly higher mean fracture loads than the screw-retained and combined cement-screw-retained crowns.
2. There was no significant difference between the screw-retained and the combined cement-screw-retained crowns.

3. The position of the screw-access hole within the occlusal surface did not significantly affect the porcelain fracture resistance.

Although *in vitro* mechanical tests are valuable aids in the comparison of restoration properties, data obtained from these studies are useful for comparative purposes only, and direct extrapolation to the clinical situation should be made with caution and supported with long-term clinical studies.

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