Differences in Volumetric Tooth Loss for Monolithic Ceramic Crowns, Occlusal Overlays, and Partial Coverage Onlays

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Purpose: To compare the volumetric loss of clinical crown structure for commonly encountered clinical situations for monolithic ceramic crowns, occlusal overlays, and partial coverage onlays. ***Materials and Methods:*** Typodont teeth made with preexisting mesio-occlusodistal (MOD) preparations for mandibular first molars and maxillary first premolars were prepared with three different preparations: a full contour monolithic zirconia crown, a lithium disilicate occlusal overlay, and mesio-occluso-disto-buccal/mesio-occluso-disto-lingual (MODB/MODL) lithium disilicate onlays for premolars and molars. 3D-metrologic software was used to evaluate the volumetric loss of clinical crown structure for each preparation type. Subsequently, the mesiolingual cusps of mandibular molars and buccal cusps of maxillary premolars were excluded for a separate analysis to simulate patient presentation with an existing restoration and sheared off cusp. ***Results:*** Full coverage monolithic zirconia crowns removed 45.37 to 219.53 mm^3 of the remaining clinical tooth structure, depending on the clinical scenario and tooth position, while lithium disilicate overlays removed 27.48 to 105.13 mm^3 and MODB/MODL lithium disilicate onlays removed 5.48 to 47.45 mm^3. In each scenario tested, MODB/MODL onlays removed significantly less clinical crown structure than overlays ($P < .001$); both MODB/MODL onlays and overlays removed significantly less structure than full coverage crowns ($P < .001$). ***Conclusions:*** Monolithic zirconia crown restorations require significantly more removal of remaining tooth structure than lithium disilicate occlusal overlays and partial coverage onlays for commonly occurring clinical situations requiring indirect restorations. *Int J Prosthodont 2024;37:XXX–XXX. doi: 10.11607/ijp.8011*

The last decade has seen a significant shift amongst practitioners' choices for indirect restorative materials. Monolithic zirconia has become the primary material used for restoring posterior teeth.[1] Meanwhile, dentists still prefer conventional cementation with a glass ionomer or resin-modified glass ionomer cement as opposed to bonding with a resin cement.[2] This would indicate that most indirect dentistry being done for individual teeth continues to be the full coverage crown with conventional retention and resistance form.

As early as the 1980s, it was recognized that full crown solutions are greatly overused and are only truly indicated for restoring individual teeth when maximum retention is needed.[3] The development of modern monolithic ceramic options gives practitioners of today even fewer requirements for maximum retention, thanks to the ability to bond restorations in place. There are numerous advantages to preserving

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Submitted September 13, 2022;
accepted November 21, 2022.

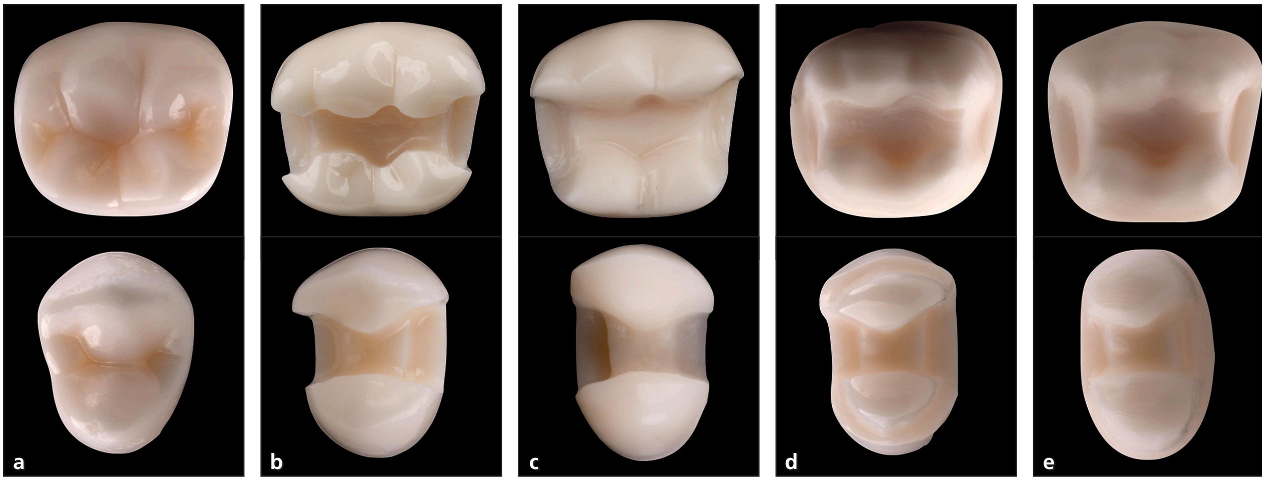

Fig 1 Occlusal photograph of the master preparations for molars (top) and premolars (bottom). *(a)* Intact typodont tooth, *(b)* preoperative tooth with existing MOD preparation, *(c)* partial coverage onlay preparation, *(d)* overlay preparation, and *(e)* crown preparation.

sound tooth structure and not using full coverage crowns. Over 50 years ago, Eissmann et al[4] identified the ideal margin placement to be supragingival, fully exposed to a cleansing action, smoothly contoured, and preferably ending in enamel. The negative effects of indirect restorative margins at or below the gingival margin have been reemphasized over time.[5] Modern bonded ceramics eliminate the need to extend margins to gain retention and resistance form or hide the tooth/restorative interface, maximizing the preservation of gingival health and remaining tooth structure.

Partial coverage glass ceramic restorations have a well-documented track record of clinical success,[6,7] equal to that of cast gold.[8] More recent studies with lithium disilicate show success rates equal to or better than older glass ceramics.[9–11] Some clinical scenarios require full coverage of the occlusal table, such as rehabilitations of severe occlusal wear or those in need of opening the vertical dimension of occlusion. Several laboratory investigations have shown bonded ceramic restorations with < 1.0-mm-thick veneering of the occlusal surface of posterior teeth to have more than adequate strength to resist fracture and function well long term.[12–14] The resulting tooth/restorative complex of various occlusal overlay designs have been found to be as resistant or significantly more resistant to fracture than teeth with full coverage crowns.[15] Multiple examples of successful clinical use of this concept with varying designs and materials have been reported in the literature,[16–19] with one study following restorations for up to 11 years with 100% survival.[19]

Previous studies have quantified the amount of tooth loss associated with partial and full coverage gold restorations,[20,21] monolithic ceramic crowns,[22–24] partial coverage glass ceramic onlays,[24] and retainers for fixed partial dentures.[25] To date, the differences between full coverage monolithic zirconia crowns and alternative partial coverage options in glass ceramic for posterior teeth have not been directly compared. The purpose of this study was to quantify and compare the volumetric loss of clinical crown structure for commonly encountered clinical scenarios for full coverage monolithic zirconia crowns, lithium disilicate overlays, and lithium disilicate partial coverage onlays for maxillary first premolars and mandibular first molars. The null hypothesis was that there would be no significant differences in volumetric loss of clinical crown structure between preparation styles for the clinical scenarios tested.

MATERIALS AND METHODS

To replicate common clinical presentations, mandibular first molars and maxillary first premolars with existing mesio-occlusodistal (MOD) preparations were selected. Typodont teeth fabricated with MOD preparations, a maxillary right first premolar (UR46, Kilgore International), and mandibular left first molar (LR66AC, Kilgore International) were mounted in a hinge typodont (Nissin 200, Kilgore International) for preparation. Prior to preparation, teeth were mounted in a special jig and scanned using a laboratory scanner (D2000, 3Shape) obtaining high-quality standardized tessellation language (STL) files as described elsewhere.[26]

The needed sample size was determined after a priori power analyses using a computer program (G*Power version 3.1.9.6, Heinrich Heine Universität Düsseldorf) referencing several previous studies.[22–25] Given the heterogenous nature of existing studies with respect to methodology and outcome measurement, a group size of n = 10 was selected to ensure adequate sample size. First a master preparation for each experimental group was completed (Fig 1). Each tooth was then prepared for its assigned preparation group using a silicone

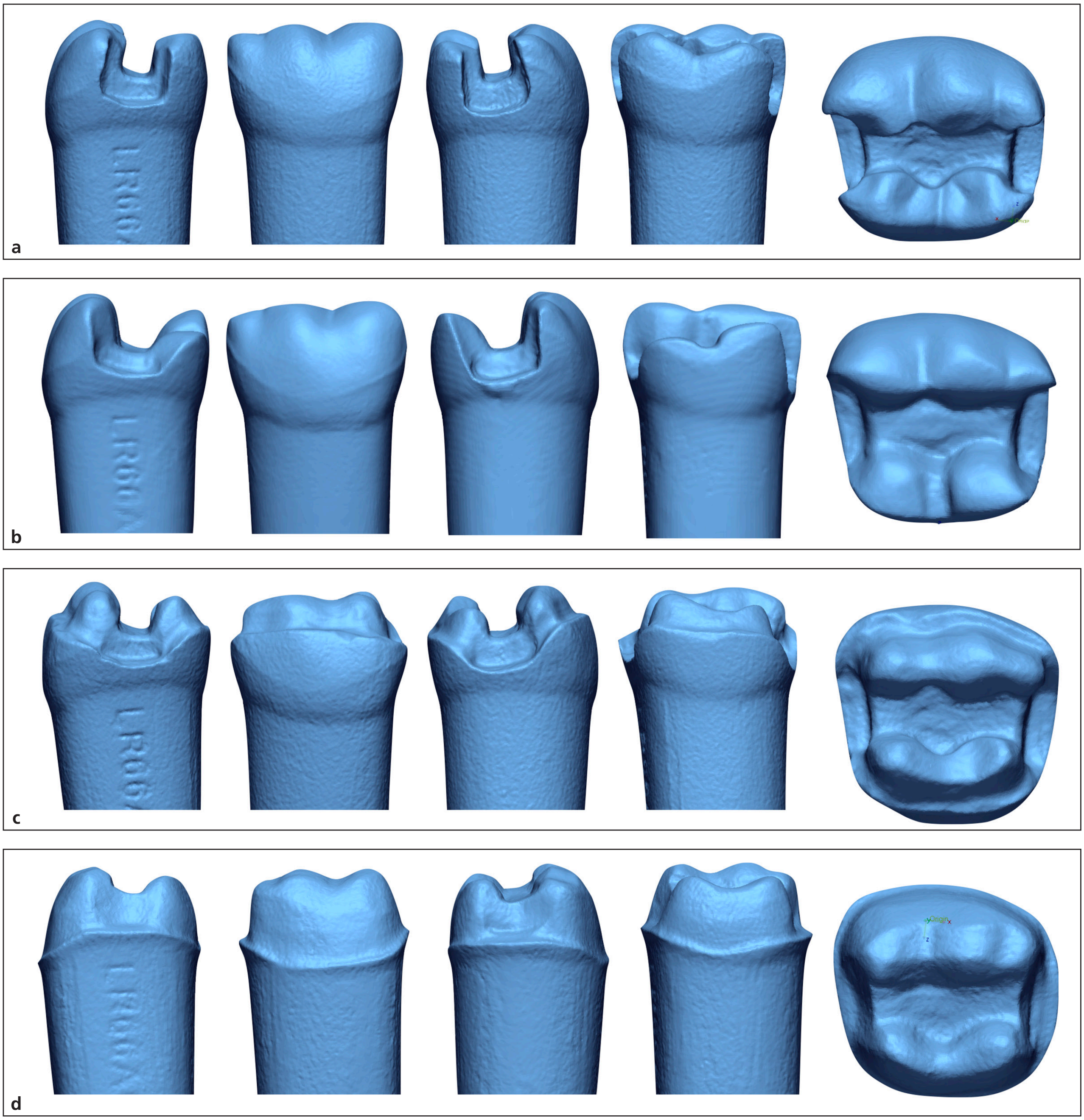

Fig 2a to 2d STL files with (from left to right) mesial, buccal, distal, lingual, and occlusal views of the preoperative tooth and preparations. *(a)* Preoperative mandibular first molar with existing MOD preparation; *(b)* MODL onlay, lower first molar; *(c)* overlay, lower first molar; *(d)* crown, lower first molar.

putty guide (Sil-Tech Plus, Ivoclar) fabricated for use in calibrating each subsequent preparation for each group. The prepared teeth were rescanned with the same laboratory scanner to create STL files for analysis (Fig 2). Groups, preparation guidelines, and the burs used (Komet USA) are summarized in Table 1. Intact typodont teeth without MOD preparations (A200-05, A200-19, Kilgore International) were also scanned in to be analyzed volumetrically, to facilitate easier comparison with previous studies, which all started with intact teeth without existing restorations or preparations.

STL files were exported and analyzed by a single calibrated examiner (E.C.Q.) using a 3D-metrological software (Geomagic Control X, 3D Systems). To ensure accuracy between preparation and master teeth, STL files were superimposed for best fit alignment. To

Fig 2e to 2h STL files with (from left to right) mesial, buccal, distal, lingual, and occlusal views of the preoperative tooth and preparations. *(e)* Preoperative maxillary first premolar with existing MOD preparation; *(f)* MODB onlay, maxillary first premolar; *(g)* Overlay, maxillary first premolar; and *(h)* crown, maxillary first premolar.

verify the alignment, a 3D color-map comparison was used, which indicated areas of adequate alignments and discrepancies with color regions, confirming that the preparation followed the desired parameters as reported in Table 1 (Fig 3). The average error between STL files was established in ± 0.3 mm. To conduct the volumetric analysis for each preparation, the volume of interest (VOI) was defined by a standardized apical plane in the premolar and molar teeth (facial cementoenamel junction [CEJ] level), and a coronal plane over the most coronal point of the tooth crown. The enclosed

Table 1 Preparation Groups, Parameters, and Burs Used

	Preparation parameters					
	Mandibular first molar			Maxillary first premolar		
Preparation groups	Monolithic zirconia crown	Lithium disilicate overlay	Lithium disilicate onlay	Monolithic zirconia crown	Lithium disilicate overlay	Lithium disilicate onlay
Occlusal reduction	1 mm	1 mm	x	1 mm	1 mm	x
Axial reduction	0.5 mm	1 mm	x	0.5 mm	1 mm	x
Axial wall height	4 mm	2 mm	x	4 mm	2 mm	x
Finish line	Heavy chamfer	Shoulder	Heavy chamfer	Heavy chamfer	Shoulder	Heavy chamfer
Buccal cusp reduction	x	x	x	x	x	1 mm
Mesial lingual cusp/ lingual groove reduction	x	x	1 mm	x	x	x
Axial reduction						
buccal cusp	x	x	x	x	x	1 mm
Axial reduction mesiallingual cusp	x	x	1mm	x	x	x
Finish line placement	x	x	1 mm coronal to CEJ	x	x	1 mm coronal to CEJ
Preparation burs (Komet USA)						
Occlusal reduction	Modified shoulder tapered diamond with depth marks, course grit (959KRD.FG.018)					
Axial reduction	Modified shoulder tapered diamond, course grit (847KRXC.FG.016)					
Smoothing, blending, and refinement	Modified shoulder tapered diamond, fine grit (8951KR.FG.017); egg-shaped diamond, fine grit (8379.FG.023)					

CEJ = cementoenamel junction

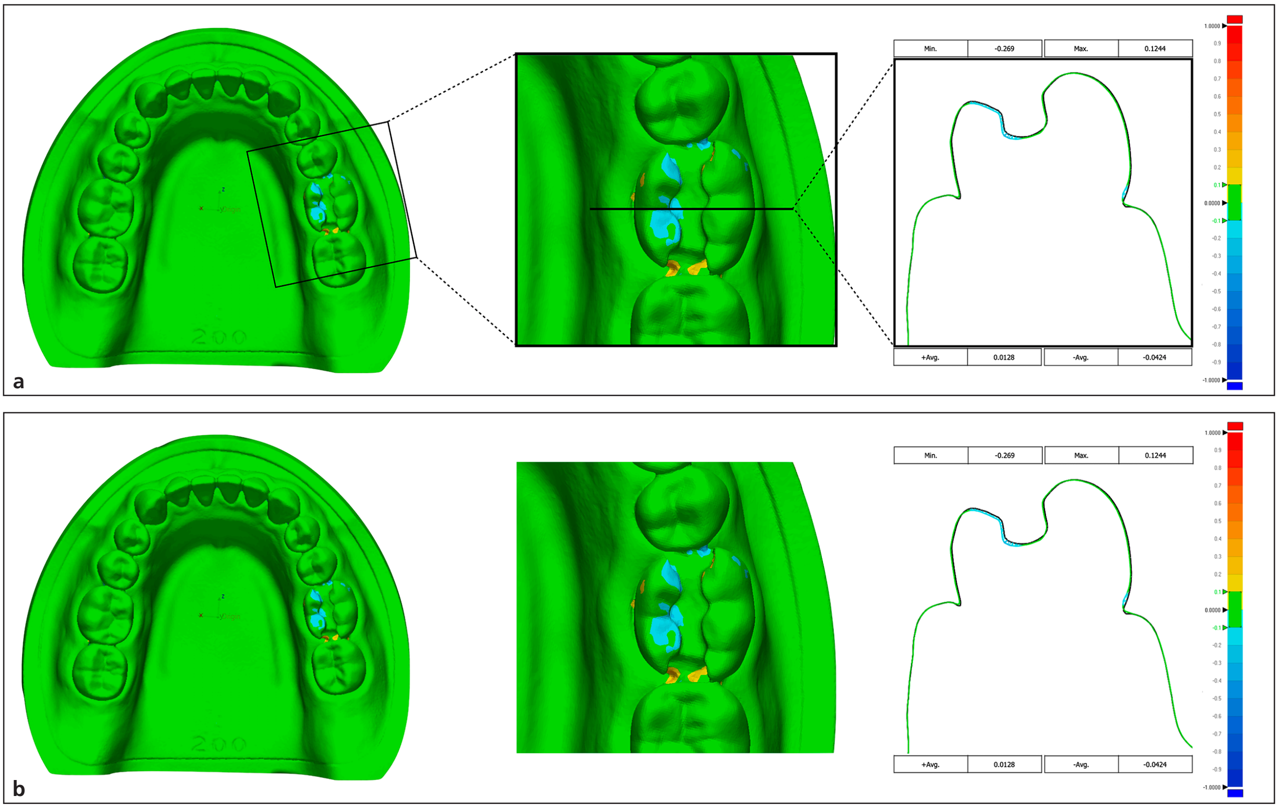

Fig 3 3D color map to verify STL file alignment between the unprepared and prepared tooth. Green color indicates areas of exact alignment, with blue and red colors representing areas of negative and positive discrepancies.

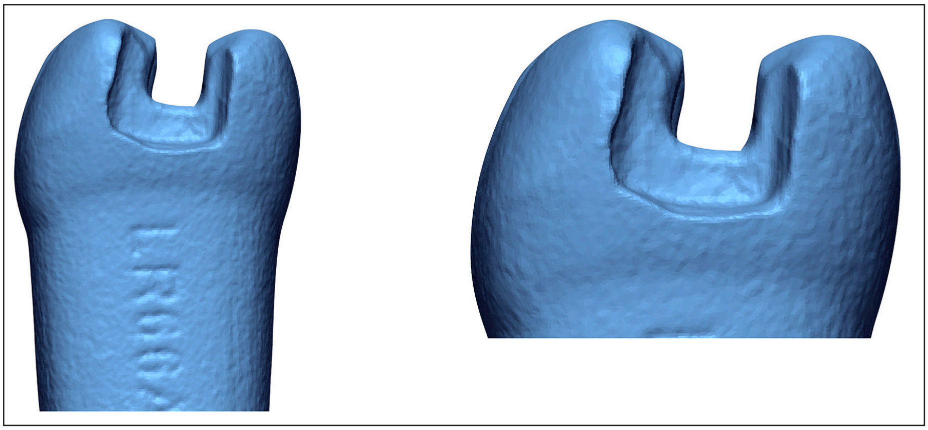

Fig 4 Area of interest for volumetric assessment of the mandibular molar.

Table 2 Volumetric Measurements of Teeth (mm^3 ± SD)

	Maxillary first premolar	Maxillary first premolar w/sheared off buccal cusp	Mandibular first molar	Mandibular first molar w/sheared off mesiolingual cusp
Intact tooth	300.30	283.08	651.21	578.69
Preoperative tooth w/MOD	264.09	240.41	621.57	559.53
Partial coverage onlay preparation	249.13 ± 1.43	234.93 ± 1.76	574.12 ± 1.73	555.95 ± 2.24
Overlay preparation	236.79 ± 3.95	212.93 ± 3.77	516.44 ± 3.23	461.03 ± 1.77
Crown preparation	205.38 ± 1.53	195.04 ± 1.30	402.04 ± 3.92	361.27 ± 4.40

All values in each column were found to be significantly different ($P < .001$).

volume between these boundaries was measured in mm^3 (Fig 4).

To conduct the volumetric analysis in a sheared-off cusp scenario, each master and prepared individual tooth was exported to another specific software package (Meshmixer, Autodesk). Buccal cusp and mesiolingual cusp removal were performed for the maxillary premolars and lower mandibular molars, respectively. The STL files were imported back into the 3D-metrologic software to quantify the volumetric difference between them, using the same protocol described previously. Mean and SD values were calculated for the volumetric reduction of tooth structure for the partial coverage onlay, overlay, and crown preparations when compared to the preoperative MOD prepared tooth. Mean change prior to and following tooth structure reduction was reported as percent change (%). A histogram of the data sets revealed a normal distribution. One-way ANOVA was used for statistical analysis with post-hoc Tukey HSD tests, with alpha set to 0.01.

RESULTS

Volumetric measurements (mm^3) for intact teeth, preoperative teeth with MOD preparations, and for each preparation group are listed in Table 2. For maxillary premolars, the MODB onlay preparation resulted in the least amount of loss of residual tooth structure with 14.96 mm^3 with the crown preparation requiring 58.71 mm^3 of tooth reduction. The overlay, with a reduction of 27.3 mm^3, required almost twice as much removal of tooth structure as the MODB onlay ($P < .01$), but > 50% less than the crown preparation ($P < .01$). When simulating the clinical presentation of the tooth with the buccal cusp already sheared off the differences between the groups were magnified, with an MODB onlay requiring only 5.48 mm^3 further volumetric reduction of tooth structure, while the overlay and crown required 27.48 mm^3 and 45.37 mm^3 more tooth reduction ($P < .01$), respectively.

For mandibular first molars, the same data trends were seen but with a higher percentage loss of clinical tooth structure (see Fig 5). MODL onlays were more than twice as conservative as overlays, with a reduction of 47.45 mm^3 vs 105.13 mm^3. Crowns, with a reduction of 219.53 mm^3, required over four times more clinical tooth structure removal than the MODL onlays ($P < .01$). For the sheared off cusp simulation groups for the mesiolingual cusp, crowns removed 198.26 mm^3 of the remaining clinical tooth structure, while overlays were twice as conservative at 98.5 mm^3 of reduction ($P < .01$). With only 3.58 mm^3 of reduction, MODL onlays were 35 times more conservative than crowns ($P < .01$).

DISCUSSION

This in vitro study evaluated the volumetric loss of clinical tooth structure for common clinical scenarios in posterior teeth. For each scenario, significant differences were found between crown, overlay, and partial coverage onlay preparations. Thus, the null hypothesis was rejected. The use of a full coverage crown resulted in removal of 25% to 38% of the remaining clinical crown structure (Figs 5 and 6). The volumetric loss for molar crowns in the present study (when an intact molar was used as a preoperative reference) was almost identical to the findings of Sadid-Zadeh et al[23] but was significantly higher in terms of percentage compared to the results obtained by Schwindling et al.[22] The differences with the latter study can be explained by differences in preparation method and parameters: in the Schwindling study,[22] occlusal reduction was 0.5 mm as opposed to 1.0 mm in the present study. They used a parallel milling machine to execute preparations and performed no preparation refinement or finishing, which the investigators acknowledged led to a systemic underestimation of reduction values.[22]

For the present study, a preparation similar to that of a cast gold restoration was used for the monolithic zirconia full crown preparation. While some in vitro data indicates that bonded monolithic 3 mol% yttria tetragonal zirconia polygon zirconia (3Y-TZP) crowns could likely be successful with a minimum thickness of only 0.5 mm,[27] other recent in vitro data indicates that nonbonded 3Y-TZP crowns resist fracture better at an increased thickness.[28] Preparation parameters were chosen based on the ideal material thickness for conventionally cemented restorations, given the continued preference of practitioners. Not to mention that if a practitioner chose to use esthetic (ie, 5 mol% yttria partially stabilized zirconia [5Y-PSZ]), the preparation would require a minimum thickness of 1.0 mm to adequately resist fracture when bonded, and even more reduction if conventionally cemented.[28] Thus, an occlusal reduction of 1.0 mm is the most widely applicable value for current clinical use.

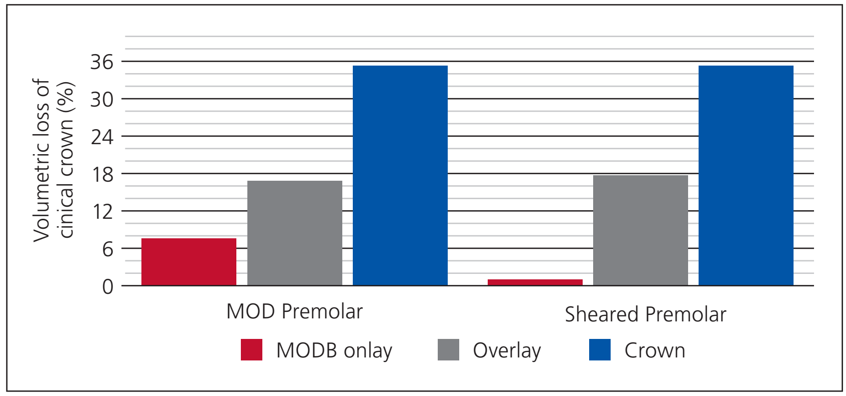

Fig 5 Graph representing volumetric loss of tooth structure (%) for premolar groups when comparing the prepared tooth to the typodont tooth with existing MOD preparation.

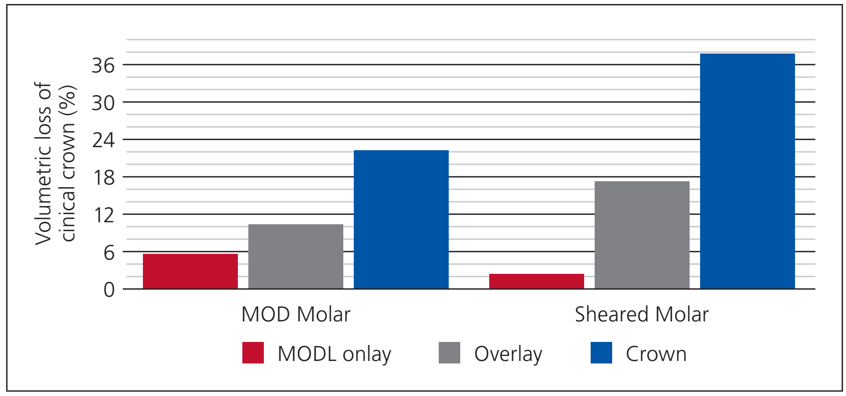

Fig 6 Graph representing volumetric loss of tooth structure (%) for molar groups when comparing the prepared tooth to the typodont tooth with existing MOD preparation.

Overlay preparations required 10% to 18% of the remaining clinical crown to be removed (see Figs 5 and 6), maintaining at least 50% more tooth structure than full crown preparations for any given clinical scenario. When compared to the findings of Edelhoff and Sorensen,[25] the overlay preparation was also significantly more conservative than their various partial coverage all-ceramic retainer designs. This result would be expected because they included isthmus and proximal box areas not included in the present study, and had higher reduction values, given the minimal thickness requirements for older glass ceramics. Also, their study was focused on designs that still had a certain amount of retention and resistance form to help with the retention of a fixed partial denture,[25] while this study is focused on single tooth preparations that require no such features.

By far the most conservative restorative option analyzed in this study was the partial coverage onlay. For molars and premolars in both given clinical scenarios, partial coverage onlays required less than 8% of the remaining clinical tooth structure to be removed (see Figs 5 and 6). These results show that for many common situations in need of indirect restorations, partial coverage onlays require little to no tooth preparation to facilitate solving the clinical problem. In contrast, the trends in volumetric tooth loss seen for overlays and crowns illustrate that a vast majority of tooth reduction required for those preparations is to facilitate the restorative solution, not to address the clinical issue. The reduction percentages for partial coverage onlays in the present study are much lower than the values that Edelhoff and Sorensen[25] found for various partial coverage all ceramic retainer designs, for reasons mentioned previously. They are also significantly lower than values found by Al-Fouzan and Tashkandi[24] who, like Edelhoff and Sorensen,[25] included proximal box and isthmus areas in their calculations, and had larger reduction parameters more appropriate for older glass ceramics.

Older investigations of volumetric tooth removal for full contour cast gold crowns reported a 40% to 56% loss of tooth structure for molars, with even higher values for premolars,[20,21] which is either similar to or significantly higher than the values found in the present study, depending on the clinical situation. The amount of reduction found for overlays in the present study was significantly less than the 34% loss of clinical crown structure that Reiber and Trappe-Krieger[21] reported for cast gold overlays on premolars and molars. Partial coverage onlay preparations in the present study were also significantly more conservative of clinical tooth structure than previously studied partial coverage gold restorations.[21] For all preparation types, the lower percentages could partly be a result of differences in measurement methodologies, as well as the fact that the older studies used intact, unrestored extracted teeth. However, even after adjusting percentages using the intact typodont tooth as a reference, the present investigation shows consistently lower percentages, especially for overlays and partial coverage onlays. This result highlights the fact that much of the difference is due to the retentive features needed for partial coverage gold designs, which had significant box and isthmus retentive features not found in the present onlay and overlay designs nor their subsequent volumetric analysis. It is readily apparent from the data available that for the given clinical situations in the current study, ceramic restorations of all types are at least as conservative as their gold counterparts, likely more so, thanks to the lack of need for retentive design features.

Given that it is now well established that monolithic zirconia restorations can be adhesively retained,[29,30] some authors have proposed their use for partial coverage restorations.[30,31] Several characteristics of monolithic zirconia are concerning, especially when used for partial coverage restorations. While it appears that adjusted, polished/adjusted, and reglazed monolithic zirconia wears enamel similarly to lithium disilicate in vitro, monolithic zirconia itself exhibits little to no wear.[29,32] This disproportionate wear could lead to complications for partial coverage restorations such as restoration debonding,[31] not to mention other issues commonly seen clinically long term when an occlusal surface wears significantly more than its antagonist and surrounding tooth structure. Laboratory survey data indicates monolithic 3Y-TZP crowns report few technical complications over up to a 7.5-year period.[33] This data is now corroborated by several clinical studies, documenting a failure rate of 6% to 13% over a 3.5 to 5-year period, primarily due to biologic complications and decementations.[34,35] Other potential concerns identified for monolithic zirconia when compared to lithium disilicate in in vitro investigations are a lack of color stability[36] and an increased risk for complicated tooth fracture.[37]

There are several inherent limitations to the present study, like other studies of the same nature. The influence of human error on specimen preparation could have affected the results, as it is well established that operators often misjudge preparation reduction and taper. Efforts to minimize this included having one operator prepare all specimens to eliminate interoperator differences (D.B.), as well as postpreparation digital evaluation of preparations to ensure each preparation stayed within the established tolerance range for the study. While every attempt was made to replicate common clinical scenarios to make values as clinically relevant as possible, every clinical situation presents with a unique set of circumstances that could influence decision making with regards to tooth preparation and material selection. Thus, the values obtained in the present study, while generally applicable, may not apply in every instance that replacement dentistry is indicated. Finally, only mandibular molars and their mesiolingual cusps, as well as maxillary premolars and their buccal cusps, were included in the present study. These teeth and surfaces were chosen based on previous epidemiologic data showing them to be the teeth and surfaces most likely to present with a cuspal fracture and in need of repair.[38] While it's reasonable to expect differences if other posterior teeth or surfaces were included, previous data from Edelhoff and Sorensen[25] shows the number of significant differences likely to be few.

Further laboratory and clinical investigations are needed to establish exactly when a cusp should be covered for best long-term results and would be of great benefit to clinicians. There should also be a return to generating prospective clinical data with medium to long term outcomes with particular attention paid to factors affecting restoration survival to further improve patient care through optimal preparation and material selection.

CONCLUSIONS

Based on the findings of this in vitro study, the following conclusions were drawn:

- For ceramic restorations on posterior teeth, monolithic zirconia crowns were significantly more destructive than lithium disilicate overlays and partial coverage onlays.

- For all clinical scenarios tested, lithium disilicate partial coverage onlays preserved significantly more clinical tooth structure.

ACKNOWLEDGMENTS

This research did not receive any specific grant from funding agencies in the public, commercial, or not-for-profit sectors. The authors declare no conflicts of interest. Author contributions are the following: conceptualization and methodology (C.D.S., E.C., W.G.R.); supervision and writing original draft (C.D.S.); visualization, review, and editing (E.C., D.B., W.G.R.); investigation (E.C., D.B.); and formal analysis (E.C.).

REFERENCES

1. Leeson D. The digital factory in both the modern dental lab and clinic. Dent Mater 2020;36:43–52.
2. Lawson NC, Litaker MS, Ferracane JL, et al. Choice of cement for single-unit crowns: Findings from The National Dental Practice-Based Research Network. J Am Dent Assoc 2019;150:522–530.
3. Shillingburg, Herbert T. Fundamentals of Fixed Prosthodontics. Quintessence, 1997.
4. Eissmann HF, Radke RA, Noble WH. Physiologic design criteria for fixed dental restorations. Dent Clin North Am 1971;15:543–568.
5. Reeves WG. Restorative margin placement and periodontal health. J Prosthet Dent 1991;66:733–736.
6. Morimoto S, Rebello de Sampaio FB, Braga MM, Sesma N, Özcan M. Survival rate of resin and ceramic inlays, onlays, and overlays: A systematic review and meta-analysis. J Dent Res 2016;95:985–994.
7. Collares K, Corrêa MB, Laske M, et al. A practice-based research network on the survival of ceramic inlay/onlay restorations. Dent Mater 2016;32:687–694.
8. Manhart J, Chen H, Hamm G, Hickel R. Buonocore Memorial Lecture. Review of the clinical survival of direct and indirect restorations in posterior teeth of the permanent dentition. Oper Dent 2004;29:481–508.
9. Van den Breemer CRG, Buijs GJ, Cune MS, et al. Prospective clinical evaluation of 765 partial glass-ceramic posterior restorations luted using photo-polymerized resin composite in conjunction with immediate dentin sealing. Clin Oral Investig 2021;25:1463–1473.
10. Malament KA, Margvelashvili-Malament M, Natto ZS, Thompson V, Rekow D, Att W. 10.9-year survival of pressed acid etched monolithic e.max lithium disilicate glass-ceramic partial coverage restorations: Performance and outcomes as a function of tooth position, age, sex, and the type of partial coverage restoration (inlay or onlay). J Prosthet Dent 2021;126:523–532.
11. Malament KA, Margvelashvili-Malament M, Natto ZS, Thompson V, Rekow D, Att W. Comparison of 16.9-year survival of pressed acid etched e.max lithium disilicate glass ceramic complete and partial coverage restorations in posterior teeth: Performance and outcomes as a function of tooth position, age, sex, and thickness of ceramic material. J Prosthet Dent 2021;126:533–545.
12. Guess PC, Schultheis S, Wolkewitz M, Zhang Y, Strub JR. Influence of preparation design and ceramic thicknesses on fracture resistance and failure modes of premolar partial coverage restorations. J Prosthet Dent 2013;110:264–273.
13. Clausen JO, Abou Tara M, Kern M. Dynamic fatigue and fracture resistance of non-retentive all-ceramic full-coverage molar restorations. Influence of ceramic material and preparation design. Dent Mater 2010;26:533–538.
14. Albelasy EH, Hamama HH, Tsoi JKH, Mahmoud SH. Fracture resistance of CAD/CAM occlusal veneers: A systematic review of laboratory studies. J Mech Behav Biomed Mater 2020;110:103948.
15. Ferraris F, Sammarco E, Romano G, Cincera S, Marchesi G. Comparison of posterior indirect adhesive restorations (PIAR) with different preparation designs according to the adhesthetics classification. Part 1: Effects on the fracture resistance. Int J Esthet Dent 2021;16:144–167.
16. Fradeani M, Barducci G, Bacherini L. Esthetic rehabilitation of a worn dentition with a minimally invasive prosthetic procedure (MIPP). Int J Esthet Dent 2016;11:16–35.
17. Schlichting LH, Resende TH, Reis KR, Magne P. Simplified treatment of severe dental erosion with ultrathin CAD-CAM composite occlusal veneers and anterior bilaminar veneers. J Prosthet Dent 2016;116:474–482.
18. Torosyan A, Vailati F, Mojon P, Sierra D, Sailer I. Retrospective clinical study of minimally invasive full-mouth rehabilitations of patients with erosions and/or abrasions following the "3-step technique." Part 1: 6-year survival rates and technical outcomes of the restorations. Int J Prosthodont 2022;35:139–151.
19. Edelhoff D, Güth JF, Erdelt K, Brix O, Liebermann A. Clinical performance of occlusal onlays made of lithium disilicate ceramic in patients with severe tooth wear up to 11 years. Dent Mater 2019;35:1319–1330.
20. Peters S. Comparison of the amount of wear on adhesive clasps and on crown [article in German]. Quintessenz 1986;37:2039–2044.
21. Reiber T, Trappe-Krieger U. Untersuchungen zum substanzabtrag von brückenpfeilern bei verschiedenen präparationsformen. Zahnarztl Welt 1994;103:217—221.
22. Schwindling FS, Waldecker M, Rammelsberg P, Rues S, Bömicke W. Tooth substance removal for ceramic single crown materials-an in vitro comparison. Clin Oral Investig 2019;23:3359–3366.
23. Sadid-Zadeh R, Farsaii A, Goodarzi A, Davis EL. Loss of tooth structure associated with preparation for two monolithic CAD-CAM complete coverage restorations. J Prosthet Dent 2018;120:403–408.
24. Al-Fouzan AF, Tashkandi EA. Volumetric measurements of removed tooth structure associated with various preparation designs. Int J Prosthodont 2013;26:545–548.
25. Edelhoff D, Sorensen JA. Tooth structure removal associated with various preparation designs for posterior teeth. Int J Periodontics Restorative Dent 2002;22:241–249.
26. Couso-Queiruga E, Ahmad U, Elgendy H, Barwacz C, González-Martín O, Avila-Ortiz G. Characterization of extraction sockets by indirect digital root analysis. Int J Periodontics Restorative Dent 2021;41:141–148.
27. Sorrentino R, Triulzio C, Tricarico MG, Bonadeo G, Gherlone EF, Ferrari M. In vitro analysis of the fracture resistance of CAD-CAM monolithic zirconia molar crowns with different occlusal thickness. J Mech Behav Biomed Mater 2016;61:328–333.
28. Abdulmajeed A, Sulaiman T, Abdulmajeed A, Bencharit S, Närhi T. Fracture load of different zirconia types: A mastication simulation study. J Prosthodont 2020;29:787–791.
29. Kwon SJ, Lawson NC, McLaren EE, Nejat AH, Burgess JO. Comparison of the mechanical properties of translucent zirconia and lithium disilicate. J Prosthet Dent 2018;120:132–137.
30. Blatz MB, Vonderheide M, Conejo J. The effect of resin bonding on long-term success of high-strength ceramics. J Dent Res 2018;97:132–139.
31. Gupta S, Abdulmajeed A, Donovan T, Boushell L, Bencharit S, Sulaiman TA. Monolithic zirconia partial coverage restorations: An in vitro mastication simulation study. J Prosthodont 2021;30:76–82.
32. Lawson NC, Janyavula S, Syklawer S, McLaren EA, Burgess JO. Wear of enamel opposing zirconia and lithium disilicate after adjustment, polishing and glazing. J Dent 2014;42:1586–1591.
33. Sulaiman TA, Abdulmajeed AA, Delgado A, Donovan TE. Fracture rate of 188695 lithium disilicate and zirconia ceramic restorations after up to 7.5 years of clinical service: A dental laboratory survey. J Prosthet Dent 2020;123:807–810.
34. Solá-Ruiz MF, Baixauli-López M, Roig-Vanaclocha A, Amengual-Lorenzo J, Agustín-Panadero R. Prospective study of monolithic zirconia crowns: Clinical behavior and survival rate at a 5-year follow-up. J Prosthodont Res 2021;65:284–290.
35. Waldecker M, Behnisch R, Rammelsberg P, Bömicke W. Five-year clinical performance of monolithic and partially veneered zirconia single crowns-a prospective observational study. J Prosthodont Res 2022;66:339–345.
36. Sulaiman TA, Camino RN, Cook R, Delgado AJ, Roulet JF, Clark WA. Time-lasting ceramic stains and glaze: A toothbrush simulation study. J Esthet Restor Dent 2020;32:581–585.
37. Saridag S, Sevimay M, Pekkan G. Fracture resistance of teeth restored with all-ceramic inlays and onlays: An in vitro study. Oper Dent 2013;38:626–634.
38. Bader JD, Martin JA, Shugars DA. Incidence rates for complete cusp fracture. Community Dent Oral Epidemiol 2001;29:346–353.