Original Article

Effect of Abutment Taper on the Fracture Resistance of all-Ceramic Three-unit Bridges

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Received: 22 February 2005
Accepted: 7 September 2005

Abstract:
Statement of Problem: The connector area is the weakest zone of an all-ceramic fixed partial denture (FPD), where most catastrophic failures of the prostheses tend to occur.
Purpose: The aim of the present study was to assess the effect of the convergence angle of abutments on the fracture resistance of three-unit fixed partial dentures made of IPS-Empress2.
Materials and Methods: Forty extracted human premolars and molars were used to reproduce twenty, 3-unit fixed partial dentures, for the replacement of second premolars. All teeth were prepared according to the guidelines outlined for all-ceramic crowns and bridges, except for the convergence angles of the abutments. The specimens were randomly divided into two groups of 10, with total occlusal convergence angles of 12° and 22°. Fixed partial dentures with a uniform thickness of 0.8 mm were fabricated using IPS-Empress2 and were bonded to the corresponding models. Connector dimensions were set to 4 mm height and 4mm width. The radius of curvature at the gingival embrasure was carved to 0.9 mm. All specimens were exposed to 10,000 pre-loading cycles and a load of 40 N at a frequency of 1.3 Hz in a standardized testing machine at a cross head speed of 1mm/min. Student t-test was performed to detect any difference in the mean fracture resistance between the two groups ($\alpha = 0.05$).
Results: Mean failure loads (and standard deviations) of the 12° and 22° groups were 1009.12 N (208.05) and 1182.72 N (144.67), respectively. Statistical analysis revealed a significant difference ($P < 0.04$) between the mean failure loads of the two groups. Most fractures occurred through the connectors.
Conclusion: The mean failure loads of the investigated fixed partial dentures were higher in the abutments with 22° taper as compared to those with a taper of 12°.

Key Words: Fixed partial denture; Fracture resistance; Dental ceramics, Lithium disilicate; All-ceramic; Glass ceramic; IPS-Empress 2

Journal of Dentistry, Tehran University of Medical Sciences, Tehran, Iran (2005; Vol: 2, No.4)

INTRODUCTION
The unique optical qualities and biocompatibility of all-ceramic materials are prompting greater clinical use of these materials in dental practice [1-3]. Available data from clinical studies on all-ceramic bridges indicate high success rates over 3 to 5 years, albeit using relatively small numbers of cases [4,5].
Clinical fracture resistance is regarded as a major primary outcome when considering the performance of all-ceramic bridges [4]. Investigation has revealed that failures in all-ceramic bridges originate either from the external surface of the connector or from the core/veneer interface within the gingival

portion of the connector [6]. Connectors represent the region of least cross section across the bridge, and thus are at high risk for fracture, because of the concentration of stresses in this region during flexure under occlusal loading [7]. It has been shown that stress concentration within the connectors of all-ceramic bridges is reduced when the height and width of the connectors are at least 4 mm [7-9].

By modifying the connector design in regions where maximum stress occurs, resistance of 3-unit bridges to fracture may be improved. For example, Oh et al [10,11], found a significant relationship between the curvature of the gingival embrasure and the fracture resistance of IPS-Empress 2 bridges. Several studies have demonstrated that fracture resistance of all-ceramic resin bonded bridges made of InCeram or IPS-Empress, may be increased by adding grooves or proximal boxes adjacent to the pontic area, or by deliberately increasing the bulk of the connectors [8,12,13].

IPS-Empress 2 (Ivoclar,Shcaan Liechtenstein) was introduced to dentistry in 1998 as a new all-ceramic system with high strength (Up to 350 ± 50 MPa) [14] to make single crowns and also to fabricate three-unit fixed partial dentures up to second premolars. IPS-Empress 2 is a highly crystalline (over 60 % of volume) lithium disilicate glass-ceramic. The fabricating procedure involves the lost-wax technique and processing cycle in a special heat-pressed furnace. The benefit of heat-pressed ceramics as opposed to the more traditional method of sintering are: net-shape processing, decreased porosity, increased flexural strength and excellent marginal adaptation [15].

It has been proposed that greater tooth preparation allowing increased thickness of all-ceramic crowns will increase their resistance to fracture [16]. Similarly, a larger axial convergence angle of the preparation should increase the fracture strength of all-ceramic crowns [17]. Esquival et al [18] reported that the taper of the preparation inversely affected the fracture strength of all-ceramic inlay restorations. Nevertheless, the effect of convergence of the abutments on the fracture resistance of all-ceramic bridges is not yet clear. Impaired retention is the major limiting factor in increasing the taper of the preparation [19,20]. Current bonding techniques permit a range of tapers [21] without dramatically affecting the retention of the bonded restorations [21-23].

The purpose of the present study was to evaluate the effect of the convergence angle of abutments on the fracture resistance of three unit bridges fabricated with IPS-Empress2.

MATERIALS AND METHODS

Forty caries-free, freshly extracted human molars and premolars were cleaned by hand-scaling and then stored in a 0.1% chloramine solution throughout the course of the study [24]. Teeth were selected if their length and width were within 1 mm of the mean values (mesiodistal dimension of premolars at the cemento-enamel junction (CEJ) =5.00 mm, buccolingual dimension of premolars at the CEJ = 8.00 mm, mesiodistal dimension of molars at the CEJ = 8.50 and buccolingual dimension of molars at the CEJ=9.50) [25]. None of the teeth had cracks or other defects. The tooth preparation design was the same as that used for all-ceramic crowns [26]. In brief, occlusal reduction of approximately 1.5 mm was followed by axial reduction with a circular 1 mm-deep shoulder finish line placed on the enamel, with rounded axio-gingival line angles (using a round-end tapered diamond No. 856-016, D-Z, Bern Switzerland). The axial wall height was made consistent for premolars at 5.0 mm and for molars at 4.5 mm, while all proximal walls were 4.0 mm. All margins and line angles were rounded and finished.

For this study the clinical situation of a missing second premolar was selected. The mesiodistal width of the pontic was 7.5 mm [25]. Abutment teeth were prepared with convergence angles of either 12° or 22°, with a sample size of 10 molars and pre-molars per group. The previously described methods for measurement of the convergence angle [27-29] were modified to determine the taper of the abutments, by replacing silhouette projection with digital photography. The convergence angles of all preparations were measured from printed photographs of each abutment. Three images were made for each abutment, two mesiodistally from the lingual and buccal aspects, and one buccolingually, using a digital camera (PowerShot G5; Canon Inc, NY, USA) at a fixed distance. On the printed images, lines were drawn parallel to the opposing sides until the two lines intersected, and the enclosed angle was then measured (Fig. 1).

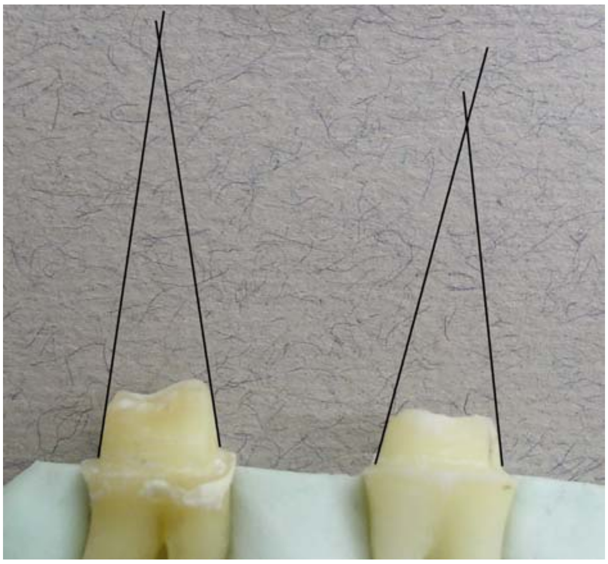

Fig. 1: Determination of the convergence angle between two opposing walls of the preparation.

To mount the teeth, the following procedures were followed: Prepared teeth were embedded in a metal box filled with melted wax (Modelling Wax; Cavex Holland BV, Haarlem, Netherlands). To align abutments both vertically and horizontally a surveyor was used (JM Ney Co,Connecticut, USA), and the mean occlusal tables of the abutments were set parallel to the horizontal plane. An occlusal index was then made using silicone impression material (Speedex light body; Coltene, Apadana Tak, Tehran Ir.) (Fig. 2 a).

In order to imitate physiological tooth mobility, all roots were covered by a uniform thin layer of polyether material (Impergum F; 3M/ESPE, Seefeld, Germany) [30-32]. To conform to the requirements of biological width, the polyether material was removed 2 mm short of the CEJ, using a scalpel. All abutments were repositioned into their silicone index. The index was then used as a guide for positioning the abutments in a sample holder filled with autopolymerizing resin (Orthoresin; Densply Detrey, Surry, UK) (Fig. 2 b).

A special tray was made with autopolymerizing resin (Major Tray; Monacalleiri, Italy) for each specimen.

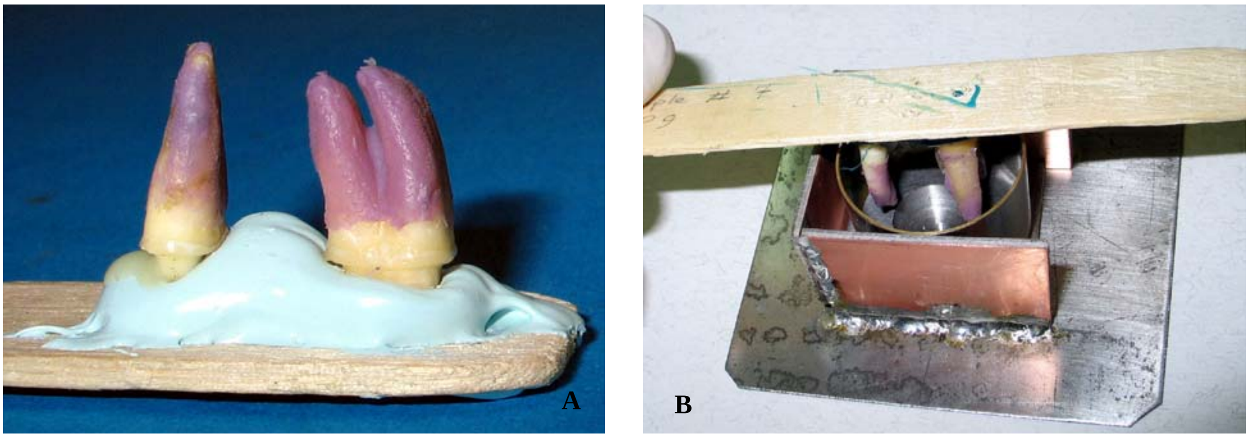

Fig. 2: Teeth were placed in the index (A), for embedding into acrylic resin (B)

An impression was taken using the putty-wash technique, with light-body silicone impression material (Imprint II Garant; 3M/ESPE, Minnesota, USA) injected around the abutments and a putty consistency used in the tray. The impression was then poured in type IV dental stone (Velmix; Kerr Corp, Orange, California, USA). Sectioned dies were prepared, and two layers of die spacer (Model Seperator; Ivoclar, Schaan, Liechtenstein) were applied. Wax-up of the core framework was performed using inlay wax (Kerr/Sybron). Connector dimensions of the framework were set to 4 mm height and 4 mm width, with a wall thickness of at least 0.8 mm. The radius of curvature at the gingival embrasure was standardized to 0.9 mm, using a carver that was shaped specifically for this purpose10 and the patterns were then sprued and invested (IPS-Empress 2 investment; Ivoclar). The investment ring was preheated, and the corresponding ingot (IPS-Empress 2 ingot 300 core material; Ivoclar) was added and formed by an automatic heat pressing process (EP 500 press furnace). The casting was cooled and rough divestment was carried out. The pressed framework was cleaned in an ultrasonic cleaner with an acidic liquid (Invex; Ivoclar) for 10 minutes. The ceramic framework was then blasted with 50µm- aluminum oxide at 1 bar pressure.

The inner surface of the retainers were abraded with aluminum oxide particles and acid etched with 4% hydrofluoric acid (Porcelain Enchant, Bisco Inc, Schaumberg, Illinois, USA) for 30 seconds, then washed and cleaned. Subsequently they were coated with a silane coupling agent (Porcelain Primer; Bisco Inc) for 60 seconds and dried lightly with air. The surface was brushed with a thin layer of light- polymerizing bonding agent (Heliobond; Ivoclar) and air dried. All abutments were etched with 37% phosphoric acid (Total Etch; Ivoclar) for 30 seconds, cleaned with water and dried with air. Dentine primer (Syntac primer; Ivoclar) was applied and air thinned after 20 seconds, which was followed by application of an adhesive (Syntac adhesive; Ivoclar) for 10 seconds; next, a bonding agent (Heliobond; Ivoclar) was applied and dispersed by compressed air. A dual cure cement (Variolink II, Ivoclar) was mixed and applied on the inner surface of all retainers. The specimens were placed on the abutments and held in place with a 5 Kg load. Excess cement was removed, and petrolatum applied to the marginal areas before light-curing the cement (Coltolux 50; Coltene/Whaleden, Cuyahoga Falls, Ohio, USA) for 60 seconds from the mesial, distal, lingual and buccal directions. Specimens were stored in a wet environment for 24 hours before the testing procedures commenced.

Each specimen was exposed to 10,000 pre-loading cycles in a computer-controlled dual-chewing machine (Oral Simulator, School of Dentistry, Tehran University of Medical Science, Iran) (Fig. 3) to disclose any gross defects in the framework.31, 32 A load of 40 N at a frequency of 1.3 Hz was applied to the center of the pontic, using an 8 mm diameter stainless steel ball as the antagonist [33-37]. After pre-loading, all specimens were loaded vertically until fracture occurred using a universal testing machine (Zwick 1490, Germany). Tin foil was placed over the occlusal surface of the pontic to achieve a homogenous stress distribution [10,38]. A

Fig. 3: Cyclic loading machine

vertical load was applied to the occlusal surface of the pontic at a crosshead speed of 1 mm/min. Modes of failure were determined and the fracture loads and curves were recorded using Zwick PC software. Statistical analysis was performed by Students t-test (α = 0.05).

RESULTS

Failure loads and modes of failure are summarized in Table I. According to the performed t-test, the mean failure loads were greater for the 22° test group as compared to the 12° study group ($P < 0.04$). The mean values (and standard deviations) for the two different divergence groups of 22° and 12° were 1190 N (145) N and 1009 N (208), respectively (Fig. 4).The mode of fracture in 15 specimens was oblique, crossing through the connectors and pontics in a gingivoocclucal direction (Fig.5), while in the remaining 5, cracks propagated bucco-lingually through the pontic. The latter pattern was observed in two specimens with 12° and in three specimens with 22° convergence angle. Most of the specimens in both groups failed through the connectors.

Table I: The failure loads and mode of fracture of specimens

12° group		22° group	
Failure loads(N)	Mode of failure	Failure loads (N	Mode of failure
766.88	Con.	1337.60	Con
830.72	Con	983.04	Con
981.12	Con	962.56	Con
1097.60	Con	1301.76	Pon
1086.72	Con	1280.64	Con
1472.00	Pon	1443.12	Con
971.22	Con	1162.24	Pon
787.20	Con	1434.88	Con
1162.24	Pon	1200.00	Pon
958.72	Con	1090.56	Con

Con = through connector; Pon = through pontic

DISCUSSION

Fracture strength tests of ceramic materials are important to gauge their probability of failure [4], however, it must be recognized that these tests cannot exactly replicate clinical situations. The loci of stress concentrations within bridges are quite different from those in bars or disks which are typically used in fracture strength and toughness tests in the dental laboratory [13]. The present study has employed an in vitro model which attempted to replicate a number of key clinical factors, using natural teeth and following a clinical sequence in fabricating and bonding the bridges. As such, the data provide some insight for clinicians in terms of performance changes that may be expected should divergence be altered.

In the present study, human extracted molars and premolars were used as abutments. In some investigations, steel or resin dies have been used for fracture testing of ceramic crowns and bridges [2,9,10]. It can be argued that a standard steel or resin die, enforces consistent preparation shape and identical physical quality of the abutments under loading, however steel or resin abutments do not reproduce the actual force distribution that occurs on crowns cemented to natural teeth [1]. Their stiffness is known to affect the

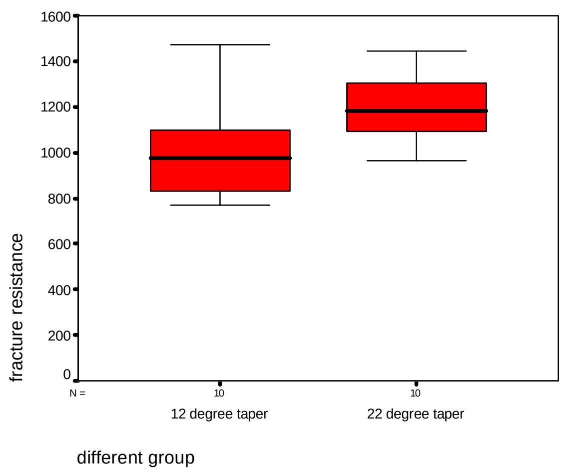

Fig. 4: Box plot showing the range of fracture resistance in two test groups (12 ° taper on the left)

Fig5: Oblique fracture through the pontic and gingival embrasure.

fracture resistance of ceramic crowns, and to increase failure under loading [39,41]. The complex interactions between dentine and adhesives cannot be tested in these die materials. In the present study, all selected teeth were similar in size, height and condition (caries free, no attrition). In addition teeth with obviously thin dentine walls were not used as abutments after preparation was completed.

Minimal tooth preparation taper has been regarded as an essential factor in retention of indirect cast metal restorations. Tylman [17] recommended a convergence angle of 4 to 10° as optimal, however small convergence angles may not be achievable clinically. Mack [40] advised 12°, while Poon et al [41] and Smith et al [42] recommended single crown convergence angles from 12° to 20°. According to Shillingburg [28], the optimum taper ranges from 14° for premolars to 24° for molars. Thus, in the present study, 12° and 24° were used.

It has been demonstrated that abutment mobility is a decisive clinical factor in the fracture resistance of bridges [6,40]. When a small amount of abutment rotation is allowed, failure is more probable. For this reason, in the present study, an artificial periodontal ligament analogue as described by Loose et al [32] and Behr et al [25] was used to simulate physiological tooth mobility. However, the cyclic loading and aqueous conditions found within the oral cavity and the different possible directions of loading which can occur under masticatory or parafunctional activities, could not be reproduced in the present study [6,42]. Bridges made of high strength core ceramics gain their strength from the core material. Veneering will increase the load required for failure, provided that there is a stable bond between the veneering layer and core ceramic [38]. Imperfections in the veneering material on the outside or at the veneer/core interface will allow crack propagation during loading and will thus contribute to failure [6]. In the present study, only the ceramic was tested to avoid the influence of the veneer/core interface on the failure process. Moreover, all specimens underwent a cycling pre-loading of 40 N applied to the occlusal surface of the mid-pontic area, to simulate a worst-case scenario condition [33]. Any grossly defective ceramic specimen would have failed during this process.

Considering the fact that contact area can influence the failure mechanisms in samples loaded under laboratory conditions, the size of the ball used for loading was selected to simulate cuspal radii in the posterior region. [37] One point contact was avoided to prevent possible failure by impact force which is rare in clinical situation [10]. The cracks which led to catastrophic failure, in the specimens used in this study, followed one of two patterns. The most common mode of failure (15/20), in which cracks propagated obliquely through the gingival embrasure and pontic, connecting the gingival embrasure to the occlusal contact area, has been noted in other studies [2,10,13]. Earlier investigations [37,41] on high strength heterogeneous ceramics have shown that the large contact area achieved with a large diameter steel ball produces a conical crack zone under blunt indentation static loading. Further cracks then propagate from this zone, resulting eventually in gross failure of the restoration.

The results of the present study indicate that increasing the convergence angle of the abutments, increases the fracture resistance of ceramic bridges. This effect can be explained by the greater bulk of material in the connector regions. Such tapering of the abutment preparations adds to the bulk of the connectors without adversely affecting the embrasure morphology. Detailed analysis of stresses in the ceramic material (e.g. by finite element analysis) would confirm the effect of geometrical changes on force distribution within the tooth-restoration complex.

It has been proposed that posterior bridges should be strong enough to withstand a mean load of 500 N [2]. The endurance limit for fatigue cycling that can be applied to dental ceramics is approximately 50% of their maximum fracture strength [2,10]. On this basis, it is reasonable to estimate that fracture strength of approximately 1000 N would be required for all-ceramic bridges. Mean failure loads in the present study were within this range and were in agreement with previous studies [2,9,10]. While caution must be exercised when extrapolating such laboratory data to clinical situations, given the above mentioned facts, it appears that three unit all-ceramic bridges may be able to replace selected anterior missing teeth or premolars.

CONCLUSION

Within the limitation of the present study the following conclusion was made: The mean failure loads of the investigated fixed partial dentures were higher in the abutments with 22° taper as compared to those with a taper of 12.

AKNOWLEDGMENT

The authors would like to thank Dr. MJ. Kharazi for statistical advice, and Mr. M. Heidari for expert assistance with some of the laboratory aspects of the study. Nikjuyan Inc. (Ivoclar Iran, Tehran Iran) provided the ceramic materials used in the study.

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تأثیر درجه تقارب تراش دندانهای پایه بر مقاومت به شکست بریجهای سه واحدی تمام سرامیک

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چکیده

بیان مسأله: ناحیه اتصال ضعیف‌ترین نقطه در پروتزهای ثابت تمام سرامیک است که می‌تواند منجر به شکستهای غیر قابل جبران این پروتزها شود.

هدف: هدف از مطالعه حاضر ارزیابی اثر زاویه تقارب تراش دندانهای پایه بر میزان مقاومت به شکست بریج‌های سه واحدی تمام سرامیک است.

روش تحقیق: تعداد ۴۰ دندان پرمولر و مولر انسانی جهت بازسازی بیست بریج سه واحدی برای جایگزینی دندان پرمولر دوم انتخاب شدند. تمامی نمونه‌ها براساس دستورالعمل تراش دندانهای پایه بریج‌های تمام سرامیکی به جز از نظر زاویه تقارب تراش آماده شدند. نمونه‌ها به طور تصادفی به دو گروه با مجموع زوایای تقارب اکلوزالی ۱۲و ۲۲ درجه تقسیم شدند. پروتزهای ثابت سه واحدی از جنس IPS-Empress ۲ با ضخامت یکنواخت ۰/۸ میلی‌متر ساخته و بر روی دندانهای پایه چسبانده شدند. عرض و ارتفاع ناحیه اتصال به اندازه چهار میلی‌متر ساخته شد. شعاع قوس امبرژور لثه‌ای در حد ۰/۹ میلی‌متر درنظر گرفته شد.

در بارگذاری اولیه هر نمونه ۱۰/۰۰۰ بار تحت نیروی معادل ۴۰ نیوتن با فرکانس ۱/۳ هر تز قرار گرفتند و سپس توسط دستگاه آزمون استاندارد (Zuick) با سرعت Cross-head یک میلی‌متر در دقیقه میزان مقاومت به شکست آنها اندازه‌گیری شد. آنالیز آماری t-student جهت مقایسه مقاومت به شکست در دو گروه با درنظر گرفتن خطای نوع اول آماری برابر ۰/۰۵ استفاده شد.

یافته‌ها: میانگین مقاومت به شکست و انحراف معیار در گروه ۱۲ درجه ۲۰۸/۰۵±۱۰۰۱۲/۱۲ نیوتن و در گروه ۲۲ درجه ۱۴۴/۶۷±۱۱۸۲/۷۲ نیوتن بدست آمد. اختلاف آماری بین این دو میزان معنی‌دار بود (P<۰/۰۵). شکستها عمدتاً در ناحیه اتصال دیده شد.

نتیجه‌گیری: میزان مقاومت به شکست پروتزهای ثابت با درجه تقارب تراش ۲۲ درجه بالاتر از درجه تقارب ۱۲ درجه است.

واژه‌های کلیدی: پروتز ثابت؛ مقاومت به شکست؛ سرامیکهای دندانی؛ لیتیوم دی‌سلیکات؛ تمام سرامیک۲ IPS-Empress

مجله دندانپزشکی دانشگاه علوم پزشکی و خدمات بهداشتی، درمانی تهران (دوره ۲، شماره ۴، سال ۱۳۸۴)