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Influence of Implant Abutment Angulations and Two Types of Fibers on the Fracture Resistance of Ceramage Single Crowns

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Abstract

Purpose: To assess the effect of three implant abutment angulations and two types of fibers on the fracture resistance of overlaying Ceramage single crowns.
Materials and Methods: Three groups, coded A to C, with different implant abutment angulations (group A/0°, group B/15°, and group C/30° angulation) were restored with 45 overlay composite restorations; 15 Ceramage crowns for each angulation. Groups A, B, and C were further subdivided into three subgroups (n = 5) coded: 1, crowns without fiber reinforcement; 2, crowns with Connect polyethylene reinforcement; and 3, crowns with Interlig glass reinforcement. All crowns were constructed by one technician using the Ceramage System. The definitive restorations (before cementation) were stored in distilled water at mouth temperature (37°C) for 24 hours prior to testing. Before testing, the crowns were cemented using Temp Bond. The compressive load required to break each crown and the mode of failure were recorded. The speed of testing was 1 mm/min. The results were statistically analyzed by two-way ANOVA ($p < 0.05$). The tested crowns were examined using a stereomicroscope at 40×, and selected crowns (five randomly selected from each group) were further examined by scanning electron microscopy (SEM) to reveal the composite–fiber interface.
Results: Fracture resistance of single crowns was not affected ($p > 0.05$) by the different abutment angulations chosen (0°, 15°, 30°) or fiber reinforcement (Connect and Interlig fibers). Crowns in group A exhibited average loads to fracture (N) of A1 = 843.57 ± 168.20, A2 = 1389.20 ± 193.40, and A3 = 968.00 ± 387.53, which were not significantly different ($p > 0.05$) from those of groups B (B1 = 993.20 ± 327.19, B2 = 1471.00 ± 311.68, B3 = 1408.40 ± 295.07), or group C (C1 = 1326.80 ± 785.30, C2 = 1322.20 ± 285.33, C3 = 1348.40 ± 527.21). SEM images of the fractured crowns showed that the origin of the fracture appeared to be located at the occlusal surfaces of the crowns, and the crack propagation tended to extend from the occlusal surface towards the gingival margin.
Conclusions: Implant abutment angulations of 0°, 15°, and 30° did not significantly ($p > 0.05$) influence the fracture resistance of overlaying Ceramage single crowns constructed with or without reinforcing fibers. The two types of fibers used for reinforcement (Connect and Interlig) had no effect ($p > 0.05$) on the fracture resistance of overlaying Ceramage single crowns.

The need for angulated abutments in implant dentistry has become necessary to enable the production of functional and esthetic restorations as a result of patient and clinician expectations. Biomechanical considerations play a role in the planning of fixed prostheses supported by osseointegrated implants, where the design of crown contour as well as occlusal form should be considered in conjunction with appropriate implant location.[1] Angulated abutments may be used to overcome non-ideal implant location due to a lack of bone.[2] However, the high stresses created by using angulated abutments at the cervical zone of an implant could be a dominant factor influencing the success of the restoration.[1] A recent review reported that identical vertical loads applied to pre-angled abutments produced higher stresses at the coronal zone of the implant compared with regular abutments.[1] Concern about the survival of implants loaded by means of angulated abutments has largely been dispelled,[3] and angulated implant placement to optimize the available bone is seen as an advantage.[4] Angulated abutments of up to 45° have been used[4] and did not compromise the long-term survival of implants. Factors that may have contributed to the high survival rate include that the implants were placed without compromising labial or palatal bone, and that longer implants were placed, maximizing the use of available bone.[4]

Using angulated abutments with different types of restorative materials to construct the overlaying crowns are significant factors in determining the amount and distribution of the stresses loaded onto the superstructure and implant under functional forces.[5] Superstructures on dental implants commonly consist of a metal framework veneered with ceramic or composite facings. The metal framework is concealed with an opaque material that limits the use of naturally translucent facings.[6] As an alternative, fixed partial dentures made of fiber-reinforced composites offer high fracture strength in combination with a tooth-colored appearance.[7] Recently, there have been considerable advances in fiber-reinforcement technology,[8] with numerous types of fiber systems being used to reinforce the overlaying veneering composite resins. Veneering composites are now manufactured as a separate group of materials. The difference between veneering and restorative composites generally involve more-intensive light curing for the veneering composites involving post-conditioning of the surface.[9] Veneering composites are mainly hybrid composites that contain slightly larger glass particles of about 0.4 μm. Ceramage (Shofu Dental Products, Inc., Kyoto, Japan) is a light-cured, zirconium silicate indirect hybrid composite recommended for use in both anterior and posterior regions. A progressive fine structure (PFS) filler of more than 73% by weight plus an organic polymer matrix is claimed to deliver superior flexural strength, elasticity, and clinically acceptable polishability. It is claimed to be highly resilient and more elastic than conventional ceramics.[9] No published data have reported the clinical potential of Ceramage restorations with/without fiber reinforcement.

It is hypothesized that since implant abutment angulations could affect the stress concentration distribution within the overlaying Ceramage composite crowns tested in the current study, the use of E glass fibers and ultra-high molecular weight polyethylene (UHMWPE) fibers could reinforce Ceramage composite restorations to improve the load-bearing capacity of the crowns used. The aim of this study was to investigate the effect of three implant abutment angulations (0°, 15°, and 30°) on the fracture resistance of Ceramage single crowns reinforced with two types of fibers (pre-impregnated Interlig glass or Connect UHMWPE reinforcements).

Materials and methods

Implants and abutments were supplied by Dentsply (York, PA) using the ANKYLOS® Plus System (ANKYLOS®, Friadent GmbH, Mannheim, Germany, Lot 20029618). Three abutment angulations were chosen: 0° (balance posterior, Lot 20031417), 15° (balance posterior, Lot 20035459), and 30° (balance posterior, Lot 20037419). Forty-five overlaying crowns were constructed using the Ceramage indirect composite system. Three groups of 15 specimens were constructed for each abutment angulation of 0° (group A), 15° (group B), and 30° (group C). Within each group, three subgroups were created (of five specimens), coded 1 to 3 [1: without fibers, 2: containing Connect (polyethylene) fibers (Kerr, Orange, CA), and 3: containing Interlig glass fibers (Interlig-Ângelus/glass, Londrina, Brazil].

A one-stage impression was taken of each implant abutment angulation using a poly(vinyl siloxane) putty and light-bodied paste (Coltene Rapid, Coltene, Altstatten, Switzerland) in a stock plastic tray painted with tray adhesive. Original impressions were cast in moonstone artificial stone (John Winter, Halifax, Yorkshire, UK) and duplicated using addition-cured silicone duplicating material into which refractory models were poured using Mirage T.J. vest refractory model material (Mirage Dental Systems, Kansas City, KS), mixed as per manufacturer's instructions under vacuum for l0 seconds. The diagnostic premolar crown wax-ups were created using a preformed putty key where liquid wax was injected and vented out the other side. In this way, a detailed reproduction of the wax pattern was obtained with full anatomical contour, and as the putty key was used for each restoration, variables in contour were reduced (Fig 1A, B). Crowns were constructed in Ceramage by one technician using a standardized technique. For subgroup 1, the crowns were made from Ceramage alone, for subgroup 2, Connect fibers were placed along the occlusal wall, while for subgroup 3, Interlig glass was placed along all the axial walls.

The manufacturing process began with isolating the stone models using the AB rubber separator (SDS, Kerr) in a thin layer over the coronal surface of each die. Copings of approximately 0.3 mm (measured with digital calipers) were formed using the opaque dentin shade of Ceramage. Before the uncured copings could be reinforced with the woven polyethylene fibers (Connect) and woven glass fibers (Interlig), they were pre-impregnated with a low-viscosity resin (Kolor Plus, SDS). The premolar crown shapes were built up with the Ceramage dentine material and light cured after each step in the Solidlite curing oven (Shofu) for 2 minutes. The marginal fit of each crown on the abutment was examined (Fig 1C), and in any specimen where the fit was considered unsatisfactory, a new impression was taken and a new crown constructed.

Each abutment attached to an implant fixture was aligned with the fixed abutment uppermost with its long axis vertical in a stainless steel mold ($15 \times 15 \times 15$ mm^3) having a 12-mm diameter central hole using an autopolymerizing acrylic resin (Palapress Vario, Kulzer, Wehrheim, Germany), which was then secured in a prefabricated steel jig to allow compressive testing (Fig 1D). The resin extended to the implant abutment junction.

Each crown was stored in distilled water at mouth temperature (37°C) for 24 hours prior to testing. The crowns were cemented using TempBond® NE unidose (SDS), which was applied as a thin layer to the walls of the crown and allowed to set for 2 to 3 minutes under gentle finger pressure before removing excess cement.

Crowns were then subjected to compressive loading at a 1 mm/min crosshead speed[10] in a universal testing machine (Shimadzu Autograph AG-50 kNE, Shimadzu Co., Ltd., Kyoto, Japan). Compressive force was applied by means of

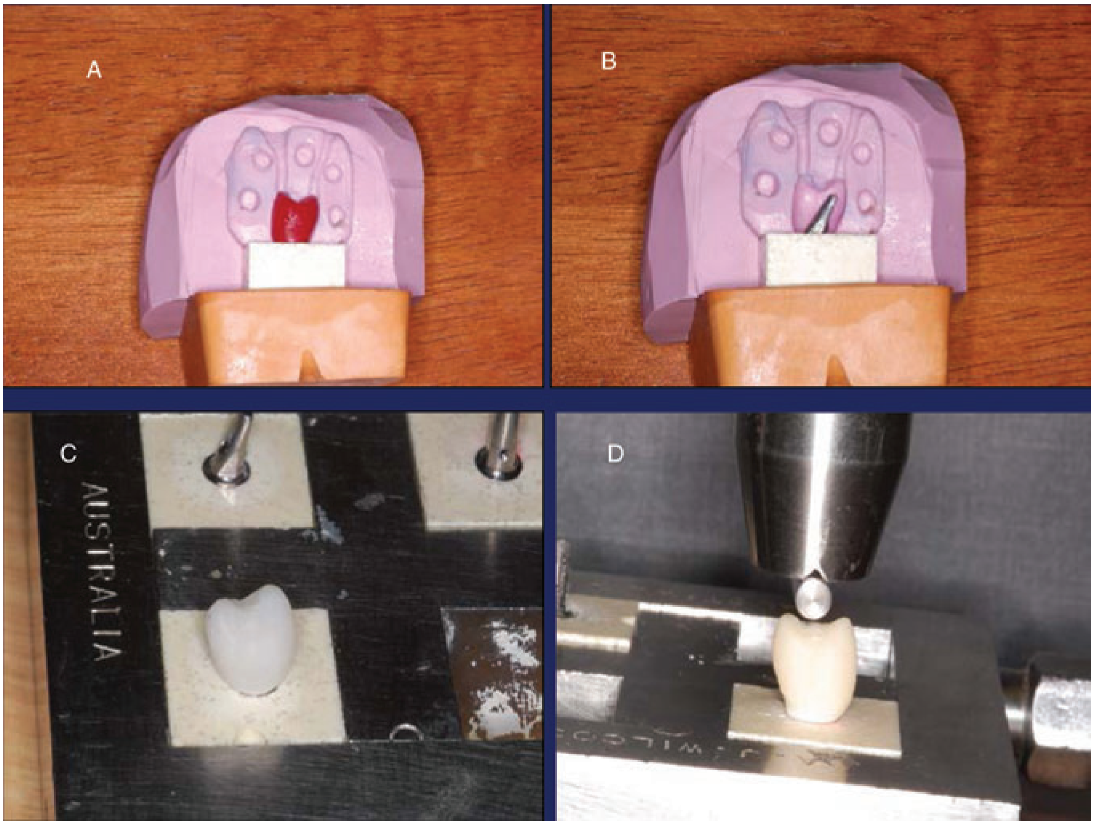

Figure 1 (A-B) Diagnostic wax set-up of the crown using a silicone putty key before processing, to standardize the external crown contour. (C-D): Photograph depicting the final form of the Ceramage crowns (C). Position of the 4 mm roller prior to testing (D).

Table 1 Classification of modes of failure modified from Ellakwa et al[10]

Code	Description
I	Minimal chipping, capable of refinishing and repair
II	Less than half the crown lost, but the fibers are not exposed
III	Crown fracture through midline, half the crown displaced or lost, and the fibers are exposed
IV	More than half the crown lost, and the fibers are exposed, but still intact
V	Severe fracture of the fibers and the crown

a 4 mm diameter steel bar placed along the midline fissure of the premolar crown. The force required (N) to cause fracture of the crown and the mode of failure were recorded using a classification designed for the investigation, according to Ellakwa et al.[10] Means and standard deviations for each group were calculated and compared. Two-way ANOVA ($p < 0.05$) was used to analyze fracture resistance data. Two dentists (raters I, II) assessed each tested crown to determine the mode of failure according to the criteria summarized in Table 1.

The interexaminer reliability was assessed using weighted kappa statistics in which a linear weighting system for the scores using a six-point scale was employed. The strength of agreement was very good (weighted kappa value = 0.87).

The broken fragments were then examined using an optical microscope under low magnification (40×). Representative failed specimens from each fracture type were selected and gold sputter coated (Emitech K550x Kent, UK) before fractographic analysis was carried out using a scanning electron microscope (Philips XL30 CP, Philips, Eindhoven, Netherlands) to identify crack propagation patterns. Special attention was focused on the loading surface and the fiber composite interface.

Results

Fracture resistance of the different groups tested are presented in Table 2. Abutment angulations (0–30°) and fiber reinforcements did not statistically significantly ($p > 0.05$) affect the fracture resistance of the tested groups. Data indicated that 71% of Ceramage crowns were still attached following fracture, and of the remaining 29% of fractured crowns (11% group A1; 11% group B1; 7% group C1), the titanium abutments used to support the crowns during testing remained intact.

The fracture modes of the tested groups are presented in numbers and proportions in Table 3. In subgroups A2, A3 (0° angulation), B2, B3 (15° angulation), and C2, C3 (30° angulation) the crowns reinforced with Connect and Interlig glass fibers produced fractures (mode I to III) that would be considered suitable for repair. SEM examination of the

Table 2 Mean fracture strength (SD) in Newtons of all tested groups

		Subgroups		
		1	2	3
Group name	Angulations	Ceramage only	Ceramage + Connect fiber	Ceramage + Interlig glass fiber
A	0°	843.57 (168.20)	1389.20 (193.40)	968.00 (387.53)
B	15°	993.20 (327.19)	1471.00 (311.68)	1408.40 (295.07)
C	30°	1326.80 (785.30)	1322.20 (285.33)	1348.40 (527.21)

Table 3 Types and numbers (percentage) of failure modes for groups A, B, and C

		Mode of failure Number (percentage)					
Group	Subgroup	I	II	III	IV	V	Intact crown
A	**1**	0	0	4(80%)	1(20%)	0	No
	2	2(40%)	1(20%)	2(40%)	0	0	Yes
	3	0	1(20%)	2(40%)	2(40%)	0	Yes
B	**1**	0	0	3(60%)	2(40%)	0	No
	2	1(20%)	3(60%)	1(20%)	0	0	Yes
	3	1(20%)	3(60%)	1(20%)	0	0	Yes
C	**1**	0	0	3(60%)	2(40%)	0	No
	2	2(40%)	2(40%)	1(20%)	0	0	Yes
	3	2(40%)	2(40%)	1(20%)	0	0	Yes

fractured interface showed the weave pattern of Connect fiber and composite pre-impregnation and the weave pattern of Interlig glass fibers (Fig 2). Microscopic examination of the fractured surfaces of the crowns revealed that the fracture origin appears to be located at the occlusal surface of the crowns (Fig 3) and radiates towards the gingival margin. It was also noted that cracks propagated from the occusal surface, and were then arrested by the fibers, with debonding occurring between the fiber and the matrix or fracture of the fiber itself (in the case of Interlig glass fibers) (Fig 3). SEM examination of unreinforced Ceramage crowns showed cracks that had propagated through the composite matrix and then were arrested by the zirconia fillers within the composite (Fig 4).

Discussion

The aim of the current study was to investigate the influence of both implant abutment angulations (0–30°) and fiber reinforcement (glass vs. UHMWPE) on the fracture resistance of the overlaying Ceramage crowns. The results suggest that if an abutment crown fails it will be through the crown material and is not related to the fiber type or implant abutment angulation. Implant abutment angulations (group A/0° to group C/30°) did not affect the fracture strength of the overlying Ceramage crowns. The current results indicated that a 30° implant abutment angulation (group C) did not significantly ($p > 0.05$) reduce the fracture resistance of the overlaying Ceramage crowns with or without fibers. Comparing these results with those of Ellakwa et al,[11] the difference in data values can be attributed to the difference in the rigidity of the two restorative materials tested.

The fracture resistance of fiber-reinforced Ceramage crowns was not superior to those of the unreinforced Ceramage crowns; however, the mode of failure was completely different. These results are in contrast to those published by Fennis et al.[12] Furthermore, differences can be due to variations in the properties of the fibers used as reinforcement and the amount of fibers placed within the crown.

The fracture resistance of unreinforced Ceramage single crowns ranged from (843.57 ± 168.20 to 1326.80 ± 785.30 N). This enhanced performance may be attributed to the ability of the fillers within the Ceramage material to absorb and resist the propagation of cracks. This was also seen during SEM examination of the fractured unreinforced single crowns, where minute cracks were arrested by the zirconia microfillers within this restorative material (Fig 4). The high performance of unreinforced crowns in the current study is consistent with those of Garoushi et al,[13] who reported that fiber reinforcement was able to improve the load capacity of crowns made from flowable composite (Sinfony, 3M ESPE, St. Paul, MN) not from Z100, which is a highly filled composite similar to the overlaying Ceramage composite used in the current study; however, it is difficult to compare failure loads reported in the literature to those found in this study, due to the different experimental variables.

The non-impregnated UHMWPE fibers used in subgroup 2 were placed occlusally, and the pre-impregnated glass fibers used in subgroup 3 were placed circumferentially due to difficulties experienced by the technician placing them occlusally. This may have affected the efficiency of reinforcement. The use of woven and pre-impregnated fibers (Fig 2) facilitated their bonding to the overlying composite but did not improve

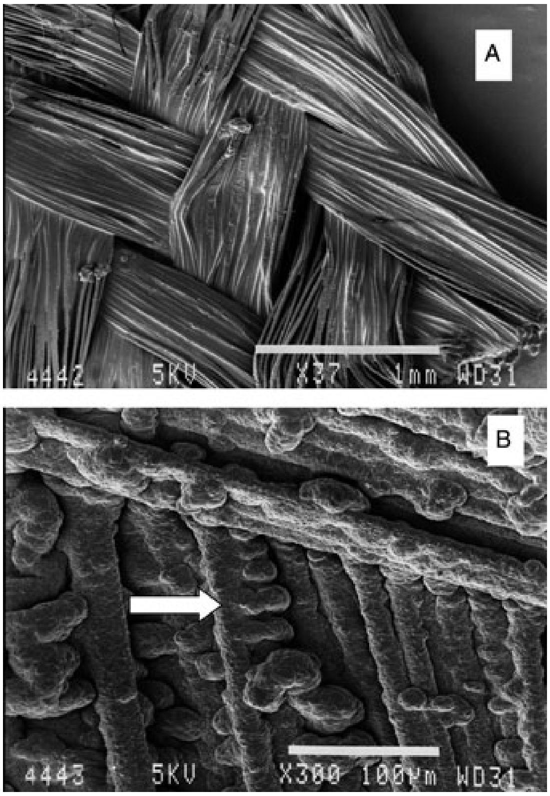

Figure 2 SEM showing the weave pattern of Connect PE fibers (A) and composite pre-impregnated (arrow) Interlig glass fibers (B).

the resistance to failure. These results are attributed to the difference between the two types of fibers in composition and position within the crown. Glass fibers are stiffer than PE, but this should not affect the fracture resistance of the Ceramage crowns. A decrease in interfacial adhesion between the fiber and the composite matrix might account for variation in the mechanical strength of fiber-reinforced crowns (Fig 3). SEM examination of the fractured fiber-reinforced crowns (Fig 3) showed that cracks were propagated from the occlusal surface towards the gingival margin, which may be attributed to different stresses generated by the degree of abutment angulation and direction of the occlusal compressive load. When comparing the fracture resistances of Ceramage crowns reinforced with both Connect and Interlig fibers, differences can be attributed to the physical properties of these two fibers and their ability to bond to the overlaying composite matrix. The durability of this bond depends on the silanization of the Interlig fibers or the amount of remaining oxygen inhibited layer following curing.[14,15] Other factors that might affect the fracture resistance of fiber-reinforced Ceramage crowns include the position, direction, architecture, and volume of the fibers within the crowns.[16] In the current study the two fibers used are woven, and this might be responsible for the insignificant difference noted between the fracture strengths of the crowns using the two fibers. According to the Krenchel formula,[16] a lower reinforcement efficiency occurs with the use of woven fibers than with unidirectional fibers.

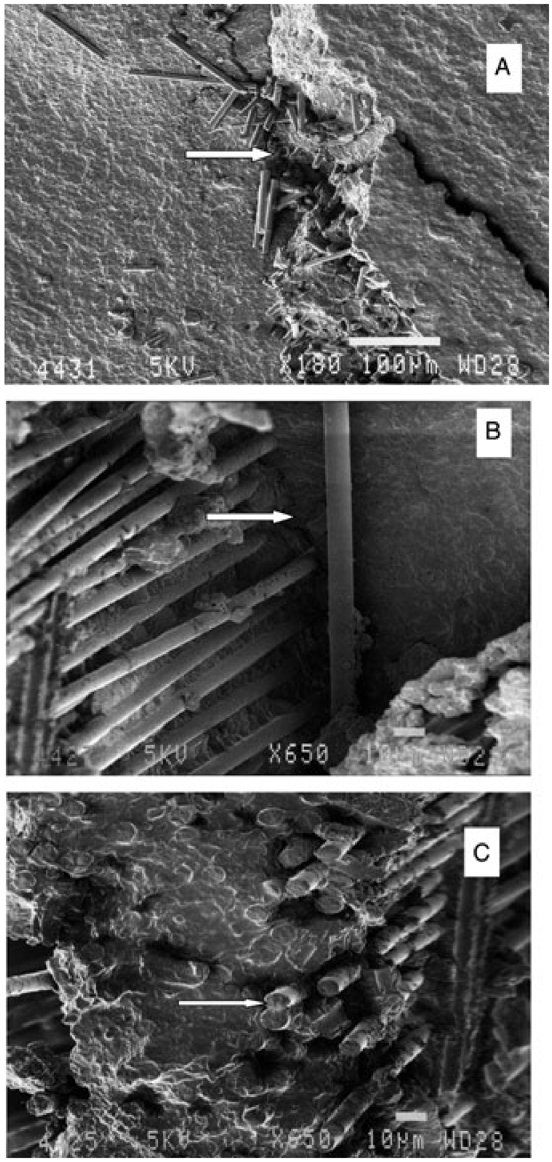

Figure 3 SEM showing the fiber matrix interface (arrow) of a fractured specimen reinforced with fibers (A); SEM of crack propagation (arrow) and debonding of the fiber from the resin matrix (B); SEM of crack propagation and fracture (arrow) of the glass fibers (C).

The volume of fibers used in this study was inadequate to make a significant difference in the fracture strength due to the limited space of premolar crowns being used. This limited volume fraction of fibers may then function as a foreign body in the mass of veneering composite,[17] possibly weakening the entire crown.

The reduced incidence of porcelain or acrylic fracture of prostheses observed with cement-retained restorations compared with screw-retained prostheses can be explained by the screw access increasing the stress concentration on the restoring material, which may lead to unsupported porcelain.[18] For this reason, cement-retained Ceramage crowns were tested in the current study. Luting agents retain and seal the crown onto

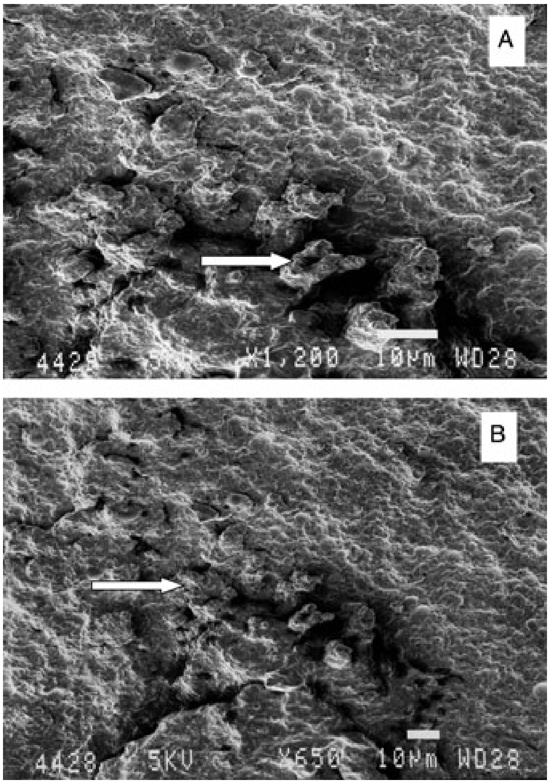

Figure 4 SEM pictures (A and B) showing the fractured surface of unreinforced Ceramage crowns where minute cracks (arrow) were arrested by the microfillers within this restorative material.

the tooth. The type and thickness of the cement layer has been shown to have both little or no effect[19,20] or a substantial effect on the fracture resistance of overlaying ceramic crowns.[21,22] In the current study, a temporary cement was used to simulate the clinical situation and also to reduce the effect of cement properties on the results. A minimal amount of cement was applied to the internal surfaces of each crown, which was fitted with gentle finger pressure. The pressure applied was not standardized; however, this should not be considered a major shortcoming of the study.

The difference in failure mode between reinforced and unreinforced crowns within the current study can be attributed to the fiber reinforcement. The modes of failure of reinforced subgroups 2 and 3 (modes I and II) indicated the possibility of repair of the fiber-reinforced Ceramage crowns.

Craig and Powers[23] reported an average biting force of 665 Ncm (approximately 150 pounds) for natural teeth in the molar region. The results of this study showed that the load to fracture of cemented Ceramage crowns was well above the average occlusal force applied in the molar region.

The results of this study must be considered in light of the model system used. This model tested a dental material in a static manner. To simulate clinical conditions, lateral forces should be considered, as should axial forces and fatigue loading. Aging processes such as alternate thermal stress, mechanical stress, wear and long-term water storage should also be taken into consideration. Stress applied to teeth and dental restorations is generally low and repetitive; however, because of a linear relationship between fatigue and static loading, the compressive static test used in the current study also provided valuable information concerning potential load-bearing capacity. In the current study, the slow crosshead speed of testing (1 mm/min) was used to enable a comparison of the current results with those of Ellakwa et al[11] and also to simulate the clinical situation by allowing time for cracks within the restoration to propagate.[7] Within this study every effort was made to standardize the occlusal surface contour of the overlying Ceramage crown, but because of the difference in implant abutment angulations, this was difficult to achieve, and further study is needed to assess the effect of the cusp angle on the scatter of compressive failure loads recorded using this model. From the results of the current study and from previously published data reporting the clinical success of angulated abutments,[24] we can recommend the use of both unreinforced and fiber-reinforced Ceramage overlaying crowns with these angulated abutments.

Conclusions

Within the limitations of this study, the following conclusions were made:

1. Implant abutment angulations of 0 to 30° did not significantly ($p > 0.05$) influence the fracture resistance of overlaying Ceramage single crowns constructed with or without reinforcing fibers.
2. The two types of fibers used for reinforcement (Connect and Interlig) did not affect ($p > 0.05$) the fracture resistance of overlaying Ceramage single crowns.

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