Load at fracture of monolithic and bilayered zirconia crowns with and without a cervical zirconia collar

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Fractures are still one of the main problems reported for ceramic restorations in clinical practice. Reports of the clinical performance of zirconia dental crowns are limited, but the available data for partial fixed dental prostheses indicate that both core fractures and adhesive fractures (chipping) are clinical problems. Monolithic, anatomic contour zirconia crowns have been introduced as alternatives to porcelain veneered crowns to increase fracture strength and reduce the risk of adhesive fractures. Recent studies have shown that fracture resistance can be improved with alternative core designs such as cervical core collars. Optimizing core design may contribute to increased clinical success and esthetically acceptable alternatives with the use of a colored zirconia. Furthermore, the single-layer design reduces the need for tooth removal, which may improve pulpal response. However, the optimal design for zirconia crowns is not certain. Many trials have attempted to evaluate the effect of the margin design, wall thickness, core-veneer ratio, test method, and materials used on fracture strength. The results are not all in agreement, and the clinical relevance is uncertain. Fractographic analyses and finite element analyses imply that the stress in dental ceramic crowns during mastication may be higher in the cervical margin than on the occlusal surface and that thin margins may be the cause of fracture.

The purpose of this study was to evaluate the effects of 2 different crown margin designs for bilayered restorations and monolithic zirconia crowns on load at fracture. Experience has shown that margins are vulnerable and that margin flaws can initiate core fractures during clinical use. An additional aim was to analyze the fracture modes by using fractographic methods to identify the fracture features and assess the clinical relevancy of the results. The hypothesis was that increased wall thickness...
Clinical Implications
A new marginal design for bilayered zirconia crowns improves their strength and reliability. However, monolithic crowns made with zirconia are the strongest crown type.

at the crown margin and in the axial walls increases the load at fracture of ceramic dental crowns.

MATERIAL AND METHODS
One cylindrical model was prepared with a shallow chamfer design and a taper of 5 degrees and rounded edges. For this model, 30 zirconia crowns (LAVA; 3M ESPE) were produced in a computerized design and milling unit (LAVA Scan ST; 3M ESPE). Ten were made with a standard coping for core-veneer crowns, 10 were made in a standard core-veneer design but with an additional 1-mm cervical zirconia collar, and 10 monolithic, anatomic contour crowns were produced to fit the model tooth (Fig. 1). A final adjustment of the crown margins was performed by hand to achieve a smooth boundary between the tooth and crown margins. The cores for the bilayered structures were veneered with veneering ceramics (e.max Ceram; Ivoclar Vivadent AG) to anatomic form. Images of all crown margins were made at ×10 magnification to identify flaws.

Crowns were luted to epoxy resin (Epoxi Resin; Struers) replicas of the preparation with zinc phosphate cement (De Trey Zink; Dentsply DeTrey GmbH). Excess cement was removed, and crowns were placed in distilled water at 37°C for 20 ± 2 hours. The crowns were subsequently loaded centrally at the occlusal surface with a steel ball 30 mm in diameter, cushioned with a 3-mm-thick ethylene propylene diene rubber disk with a hardness of 90 Shore A (EPDM 90A) to avoid contact damage. The load was applied in a universal testing machine (Zwick Roell) with a crosshead speed of 0.5 mm/min until fracture occurred. Crowns were immersed in water at 37°C during testing, and the load at fracture was recorded. Fractured crowns were analyzed by fractographic methods to evaluate the fracture modes and determine the fracture origins. Statistical software (SPSS v19; IBM Corp) and nonparametric statistics were used to calculate differences among groups (Kruskal-Wallis) and between groups (Mann-Whitney U test). Spearman rho (r) was used to calculate correlations (α = .05).

RESULTS
Statistically significant differences were found in the load at fracture among the test groups (P < .001) (Fig. 2). Fractographic analyses revealed that the fracture origins were mostly in the cervical margin in the proximal region and were similar to clinical fractures (Fig. 3-5, Table 1). One monolithic crown had an occlusal fracture origin. Fractographic features such as hackle, arrest lines, and crack branching were observed in both core and veneer. Fracture origin was typically a flat, smooth region in the core material (mirror), followed by a rougher region with flaking of the zirconia core (mist) region before the fracture surfaces smoothed out and the hackle and arrest lines could be seen (hackle region). The monolithic crowns fractured in more pieces than the core and collar groups. Most of the crowns in the core group fractured in 2 or 3 pieces, whereas crowns in the collar group displayed more than 3 fracture lines. Twenty-six of the 30 crowns had minor flaws or edge chips in the margin before testing (Fig. 6). In 10 crowns, the fracture origin was in a pre-existing margin flaw, whereas in the remaining 20 specimens, no flaws were detected in that region before testing. Cracks in the veneer of the bilayered crowns were both seen and heard at loads that were 500 to 1000 N lower than the load at complete fracture, but the exact load at the first crack was not registered. The veneer did not separate from the core before complete fracture occurred in any crowns. The load was interrupted at 2500 N in the first trial for 2 crowns in the core group. Both of these crowns exhibited cracks (infracture) in the veneer originating from the crown margin but no core damage (Fig. 7). These crowns were remounted and subjected to load until complete fracture (3960 and 5290 N, respectively). Because of the possibility of damage to either crown or abutment during the first test, these were excluded from further analysis.

No statistically significant correlation (P = .5) was found between the location of fracture origin and load at fracture. No correlation (P = .8) was found between the observed flaws at fracture origin and the load at fracture in any of the test groups.

DISCUSSION
The fact that the monolithic crowns fractured at a statistically significant higher load and presented more complicated fracture modes than the core-veneer crowns indicates that the crown wall thickness affects the fracture strength of zirconia crowns. Monolithic crowns are, thus, well-suited for clinical use in areas of high stress. The load at fracture for the monolithic crowns, however, was not much higher than that for the core-veneer crowns, as might have been expected based on the increase in material thickness alone and previous studies. This indicates that the crown margin design affects fracture strength more than wall thickness. Differences in load and fracture modes between the bilayered crowns with and without the cervical collar indicate that small modifications in marginal design can reduce the risk for both core fractures and adhesive fractures. The cervical collar...
seems to function as a reinforcing ferrule, reducing the strain in the cervical region of the crown. A larger collar would probably have a larger effect on load at fracture.

Previous studies have focused chiefly on the thickness of the material at the finish line and not especially on the design of the crown margin.20-23 Most in vitro studies have been based on tests performed on standardized crowns with a uniform design along the circumference of the crown and the use of a deep chamfer design.24,25,30,31 One study tested a similar circumferential collar design on a shallow chamfer as in this study but found no effect.20 Another study tested different wall thicknesses and margin designs on a deep chamfer and found an effect of wall thickness only.17 Most fractures in these studies seemed to originate from contact damage at the occlusal loading point and may thus have limited clinical significance.30,31,37 The fracture patterns found in the present study were similar to those found in zirconia crowns fractured during clinical function, which often reveal a fracture pattern that indicates a fracture origin in the cervical margin in the proximal area where the finish line curves toward the occlusal surface.18,34,36,38,39 This indicates that the results are highly relevant clinically. This area has limited space between the pulp and the neighboring tooth for adjustments of the wall thickness.

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**Figure 1.** A, Shallow chamfer preparation and 3 different crowns designed for this preparation. B, Core for bilayered core-veneer design. C, Collar for core-veneer design with cervical collar of zirconia. D, Monolithic, anatomic contour zirconia design. Dotted line indicates preparation contour.

**Figure 2.** Boxplot diagram of load at fracture (in N). Boxes represent 25th and 75th percentiles of findings, horizontal bars represent median values, and error bars represent minimum and maximum values. Statistically significant differences were found among groups (P<.001, Kruskal-Wallis). P values on horizontal bars indicate statistical differences among groups (Mann-Whitney U test). *n = 8 in core-veneer group.
or crown margin. The mesial and distal margins of a ceramic crown preparation exhibit highest stress values during compression. The current findings indicate that the proximal region is the weakest part of the crown. Previous findings of failure modes of both in vitro and in vivo crowns support this. The curvature of the finish line was equal on the mesial and distal side, yet 18 fractures originated on the mesial side compared with 9 on the distal side. A small difference in the preparation between the 2 sides may have contributed to this difference.

The finding that most crowns had flaws distributed along the crown margins indicates that marginal flaws are an intrinsic part of this restoration, or at least an important to fracture origin. One-third of the fractures originated in flaws, but the lack of correlation between observed margin quality and the load at fracture indicates that margin quality does not greatly affect the fracture strength of dental crowns during static loading. However, margin flaws will likely be more vulnerable to aging and thus more detrimental to strength because of the stress accumulations at the flaws. Previous studies of both clinical failures and in vitro failures have shown both flaw-induced fractures and fractures originating from apparently flawless margins. The findings indicate that more attention should be paid to reducing the margin flaws of ceramic restorations in order to improve clinical quality and reliability.

An advantage of the collar and anatomic contour crowns is the simplified application of veneer ceramics. Previous analyses of crowns fractured during clinical function have revealed that veneering material on the inside of the core is a relatively common occurrence. This will affect the seating, the fit, and the stress

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**Table 1.** Location of fracture origin in different test groups and number of fractures that originated from pre-existing defects

<table>
<thead>
<tr>
<th>Fracture Mode</th>
<th>Mesial Margin</th>
<th>Distal Margin</th>
<th>Palatal Margin</th>
<th>Occlusal Margin</th>
<th>Origin of Defect</th>
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<td>Core</td>
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<td>3</td>
<td>1</td>
<td>0</td>
<td>2</td>
</tr>
<tr>
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<td>3</td>
<td>1</td>
<td>0</td>
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<td>Monolithic</td>
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<td>3</td>
<td>0</td>
<td>1</td>
<td>5</td>
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</tbody>
</table>

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**Figure 3.** A, B. Fracture modes in core group typically displayed 1 major fracture line from mesial to distal side of crown. Cracks often branched into 1 or 2 partial or complete additional fracture lines. Typical fracture features such as hackle and arrest lines are seen in both veneer and core material. Direction of crack propagation is indicated by dashed arrows. C, D, and E. Reassembled crown after fracture. Fracture origin is on crown margin and crack propagation across occlusal surface where it branches off into 2 fracture lines. One branch has stopped on occlusal surface, while the other continued across to other surface. Some veneer has chipped off during testing. Note that there was no contact damage from loading. Horizontal white lines indicate 1 mm.
Figure 4. Fracture modes in collar group were similar to core group. Fatal cracks often branched off into more fracture lines than in core group. Fracture features were visible in both core and veneer. A, Compression curl is evident where cracks have branched off. B, C, Areas in boxes in image A at higher magnification, where wake hackle shows direction of crack propagation, dashed arrows. D, E, reassembled fractured crown. Fracture origin is located in palatal crown margin. In an occlusal view, main fracture line has branched off into 4 fracture lines. Horizontal white lines indicate 1 mm.

Figure 5. A, Monolithic crowns usually fractured into several pieces, and reassembly was difficult. Images show piece where fracture features clearly show crack propagation (dashed arrows) from margin towards occlusal surface. B, Boxed area at higher magnification in connected image. Area of origin is flat and regular (mirror) followed by a region with lots of flaking and irregularities (mist), while remaining fracture surfaces are remarkably smooth. Horizontal white lines indicate 1 mm.
distribution of the crown and may be a cause of early failures. A cervical collar without the need for veneer will probably reduce the risk for contamination inside the core. Furthermore, smooth transitions between the tooth, core, and veneer facilitate biofilm removal.

Chipping is reported as one of the major clinical problems with zirconia restorations in clinical use for both tooth- and implant-based restorations.3-6 Findings indicate that anatomic contour crowns or crowns with a cervical collar are stronger and may reduce the risk of chipping. Differences in thickness and thermal and residual stress due to lack of compatibility between the core and veneer may influence the chipping of zirconia cores.19,26-29,30,51 The findings that infractions occurred in the veneering ceramic before complete fracture indicate that differences in the flexural properties of the core and the veneer may also affect the rate of chipping. The loads at the first infraction crack were, however, above clinically relevant loads and indicate that all designs are suited for clinical use. Previous studies of alternative core designs indicate that the rate of chipping is reduced for cores with cervical collars in the proximal and lingual regions.13-15 The collar or anatomic contour design may reduce the need of invasive tooth preparation in certain areas of the mouth. The zirconia core materials can be produced in several different degrees of translucency and in multiple tooth-colored shades. The esthetic needs should therefore be achievable in most patients in both the premolar and molar regions with either the anatomic contour or strengthening collar design.

CONCLUSIONS

The crown wall thickness and the marginal crown design affect the load at fracture of zirconia crowns. Monolithic, anatomical contour design gave higher loads at fracture than traditional core-veneer design. Crowns with cervical zirconia collar had higher load at fracture than the core-veneer design, but lower than the monolithic crowns.
REFERENCES


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