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Original Article

Effect of pulp-chamber lateral wall thickness and number on fracture resistance in endocrown-restored molars: An in vitro study

Zhi Li [a†], Jun-Xin Zhu [b†], Yong-Xiang Xu [c], Xu-Dong Bao [a*], Xiao-Yan Wang [a]**

[a] *Department of Cariology and Endodontology, Peking University School and Hospital of Stomatology, Beijing, China*
[b] *Second Dental Center, Peking University School and Hospital of Stomatology, Beijing, China*
[c] *Department of Dental Materials, Peking University School and Hospital of Stomatology, National Clinical Research Center for Oral Diseases, National Engineering Laboratory for Digital and Material Technology of Stomatology, Beijing Key Laboratory of Digital Stomatology, Beijing, China*

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KEYWORDS
Computer-aided design/computer-aided manufacturing;
Endocrown;
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Fracture resistance

Abstract *Background/purpose:* It remains unclear how the thickness and number of pulp-chamber lateral walls (PCLWs) affects fracture resistance in endocrown-restored teeth.
Materials and methods: 64 mandibular molars were collected and randomly divided into eight groups (n = 8). In group C (control group), the teeth were untreated. In groups T1, T2, and T3, the teeth were subjected to endodontic treatment and restored with nanoceramic endocrowns exhibiting different PCLW thicknesses (T1: 0.5 mm, T2: 1.0 mm, and T3: 1.5 mm). In groups N1, N2, N3, and N4, the numbers of missing PCLWs in prepared teeth were one (N1), two (N2), three (N3), and four (N4). All restored teeth were subjected to axial loading until fracture using a universal testing machine. The mean fracture loads were recorded and compared by one-way analysis of variance; the fractured samples were observed under a stereo microscope.
Results: The results showed no statistically significant differences in fracture load among groups T1, T2, and T3 ($P > 0.05$). Although the fracture loads gradually decreased as the number of missing PCLWs increased, there were no statistically significant differences in fracture load among groups C, N1, N2, and N3, and N4 ($P > 0.05$).

* Corresponding author. Department of Cariology and Endodontology, Peking University School and Hospital of Stomatology, #22 Zhongguancun South Avenue, Haidian District, Beijing, 100081, China.
** Corresponding author. Department of Cariology and Endodontology, Peking University School and Hospital of Stomatology, #22 Zhongguancun South Avenue, Haidian District, Beijing 100081, China.
E-mail addresses: baoxudong@vip.163.com (X.-D. Bao), wangxiaoyan@pkuss.bjmu.edu.cn (X.-Y. Wang).
† These two authors contributed equally to this work.

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Conclusion: Both thickness and remaining number of PCLW does not affect fracture resistance in endodontically treated molars restored with nanoceramic endocrowns.

Introduction

The rehabilitation of endodontically treated teeth with massive coronal loss remains challenging for clinicians. Complete crowns, which mainly rely on extracoronal retention, are regarded as conventional restorations.[1] For endodontically treated teeth that cannot provide the retention required by complete crowns, post-retained restorations relying on extracoronal and intraradicular retentions are recommended.[2,3] Advances in adhesive technologies and ceramic materials have enabled endocrowns to serve as restorations for such teeth in recent years, particularly in situations where the occlusal-gingival distance is limited or there is insufficient space for post placement in a root canal.[4] Previous in vitro studies showed similar fracture resistances among endodontically treated teeth restored with endocrowns and conventional restorations.[5–7] In clinical studies, endocrown-restored molars exhibited an acceptable survival rate.[8–10] Therefore, the restoration of endodontically treated molars (ETMs) with endocrowns constitutes a conservative approach.

Fracture resistance in endocrown-restored teeth could be affected by various factors, such as the tooth site, the design of the restoration, the elastic moduli of the restorative materials and bonding system, and the extent of remaining dental hard tissue.[11–14] The extent of remaining dental hard tissue can be subdivided into three factors: height of the pulp-chamber lateral wall (PCLW), thickness of the PCLW, and number of remaining PCLWs surrounding the endocrowns. Several studies have investigated the effects of PCLW height on the biomechanical behavior of restored teeth;[11,14,15] however, there is limited information regarding the relationship between PCLW thickness and fracture resistance. Although Zhu et al.[15] examined the effect of PCLW thickness on stress distribution and failure probability among endocrown-restored molars, their analysis solely comprised numerical simulation. In addition to PCLW thickness, the number of PCLWs can also affect fracture resistance in restored teeth. Demachkia et al. studied the effects of the number of remaining PCLWs on fatigue resistance in endocrown-restored premolars using various restorative materials.[16] However, the mechanical characteristics of restored ETMs may differ from those of endocrown-restored premolars because both the anatomical characteristics and height-width ratio between molars and premolars are considerably different. Thus far, few studies have explored the effect of the number of remaining PCLWs on fracture resistance in endocrown-restored molars.

Although endocrowns are widely used, their indications and preparation criteria remain controversial. Thus, there is a need to explore the relationships of PCLW thickness and number with the biomechanical behaviors of restored teeth. ETMs restored with nanoceramic endocrowns have demonstrated favorable clinical performances and fracture patterns.[17,18] The present study explored the effects of PCLW thickness and number on fracture resistance in ETMs restored with nanoceramic endocrowns, with the following null hypothesis: both PCLW thickness and number do not affect fracture resistance in ETMs restored with nanoceramic endocrowns.

Materials and methods

In total, 64 mandibular molars freshly extracted were selected. A stereo microscope was used to confirm that all teeth were free of caries and cracks. They were randomly divided into eight groups ($n = 8$). In group C (control group), the teeth were untreated. In groups T1, T2, and T3, the teeth were subjected to endodontic treatment and restoration with nanoceramic endocrowns exhibiting different PCLW thicknesses (T1: 0.5 mm, T2: 1.0 mm, and T3: 1.5 mm). In groups N1, N2, N3, and N4, the numbers of missing PCLWs in the prepared ETMs were one (N1), two (N2), three (N3), and four (N4).

Endodontic procedures

All procedures were performed by the same clinician who had 3-year experience in clinical work. Among the 64 mandibular molars, eight were untreated; the remaining 56 M were horizontally transected at 3 mm above the cementoenamel junction (CEJ). K-files were used to explore and negotiate the root canals. Root canal preparations were performed with M3 nickel-titanium files (United Dental, Shanghai, China) using a crown-down technique; irrigation was conducted with 2.5% NaOCl. Next, the root canals were obturated with gutta-percha cones (Dentsply, Milford, DE, USA) and root canal sealer (AH Plus; Dentsply) using a thermoplastic gutta-percha technique. Filtek Z350 XT flowable composite resin (3M ESPE, Saint Paul, MN, USA) was used to fill the orifices, as well as concave regions on the sidewalls.

Endocrown preparation

After endodontic treatment, irregular regions of the pulp chamber floor in each ETM were relined with AP-X composite resin (Kuraray, Osaka, Japan) to maintain PCLW height (H) at 5 mm (Fig. 1). In this study, PCLW thickness (T) was defined as the width at the coronal surface of an ETM. As shown in Fig. 2a, ETMs in group T1 were prepared as

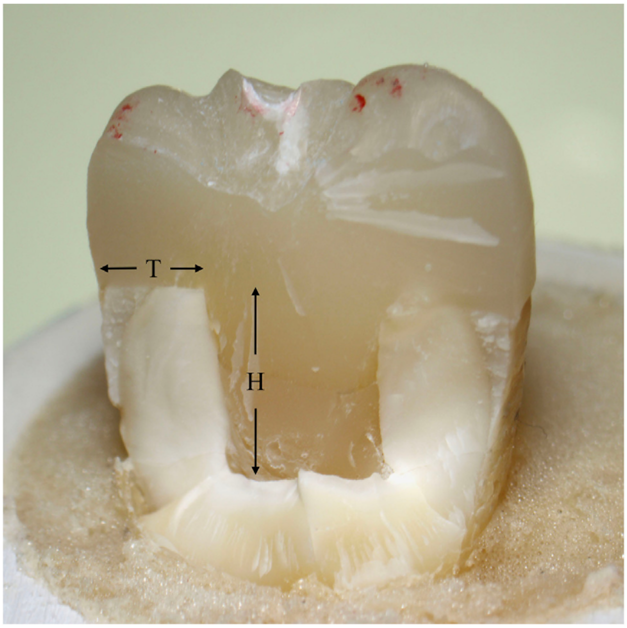

Figure 1 Schematic diagram of PCLW height and thickness in endocrown-restored molars.

follows. Dental diamond burs (TF-22; Mani Inc., Tokyo, Japan) were used to uniformly remove inner lateral dentinal walls around the pulp chamber until the PCLW thickness reached 0.5 mm. ETMs in groups T2 and T3 were prepared in a manner similar to ETMs in group T1, except that the PCLW thicknesses were 1.0 mm in group T2 and 1.5 mm in group T3 (Fig. 2b and c).

Among groups N1, N2, N3, and N4, prepared ETMs solely differed according to the number of missing PCLWs. In group N1, ETMs were prepared as described for ETMs in group T1, except that one interproximal wall above the CEJ was completely removed; this led to a PCLW height of 2 mm on the defect side and a height of 5 mm on each of the remaining three non-defect sides (Fig. 3a). In group N2, the mesial and distal PCLWs above the CEJ were both removed (Fig. 3b). In group N3, the mesial, distal, and buccal PCLWs above the CEJ were removed (Fig. 3c). In group N4, all PCLWs above the CEJ were removed (Fig. 3d).

Endocrown fabrication

The biomechanical behavior of a tooth can be greatly affected by occlusal contacts.[19] To ensure consistency in the location and contact area of applied loads, all prepared samples were scanned with 3Shape TRIOS 2 (3Shape, Copenhagen, Denmark). An endocrown made of nanoceramic (Upcera, Shenzhen, China) was generated via computer-aided design and computer-aided manufacturing based on a prepared sample; this endocrown was regarded as the standardized template. The remaining ETMs were restored with nanoceramic endocrowns exhibiting identical anatomical morphology.

The nanoceramic endocrowns were polished and ultrasonically cleaned. The intaglio surfaces were sandblasted with 50-μm alumina particles (Ronvig, Daugaard, Denmark) for 10 s, thoroughly cleaned using anhydrous alcohol, and dried with oil-free air for 30 s 3M universal adhesive (3M ESPE) was applied to the intaglio surfaces for 20 s. The intaglio surfaces were then gently dried with oil-free air to evaporate the solvent.

The tissue surfaces of prepared teeth were etched with 37% phosphoric acid (Dentex, Changchun, China) for 15 s, thoroughly rinsed with distilled water for 30 s, and gently dried with oil-free air. Subsequently, the surfaces were treated with 3M universal adhesive in the manner used for the intaglio surfaces of endocrowns, then light-cured (Ivoclar Vivadent, Liechtenstein, Germany) for 10 s. After RelyX U200 dual-curing resin cement (3M ESPE) had been applied to the intaglio surfaces, the endocrowns were properly seated in the prepared teeth, pre-cured for 1–2 s to remove excess cement, and finally light-cured on each axial surface for 20 s.

To simulate the conditions of teeth within the alveolar bone, the portions of all teeth below the CEJ were embedded in self-curing acrylic resin (Feiying, Zhengzhou, China).

Fracture resistance testing

Fracture tests were performed using a universal testing machine (Intron 5969; Intron, Norwood, MA, USA). Each sample was placed in the same position each time. A pre-

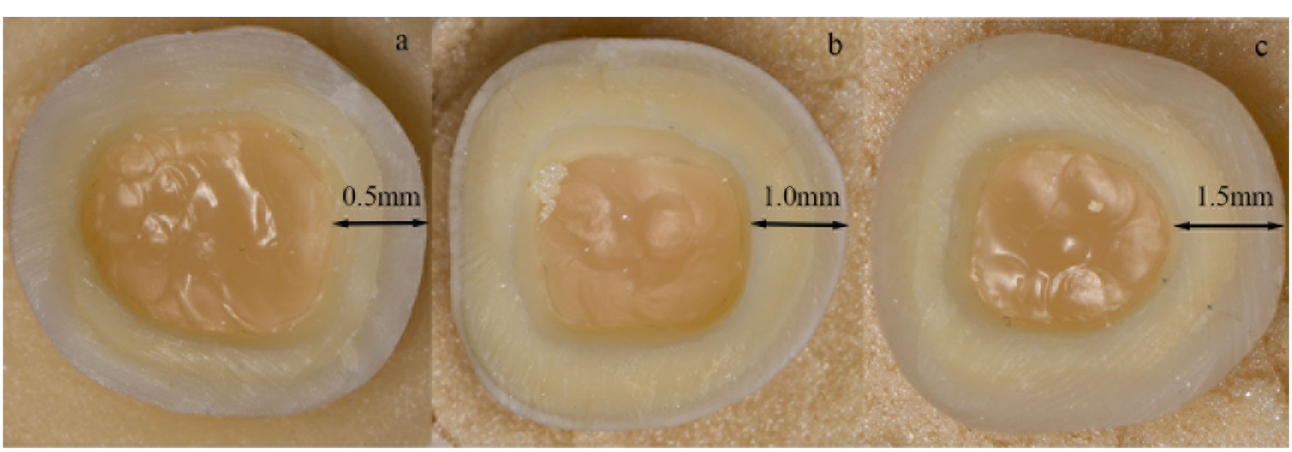

Figure 2 PCLW thickness in endodontically treated molars after preparation for endocrowns in groups (a) T1, (b) T2, and (c) T3.

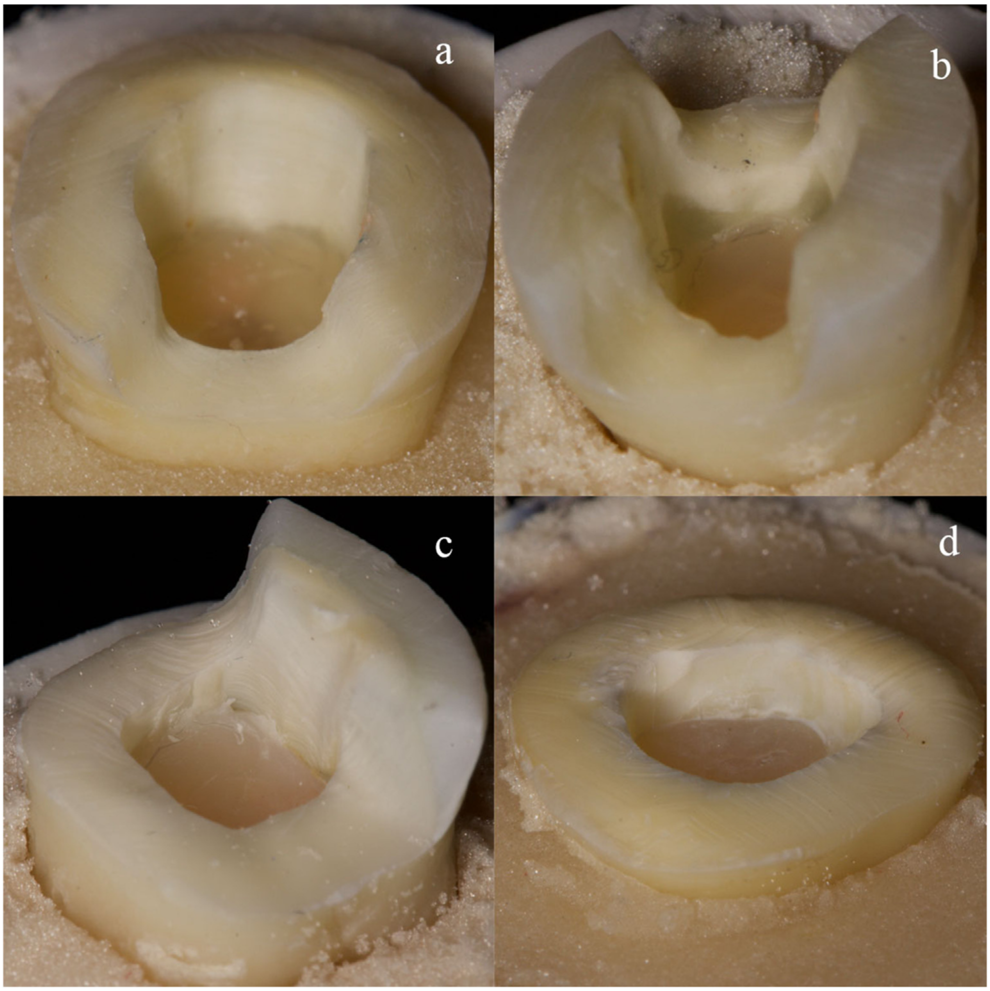

Figure 3 ETMs prepared for endocrowns in groups (a) N1, (b) N2, (c) N3, and (d) N4.

load of 5 N was vertically applied to the occlusal surface through a 6-mm-diameter stainless steel ball, forming a stable three-point contact between the loading head and the tooth (including the distal buccal, mesial lingual, and distal lingual cusps); the loading head was then loaded at a speed of 1 mm/min until the tooth fractured, and the fracture load was recorded in newtons (N).

A stereo microscope (SZ-61 Olympus; Olympus Corporation, Tokyo, Japan) was used to observe the fracture mode at 6.7× magnification. Sample fracture patterns were classified into two types: repairable (cracks extending above the CEJ) and non-repairable (cracks extending into the root below the CEJ). The percentage of repairable fractures (%) was calculated by dividing the number of restored teeth experienced repairable fractures by the total number of restored teeth in each group.

Statistical analysis

Statistical analyses of fracture loads were performed using IBM SPSS software (v26.0; IBM Corporation, Armonk, NY, USA). The Levene test was used to determine homogeneity of variance, whereas the Shapiro–Wilk and Kolmogorov–Smirnov tests were used to assess whether the data exhibited a normal distribution. One-way analysis of variance was used to analyze intergroup differences. A *P*-value of <0.05 was considered statistically significant.

Results

As shown in Table 1, the fracture loads of endocrown-restored molars did not significantly differ among groups T1, T2, and T3 ($P > 0.05$).

As shown in Table 2, the mean fracture load gradually decreased in the following order: N1, N2, N3, and N4. Statistical analysis revealed no significant differences in fracture load among groups C, N1, N2, N3 and N4 ($P > 0.05$).

As shown in Fig. 4, group C had the highest percentage (75%) of repairable fractures after fracture resistance testing. In groups N1 and N2, all fractures were non-repairable; as the number of missing PCLWs increased, the percentage of repairable fractures tended to increase (from approximately 14.3% in group N3 to 25% in group N4).

Discussion

The use of endocrowns is considered an alternative method for restoring ETMs because of the procedural simplicity and acceptable survival rate. The effect of PCLW height on the

Table 1 Fracture loads (mean ± standard deviation) (in newtons, N) among groups T1, T2, and T3.

Group	Mean ± SD
T1	3027.28 ± 854.17
T2	3761.74 ± 784.14
T3	2889.97 ± 1020.43
P-value	0.135

There were no significant differences among Groups T1, T2 and T3 ($P = 0.135$).
SD, standard deviation.

Table 2 Fracture loads (mean ± standard deviation) (in newtons, N) among groups C, N1, N2, N3, and N4.

Group	Mean ± SD
C	3069.34 ± 939.50
N1	3326.46 ± 1062.94
N2	3096.22 ± 1135.80
N3	2675.87 ± 907.92
N4	2075.27 ± 762.38
P-value	0.108

There were no significant differences among Groups C, N1, N2 N3 and N4 ($P = 0.108$).
SD, standard deviation.

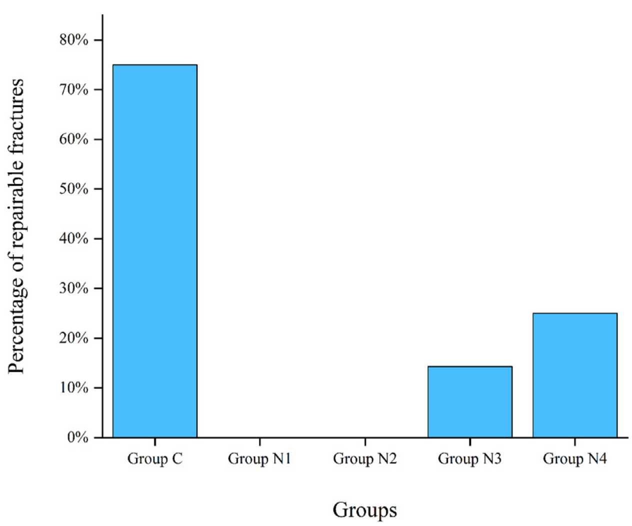

Figure 4 Percentages of repairable fractures in groups C, N1, N2, N3, and N4.

biomechanical performance of endocrown-restored posterior teeth has been explored in several studies.[11,15,16] Published literature contains minimal information regarding the relationship between PCLW thickness and the effectiveness of tooth restoration. The present study revealed that when nanoceramic endocrowns were used, restored ETMs with various PCLW thicknesses exhibited similar fracture resistance. Therefore, the first portion of the null hypothesis—PCLW thickness does not affect fracture resistance in ETMs restored with nanoceramic endocrowns—is accepted. Zhu et al. studied the biomechanical behaviors of endocrown-restored molars under oblique loads; they found that stress distributions and failure probabilities were similar in restored molars with various PCLW thicknesses, regardless of the restorative materials used.[15] This phenomenon can be explained as follows: compared with the surrounding dental hard tissue, an endocrown constitutes the majority of the coronal portion of the restored tooth. The restoration directly receives the occlusal force and absorbs most of that force; the remaining force is transmitted to PCLWs around the endocrowns, along with the root regions below restorations. As dentin around the central retainer is removed, the PCLW thickness decreases. Although there is a decrease in the amount of dentin, the extent is considerably smaller than the total volume of endocrowns; thus, it has a limited effect on fracture resistance in the repaired tooth. Debonding is a primary cause of failed repair in endocrown-restored teeth.[4,8] The present results suggest that the removal of sclerotic dentin from PCLWs during endocrown preparations to achieve favorable bonding quality is acceptable because PCLW thickness does not affect fracture resistance.

Among endocrown-restored posterior teeth with four intact axial walls, fracture resistance is equal to or better than fracture resistance in intact teeth.[5–7] The present study further revealed that, among restored molars with one proximal wall missing, fracture resistance was similar to the resistance of intact teeth. This result implies that for ETMs with MO or DO preparations, the use of endocrown restorations could partially re-establish the biomechanical function. As the number of missing axial walls increased, the fracture loads of restored molars with MOD or MODB preparations tended to decrease. However, there were no significant differences in fracture loads among intact molars and restored molars with MO, DO, MOD, or MODB preparations, indicating that endocrown-restored molars with various numbers of missing axial walls have similar fracture resistance characteristics. Demachkia et al. also demonstrated that the number of remaining axial walls did not affect fatigue resistance in endocrown-restored premolars.[16] Thus, for ETMs with MO, DO, MOD, or MODB preparations related to trauma, interproximal caries, or tooth preparation, endocrowns can be regarded as potential restorations.

The present study also examined fracture resistance in endocrown-restored molars lacking all four axial walls, which are equivalent to restored molars with lower PCLW height. Compared to intact molars and endocrown-restored molars with one, two and three interproximal wall missing, the mean value of fracture loads in restored molars with four interproximal wall missing decreased. However, no significant differences in fracture load were found among them, indicating that PCLW height does not influence fracture resistance in endocrown-restored ETMs. This finding is consistent with those of previous studies.[11,14,15] In addition, the fracture load of endocrown-restored molars lacking four axial walls was approximately 2000 N according to our research, which was much higher than the maximum bite force in the molar region (424—630 N).[20] This result implies that for ETMs with coronal surfaces that approach the CEJ, endocrowns made of nanoceramic may remain appropriate restorative prostheses according to their mechanical characteristics. Although the present study considered that PCLW height does not impact the fracture resistance of endocrown-restored molars, it is still necessary to perform minimally invasive preparation to preserve the maximal amount of dental hard tissues, not only to retain the strength of residual tooth structure. Cohesive failure is considered as the main reason for restoration failure.[21] Preserving more healthy dental hard tissues allows for a larger bond area on prepared ETMs, thus leading to increased long-term survival rate for molars restored with endocrowns.

In contrast to the fracture pattern of intact teeth, most fractures in endocrown-restored teeth were non-repairable. In the present study, restored molars lacking one and two interproximal walls all experienced non-repairable fractures. Intriguingly, the percentage of repairable fractures gradually increased as the number of missing axial walls increased. Various factors may contribute to this phenomenon. In teeth lacking three PCLWs, the restored molars with MODB preparation did not exhibit the support of the buccal axial wall. The absence of the buccal axial wall increased the probability that the endocrown-restored molars would fracture at the location above the CEJ on the buccal side, leading to a higher percentage of repairable fractures. When the final remaining PCLW was removed, the rate of repairable fractures further increased because of the leverage effect. When the molars were subjected to a vertical load, the axial walls resisted the horizontal force component; the connection between the pulp chamber floor and PCLWs below the CEJ served as the fulcrum. The decrease in PCLW height caused reductions in the lever arm, thereby lowering the probability of fracture at the connection below the CEJ. Accordingly, endocrown-restored molars with lower PCLW height are more likely to experience repairable fractures.

There were some limitations in this study. Firstly, only nanoceramic was used to fabricate endocrowns; however, the effect of PCLW thickness and number on fracture resistance may be different in endocrown-restored teeth with different materials. Secondly, although teeth in the oral environment are more likely to fracture because of fatigue load rather than static load, fatigue load was not considered in this study. Moreover, the quality of adhesion between restorations and prepared teeth decreases over time; the speed of this decrease can be influenced by factors such as temperature changes, adhesive dissolution, and microbial degradation. Further studies regarding the above factors are needed.

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

Both thickness and remaining number of PCLW does not affect fracture resistance in endodontically treated molars restored with nanoceramic endocrowns.

Declaration of competing interest

All authors declare there are no conflict of interest for this submission.

References

1. Aquilino SA, Caplan DJ. Relationship between crown placement and the survival of endodontically treated teeth. *J Prosthet Dent* 2002;87:256—63.
2. Raedel M, Fiedler C, Jacoby S, Boening KW. Survival of teeth treated with cast post and cores: a retrospective analysis over an observation period of up to 19.5 years. *J Prosthet Dent* 2015;114:40—5.
3. Guldener KA, Lanzrein CL, Guldener BES, Lang NP, Ramseier CA, Salvi GE. Long-term clinical outcomes of endodontically treated teeth restored with or without fiber post-retained single-unit restorations. *J Endod* 2017;43: 188—93.
4. Govare N, Contrepois M. Endocrowns: a systematic review. *J Prosthet Dent* 2020;123:411—8.
5. Guo J, Wang Z, Li X, Sun C, Gao E, Li H. A comparison of the fracture resistances of endodontically treated mandibular premolars restored with endocrowns and glass fiber post-core retained conventional crowns. *J Adv Prosthodont* 2016;8: 489—93.
6. Biacchi GR, Basting RT. Comparison of fracture strength of endocrowns and glass fiber post-retained conventional crowns. *Operat Dent* 2012;37:130—6.
7. Chang CY, Kuo JS, Lin YS, Chang YH. Fracture resistance and failure modes of CEREC endo-crowns and conventional post and core-supported CEREC crowns. *J Dent Sci* 2009;24:110—7.
8. Bindl A, Richter B, Mörmann WH. Survival of ceramic computer-aided design/manufacturing crowns bonded to preparations with reduced macroretention geometry. *Int J Prosthodont (IJP)* 2005;18:219—24.
9. Belleflamme MM, Geerts SO, Louwette MM, Grenade CF, Vanheusden AJ, Mainjot AK. No post-no core approach to restore severely damaged posterior teeth: an up to 10-year retrospective study of documented endocrown cases. *J Dent* 2017;63:1—7.
10. Otto T, Mörmann WH. Clinical performance of chairside CAD/CAM feldspathic ceramic posterior shoulder crowns and endocrowns up to 12 years. *Int J Comput Dent* 2015;18: 147—61.
11. Taha D, Spintzyk S, Schille C, et al. Fracture resistance and failure modes of polymer infiltrated ceramic endocrown restorations with variations in margin design and occlusal thickness. *J Prosthodont Res* 2018;62:293—7.
12. Ahmed MAA, Kern M, Mourshed B, Wille S, Chaar MS. Fracture resistance of maxillary premolars restored with different endocrown designs and materials after artificial ageing. *J Prosthodont Res* 2022;66:141—50.
13. Gresnigt MMM, Özcan M, van den Houten MLA, Schipper L, Cune MS. Fracture strength, failure type and Weibull characteristics of lithium disilicate and multiphase resin composite endocrowns under axial and lateral forces. *Dent Mater* 2016; 32:607—14.
14. Tribst JPM, Oliveira Dal Piva AMD, Madruga CFL, et al. The impact of restorative material and ceramic thickness on CAD＼CAM endocrowns. *J Clin Exp Dent* 2019;11:e969—77.
15. Zhu J, Li S, Wang D, Li D, Wang X, Rong Q. Effect of remaining pericervical dentin on biomechanical behavior of endocrown-restored molars with different materials: three-dimensional finite element and Weibull analyses. *Dent Mater J* 2023;42: 683—91.
16. Demachkia AM, Velho HC, Valandro LF, et al. Endocrown restorations in premolars: influence of remaining axial walls of tooth structure and restorative materials on fatigue resistance. *Clin Oral Invest* 2023;27:2957—68.
17. Taha D, Spintzyk S, Sabet A, Wahsh M, Salah T. Assessment of marginal adaptation and fracture resistance of endocrown restorations utilizing different machinable blocks subjected to thermomechanical aging. *J Esthetic Restor Dent* 2018;30: 319—28.
18. El-Damanhoury HM, Haj-Ali RN, Platt JA. Fracture resistance and microleakage of endocrowns utilizing three CAD-CAM blocks. *Operat Dent* 2015;40:201—10.

19. Wang M, Mehta N. A possible biomechanical role of occlusal cusp-fossa contact relationships. *J Oral Rehabil* 2013;40:69—79.
20. de Abreu RAM, Pereira MD, Furtado F, Prado GPR, Mestriner Jr W, Ferreira LM. Masticatory efficiency and bite force in individuals with normal occlusion. *Arch Oral Biol* 2014;59:1065—74.
21. Govare N, Contrepois M. Endocrowns: a systematic review. *J Prosthet Dent* 2020;123:411—8.