Influence of cervical finish line type on the marginal adaptation of zirconia ceramic crowns

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Abstract

The current study evaluated the effect of different cervical finish line designs on the marginal adaptation of a zirconia ceramic. Four different marginal finish lines (c: chamfer, mc: mini-chamfer, fe: feather-edge and s: rounded shoulder) were prepared on phantom incisors. Die models for each preparation group (N = 28, n = 7 per finish line design group) were made of epoxy resin. Y-TZP (ICE Zirkon) frameworks were manufactured by a copy-milling system (Zirconzahn) using prefabricated blanks and tried on the master models for initial adaptation of the framework; they were then sintered, followed by veneering (Zirconzahn). The finished crowns were cemented with a polycarboxylate cement (Poly F) under 300 g load and ultrasonically cleaned. The specimens were sliced and the marginal gap was measured, considering absolute marginal opening (AMO) and marginal opening (MO) for each coping under a stereomicroscope with image processing software (Lucia). The measurements were statistically analyzed using the Kruskal Wallis, Mann Whitney and Wilcoxon Signed Ranks tests at a significance level of alpha = 0.01. Means of AMO measurement (microm) for the feather-edge finish line (87 +/- 10) was significantly lower than that of the chamfer (144 +/- 14), shoulder (114 +/- 16) and mini-chamfer finish line types (114 +/- 11) (p < 0.01). Means of MO measurements was the lowest for feather-edge finish line (68 +/- 9) (p < 0.01) and then, in ascending order, shoulder (95 +/- 9), mini-chamfer (97 +/- 12) and chamfer (128 +/- 10). The cervical finish line type had an influence on the marginal adaptation of the tested zirconia ceramic. Although the feather-edge finish line resulted in lower AMO and MO values, with its proven mechanical disadvantage, it cannot be recommended in clinical applications of zirconia crowns. This type of finish line has acted solely as a control group to test the null hypothesis in the current study. For better marginal adaptation, both shoulder and mini-chamfer finish line types could be suggested for zirconia crowns.
Influence of Cervical Finish Line Type on Marginal Adaptation of Zirconia Ceramic Crowns

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Running title: Effect of finish line type on zirconia crown adaptation

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SUMMARY

This study evaluated the effect of different cervical finish line designs on marginal adaptation of a zirconia ceramic. Four different marginal finish lines (c: chamfer, mc: mini-chamfer, fe: feather-edge and s: rounded shoulder) were prepared on phantom incisors. Die models for each preparation group (N=28, n=7 per finish line design group) were made of epoxy resin. YTZP (ICE Zirkon) frameworks were manufactured by a copy-milling system (Zirconzahn) using prefabricated blanks and tried on the master models for initial adaptation of the framework and then sintered followed by veneering (Zirconzahn). The finished crowns were cemented with a polycarboxylate cement (Poly F) under 300 g load and ultrasonically cleaned. Specimens were sliced and marginal gap was measured considering absolute marginal opening (AMO) and marginal opening (MO) for each coping under a stereomicroscope with image processing software (Lucia). The measurements were statistically analyzed using Kruskal Wallis, Mann Whitney and Wilcoxon Signed Ranks tests at significance level of \( \alpha = 0.01 \). Mean AMO measurement (µm) for feather-edge finish line (87±10) was significantly lower than those of chamfer (144±14), shoulder (114±16) and mini-chamfer finish line types (114±11) \( (p<0.01) \). Mean MO measurements for feather-edge finish line (68±9) were significantly lower than those of chamfer (128±10), shoulder (95±9) and mini-chamfer (97±12) \( (p<0.01) \) with chamfer having significantly higher MO values. Cervical finish line type had an influence on the marginal adaptation of the zirconia ceramic tested. Although feather-edge finish line resulted in lower AMO and MO values, from the biological and technical standpoint, shoulder and mini-chamfer can be recommended in clinical applications of zirconia crowns with which the second least marginal opening values were obtained.

Key words: Finish line, Marginal adaptation, Stereomicroscope, Zirconia crowns
INTRODUCTION

Achieving close marginal adaptation is crucial for long-term clinical success of single or multiple unit fixed-partial-dentures (FPD) as well as for the prognosis of the restored tooth. Luting agent solubility may, in time result in a gap between the tooth and the restorative material leading to microleakage, plaque accumulation, caries and subsequent failure of the restoration. While clinically acceptable range of marginal discrepancies are reported to be less than 120 µm,¹ ADA Standard recommends marginal opening to be less than 50 µm in order for a restoration to be clinically acceptable.² On the other hand, in CAD/CAM or copy-milling systems, the marginal opening has been reported to range between 60 µm and 300 µm.³

Several in-vitro studies demonstrated that marginal adaptation of metal-ceramic FPDs is influenced by the type of cervical finish line, shrinkage after firing procedures of veneering ceramic,⁴,⁵ differences in thermal expansion coefficients of the framework and veneering ceramic and most importantly the amount of circumferential ceramic thickness of the substructure.⁶ However the results on the effect of finish line design on the marginal discrepancies are controversial in the dental literature.⁴,⁵,⁷ Some studies on metal-ceramic restorations revealed that the finish line design had no influence on marginal adaptation,⁵,⁷ while others reported that shoulder type of preparation had less marginal distortion than chamfer type after repeated ceramic firings regardless of the mini-chamfer applications.⁴,⁷,⁸

Yttrium tetragonal zirconia polycrystal (Y-TZP) (hereon: zirconia) frameworks can be fabricated mainly with the help of CAD/CAM or copy-milling techniques by means of grinding a zirconia block. These blocks can be milled either in the green, pre-sintered or completely sintered stage.⁹,¹⁰ Frameworks made from green and pre-sintered zirconia are milled in an enlarged form to compensate for the shrinkage that occurs during sintering, which usually equals to 20-25% for partially sintered frameworks.¹⁰ Completely sintered Y-TZP blocks are prepared by presintering at temperatures below 1500°C and then processed by hot isostatically
pressed (HIP) technique at temperatures between 1400 and 1500°C under high pressure in an inert gas atmosphere. This leads to a very high density in excess of 99% of the theoretical density. The blocks can then be machined using a specially designed milling system. The milling of pre-sintered zirconia blocks is faster and causes less mechanical damage to the material compared to milling of fully sintered blocks. The milled frameworks are then veneered with feldspar or glass-ceramics appropriate for the zirconia used. However, the mechanical properties of zirconia ceramic are affected during the veneering stage performed at relatively higher temperatures. The framework is subjected to distortion and shrinkage during sintering and veneering stages. This will consequently have a negative effect on the marginal adaptation.

In a recent clinical study on zirconia FPDs, the overall survival rate was found to be 73.9% with marginal integrity problems and thereby secondary caries (21.7%) and ceramic debonding (15.2%) being major causes of failure. Unfortunately, in that study the type of cervical finish lines were not reported. The amount of tooth structure removed during tooth preparation varies according to the finish line design. Therefore, the aim of this study was to evaluate the effect of cervical finish line design on marginal adaptation of veneered zirconia crowns.

METHODS AND MATERIALS

Specimen preparation

Phantom teeth of maxillary right central incisors (N=28) (Frasaco, Frasaco GmbH, Tettnang, Germany) were stabilized at their apex and embedded in autopolymerizing polymethylmethacrylate (Palapress, Vario, Heraeus Kulzer, Wehrheim, Germany) with their long axes oriented perpendicular to the surface of the block up to 1 mm below their cemento-enamel junction. Teeth were prepared with four different cervical finish line designs, namely
circumferential rounded shoulder (s) (1.2 mm), chamfer (c) (1.2 mm), mini-chamfer (mc) (0.9 mm) and feather-edge (fe) following axiogingival radii (Fig. 1a). The preparations were made by the same investigator with new diamond burs each time (Brasseler, Savannah, GA, USA) using a high-speed hand-piece under water cooling. A parallelogram (NEY surveyor, Dentsply, Ceramco, NJ, USA) and a digital slide gauge (Mitutoyo Corp., Tano-cho, Japan) were used in order to ensure standardized tooth preparations with approximately 2.5 mm incisal reduction and convergence angle of 6°. The impressions were made with a polyvinylsiloxane impression material (Affinis, Coltene Whaledent, Switzerland) and die models for each preparation group (n=7/group) were made of epoxy resin (EP85-215, Eager Plastics, Chicago, IL, USA). A total of 28 zirconia frameworks (n=7 zirconia copings/finish line design) were manufactured by a copy-milling system (Zirconzahn, Bruneck, Italy) using prefabricated blanks of zirconia ceramic (ICE Zirkon, Zirconzahn, Bruneck, Italy). All specimens were fabricated by one experienced dental technician and tried on the master models for initial adaptation of the framework. Since zirconia framework shrinkage occurs even after veneering process affecting the marginal adaptation, zirconia specimens were sintered followed by veneering and glazing (Zirconzahn Veneering Ceramic, Bruneck, Italy) in order to simulate a finished crown as in the clinical situation. Each finished crown was tried on its corresponding die and minor adjustments were made when necessary. Then the crowns were cemented with a polycarboxylate cement (Poly F, Dentsply, UK) under 300 g load for 10 minutes.

**Measurement of marginal adaptation**

Each specimen was sectioned perpendicular to its longitudinal axis using a diamond disk (Isomet, Buehler Ltd., Lake Bluff, IL, USA) under a stream of water, to produce beams (thickness: 1mm). Four beams were obtained per specimen. The outer mesial and distal residual parts were removed. Then, each surface was ground with 600-grit silicon carbide paper under running water prior to measurement procedure.
The marginal adaptation was evaluated by considering 2 parameters; (1) absolute marginal opening (AMO), referring to the gap from the most external point at the crown margin to the most external point at the preparation margin and (2) marginal opening (MO) defining the distance from the external crown margin to the opposite preparation line or surface at the point in shortest perpendicular distance (Fig. 1b). Measurements were made under a stereomicroscope with image processing software (Lucia, Nikon Corporation, Tokyo, Japan) (at original magnification x250).

One calibrated examiner made and recorded all of the measurements. Four MO (approximately with 200 µm intervals) and one AMO measurement were made from each marginal aspect (buccal and lingual aspects) leading to a total of 64 MO and 16 AMO measurements from each specimen. The marginal fit of a crown was defined as mean values of (mean±standard deviation in µm) MO and AMO measurements/crown separately (Figs. 2a-d). In this study, the maximum clinically acceptable marginal opening was accepted as 120 µm.1-3 Based on this information a further classification was made for acceptable and non-acceptable crowns in terms of marginal adaptation.

Statistical analysis

The obtained data obtained from the cross sections and total measurements of the die/crown assembly were statistically analyzed (SPSS 15.0 for Windows, Chicago, IL, USA) by Kruskal Wallis, Mann-Whitney and Wilcoxon Signed Ranks tests at significance levels of 0.05 and 0.01.

RESULTS

The mean AMO measurement (µm) for feather-edge type of cervical finish line (87±10) was significantly lower than those of chamfer (144±14), shoulder (114±16) and mini-chamfer (114±11) finish line types (p<0.01) (Kruskal Wallis and Mann-Whitney Tests). Chamfer finish
line showed significantly higher AMO values than those of other groups. The differences between mini-chamfer and shoulder type of finish lines were not significant \((p>0.01)\). The results of the AMO measurements for all types of finish line designs between buccal and lingual aspects revealed statistically no significant differences \((p>0.01)\) (Wilcoxon Signed Ranks Test) (Fig. 3).

Mean values of MO measurements for feather-edge type of finish line \((68\pm9)\) were significantly lower than those of chamfer \((128\pm10)\), shoulder \((95\pm9)\) and mini-chamfer \((97\pm12)\) finish line types \((p<0.01)\) with chamfer having significantly higher MO values. The differences between mini-chamfer and shoulder were not statistically significant \((p>0.01)\). Differences in MO measurements for all types of finish line designs between buccal and lingual aspects were also not significant \((p>0.01)\) (Fig. 3).

There were 7, 6, 2, 1 acceptable crowns out of 7 in the fe, s, mc and c groups, respectively when AMO measurements were considered. MO measurements on the other hand revealed 7, 7, 7, 2 acceptable crowns out of 7 for fe, s, mc and c groups, respectively.

DISCUSSION

In this in vitro study, marginal integrity of veneered zirconia crowns with four different finish lines, namely chamfer, rounded shoulder, mini-chamfer and feather-edge were evaluated using optical image processing software. It was reported in a previous study that both scanning electron microscope (SEM) imaging and light microscopy measurement techniques can be used to measure marginal discrepancies since there was no significant difference between the accuracy of the two techniques.\(^{15}\) In this study, light microscopy imaging software was preferred due to the automatic detailed measurement with the software providing means, standard deviations and minimum-maximum values at a time that would result in more
standardized processing than SEM imaging measurements based on visual determination of the measurement areas.

The AMO has been used as a generic term in most studies where fit of the crown was assessed. However, since AMO might vary significantly depending on the over-extension or under-extension of the crowns, the locations of marginal measurement may vary among studies. It is usually due to the fact that the margins of the crown and die may seem to be sharp clinically, but appear rounded when microscopically viewed. This makes it difficult to select a point where the marginal opening is to be measured. Therefore, in this study not only AMO but also MO was measured in order to obtain mean values along the whole cervical finish line.

The results of the measurements revealed that feather-edge type of finish line design exhibited the least marginal discrepancy (AMO and MO). This was attributed to the fact that the more the restoration margin ends with an acute angle, the shorter the distance between the restoration margin and the tooth which had been described previously by Schillinburg with the following formula:

\[ d = D \sin m \] (d: marginal opening; D: the distance by which a crown fails to seat and m: the acute angle of the margin). Although, feather-edge type of finish line exhibited the least AMO and MO values, it is not highly recommended for clinical practice since it triggers a wedging effect at the margins and may provide additional marginal bulk. Given the fact that the marginal discrepancy in chamfer finish line design was shown to be lower, the results of the present study were not in accordance with this suggestion. On the other hand, the results of this study were concurrent with an earlier study in which heavy chamfer finish line exhibited more marginal opening than rounded shoulder on In Ceram Alumina crowns. Although a 90° shoulder with a rounded axiogingival line angle design is recommended for the preparation of all-ceramic and metal-ceramic crowns rather than a chamfer preparation, the rheological
properties of zirconia framework material differ from these materials in many aspects such as creep behaviour.\textsuperscript{21} This might be the cause of the poor-fitting crowns with chamfer finish line design in the present study. Furthermore, it was stated that shoulder type of preparation is more resistant to distortion.\textsuperscript{17}

In a previous study, it has been shown that there were no significant differences between shoulder and chamfer preparation designs in In-Ceram crowns.\textsuperscript{22} However, a recent study recommended the use of shoulder finish line for all-ceramic crowns.\textsuperscript{23} In our study, mini-chamfer finish line also showed similar values to that of shoulder finish line and the differences among overall means according to finish line type revealed that the difference between mini-chamfer and shoulder was not significant. In principle, due to maintenance of the biological integrity at the cemento-enamel junction and necessity of room for the core and veneering ceramic, although the best results were obtained with the feather-edge finish line design, this cannot be recommended for clinical applications. Given the above mentioned results and also considering the biological aspects and technical reasons,\textsuperscript{24} shoulder finish line as well as mini-chamfer that gave the second best results could be preferable.

A previous study tested the marginal adaptation of IPS\textsuperscript{E}mpress 2 (Ivoclar Vivadent, Schaan, Liechtenstein) maxillary incisor crowns and found the mean marginal opening to be 62 µm.\textsuperscript{23} However another study on the marginal gap measurement of In-Ceram crowns revealed that the mean marginal openings were between 120 and 160 µm.\textsuperscript{16} Tischert et al. reported that the mean marginal discrepancies ranged from 61 µm to 74 µm for the zirconia ceramic FPD frameworks fabricated with the Precident DCS system (DCS, Allschwil, Switzerland).\textsuperscript{25} The marginal fit values of experimental all-ceramic FPDs ranged between 89 and 130 µm in an in vivo study.\textsuperscript{26} On the other hand, the findings of an in vitro study revealed mean marginal gap values of Empress 2 FPDs between 58 and 68 µm.\textsuperscript{27} An explanation for these differences in literature regarding marginal gaps in all-ceramic crowns might be
attributed to many parameters such as measurement methodology and measuring instruments used, the differences in material properties, sample size and the number of measurements per specimen. Nevertheless, all these range of reported results are in accordance with the results obtained in this study.

The rationale for choosing the cross-section method in this study was that the measurements could be obtained not only from one point, but along the whole finish line starting from the axial wall to the outermost extension point as well as providing measurements after cementation. When cross-section method is used, the reference measurement points in different studies may demonstrate different cement thicknesses, since a uniform cementation space between the intaglio surface of the crown and the die may not be provided. Moreover, cementation procedures may affect the marginal fit because of the differences in viscosity of luting agents and seating forces. Therefore, in this study, a polycarboxylate cement was chosen owing to its good visibility in measurements as opposed to the resin cements and cementation was performed in a controlled manner under constant load in order to minimize these effects. However, although pre-cementation marginal opening measurements were not made in our study, an increase in marginal opening width after cementation must also be considered because of the minimal grain size of the dental cement when other faults do not occur. Although detailed cross-sections were obtained allowing also for internal fit measurements of crowns, it was not assessed in the present study since the aim was to offer an appropriate finish line design against debate on the marginal fit of the zirconia crowns.

It was reported that there were no significant differences between shoulder and chamfer preparation types and among mesial, distal, buccal and lingual aspects in a study conducted on Cerec3 crowns. In that study each crown margin was evaluated in 360° and another study revealed non-significant differences in marginal fit between metal-ceramic and all-ceramic crowns where the margins were evaluated in 360°. The differences between buccal and
lingual marginal opening measurements were also not significant in this study where most of the measured crown margins were overextended, most probably due to the milling process related with the Zirconzahn system. Thus, final manual trimming of the crown margins should be controlled under a light microscope to ensure that excess material that remains after the milling process, is completely removed from the preparation finish line.

The adaptation of zirconia ceramic restorations may be affected by the preparation design, milling process, size of milling burs, and material conditions during the milling procedure. It has been previously shown that green and pre-sintered four-unit zirconia ceramic FPD frameworks of straight design exhibited better marginal adaptation compared to curved design. These results were attributed largely to the distortion of the framework due to shrinkage of the ceramics during the final sintering stage. However, in that study, the marginal discrepancies of four-unit FPD frameworks had been measured with no veneering ceramic. There is a lack of information on the effect of the application of veneering ceramic on the marginal adaptation on single and multiple unit zirconia FPDs. In our study, although only zirconia crowns were evaluated, all crowns were veneered with veneering ceramic in order to simulate the clinical situation and thereby obtain more clinically relevant results. Since there is no clinical evidence to support the concept that marginal gaps lead to secondary caries and chippings at the margins with zirconia FPDs, future clinical studies with such restorative materials should accompany marginal and internal fit findings.

CONCLUSIONS

From this study, the following could be concluded:

1. Although feather-edge finish line resulted in lower AMO and MO values, from the biological and technical standpoint, shoulder and mini-chamfer finish lines can be recommended in clinical
applications of zirconia crowns with which the second least marginal opening values were obtained.

2. Measurements from lingual aspect revealed statistically no significant differences among cervical finish lines except for shoulder type with significantly lower values.

3. Mean values for all finish lines were within clinically acceptable range of marginal openings according to the suggested values in fixed prosthodontics. However, marginal openings were higher than ADA specifications of 50 µm indicating the necessity of adhesive cementation.

4. Measured marginal discrepancies may be attributed to the difficulties or insufficient precision during the milling process of the zirconia framework material. Clinically, final preparation margins should be controlled under magnification.

**Clinical Relevance**

Cervical finish line type has an influence on the marginal adaptation of Y-TZP restorations. After feather-edge, which cannot be recommended for all-ceramic FPDs due to technical and biological reasons, both shoulder and mini-chamfer exhibited the least marginal opening values for zirconia crowns and can be recommended for clinical applications.
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Captions to the legends

Figures

Figs. 1a-b. a) Preparation design of phantom teeth and cervical finish line forms and depths. b) Schematic view of Absolute Marginal Opening (AMO) (1) and Marginal Opening (MO) (2) measurements with 200 µm intervals

Figs. 2a-d. Representative buccal cross-sections of die/crown assemblies. (A: Mini-chamfer, B: Chamfer, C: Feather-edge, D: Rounded shoulder; c: Cement, ed: Epoxy die, f: Zirconia framework, v: Veneering ceramic)

Fig 3. Absolute marginal (AMO) and marginal openings (MO) (µm) for four cervical finish line types
**Figs. 1a-b.**  
**a)** Preparation design of phantom teeth and cervical finish line forms and depths.  
**b)** Schematic view of Absolute Marginal Opening (AMO) (1) and Marginal Opening (MO) (2) measurements with 200 µm intervals

**Figs. 2a-d.**  
Representative buccal cross-sections of die/crown assemblies. (A: Mini-chamfer, B: Chamfer, C: Feather-edge, D: Rounded shoulder; c: Cement, ed: Epoxy die, f: Zirconia framework, v: Veneering ceramic)
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