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Fracture Strength of Minimally Prepared Resin Bonded CEREC Inlays

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Clinical Relevance

Minimal preparation designs for inlay restorations are a viable option for CAD/CAM systems (CEREC) and could potentially strengthen the restored tooth.

SUMMARY

Purpose: This study compared the structural integrity and fracture mode of teeth restored with traditionally and minimally prepared resin-bonded CAD/CAM inlays fabricated from the same material.

Methods: Forty intact maxillary premolars were used and divided into four groups. Two groups were prepared according to a traditional inlay preparation design (2.0 mm occlusal reduction, a 1.5 mm wide proximal box and divergent walls) and two groups were prepared according to a newly proposed minimal preparation design (round shaped cavity with 1.0 mm occlusal reduction, a U-shaped proximal box 1.0 mm wide and parallel walls). Two restorative systems were tested: a composite system comprised of Paradigm MZ100 (3M ESPE) blocks and RelyX Unicem (3M ESPE) resin cement and a ceramic system comprised of ProCAD blocks (Ivoclar-Vivadent) and Variolink II (Ivoclar-Vivadent) resin cement. The inlays were cemented according to the manufacturers' instructions. Each specimen was loaded axially to its occlusal surface at a crosshead speed of 0.5 mm/minute in a universal testing machine until fracture. The fracture load data were analyzed using ANOVA, comparing inlays of the same restorative material. Also, the mode of fracture of the inlays was recorded and analyzed using a non-parametric test (Kruskal-Wallis).

Results: In the composite system case, the mean fracture load and SD were 1322 N (±445) for the traditional inlays and 1511 N (±395) for the mini-

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mal inlays, while in the ceramic system case, those values were 1135N (±450) for the traditional inlays and 1761 N (±494) for the minimal inlays. Statistical analysis of the results showed that there was no statistically significant difference between the two designs for the composite system, while for the ceramic system, the minimally prepared teeth showed higher mean fracture strength. Non-parametric analysis (Kruskal-Wallis) of the mode of fracture showed that there was no statistically significant difference between traditionally and minimally prepared inlays for both systems (p>.05).

Conclusions: Under the conditions of this experimental study, only the ceramic inlays, when prepared with a minimal preparation design, demonstrated a higher fracture strength as compared to the traditionally prepared teeth. Use of the proposed minimal preparation design did not compromise the immediate post-operative structural integrity of teeth restored either with resin composite or ceramic inlays.

INTRODUCTION

Minimal intervention dentistry is considered to be state-of-the-art in operative dentistry, and the rationale behind this concept is the maximum preservation of sound tooth tissues.[1] The development of adhesive dentistry makes it possible to conserve tooth structure using minimally invasive cavity preparations, since adhesive materials do not require the incorporation of mechanical retention features.

Composite restorations are being increasingly placed in both anterior and posterior regions of the mouth due to the improved esthetic qualities, strength, wear resistance and reduced water sorption of contemporary resin composite restorative materials as compared to their earlier versions.[2] However, polymerization shrinkage[3-4] and microleakage[5] of resin-based materials are still unsolved problems in clinical dentistry. In order to reduce polymerization shrinkage, resin bonded ceramic and resin composite inlay restorations, whose clinical application has demonstrated promising results, have been suggested.[6-10]

In addition to the development of new restorative materials, new fabrication methods for dental restorations have also emerged. One of the latest achievements in restorative dentistry is the introduction of CAD/CAM systems. CEREC is one such system that can utilize both resin composite and ceramic materials for the fabrication of indirect restorations and, particularly, inlays. Since the introduction of CEREC, numerous studies have evaluated the clinical performance of these restorations.[11-14] Recently, the marginal adaptation using conservative proximal inlay boxes has shown promising results.[15] Another advantage of this system is the ability to prepare cavities following minimally invasive procedures.[16] The ability to acquire images of minimally prepared designs using the CEREC system has been investigated and new minimal preparation designs have been proposed.[17] However, the structural integrity of inlay restorations constructed according to these new preparation designs has not been examined.

The current study evaluated the structural integrity and fracture mode of CAD/CAM-produced resin composite and ceramic inlays using minimal preparation designs. The null hypothesis was that the structural integrity of teeth restored with resin bonded minimal CAD/CAM inlays, ceramic or composite is not compromised compared to teeth that have been restored using the more traditional design.

METHODS AND MATERIALS

Forty intact, caries-free and crack-free maxillary first premolars were used for this part of the study. Four groups (I, II, III and IV) of 10 teeth each were formed. Care was taken so that all the teeth had similar bucco-palatal widths (BPW—the distance from the maximum convexity on the buccal and palatal surfaces). The mean BPW did not vary more than 2.5% over all groups. The teeth were cleaned of any calculus and soft tissues using a hand scaler and stored in a thymol solution (0.5%). A blue die stone was used to fix each tooth, crown uppermost and long axis vertical, in a plastic mold that had a central cylindrical hole 30 mm in diameter. The die stone was placed 1.0 mm from the cementoenamel junction of each tooth. Two restorative materials were used for the fabrication of the inlays: a resin composite material (Paradigm MZ100, 3M ESPE AG, ESPE Platz, Seefeld, Germany) and a leucite reinforced glass ceramic material (ProCAD, Ivoclar-Vivadent Bendererstrasse 2, Schaan, Liechtenstein).

A classic inlay preparation design with a 2.0 mm occlusal reduction, a 1.5 mm width proximal box and divergent walls was performed for Groups I and II. A minimal inlay preparation design was applied on Groups III and IV, which was comprised of a round-shaped cavity with a 1.0 mm occlusal reduction, a U-shaped proximal box 1.0 mm wide and parallel walls (Figure 1). A paralleling device and gauged burs were used to standardize the preparation procedures (for the minimal design: 838 FG 012, 838F 012, Hager & Meisinger GmbH, Neuss, Germany; for the traditional design: Intensiv Advanced CEREC Kit: Intensiv No 8714, 3414, Intensiv SA, Grancia, Switzerland). A high-speed handpiece attached to the paralleling device was used for tooth preparation.

Impressions of the prepared teeth were taken using a one-stage impression technique following the manufacturer's instructions (3M Express STD-Putty, 3M

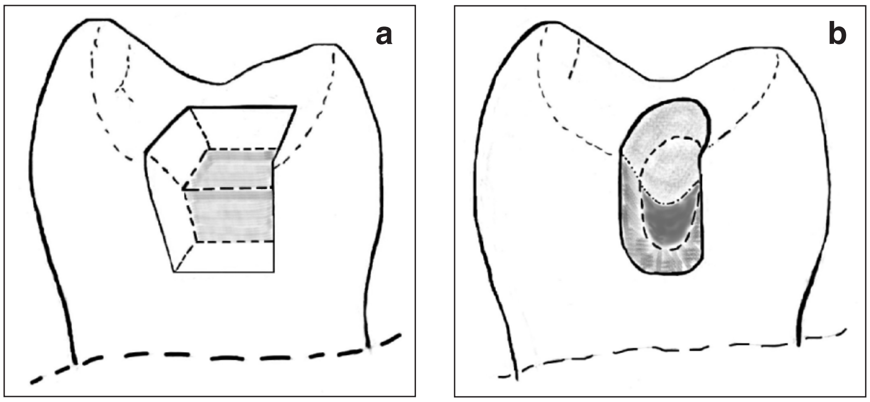

Figure 1. *A diagram of the two designs: The traditional (Figure 1a) and the minimal inlay design (Figure 1b).*

ESPE Imprint—light body [St Paul, MN, USA]). All the impressions were cleaned and sprayed with a surface tension reduction agent (Tensilab, Lot C199E, Zehnmack, Italy). The reduction agent was then gently air-dried to permit a more accurate flow of the die stone and inhibit any bubble formation. Forty casts were fabricated using a special die stone for the CEREC system (CAM-base, Dentona AG, Dortmund, Germany).

The preparations were scanned using the CEREC Scan system and the inlays were designed using software v2.10 R1500. The default milling mode and the default cutting burs (CEREC Cone-shaped Cylinder Diamond 1.6- Art Nr58 55 734 D3329, CEREC Cylinder Diamond 1.6- ArtNr5466193b D3268, Sirona Dental Systems GmbH, Bensheim, Germany) were used for the milling of the fitting surface of the inlays. A lubricant (Dentatec Lubricant, Sirona Dental Systems GmbH) provided with the system was used during cutting, according to the manufacturer's instructions. Groups I and III were restored with the composite material, while Groups II and IV were restored with the ceramic material. In effect, 10 inlays were milled for each group using Paradigm MZ100 and ProCAD blocks producing 20 Paradigm MZ100 inlays and 20 ProCAD inlays in total. The inlays were examined for defects and cracks prior to cementation.

The cement used for the cementation process was of the type recommended by the manufacturers. For the Paradigm MZ100 material (Groups I & III), the cement recommended by the manufacturer was RelyX Unicem Aplicap (3M ESPE), which is a self-adhesive dual-cured resin cement. The fitting surface of the inlays was cleaned thoroughly under running water and air-dried prior to cementation. No pretreatment of the fitting surface was performed, as it was reported that the as-milled surface provided excellent bond strength.[18] The cementation procedure was setup according to the manufacturer's instructions. After cementation of the inlays, the outer surface was polished with fine diamond burs and polishing discs (Intensiv Advanced CEREC Finishing Kit, Intensiv SA; 3M ESPE Sof-Lex Finishing and Polishing System, 3M ESPE).

For the ProCAD system (Groups II & IV), the cement recommended by the manufacturer was Variolink II (Ivoclar-Vivadent AG). The fitting surface of the inlays was cleaned thoroughly under running water, then etched with hydrofluoric acid (IPS Ceramic etching gel, 4.9%, Ivoclar-Vivadent AG) for 60 seconds. The fitting surface was then silanized (Monobond-S, Ivoclar-Vivadent AG) for 60 seconds. A thin layer of a light-curing bonding agent (Heliobond, Ivoclar-Vivadent AG) was applied on the etched and silanized ceramic surface. To avoid premature setting of the resin, the inlay was stored in a dark place to protect it from light. The prepared teeth were also pretreated before cementation. The preparations were cleaned with water and dried with water- and oil-free air, taking care not to cause over-drying of the tooth surface. The bonding area was etched with phosphoric acid gel (Total Etch 37% wt, Ivoclar-Vivadent AG) for 30 seconds. A two-phase adhesive system (Syntac, Primer and Adhesive, Ivoclar-Vivadent AG) was used and applied according to the instructions. A bonding agent (Heliobond, Ivoclar-Vivadent AG) was brushed and air-thinned on the pre-treated enamel and dentin. A dual-curing luting composite system (Variolink II, Ivoclar-Vivadent AG) was used for cementation of the inlays. The restorations were placed with slight pressure using a brush to remove any excess cement; the pressure was then increased and maintained for 15 seconds. Any excess Variolink II was removed with a brush. The inlay was then polymerized for 40 seconds per segment. After cementation of the inlays, all the specimens were stored in water for 24 hours. Before performing the fracture strength test, the specimens were mounted using an acrylic resin (Sampl-Kwick Fast Cure Acrylic, Buehler, Lake Bluff, IL, Kit No 20-3560). The occlusal part of each tooth was affixed on a glass slide using sticky wax, then the roots were embedded in acrylic resin.

Each tooth was loaded axially to its occlusal surface at a crosshead speed of 0.5 mm/minute in a universal testing machine (Lloyds Instrument Model LRX, Lloyd Instruments Ltd, Hants, UK). A plunger with a steel ball (4.24 mm diameter) was used to transmit the compressive force until fracture occurred. The ball was positioned in the middle of the occlusal plane, between the buccal and palatal cusp. A piece of rubber dam was placed as a stress breaker between each tooth sample and the steel ball in order to remove any potential stress concentration due to surface irregularities and

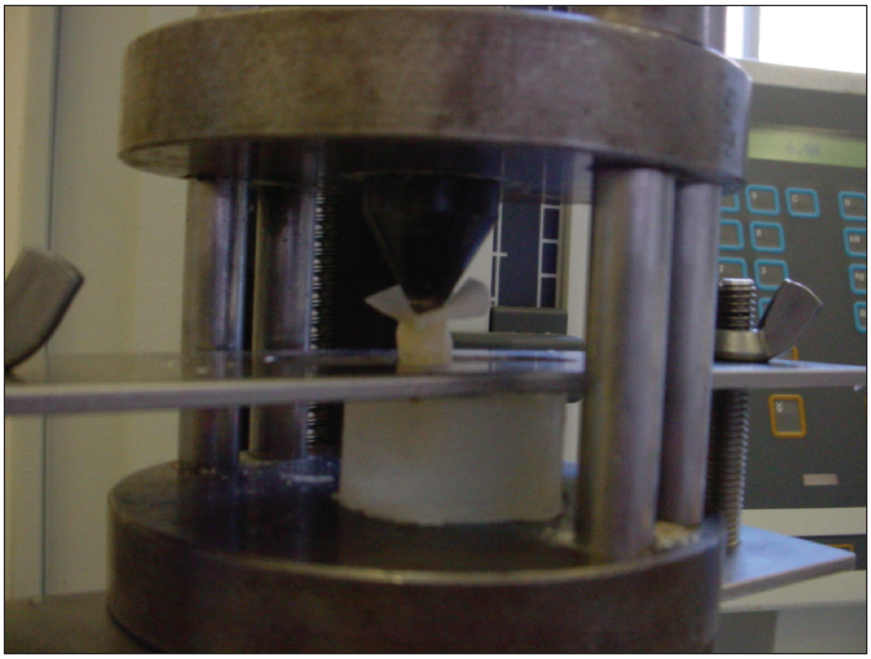

Figure 2. *The restored tooth under load. A piece of rubber dam was used as a stress breaker.*

formed between the traditional and minimal inlays of the same restorative material to identify significant differences. The mode of fracture of the restored teeth was detected after failure (Table 1).

to better distribute contact of the steel ball with the inlay (Figure 2). In order to keep the specimen firmly in place, a custom-made holder was placed on the test machine. Fracture loads (N) were recorded. The mode of fracture was also detected and recorded for both systems.

The load data recorded for the traditional and minimal inlays of both cementation types were entered into the statistical package SPSS v14 for statistical analysis. One-way analysis of variance (ANOVA) was performed between the traditional and minimal inlays of the same restorative material to identify significant differences.

RESULTS

For the composite system (Groups I and III), the mean fracture loads and standard deviations (SD) reported for the traditional inlays (Group I) were 1322N (± 445) and 1511N (± 395) for the minimal inlays (Group III). The statistical analysis showed that there was no statistically significant difference between the traditional and minimal designs (p=0.328). A bar graph of the mean fracture load and SD for the two designs is shown in Figure 3.

As far as the ceramic system (ProCAD) is concerned (Groups II and IV), the mean fracture loads and SDs reported for the traditional inlays (Group II) were 1135N (± 450) and 1761N (± 494) for the minimal inlays (Group IV). The statistical analysis revealed a statistically significant difference between the two designs (p=0.008) for this material group. A bar graph of the mean fracture load and SD for the two designs is shown in Figure 4.

The mode of fracture of the specimens is reported in Tables 1 and 2 for each material, respectively. A fracture of a restored tooth immediately after the test is shown in Figure 5. The non-parametric analysis (Kruskal-Wallis) of the mode of fracture for the minimal and traditional inlays showed that there is no sta-

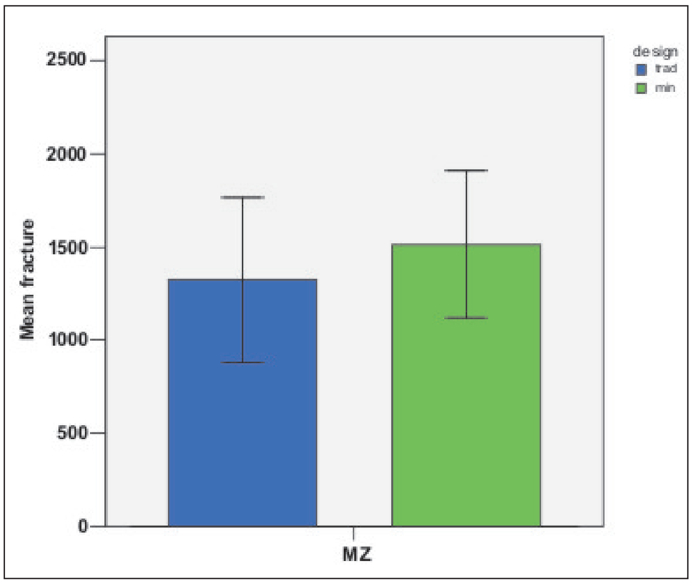

Figure 3. *A comparison of the mean fracture strength of traditional and minimal inlays for the composite group.*

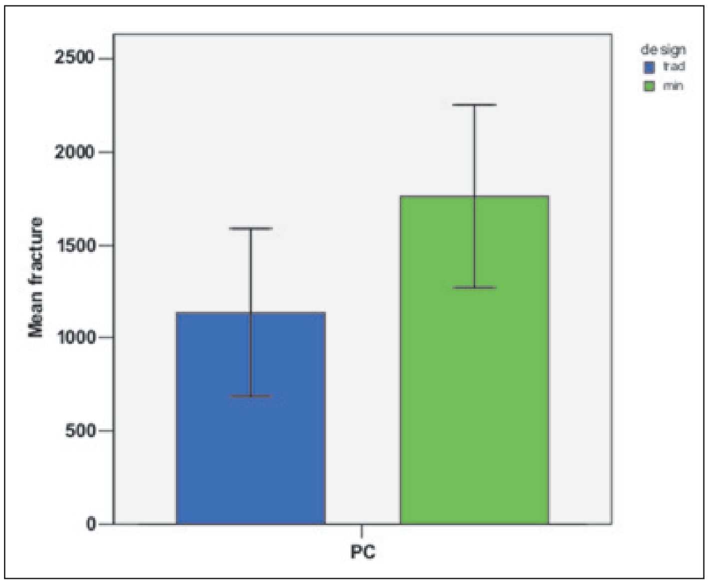

Figure 4. *A comparison of the mean fracture strength of traditional and minimal inlays for the ceramic group.*

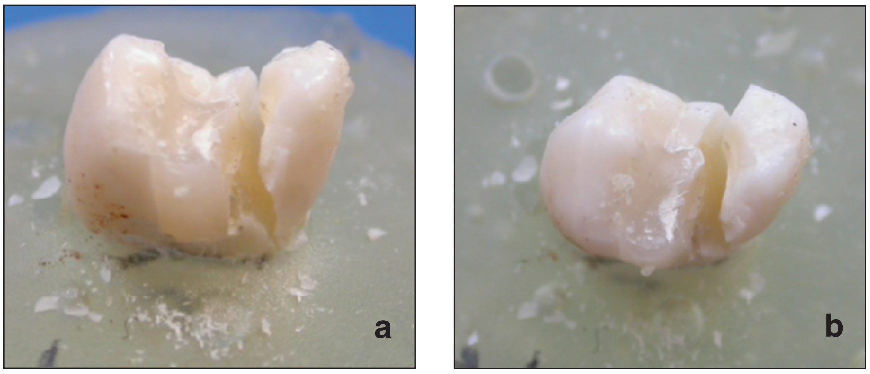

Figure 5. *Lingual cusp displacement with the restoration remaining bonded on the buccal cusp. Side (Figure 5a) and top view (Figure 5b) of the tooth after loading.*

tistically significant difference between the two designs for both materials ($p>0.05$).

DISCUSSION

The current study evaluated the structural integrity of minimally prepared resin bonded CEREC inlays that had been constructed according to new minimal design concepts and compared them to traditional ones in order to determine if there was any change in fracture strength immediately post-operatively when a minimal intervention technique is employed. Groups of inlays fabricated from the same restorative material were compared. Two materials, a composite (Paradigm MZ100) and a ceramic (ProCAD), with the respective cementation technique proposed by their manufacturers, were used, forming in that way two restorative systems—the MZ100 system and the ProCAD system. It was not the intention of the current study, though, to compare the effect of different cementation techniques or restorative materials on fracture strength of the inlays and, for that reason, no direct comparisons between the two restorative systems were performed.

The same minimal preparation design was performed for both materials, as it was found that the CEREC system could produce acceptable restorations for both the composite and the ceramic material.

The mean fracture load reported in the current study for traditional, minimal composite and ceramic inlays ranged between 1135N and 1761N. For the Paradigm MZ100 restorative system, the minimal design exhibited no statistically significant difference from the traditional design, while for the ProCAD system, it was found that there was a statistically significant difference between the two designs, with the minimally prepared inlays showing a higher mean fracture strength.

The main point to emphasize is that the use of a minimal preparation design does not compromise the immediate post-operative structural integrity of the restored tooth. In addition, this finding applies to both composite and ceramic restorations. In fact, regarding ceramic inlays, there may an additional benefit in that the mechanical integrity is improved. A possible explanation for this finding could be the fact that more enamel was left with the minimal preparation design, which improved the bond between the ceramic and tooth tissues. Furthermore, with minimal preparation, more tooth structure and enamel is preserved and thus a stiffer substructure is produced that can improve the stress distribution to the restoration under a given load. This is potentially more beneficial for the ceramic than the composite, as ceramics have a higher modulus of elasticity (70-224 GPa).[19-21] In contrast, since composite is a more flexible material with a lower modulus of elasticity (8.8-18.5 GPa),[22-23] it is possibly better able to cope with a lower stiffness substructure. In addition, the high conversion of composite blocks and the lack of adequate unconverted C=C sites on the inlay substructure may not allow for a sufficient bond with

Table 1: *Types of Fracture Recorded After Loading for the Composite Group*

Type of Fracture	Traditional Composite Inlay (Group I)	Minimal Composite Inlay (Group III)
Lingual cusp only	2	1
Lingual cusp and part of restoration	3	5
Buccal cusp only	0	0
Buccal cusp and part of the restoration	0	0
Severe fracture of the tooth	5	4
Other parts of the tooth	0	0

Table 2: *Types of Fracture Recorded After Loading for the Ceramic Group*

Type of Fracture	Traditional Ceramic Inlay (Group II)	Minimal Ceramic Inlay (Group IV)
Lingual cusp only	2	2
Lingual cusp and part of restoration	5	4
Buccal cusp only	0	0
Buccal cusp and part of the restoration	0	0
Severe fracture of the tooth	2	3
Other parts of the tooth	1	1

dentin, such that the more residual free carbon bonds available, the better the bond between the inlay and lute. No other pretreatment for mechanical retention was made in composite inlays, because, according to the manufacturer, the as-milled surface provides excellent bond strength.[18,24] The above mentioned reasons might explain the lack of statistically significant difference between the minimal and traditional group for the composite material.

A significant variability in fracture load of the restored teeth was also observed. This is consistent with a brittle fracture system with a dispersion of flaws of different sizes.[24] It is impossible to control the size and distribution of the internal flaws of each tooth structure or milling block, although the procedures of collecting, storing and preparing the teeth and the conditions of milling the inlays had been standardized.

The mode of failure reported for the traditional and minimal CEREC inlays was similar for both restorative systems. Observation of the fracture pattern of the inlays showed that mainly the lingual cusp was involved with the failure of the restoration. Quite interestingly, this finding is consistent with other studies testing the fracture of restored premolars.[26] Eakle and others also reported that lingual cusps of maxillary premolars fracture more often than buccal cusps *in vivo*.[27] One interesting observation was for the ProCAD groups where, for two specimens, the inlays remained bonded to the buccal and lingual cusps and the teeth fractured on the other proximal side. However, this may only be a coincidental event, as it happened for both the traditional and minimal design, so it could not be attributed to the increased bond strength of the minimal inlay. No direct comparison could be made with other studies; based on the authors' knowledge, there are no studies in the literature testing the fracture strength of minimally prepared CEREC inlays. In the current study, the mean fracture loads reported for MZ100 and ProCAD traditional/minimal inlays are well above the forces that would normally occur in the oral cavity. The mean masticatory forces during mastication and swallowing reported in humans are approximately 40N, while the average maximum posterior masticatory forces vary from 200 to 540N,[28-29] which are well below even the lowest values reported in the current study.

The existing study examined the immediate post-operative structural integrity of the restored teeth; whereas dental restorations usually fail as a result of many loading cycles or from an accumulation of damage from stress and water.[30] In terms of *in vivo* loading, the masticatory cycle consists of a combination of vertical and lateral forces, subjecting the restoration to a variety of off-axis loading forces.[31] However, it was the intention of the current study to give an indication as to whether or not the proposed minimal design would provide inlays with a similar structural integrity to traditionally prepared CEREC inlays.

Before engaging in any time-consuming durability tests, it is first necessary to establish that the structural integrity of the restored tooth has not been fatally compromised by the use of a minimal and untested design. The current study has shown that this is not the case and, if anything, the structural integrity has been improved. The next phase of work in assessing the strength of the proposed minimal preparation designs for inlays is to undertake more complex durability tests. To undertake such tests prior to checking the initial structural integrity of the inlays would have been redundant, if the immediate post-operative structural integrity was found to be severely compromised.

The results of the current study showed that the structural integrity of minimally prepared teeth for inlay restorations is similar to traditionally-prepared teeth when a resin composite is used. In the instance of a ceramic material being used, it was found that the minimally prepared teeth showed increased strength when compared to traditionally prepared teeth. Thus, the null hypothesis was accepted for the composite material, while, for the ceramic material, it had to be rejected, as it was found that the structural integrity of the minimally prepared teeth was superior to that of traditionally prepared teeth.

CONCLUSIONS

Structural integrity tests of traditionally designed inlays, compared with minimally prepared inlays following new design parameters, have shown that:

- Teeth restored with the proposed minimal composite inlays demonstrated similar fracture strength to traditionally prepared ones.
- Teeth restored with the proposed minimal ceramic inlays demonstrated a small but significant increase in fracture load compared to that of traditionally prepared teeth.

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