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Laboratory Research

Endodontic Access Effect on Full Contour Zirconia and Lithium Disilicate Failure Resistance

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Clinical Relevance

Although more investigation is required, replacing adhesively luted, all-ceramic yttria-stabilized zirconium dioxide and lithium disilicate crowns may not be required after endodontic access.

SUMMARY

Objectives: To evaluate the effect of endodontic access on the failure load resistance of both adhesively and conventionally luted, full-contour monolithic yttria-stabilized zirconium dioxide (Y-TZP) and adhesively luted lithium disilicate (LD) crowns cemented on prepared teeth.

Methods and Materials: Seventy-two human maxillary molars were prepared per respective guidelines for all-ceramic crowns with one group (n=24) restored with LD and the other (n=48) receiving Y-TZP crowns. Preparations were scanned using computer-aided design/computer-aided milling (CAD/CAM) technology, and milled crowns were sintered following manufacturer recommendations. All LD crowns and half (n=24) of the Y-TZP crowns were adhesively cemented, while the remaining Y-TZP specimens were luted using a conventional glass ionomer cement (GIC). One LD group, one Y-TZP adhesive group, and one GIC-luted group (all n=12) then received endodontic access preparations by a board-certified endodontist: the pulp chambers were restored with a dual-cure, two-step, self-etch adhesive and a dual-cure resin composite core material. The access preparations were restored using a nano-hybrid resin composite after appropriate ceramic margin surface preparation. After 24 hours, all specimens were loaded axially until failure; mean failure loads were analyzed using Mann-Whitney U test (α=0.05)

Results: Endodontic access did not significantly reduce the failure load of adhesively luted LD or Y-TZP crowns, but Y-TZP crowns with GIC cementation demonstrated significantly less failure load.

Conclusions: These initial findings suggest that endodontic access preparation may not significantly affect failure load resistance of

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adhesively luted Y-TZP and LD crowns. Definitive recommendations cannot be proposed until fatigue testing and coronal seal evaluations have been accomplished.

INTRODUCTION

Full-contour crown restorations are indicated for teeth that have suffered extensive structure loss due to trauma and/or disease, with over 54 million units (crowns, pontics, retainers) reportedly placed in the United States in 2012.[1] Tooth preparation for a complete crown is not a conservative procedure, and. depending on the specific situation, crown preparation may require approximately 24% to 70% of the existing tooth structure to be removed.[2,3] During this procedure, the dental pulp can be subjected to heat and mechanical trauma,[4] and historically it has been suggested that the dental pulp may not fully recover from insults (eg, stressed pulp condition).[5] Hence, a potential chronic pulp inflammation combined with potential insults added during crown preparation[6-9] suggests that vital teeth receiving full metal and porcelain fused to metal crown restorations could be more likely to require future endodontic treatment. Clinical retrospective studies have reporting that crowns requiring endodontic intervention range from 4% to 18% compared with control ranges of 0.5% to 2%.[10-15] Moreover, greater knowledge of identified pulp tissue inflammation biological mechanisms involving heat, mechanical stress, and chemical insult from resin monomer infiltration[4,16-20] that occur during crown preparation and restoration adds emphasis to the idea that crown-restored vital teeth may be more vulnerable to requiring future endodontic intervention.[21-24] Furthermore, an estimated 20% to 50% of nonsurgical root canal treatments are performed via endodontic access through crowns,[25] and surveys report that up to 72% of clinicians prefer to maintain the repaired crown as the definitive post-endodontic restoration.[26,27] As the maintenance of a coronal seal is paramount for long-term success of endodontic treatment,[27-37] concern exists due to the present difficulty with obtaining reliable adhesion and seal with metal and porcelain materials,[35,36] even more so with high-crystalline ceramic surfaces.[37-40]

For all-ceramic crowns, retrospective evaluations report that endodontic intervention ranges from 2.5% to 8.6%.[13,41,42] The effect of endodontic access through all-ceramic restorations on the crown mechanical and physical properties has been a subject of many *in vitro* studies.[42-53] Access preparations through ceramic crowns are usually accomplished with high-speed diamond burs, which produce a machining loading strain process that is said to initiate both surface and subsurface ceramic cracks that lead to structural weakness.[54-59] Accordingly, the all-ceramic crown endodontic access preparation has been suggested as the nidus of following catastrophic complete crown failures,[48,49] while work by Grobecker-Karl and colleagues[60] report that monolithic zirconia is less susceptible to chipping and cracking due to endodontic access. Furthermore, it has been reported that flaw generation is independent of access technique and instruments used, as high-efficiency cutting instruments have been reported to cause ceramic flaws, regardless of the instrument composition.[48] Adhesive technology under *in vitro* conditions have shown some promise in strengthening some ceramic systems,[61,62] but these results are difficult to relate clinically, as *in vitro* ceramic evaluations have yet to correlate with clinical failure patterns.[63-66] Additionally, a recent systematic review could not identify a best practice guideline for endodontic access repair within all-ceramic complete crowns.[67] *In vitro* studies that approximate the clinical conditions involving endodontic access on full-contour ceramic crowns luted on prepared tooth structure are limited. The purpose of this study was to evaluate the effect of endodontic access preparation upon the failure load resistance of adhesively luted lithium disilicate (LD) and monolithic yttria-stabilized zirconium dioxide (Y-TZP) crowns luted both conventionally and adhesively to prepared teeth. The null hypothesis was that there would be no difference in the failure load between intact and endodontically accessed all-ceramic, full-crown restorations.

METHODS AND MATERIALS

Seventy-two freshly extracted human maxillary molars were used in this evaluation. These teeth were removed due to routine clinical indications in local oral and maxillofacial surgery clinics. The teeth were first mounted in autopolymerizing denture base methacrylate resin (Diamond D, Keystone Industries, Gibbstown, NJ, USA). The specimens were then assigned to groups per Figure 1. The specimens were first randomly divided into two groups. One group (n=48) was designated as the Y-TZP (InCoris TZI, Dentsply Sirona USA, York, PA, USA) monolithic crown group, while the second group (n=24) served as the LD (IPS eMax CAD, Ivoclar Vivadent, Amherst, NY, USA) complete crown group. The LD group was further subdivided

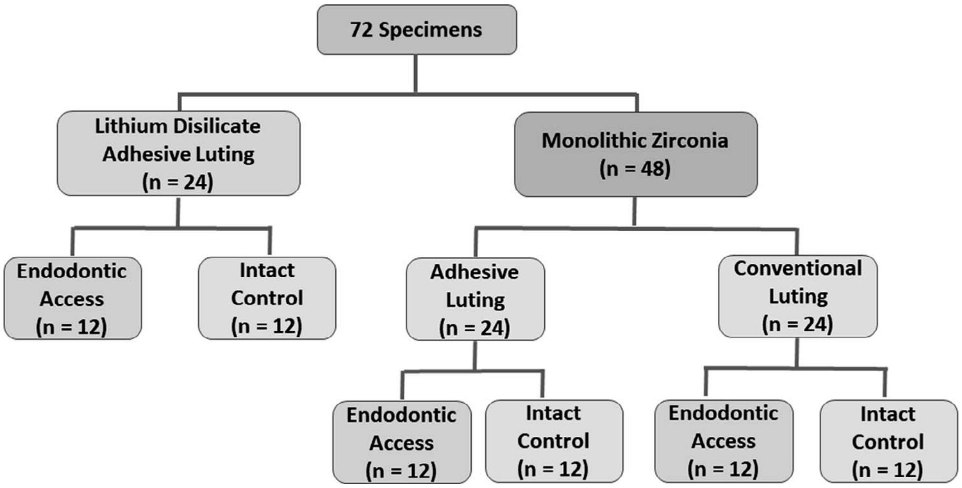


Figure 1. *Study protocol outline.*

into two groups (n=12): one restored group received endodontic access, while the other received no further treatment and served as a control. The Y-TZP group (n=48) was subdivided into two groups (n=24): one group received an adhesively luted complete Y-TZP crown, while the remaining group (n=24) was conventionally cemented using a glass ionomer luting agent. Based on luting strategy, each Y-TZP group was then further subdivided (n=12): one group was prepared with an endodontic access, while the other served as a control.

Specimen occlusal surfaces were ground flat to approximately 1 mm below the marginal ridge and then prepared by one researcher following manufacturer preparation recommendations for each crown substrate. A high-speed electric dental handpiece (EA-51LT, Adec, Newburg, OR, USA) with a diamond bur (8845KR.31.025, Brassler USA, Savannah, GA, USA) was used under continuous water coolant spray. A total occlusal convergence of 10° with a 3 mm occlusogingival axial wall height was standardized by using the handpiece in a fixed lathe arrangement. Preparation features and preparation surface area were confirmed and recorded with a digital recording microscope (KH-7700, Hirox USA, Hackensack, NJ, USA). All scanning and restoration procedures were then completed by a second researcher. The prepared molars were inserted into a quadrant template representing clinical conditions with a digital image captured using a computer-aided design/computer-aided milling (CAD/CAM) acquisition device (inEos Blue, Dentsply Sirona]), while CAD/CAM software (in Lab, version 4.0.0, Dentsply Sirona) was used for restoration design. Restoration contours and anatomy were standardized using a biomimetic copy with the Y-TZP restorations designed with a minimal 1.5 mm occlusal thickness following recommendations at that time, while the LD restorations had 2.0 mm minimal occlusal thickness. The LD groups were milled (MCXL, Dentsply Sirona) and after fit verification were crystallized in a dental laboratory furnace (Programat P700, Ivoclar Vivadent). Each restoration received post-crystallization adjustment and preparation seating verification using disclosing powder (Occlude, Pascal International, Bellevue, WA, USA) followed by steam cleaning and drying with oil-free compressed air. The restoration intaglio surface was treated with 5% hydrofluoric acid (IPS Ceramic Etching Gel, Ivoclar Vivadent) for 20 seconds, rinsed, and dried, which was then followed by ceramic primer application (Clearfil Ceramic primer, Kuraray America, Houston, TX, USA) that was dried using compressed air. All manufacturer recommendations that were current at the time of this evaluation were followed.

The tooth surface was prepared for luting using a pumice water slurry followed by rinsing and drying of the dentin surface. The restoration was then luted with a self-adhesive resin cement (RelyX Unicem2, 3M ESPE, St Paul, MN, USA) to margin closure using digital pressure; excess cement was removed followed by light activation using a Polywave light-emitting diode (LED) visible light curing unit (Bluephase G2, Ivoclar Vivadent) for 20 seconds on the facial, lingual, and occlusal surfaces.

The Y-TZP crowns were milled (MCXL, Dentsply Sirona) followed by sintering in a laboratory furnace (inFire, Dentsply Sirona) following manufacturer recommendations. Sintered restorations were seated and adjusted in the same manner as the LD groups. After cleaning and drying, half (n=24) of the Y-TZP intaglio surfaces were treated using 30 μm silicatized

Table 1: *Mean Preparation Parameters*

Group (n=12 each)	Mean Surface Area (mm^2)	Mean Axial Wall Height (mm)	Mean Total Occlusal Convergence (degrees)	Mean Endodontic Access Opening (mm^2)	Mean Endodontic Access Opening Percentage of Occlusal Surface (%)
1 ZR-KC	115.5 (9.6)	3.03 (0.05)	10.1 (1.01)	NA	NA
2 ZR-KC endodontic access	113.5 (14.9)	3.02 (0.04)	10.3 (0.8)	6.01 (0.64)	11.02 (1.1)
3 ZR-RX	131.3 (13.1)	3.02 (0.05)	10.4 (0.8)	NA	NA
4 ZR-RX endodontic access	112.6 (9.0)	3.03 (0.05)	10.4 (0.6)	8.6 (0.97)	14.2 (1.2)
5 LD-RX	101.8 (7.8)	3.02 (0.03)	10.6 (0.7)	NA	NA
6 LD-RX- endodontic access	102.1 (16.8)	3.02 (0.04)	10.6 (0.5)	9.11 (1.56)	15.5 (2.8)

Abbreviations: LD-RX, lithium disilicate luted with self-adhesive resin cement; NA, nonapplicable; ZR-KC, zirconia luted with conventional glass ionomer cement; ZR-RX, zirconia luted with self-adhesive resin cement.

sand (CoJet System, 3M ESPE) applied with 2-3 bar pressure followed by ceramic primer application (Clearfil Ceramic Primer, Kuraray America) then luted in the same manner as the LD specimens using a self-adhesive resin luting agent (RelyX Unicem 2, 3M ESPE). The remaining (n=24) Y-TZP complete crown intaglio surfaces were treated with 40 μm alumina and were luted with a conventional glass-ionomer luting agent (Ketac Cem, 3M ESPE). All materials were applied following manufacturer recommendations. All specimens were then stored under dark conditions at 37°C ± 1°C and 98% ± 1% humidity. After 24 hours, two of the Y-TZP restored groups and one of the LD restored groups received endodontic access preparation by a board-certified endodontist using diamond burs (Predator Zirconia Bur, Clinicians Choice, New Milford, CT, USA). To somewhat follow clinical conditions, the endodontic access opening area was not standardized but was determined by the endodontist's professional judgment regarding access to and instrumentation of the specimen's canals. Endodontic access opening area and approximate occlusal surface area were measured using a digital recording microscope (7700, Hirox USA).

The pulp chambers were restored using a self-etch, dual-cure adhesive (Clearfil DC, Kuraray America) with a dual-cure, resin core material (Gradia Core, GC America, Alsip, IL, USA). The coronal preparation of the LD specimens was repaired with a nano-hybrid resin composite (Tetric Evo Ceram, Ivoclar Vivadent) after 5% hydrofluoric acid (IPS Ceramic Etching Gel, Ivoclar-Vivadent) treatment of the endodontic access ceramic margin, primer solution application, (Clearfil Ceramic Primer, Kuraray America), and a self-etch, two-step adhesive (Clearfil SE, Kuraray America). The Y-TZP specimen access was repaired in a similar fashion except that the endodontic access marginal area was prepared using silicatized sand (CoJet System, 3M ESPE) followed by ceramic primer application (Clearfil Ceramic Primer, Kuraray America). All materials were used following manufacturer directions. Any required photopolymerization was provided by a Polywave LED visible light curing unit (BluePhase G2, Ivoclar Vivadent) in which performance (1200 mW/cm^2) was periodically assessed with a radiometer (bluephase Meter II, Ivoclar Vivadent). All restored specimens were stored in 100% humidity at 37°C for 24 hours until testing.

Specimens were placed into a fixture mounted on a universal testing machine (RT-5, MTS Corporation, Eden Prairie, MN, USA) and loaded axially until failure at a rate of 0.5 mm per minute using a hardened, 3 mm diameter, stainless steel piston containing a 0.5 m radius of curvature.[66] Mean failure load results were first analyzed with the Shapiro-Wilk and Bartlett tests, which identified both a non-normal data distribution and variance inhomogeneity. Mean data for each material and luting strategy were analyzed using Mann Whitney U test at a 95% level of confidence (α=0.05).

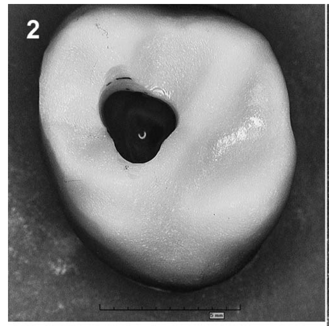
RESULTS

Resultant mean preparation parameters are listed in Table 1. Preparation standardization was reasonably achieved, with surface area covariance ranging from 8% to 16% within each group with an overall coefficient of variation approximating 10% between the groups. Endodontic access openings were less than 10 mm^2 and did not represent greater than 16% of the estimated occlusal surface. The mean failure load results are listed in Table 2. Failure load results found that fracture strength was not significantly affected by endodontic access through both adhesively luted LD and Y-TZP crowns. However, the fracture strength of the conventional glass ionomer

Table 2: *Mean Failure Load Results*

Group (n=12 each)	Failure Load (N)[a]
ZR-KC	7473 (2201)[Y]
ZR-KC endodontic access	5404 (1141)[Z]
p value	0.0068
ZR-RX	5805 (1373)[Y]
ZR-RX endodontic access	4852 (1520)[Y]
p value	0.12
LD-RX	2492 (835)[Y]
LD-RX endodontic access	1787 (487)[Y]
p value	0.078

Abbreviations: LD-RX, lithium disilicate luted with self-adhesive resin cement; ZR-KC, zirconia luted with conventional glass ionomer cement; ZR-RX, zirconia luted with self-adhesive resin cement.
[a] Groups with same capital letter are similar within each group only (Mann Whitney U, $p=0.05$).



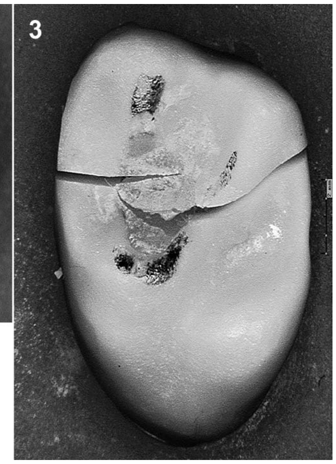


Figure 2. *Zirconia crown with endodontic access.*

Figure 3. *Failed view of the crown depicted in Figure 2.*

luted Y-TZP crowns were significantly reduced by endodontic access preparation.

DISCUSSION

Clinicians may encounter a tooth restored with a complete ceramic crown that requires endodontic treatment. Current estimates suggest that almost 50% of nonsurgical root canal treatments are performed through full-coverage restorations[26,27] with the repaired crown serving as the definitive restoration approximately three fourths of the time.[27] In contrast to metal, ceramic materials are brittle, and mechanical preparation may induce fractures, defects, and crack initiation.[51-54] Physical and mechanical properties may be impaired, and some authors suggest that the endodontic access is the source of any ensuing catastrophic failure of repaired ceramic crowns.[46] Despite the myriad factors affecting the durability of a ceramic crown containing an endodontic access, a recent systematic review of *in vitro* studies could not identify a best-practice protocol for improving the fracture resistance of ceramic crowns containing an endodontic access.[67]

The present study investigated the effect of endodontic access preparation on the failure load of LD and monolithic Y-TZP all-ceramic crowns luted onto prepared teeth. Adhesive luting protocols were used for both monolithic Y-TZP and LD materials, with additional Y-TZP groups evaluated using a conventional glass ionomer luting strategy. Preparations were accomplished by one researcher using a lathe-type device, which allowed standardization to be reasonably attained with intragroup covariance less than 16% and overall variation between the groups less than 10%. Conservative endodontic access preparations were also plausibly homogeneous with preparation areas less than 10 mm^2 that involved less than 16% of the occlusal surface area (Figure 2). Although the endodontic access opening and the calculated surface area of the testing probe were similar, anatomy of the molar occlusal surface ensured that the piston contact area was usually outside the access preparation margins, as outlined in Figure 3. Under the conditions of this study, the endodontic access dimension did not significantly decrease the failure load of adhesively luted monolithic Y-TZP and LD crowns. However, this was not observed with conventional glass ionomer cementation of Y-TZP. While adhesive resin techniques have been suggested to ameliorate surface flaws with predominantly glassy ceramics,[61-63] the authors advise caution regarding speculation that resin infiltration was a significant factor in this study, especially when the current status of reliable bonding to Y-TZP is considered.[38-40]

A number of previous studies concerning endodontic access preparations on molar all-ceramic crowns have used resin die substrates instead of prepared tooth surface. While resin die materials allow substrate uniformity, the authors maintain that prepared tooth structure substrates more closely approximate the clinical situation. Even so, Bompolaki and others[46] and Wood and others[47] found that endodontic access significantly weakened LD, laminated Y-TZP core, and alumina crowns, respectively. Qeblawi and others[48] reported that the adhesive cementation did improve endodontically accessed LD fracture resistance compared with those luted with zinc phosphate. Furthermore, a similar LD milled materials outcome was observed with the findings of Bompolaki and others[46] as endodontic access did not significantly reduce failure load.The results for the LD control group compare favorably with that of Okada and others,[68] Mörmann and others,[69] and Carvalho and others.[70] The results of this study are similar to the recent report by Scioscia and colleagues[71] in that the intact adhesively luted Y-TZP crowns failure load was similar to that found in this study. While the present study's focus did not concern endodontic access repair protocols, different materials were used in contrast to that of Scioscia and others[71] with diverse results. This disparity can be somewhat reconciled in that the present study used a more conservative endodontic access preparation and that thermomechanical loading was not available as well.

The endodontic access preparations were not standardized in this study. To simulate clinical conditions, access cavity dimension was determined by a board-certified endodontist's ability to access all root canals for proper instrumentation. Accordingly, endodontic access cavity preparation size and form within all-ceramic crowns are a topic of interest and controversy. Earlier studies[72-76] have reported some benefits with a conservative (eg, contracted, ninja) endodontic access. Recently, Corsentino and others[77] found that that access cavity size was not a significant factor in fracture strength of endodontically treated molars, which was reinforced by Rover and others[78] and Moore and others.[79] Özyürek and others[80] reported no difference in fracture strength of mandibular first molars between conservative and traditional access preparations, and Jiang and others,[81] using an *in silico* finite element analysis, found no occlusal stress distribution differences between conservative, traditional, and extended endodontic access preparations. Furthermore, Silva and others[82] conducted a systematic review of all *in vitro* studies that concluded that the conservative endodontic access provided no observed advantage. Based on this more recent information, the authors reasoned that the disparity in endodontic access preparation size would have a minimal effect on this study's results.

Under this study's conditions, the null hypothesis was upheld in the situation of adhesive resin cementation. The conservative endodontic access preparation did not significantly reduce the adhesively luted Y-TZP and LD all-ceramic crown failure loads. However, the null hypothesis was rejected as significantly lower failure load resistance was observed with monolithic Y-TZP crowns containing an endodontic access when a conventional glass ionomer cement was used. A curious result of this study was that the Y-TZP crowns luted with a conventional glass ionomer cement luting agent demonstrated greater failure loads compared with the adhesive resin luting method. The authors have no current definitive explanation for this unexpected finding, as the mechanical and physical properties of the self-adhesive resin luting agent are overall greater than that of the conventional glass ionomer cement.[83,84] Since the results were the same for more than one group, the authors strongly suspect that some aspect of the testing conditions was involved, as well as possible difference with supporting tooth structure to a minor extent.

This study contains definite limitations, which are the subject of ongoing studies. Due to technology access constraints, this initial evaluation used axial static loading forces and could not contain an environmental fatigue component, as cyclic loading under wet conditions is suggested to produce failure results that may have more clinical relevance.[85,86] It can also be successfully argued that the failure modes demonstrated during this evaluation did not replicate that usually observed with clinical failure. To wit, retrieved clinically failed ceramics are thought to initiate from internal flaws enabling stress concentrations leading to cracks and defects at the ceramic-cement interface, all of which are accentuated from masticatory occlusal forces. [64,65,87,88]

Some authors suggest that *in silico* finite element analysis methods may provide more clinically pertinent evidence[86,89-92] and allow investigation into such parameters as endodontic access geometry and area, which would be difficult to standardize.[86] Since a preexisting study with similar testing conditions as the current investigation was not available in the current literature, the chosen sample size was an empirical increase to a slightly larger number than that usually observed in most studies. Work is planned using the present findings to establish more robust testing conditions to hopefully proffer future results with improved statistical analytical capability.

Furthermore, this study's results reflect restorations that were prepared using manufacturer recommendations that have recently been updated. Nevertheless, the authors maintain that this initial evaluation provides meaningful information noting that a conservative endodontic access did not significantly decrease the failure load resistance of monolithic Y-TZP and LD crowns. Further ongoing studies in this research series will include updated crown parameter dimensions and employ dynamic environmental functional fatigue testing. Most importantly, clinicians should be strongly cautioned not to be emboldened by these initial results until further investigations have been accomplished.

CONCLUSION

Under this study's conditions, *in vitro* static testing suggests that a conservative endodontic access preparation does not significantly affect the failure load resistance of adhesively luted monolithic Y-TZP and LD crowns. Definitive recommendations cannot be proposed until further studies involving fatigue testing and the ability to establish an effective coronal seal have been accomplished.

Acknowledgement

Any opinions expressed in this work are of the authors only and do not represent the official opinion of the United States Air Force, Department of Defense, or the United States Government.

Regulatory Statement

This study was conducted in accordance with all the provisions of the local human subjects oversight committee guidelines and policies of the 81rst Medical Group. The approval code for this study is: FKE20160007N.

Conflict of Interest

The authors of this manuscript certify that they have no proprietary, financial, or other personal interest of any nature or kind in any product, service, and/or company that is presented in this article.

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