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A handwritten signature in black ink, appearing to read "S. Arnason".

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Fracture Resistance of Bonded CAD/CAM Restorations with Standard or Extended Preparations

ABSTRACT

Colloquial conversations have been reported, in both educational and private practice settings that bonded CAD/CAM restorations reinforce cusps with wide, extended preparations and reduced cuspal thickness. The purpose of this study was to evaluate the fracture resistance of teeth with standard or extended preparations bonded with CAD/CAM materials. Extracted third molars were prepared and scanned with a CAD/CAM acquisition unit. Ten teeth per preparation type (standard or extended) were restored with milled lithium disilicate or resin nano ceramic materials, or left unrestored (negative control). An additional ten teeth were not prepared nor restored (positive control). After thermocycling and cyclic loading, specimens were fractured in a material testing device. Although bonded CAD/CAM restorations reinforced tooth structure, fracture load was significantly lower with teeth with extended preparations. The type of CAD/CAM restorative material did not significantly affect fracture load.

INTRODUCTION

The introduction of computer-aided design and computer-aided manufacturing (CAD/CAM) has drastically changed the landscape of dentistry today. CAD/CAM technology was initially developed primarily to solve the challenge of making tooth restoration easier, faster, and more accurate.¹ Practitioners are most often able to provide patients with a definitive restoration on the same day as tooth preparation. Among other things, same day delivery eliminates perhaps the most difficult component of conventional inlay and onlay procedures, the provisional restoration, due to the non-retentive design of the preparations.² Accuracy has also been significantly improved by this modern technology. It has been reported that marginal adaptations as good as 9-15 μ m have been achieved in milled restorations.³ Additionally, CAD/CAM

fabricated restorations allow for the elimination of porosities inherent in hand-applied porcelain restorations.⁴

Since its introduction in the mid-1980s, CAD/CAM technology has seen a multitude of restorative materials used throughout the years. Early material options such as feldspathic porcelain and leucite-reinforced porcelain fundamentally demonstrated reduced flexural strength and fracture toughness. These included Vita Mark I and Vita Mark II (Vita, Yorba Linda, CA) and IPS Empress CAD (Ivoclar Vivadent, Amherst, NY), to name a few. Moderate gains in strength were gained with the advent of a lithium-disilicate-based CAD/CAM material (IPS e.max CAD, Ivoclar Vivadent).⁵ These lithium disilicate glass-ceramic blocks are machined in the partial crystallization phase, or blue phase, and then tempered to reach their final state. During this process, lithium-disilicate crystals are formed giving the ceramic the final shade and desired high flexural strength, reported by the manufacturer as high as 500 MPa. Additionally, the modulus of elasticity of the fully crystalized state has been reported as 95 GPa.^{6,7} Unfortunately, this additional laboratory procedure, as well as any necessary correction firings, further increases chair time and delays restoration delivery.

Unlike ceramic blocks, inherent properties of millable composite-resin blocks allow for the material to be more easily adjusted, polished, and repaired.⁵ Lava Ultimate (3M ESPE, St. Paul, MN) is a newer resin nano ceramic containing approximately 80% by weight of nanoceramic particles bound in a resin matrix. The filler particles consist of both nanoclusters and nanomer particles. Specifically, the nanoclusters are made from nanomer particles - silica (20 nm) and zirconia (4-11 nm) that amass to form aggregates. According to 3M ESPE, the nanotechnology and resin achieve a combination of exceptional flexural strength (204 MPa) and esthetics with shorter milling times, greater edge quality, and the ability to be repaired by traditional composite resin restorative materials. Additionally, the manufacturer reports that Lava Ultimate has a flexural modulus of 12.8 MPa, which is similar to the value of human dentin (17.5).^{8,9} Lava Ultimate restorative material is indicated for inlays, onlays, and veneers.⁸

Conventional inlay preparation guidelines still apply to CAD/CAM preparations, with increased emphasis on well-defined cavosurface margins and rounded internal line angles necessary for accurate image acquisition. The occlusal aspect of the preparation should be at least 1mm-1.5mm thick in the central fissure, depending on material, and have a 90-degree butt-joint configuration at cavosurface margins.² Additionally, cavity walls of proximal boxes should have at least 6 to 8 degrees of taper.¹⁰ However, the literature is controversial on what extent wider preparations may be restored with inlay restorations.^{5,11-13} Anecdotal observations made at dental conventions and continuing education circuits undoubtedly include a multitude of millable restorative materials used to restore teeth with extended preparations. Additionally, colloquial conversations have been reported in both educational and private practice settings that bonded CAD/CAM restorations reinforce teeth with wide preparations.

Mehl et al. evaluated the reinforcement effects of a milled feldspathic ceramic (Vita Mark II, Vita) and an indirect composite inlay made from a direct composite restorative material (Tetric, Ivoclar Vivadent) in various extended MOD inlay cavities.¹⁴ The preparations of different isthmus widths were restored and loaded in a chewing simulator, and fracture resistance was established. Their study determined that the milled ceramic provided significantly greater reinforcement than the indirect composite inlay. Nevertheless, this reinforcement effect was reduced in the case of extremely extended preparations (e.g., 1.3mm or less of the remaining cuspal thickness). Although the Mehl et al. study had significant clinical implications, newer materials have been introduced such as lithium disilicate and resin nano ceramic.¹⁴ Unfortunately, no current literature has been published on the evaluation of the potential reinforcement of tooth structure with wide preparations with these newer materials.

The objective of the present study was to examine and compare the extent to which CAD/CAM lithium disilicate glass-ceramic (IPS e.max CAD) and resin nano ceramic (Lava Ultimate) inlays can predictably reinforce extended Class II preparations. To accomplish this, the fracture resistance after mechanical fatigue loading of several design preparations were

determined *in vitro*. The null hypotheses were that there would be no difference in fracture load based on 1) preparation type or 2) restorative material. Another hypothesis was that there would be no difference in fracture load between any of the groups and the unprepared control.

MATERIALS AND METHODS

Seventy extracted, caries-free mandibular third molars of similar size were used in this study. Each tooth was embedded in self-cured bis-acrylic resin (Integrity, Dentsply, Milford, DE) to 2mm below the CEJ in a custom cylindrical block. In thirty teeth, standardized MOD preparations were prepared, with 4.5mm buccal and lingual/palatal wall thickness remaining and proximal boxes extending 1mm coronal to the cemento-enamel junction. See Figure 1. In thirty teeth (extended preparation), the buccal and lingual/palatal walls were reduced to a thickness of 3mm. See Figure 2. Groups were divided into seven groups of ten teeth each and consisted of the following:

- 1) resin nano ceramic, Lava Ultimate - standard preparation;
- 2) lithium disilicate, IPS e.max CAD - standard preparation;
- 3) resin nano ceramic, Lava Ultimate - extended preparation;
- 4) lithium disilicate, IPS e.max CAD - extended preparation;
- 5) unrestored standard preparation (negative control group #1);
- 6) unrestored extended preparation (negative control group #2);
- 7) unprepared teeth (positive control).

Twenty standard and twenty extended preparations were digitally scanned with a CEREC Omnicam Acquisition Unit (Sirona, Charlotte, NC). Following the digital design using the CEREC software (Version 4.4, Sirona), inlay restorations were milled from their respective blocks (size C14, shade A2) using a milling unit (MCXL, Sirona).

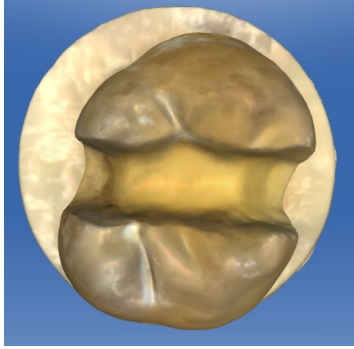


Figure 1: Scanned standard preparation

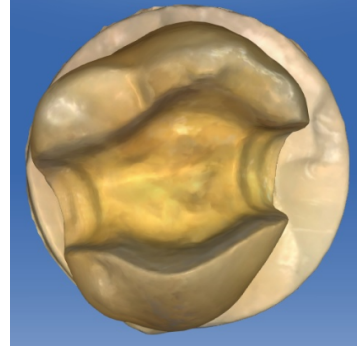


Figure 2: Scanned extended preparation

After fitting all inlays, the restorations were cemented according to their respective manufacturer recommendations. For Lava Ultimate restorations, the intaglio of the Lava Ultimate inlays were sandblasted with 50µm aluminum oxide at two bars (30 psi) (Basic Quattro IS, Renfert, Chicago, IL) and then steam cleaned (i700B, Reliable, Toronto, Ontario). Scotchbond Universal Adhesive (3M ESPE) was applied for 20 seconds and then air dried for 5 seconds using a three-way syringe. Enamel was selectively etched with 37.5% phosphoric acid (3M Scotchbond Etchant, 3M ESPE) for 15 seconds, then rinsed and lightly air dried. Scotchbond Universal Adhesive was applied to the enamel and dentin. Next, a uniform layer of Rely X Ultimate Adhesive Resin Cement (3M ESPE) was mixed according to the manufacturer's recommendations and applied to the restorations. The restorations were then completely seated, tack cured for 1 second with a curing light (Bluephase G2, Ivoclar Vivadent) and then excess cement was removed with a sharp instrument. Lastly, the restorations were light cured for 20 seconds per surface. Irradiance was recorded with a power meter (PowerMax, Coherent, Inc, Santa Clara, CA) and considered acceptable if greater than 1000 mW/cm².

For IPS e.max CAD restorations, the intaglio of the IPS e.max CAD inlays were etched with 5% hydrofluoric acid (IPS Ceramic Etching Gel, Ivoclar Vivadent) for 20 seconds, rinsed, and thoroughly dried. Next Monobond Plus (Ivoclar Vivadent) was applied to the etched surface, allowed to react for sixty seconds, and dried. On the prepared teeth, Multilink Primer A and B (Ivoclar Vivadent) was applied to enamel and dentin. Next, Multilink Automix resin cement (Ivoclar

Vivadent) was applied directly onto the etched and silanated restorations. The restorations were then completely seated, tack cured for 1 second with a curing light, and then excess cement was removed with a sharp instrument. Lastly, the restorations were light cured for 20 seconds per surface. After removing excess cement, the specimens were polished following the manufacturer's recommendations.

For Lava Ultimate, the surfaces of the restoration were finished with the Sof-Lex Spiral Finishing Wheel (3M ESPE) and polished with the Sof-Lex Spiral Polishing Wheel (3M ESPE). For IPS emax.CAD, the surfaces of the restorations were polished with the Dialite LD Extra-Oral Polishing System (Brasseler, Savannah, GA).

Finally, all teeth from the seven groups were stored in distilled water solution at 37°C for 24 hours in an incubator (Model 20 GC, Quincy Labs, Chicago, IL). After storage in distilled water, each tooth specimen was thermocycled in distilled water for 2000 cycles at 5°C and 55°C with a dwell time of 30 seconds at each temperature (Sabri Dental Enterprises, Downers Grove, IL) and then mechanically loaded in the chewing simulator (Sabri Dental Enterprises) in order to simulate clinical loading. The machine subjected the mounted teeth submerged in distilled water to a cycling force of 10 - 150 N at a rate of 1 hertz for 100,000 cycles parallel to the occlusal surface using a 12.7mm diameter flat-ended cylindrical piston resting on the cusp tips. Ten teeth per group were loaded simultaneously in the machine. The load was verified using a digital force meter (Infinity CS, Cooper Instruments, Warrenton, VA) before each load sequence.

Static fracture loading was initiated subsequent to fatigue loading. The teeth were oriented so that a 6-mm diameter round-ended probe applied the load to the center and long axis of the molars with the edges of the probe resting on the occlusal inclines of the buccal and lingual cusps of the natural tooth. Loading was performed in a universal testing machine (Instron 5943, Norwood, MA) at a crosshead speed of 1 mm/min until the first fracture occurred. The fracture force was recorded in Newtons and a mean and standard deviation was determined per group.

The data were analyzed with a two-way ANOVA and Tukey's post-hoc test to evaluate the effect of preparation type (2-levels) or materials/no-material (3-levels) on fracture load ($\alpha = 0.05$). The data were also analyzed with Dunnett's test to compare the fracture load of all groups to the unprepared control ($\alpha = 0.05$). The data from the restored groups were also compared between extended and standard preparations and between material types with unpaired t-tests ($\alpha = 0.05$).

Lastly the fracture mode of each specimen was analyzed visually and categorized according to the following criteria modified from Burke et al. (1993):¹⁵

Type I: isolated fracture of restoration

Type II: isolated fracture of small portion of the tooth

Type III: restoration fracture involving one cusp

Type IV: fracture involving more than half of the tooth, without periodontal involvement

Type V: fracture with periodontal involvement

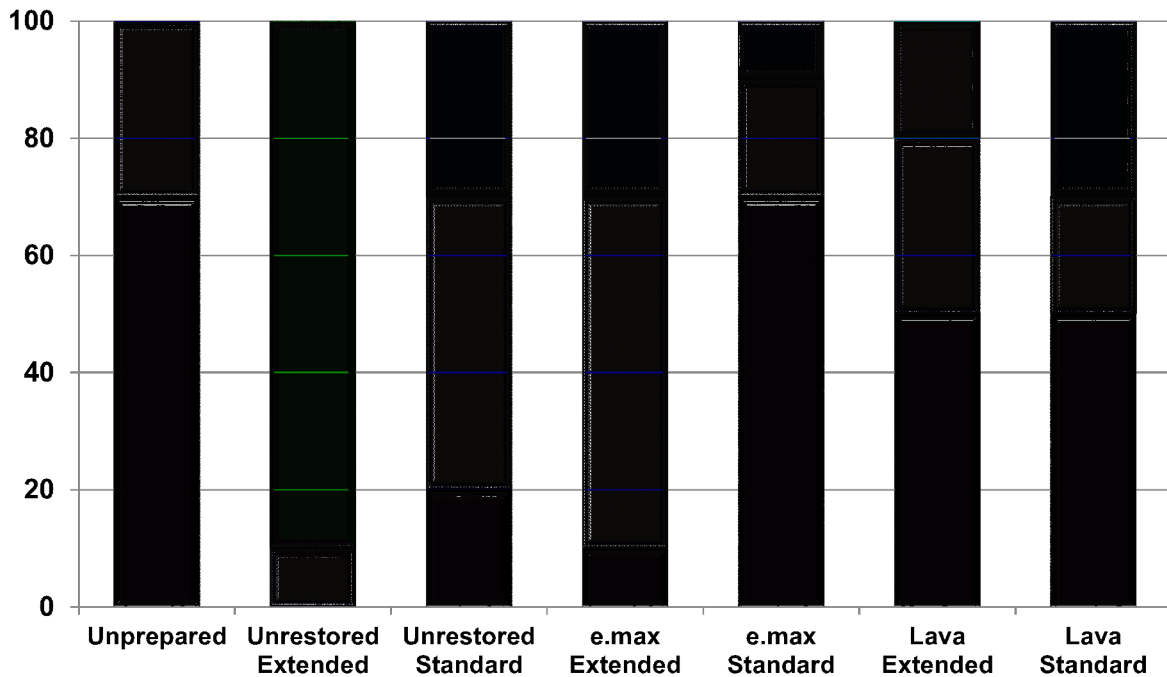
RESULTS

The mean fracture loads and standard deviations are reported in Table 1. The extended preparations resulted in significantly less fracture load than the standard preparations ($P < 0.05$). The unrestored teeth had significantly less fracture load than the restored teeth ($P < 0.05$), which were not significantly different from each other ($P = 0.623$). All groups were significantly less than the unprepared group ($P < 0.007$).

	Fracture Load		Mean
	Newtons (st dev)		
	Preparation Type		
	Standard	Extended	
IPS e.max CAD	3248.2 (781.2) Aa	2547.9 (468.7) Ab	2936.9 (736.0) A
Lava Ultimate	3504.9 (916.4) Aa	2736.9 (524.6) Ab	3120.9 (826.7) A
Unrestored	1586.6 (436.8) Ba	731.0 (290.2) Bb	1158.8 (568.2) B
	Unprepared 4475.3 (797.4) C		

Table 1: Fracture load of groups. Groups with the same upper case letter per column or lower case letter per row are not significantly different ($P>0.05$).

The mode of fracture of the specimens for each material is represented in Figure 3. In general, all of the restored teeth had a large number of Type 4 or Type 5 fractures - fracture of more than half the tooth and fracture involving the periodontium respectively. Of the restored teeth, the extended preparations restored with IPS e.max CAD had the least catastrophic fractures (Type 5). Overall, the restored standard preparation groups demonstrated a greater number of unfavorable fractures compared to the restored extended preparation groups. The unrestored extended preparation group (negative control) demonstrated the most favorable fracture mode. Lastly, the positive control group (unprepared teeth) demonstrated the greatest number of catastrophic, non-restorable fractures (Type 5).



- Type 1: Isolated Fracture of Restoration
- Type 2: Isolated Fracture of a Small Portion of Tooth
- Type 3: Restoration Fracture Involving 1 Cusp
- Type 4: Fracture Involving More Than Half fo the Tooth, w/o Periodontal Involvement
- Type 5: Fracture with Periodontal Involvement

Figure 3: Fracture modes of groups

The purpose of this *in vitro* study was to evaluate the fracture resistance of teeth with and without extended tooth preparations bonded with lithium-disilicate and resin nano ceramic restorations. The null hypothesis based on preparation type was rejected. There was a difference in fracture load based on preparation type. The extended preparations with reduced cuspal thickness resulted in significantly less fracture load than the standard preparations. While the

mean fracture load of the restored extended preparation groups was 2642.4 ± 479.4 N, a mean failure load of 3376.55 ± 817.9 N was observed for the restored standard preparation groups. Furthermore, all preparation groups were significantly less than the unprepared group, which demonstrated mean a fracture load of 4475.3 ± 797.4 N. These findings were consistent with results seen in a study with a similar design, which found a significant reduction in fracture load of feldspathic ceramic and composite inlays in teeth with extended preparations.¹⁴ However, the results of this study contradicted Morimoto et al, who reported that the fracture load of teeth restored with ceramics inlays was similar to intact teeth.¹⁶ But, their study involved only one material type (feldspathic porcelain) and only one type of inlay preparation, defined as having an isthmus width of 1/2 of the intercuspal distance. Overall, the findings of this study suggest that the evaluated restorative materials reinforce teeth, but to a far lesser extent with reduced cuspal thickness.

This study failed to reject the null hypothesis based on restorative material. The type of material did not affect fracture load. These results were achieved, despite the fact that two very different materials with very different properties were used. As stated previously, lithium disilicate (IPS e. max CAD) has a reported flexural strength as high as 500 MPa (IPS e.max CAD, Ivoclar Vivadent), compared to a reported 204 MPa for the resin nano ceramic, Lava Ultimate. Conversely, the resin nano ceramic material has a much lower modulus of elasticity (12.8 GPa) than lithium disilicate (95 GPa).¹⁷ Compared to lithium disilicate, the resin nano ceramic material used in this study is more similar to human dentin in terms of flexibility under function, which may help compensate for the lower flexural strength property. Lastly, the design of this study and the design of fracture studies in teeth ultimately test not just the physical properties of the materials in question, but the teeth as well. Clearly, the thermal and mechanical loading of the restored tooth creates a more dynamic process than simple physical property tests of the materials. For example, the 6-mm diameter round-ended probe engaged natural tooth structure on the occlusal

inclines of the buccal and lingual cusps, perhaps allowing the lower modulus resin-ceramic material to flex with the tooth prior to fracture of the tooth and/or restoration.

Some general observations can be made concerning fracture modes. The fracture mode of the unrestored extended preparations had the most favorable fractures. Without the bonded restorative material, the force applied to the extended preparations resulted in significantly lower fracture load, but a more favorable fracture mode. Conversely, the unprepared tooth required the greatest amount of force to fracture, but resulted in the most catastrophic fractures involving the periodontium. In general, the force applied to the tooth structure in the restored extended preparation groups resulted in less favorable fracture modes compared to the unrestored extended preparation group, but better than the restored standard preparation groups. The extended preparations restored with IPS e.max CAD had the least catastrophic fractures, but the lowest fracture load of the restored groups. It is important to note, however, that the fracture loads reported in this study are well above the forces that normally occur in the oral cavity. The mean masticatory forces during mastication reported in humans is approximately 40 N, while the average maximum posterior masticatory forces vary from 200 to 540 N.¹⁸ Static fracture tests may screen for the durability of restorative materials. Repeated stresses of cyclic loading can predispose restorations to fail under fatigue. This study subjected the specimens to thermal (2000 cycles) and mechanical loading (100,000 cycles) before application of a static load. Studies demonstrate that mean fracture resistance decrease significantly when the number of cycles exceed one million. However, fatigue loading will decrease the load to failure regardless of the number of cycles.¹⁹

The purpose of this study was to evaluate the colloquial claims that CAD/CAM restorations reinforce teeth with wide preparations and reduced cuspal thickness. Limited *in vitro* and, to the authors' knowledge, no *in vivo* studies have addressed this practice. Additional research should evaluate additional preparation designs such as inlay preparations with further extended preparations along with other CAD/CAM restorative material types (e.g., leucite-reinforced,

polycrystalline ceramics). A limitation to this study is that the force was only applied along the long axis of the tooth.

The results of this study suggest that bonded CAD/CAM restorations reinforce tooth structure compared to unrestored prepared teeth. However, this reinforcement decreases as the remaining cusp width decreases. Although more favorable fracture modes occurred with extended preparations, the load to failure was significantly higher with standard preparations. Therefore, caution is advised in restoring teeth with wide preparations. Practitioners should consider covering the cusps with the CAD/CAM restorative material to reduce the potential for fracture in cases with reduced cuspal thickness, especially in patients with heavier occlusion or functional load.

CONCLUSIONS

Within the limitations of this study, the following statements can be made. The type of CAD/CAM restorative material did not significantly affect fracture load. Although bonded CAD/CAM restorations reinforced tooth structure, the fracture load was significantly lower with teeth with extended preparations.

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REFERENCES

1. Davidowitz G, Kotick PG. The use of CAD/CAM in dentistry. *Dent Clin North Am* 2011;55:559-570.

2. Fasbinder DJ, Neiva G, Robbins JW, Hilton TJ, Esthetic Inlays and Onlays. In: Hilton TJ, Ferracane JL, Broome J. Summitt's Fundamentals of Operative Dentistry: a Contemporary Approach. 4th ed. Chicago: Quintessence Publishing Co. Inc.; 2013:501-523.
3. Beuer F, Naumann M, Gernet W, Sorensen JA. Precision of fit: zirconia three-unit fixed dental prostheses. *Clin Oral Investig* 2009;13(3):343-349.
4. Tinschert J, Zvez D, Marx R, Anusavice DJ. Structural reliability of alumina-, feldspar-, leucite, mica-, and zirconia-based ceramics. *J Dent* 2000;28:529-535.
5. Fasbinder DJ, Neiva GF, Dennison JB, Heys DR. Clinical performance of CAD/CAM-generated composite inlays after 10 years. *J Cosmetic Dent* 2013;28:134-145.
6. IPS e.max CAD Scientific Documentation, Ivoclar Vivadent, Schaan, Liechtenstein: accessed 21 August, 2015 at <http://www.ivoclarvivadent.com/zoolu-website/media/document/9793/IPS+e-max+CAD>
7. Lien W, Roberts HW, Platt JA, Vandewalle KS, Hill TJ, Chu TM. Microstructural evolution and physical behavior of a lithium disilicate glass-ceramic. *Dent Mater*. 2015 Aug;31(8):928-940.
8. 3M ESPE Lava Ultimate Technical Product Profile, 3M ESPE Dental Products, Neuss, Germany: accessed 21 August, 2015 at <http://multimedia.3m.com/mws/media/747392O/lava-ultimate-restorative-instructions-for-use-english.pdf>
9. Plotino G, Grande NM, Bedini R, Pameijer CH, Somma F. Flexural properties of endodontic posts and human root dentin. *Dent Mater*. 2007 Sep;23(9):1129-35. Epub 2006 Nov 20.
10. Poticny DJ, Klim J. CAD/CAM in-office technology: Innovations after 25 years for predictable, esthetic outcomes. *J Am Dent Assoc* 2010;141(suppl 2):5S–9S.
11. Hickel R, Manhart J. Longevity of restorations in posterior teeth and reasons for failure. *J Adhes Dent* 2001;3:45-64.
12. Thordrup M, Isidor F, Horsted-Bindslev P. A 5-year clinical study of indirect and direct resin composite and ceramic inlays. *Quintessence Int* 2001;32:199-205.
13. Otto T, Schneider D. Long-term clinical results of chairside CEREC CAD/CAM inlays and onlays: a case series. *Int J Prosthodont* 2008;21:53-59.
14. Mehl A, Kunzelmann KH, Folwaczny M, Hickel R. Stabilization effects of CAD/CAM ceramic restorations in extended MOD cavities. *J Adhes Dent* 2004;6:239-245.
15. Burke F, Wilson N, Watts D. The effect of cavity wall taper on fracture resistance of teeth restored with resin composite inlays. *Oper Dent* 1993;18:230-236.
16. Morimoto S, Vieira GF, Agra CM, Sesma N, Gil C. Fracture strength of teeth restored with ceramic inlays and overlays. *Brazilian Dent J* 2009;20(2):143-148.
17. 3M ESPE Lava Ultimate Technical Product Profile, 3M ESPE Dental Products, Neuss, Germany: accessed 21 August, 2015 at <http://multimedia.3m.com/mws/media/777230O/lava-ultimate-cad-cam-restorative-tpg-us.pdf>

18. Jung YG, Peterson IM, Kim DK, Lawn BR. Lifetime limiting strength degradation from contact fatigue in dental ceramics. *J Dent Res* 2000;79(2):722-731.

19. Coray R, Zeltner M, Ozcan M. Fracture strength of implant abutments after fatigue testing: A systematic review and meta-analysis. *J Mech Behav Biomed Mater*. 2016 Sep;62:333-46.