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Cyclic Loading of Endodontically Treated Teeth Restored with Glass Fibre and Titanium Alloy Posts: Fracture Resistance and Failure Modes.

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Abstract - *The aims of this in-vitro investigation were to compare the fracture resistance and the failure modes of endodontically treated teeth restored with glass fibre-reinforced posts with those of teeth restored with titanium-alloy posts. A total of 60 single-rooted human mandibular premolars were endodontically treated. The teeth were divided into two experimental and one control group. Post spaces 9mm long were prepared in the roots of the experimental groups in which glass fibre-reinforced posts (Group A) and titanium-alloy posts (Group B) were cemented. In the control group (Group C), no post was inserted. The specimens were stored in normal saline for a period of three weeks before being intermittently loaded at an angle of 30° degrees to the long axis of the tooth at a frequency of two loads of 40N per second. Log-rank test used for the overall analysis revealed that there was no significant difference of fracture resistance between teeth restored with glass fibre-reinforced posts (Group A) and titanium-alloy posts (Group B). The survival of the control group was found to be significantly inferior to that of the experimental groups. There was no significant difference in the number of failures between the two experimental groups. There was significantly more core and post failure for the glass fibre-reinforced posts, root and core failure for the titanium-alloy posts and core failure for the control group. The results suggest that post failures are more frequent in teeth restored with quartz fibre posts and root fractures are more frequent in teeth restored with titanium posts.*

KEY WORDS: Fibre posts, Titanium posts, Endodontics, Fracture test

INTRODUCTION

Endodontically treated teeth with severe loss of coronal tooth structure are frequently restored by using individually cast posts and also prefabricated metal and fibre posts supporting composite or amalgam cores. Among metal posts, prefabricated posts made of titanium alloys are becoming increasingly popular because of their favourable physical properties and their resistance to corrosion. An ideal post is capable of providing retention and support to the core. It also allows forces to be transferred to the tooth in a way as not to induce root fracture[1].

In retrospective clinical studies the prevalence of root fractures of teeth restored with cast posts was found to be higher than that of teeth restored with prefabricated metal and fibre-reinforced posts[2,3]. Three prospective clinical studies have been published showing the complete absence of root fractures in teeth restored with fibre posts and composite cores[4,5,6]. However, the superior flexibility of fibre-reinforced posts has been thought to be the cause of the high number of decementations of fibre posts reported in an alternate study[7].

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The fracture resistance of teeth restored with metal and fibre posts has been investigated using fatigue testing[8,9]. This pattern of loading attempts to simulate the cyclic masticatory forces *in vivo*. A cyclic loading test evaluating post-core restorations of teeth covered with metal crowns showed that fibre-reinforced post-composite core restorations were less likely to generate root fractures than their stainless steel post and composite core counterparts[10]. Similarly, more root fractures associated with metallic posts were demonstrated when compared with the more benign fracture type within the fibre-reinforced post group. In all of these studies the posts included were different in shape, therefore the results of these cyclic loading tests might be due not only to the post material but also to the post shape.

Glass fibre reinforced posts (Fibre White ParaPost) and titanium posts (Para Post XP) of identical shape and sizes are now available. Therefore, the objectives of this study were twofold firstly to compare the resistance to fracture of endodontically treated teeth restored with glass fibre-reinforced posts, prefabricated titanium-alloy posts and those without posts and secondly to compare the mode of failures i.e. either retrievable or irretrievable between the experimental groups. The most significant mode of failure within each of the experimental groups was also evaluated.

The following null hypotheses were tested:

1. There is no effect of post type on fracture resistance
2. There is no effect of post type on mode of failure.

MATERIALS AND METHODS

Sample preparation

Sixty extracted singled-rooted human lower premolars were selected. Caries-free and intact teeth extracted for orthodontic and periodontal reasons were included in this study, which had received appropriate ethics committee approval. All teeth were kept hydrated in saline solution during all procedures. The teeth were divided into 3 groups of 20 each. The experimental model used was that described by Isidor[8] (1996) with some modifications. The crowns were removed with a round end tapered, size no.2 diamond bur mounted on a turbine handpiece. A length of 14mm was established for all roots and canal access was carried out using the round head, no.2 diamond bur. The pulp remnants were removed using barbed broaches where necessary and the canals were prepared chemo-mechanically using a crown-down technique with 25 mm Hedstroem hand files, with sizes ranging from 10 to 35. 1% w/v sodium hypochlorite (Milton sterilising fluid) was used to irrigate the root canals and then dried with absorbent paper points and air. Root canal obturation was performed using cold lateral condensation of gutta-percha with a non-eugenol root canal sealer (Sealapex). The bucco-lingual and mesio-distal diameters of the roots were noted and the samples left undisturbed for a period of 24 hours to allow the materials to set.

The samples were ranked according to size and placed into the 3 groups using a stratified sampling method so each group included samples of approximately the same size. After 24 hours, the samples in Groups A and B were prepared to receive the appropriate posts. Gates Glidden drills (sizes 2, 3 and 4,) were utilized to remove 9 mm of the gutta-percha root canal filling material, leaving 5 mm as the undisturbed apical seal. In all groups, the root canals were enlarged with slow-speed post drills provided by the manufacturers. The depth of the posthole was 9 mm. The post length was 11.5 mm with 2.5 mm extended coronally in order to hold the resin core. Table 1 shows the different post and core systems used in this study. The canals were rinsed with water spray and gently dried using paper points and air. The post diameter used in all cases was 1.14mm. RelyX Unicem Maxicap dual resin luting cement was applied into the canal and to the surface of the posts in Group A (Fibre White ParaPost) and Group B (Titanium-alloy ParaPost XP). The posts were inserted into the canals and the luting cement was light cured and allowed to set. The remaining coronal surface of the tooth was etched with 35% phosphoric acid for 30 seconds and the dual-cured ParaCore Automix resin system was used to manufacture the sample cores. The etchant gel was rinsed off with water spray and water excess was removed with a short blast of air. A moist bonding technique was employed using a mixture of the supplied Adhesive conditioner A and Adhesive Conditioner B, prepared to L 1 ratio. The mixed conditioner was scrubbed with a brush onto both dentine and enamel and allowed to take effect for 30 seconds. Gentle air spray was applied to help create a smooth surface. The appropriate size of ParaForm core formers, were used to construct resin core build-ups of similar sizes. The dual cure resin ParaCore Automix was extruded directly into the Paraform core formers using the automix dispenser. The filled core former was seated gently over the tooth/post and excess was removed with a flat plastic instrument. Each surface was light cured for 40 seconds and the resin build up was finally polished with rotary instruments. No posthole preparation was made in the control group samples and only 3 mm of the coronal part of the gutta-percha root canal filling was removed with size 4 Gates Glidden drills. The coronal part of the canal was filled with Para Core Automix and the core build-up was then performed using the same dual cure resin. A thin layer of soft silicone putty (Aquasil) was applied along the root surface to simulate the periodontal ligament. A custom-made brass metal mould was made prior to preparing the resin blocks in order to standardise the dimensions. The roots were mounted in symmetrical, cylindrical self-cured acrylic resin blocks. The teeth were seated in the blocks protruding 6 mm. Figure 1 shows a diagrammatic scheme of each experimental sample. The prepared specimens were stored in sterile saline solution for three weeks before cyclic loading. The specimens were mounted on an angulated jig at 30° to the long axis of the root, custom-made to allow the exact placement of all the specimens at the desired angle and later mounted using metal screws onto a SMAC testing machine. The cyclic load was applied at a 30° angle to the long axis of the tooth in accordance with many published reports on post and core fracture and fatigue tests for posterior teeth[19]. This arrangement provided an even force distribution along and perpendicular to the tooth and replicated flexion stresses resulting from protrusion. The magnitude of the applied load (40 N at 2 Hz) was chosen after a series of pilot studies in which an initial load of 80N was applied but it was observed that most of the pilot specimens failed early and it was concluded that this was not suitably fatiguing the specimens. Therefore, 40 N was chosen to have a greater fatigue effect on the specimens used in this study.

The load was applied to the buccal surface of the premolars and was automatically discontinued when the restorative system failed. The SMAC machine was programmed to stop after 40,000 cycles or when the distance between the load applicator and the sample was more than 0.5 mm, if no failure had occurred. Throughout the loading test, the teeth were submerged in a water bath to mimic the wet environment of the oral cavity.

The data was statistically analysed, significance was predetermined at p-value = 0.05. The survival rates of the three experimental groups were analysed with Kaplan-Meier survival estimates analysis. Comparisons between and within the groups were evaluated with a log-rank test. Modes of failures were classified as retrievable or irretrievable/catastrophic (see Table 2). A failure was considered retrievable when it occurred above the resin block margin and irretrievable/catastrophic when a root fracture occurred below the level of the resin block margin. Modes of failures, either retrievable or irretrievable/catastrophic were evaluated using the Kruskal-Wallis non-parametric analysis of variance. The effect of post type was evaluated using the Chi-square test of independence.

Table 1. *Post systems, core and luting materials used*

Group	Post System	Length (mm)	Diameter (mm)	Core System	Luting System
	Fibre White	11.5	1.14	ParaPost®	RelyX™
A	ParaPost®			Para Core	Unicem
	(Glass fibre)			Automix	Maxicap™
	ParaPost®	11.5	1.14	ParaPost®	RelyX™
B	XP			Para Core	Unicem
	(Ti-alloy)			Automix	Maxicap™
	No Post	-	-	ParaPost®	RelyX™
C				Para Core	Unicem
				Automix	Maxicap™

Table 2. *Failure modes of the tested specimens*

Mode of failure	Retrievable	Irretrievable
Core	Core fracture	
Post	Bent post	
	Post fracture	
Tooth	Root fracture (above resin block)	Root fracture (below resin block)

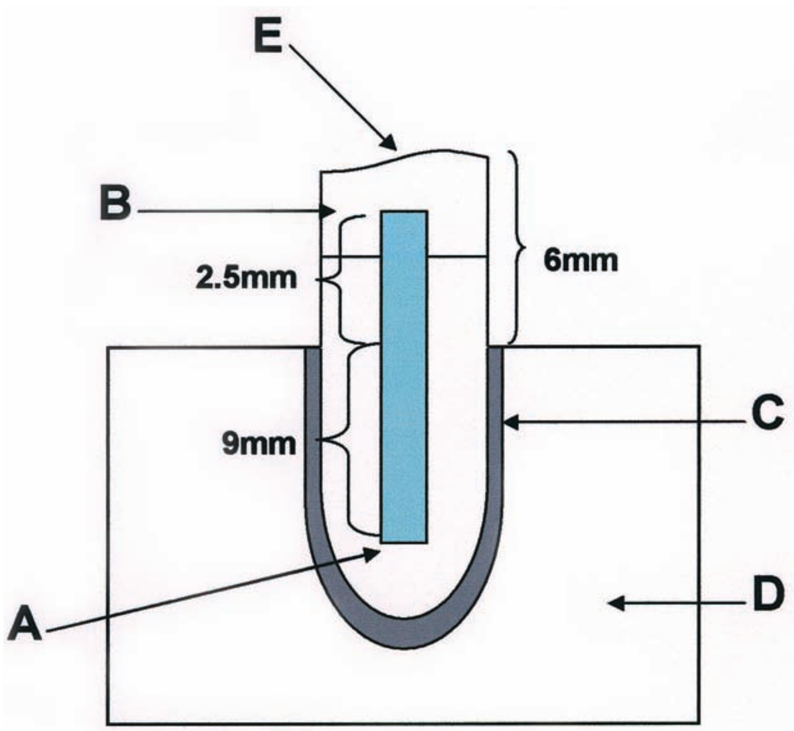

Figure 1. *Diagrammatic scheme of an experimental root sample. A=post, B=resein, C=silicone layer, D=acrylic resin, E=30° load angle*

RESULTS

The results obtained are shown in Table 3. All specimens (100%) in Group A failed. 17 specimens (85%) in Group B had failures but 3 specimens (15%) did not fail after 40000 cyclic loading. All specimens (100%) in Group C (control group) failed. Multiple comparisons were carried out using Bonferroni's correction. There was a significant difference of survival between the controls and glass fibre posts, and the controls and titanium-alloy posts. There was no significant difference of survival between glass fibre posts and titanium-alloy posts.

Mode of failures within group

Initial analyses of failure within each group are illustrated in Figures 2-4. The log-rank test was used to analyse the overall failures. The results indicated that there was no significant difference between the mode of failure or failure type in Group A. The results also showed that there was no significant difference between the mode of failure or failure type in Group B.

Retrievable and irretrievable failures between groups

The Kruskal-Wallis non-parametric analysis of variance at the 0.05 level of significance showed that there was no significant difference in the number of failures between the three groups.

Effect of different post type on the mode of failure for each group

Chi-Square test for independence was applied to determine the effect of different post type on the mode of failure for each group. The results showed that there was significantly more core-post failures in teeth restored with a glass fibre-reinforced post, root-core failures in teeth restored with a titanium-alloy post and core failures in the control group (no post).

DISCUSSION

The results from this study showed that teeth restored with glass fibre-reinforced posts did not suffer irretrievable root fractures. These findings are similar to results from other studies on the fracture resistance of teeth restored with fibre-reinforced posts (8,11,12). Teeth in the control group did not suffer root fractures but all the cores failed. The significantly inferior survival rate of the teeth without posts supports the guidelines suggested in the scientific literature that a post is required to retain a core when all coronal tooth structure is lost[13,14].

The canals were all obturated with gutta-percha and sealed with a non-eugenol root canal sealer in order to minimise the inhibition of the resin polymerisation process of the core material by phenolic compounds, such as eugenol (2-methoxy-4-allyphenol) contained in many of the commercially available endodontic root canal sealers and temporary filling materials.

In some previous *in-vitro* studies, the specimens were kept dry during the loading[8,20].

The ability of fibre-reinforced posts to preserve their flexural strength is essential to reduce the chances of failure, because when they become more flexible, any applied force to the post-resindentine interface may lead to core-post failure. In this study, specimens had only composite core build-ups as the definitive restoration. It was considered that as long as the fibre-reinforced posts are protected from water contact (by the composite core), no significant reduction of flexural strength should occur.

In a study of the fracture resistance of teeth restored with Composipost carbon fibre-reinforced posts[8] it was reported that tooth fractures were uncommon and that the most frequent site of failure was the post and the core interface. The findings of the present study demonstrated that 70% of the failures observed were post and core fractures in teeth treated with glass fibrereinforced posts. By contrast, fracture of the roots was observed in 35% of the specimens treated with titanium-alloy posts. Breakage of the fibre posts was the most frequently observed failure mode in Group A. More than one third (35%) of the titanium-alloys specimens had unrestorable root fractures whilst the posts themselves survived. The modulus of elasticity of coronal mineralised dentine was measured using modern nano-indentation techniques[35]. It was found to be of the order of 14-19 GPa. Stiffness, elastic limit and strength of fibre posts (1.4 and 1.8 mm in diameter) were found to be significantly lower than titanium posts (1.6-2.0 mm in diameter)[1].

This difference in the modulus of elasticity may explain the more catastrophic root fractures observed in Group B. Moreover, the absence of a post may have the effect of reducing the incidence of root fractures; indeed, breakage of the resin core was the only failure mode observed in the control group.

Table 3. *Results*

Post type	Root and core fratcure/cycles	Mean and sd	Core and post fratcure/cycles	Mean and sd	Core fratcure/ cycles	Mean and sd
Glass fibre	0	0	14	21032.43 sd-13760.89	6	19508 sd=18839.99
Titanium	7	14048.14 sd=12251.07	2	33481 sd=9219.258	8	10687.88 sd=7544.847
No post	0	0	20	5798.6 sd=5344.738	0	0

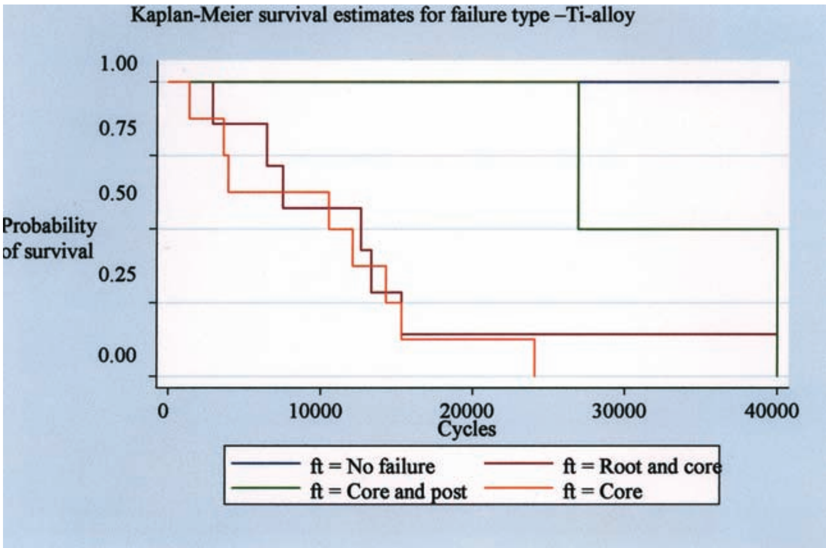

Figure 2. *Kaplan-Meier survival estimates showing modes of failure of titanium-alloy posts*

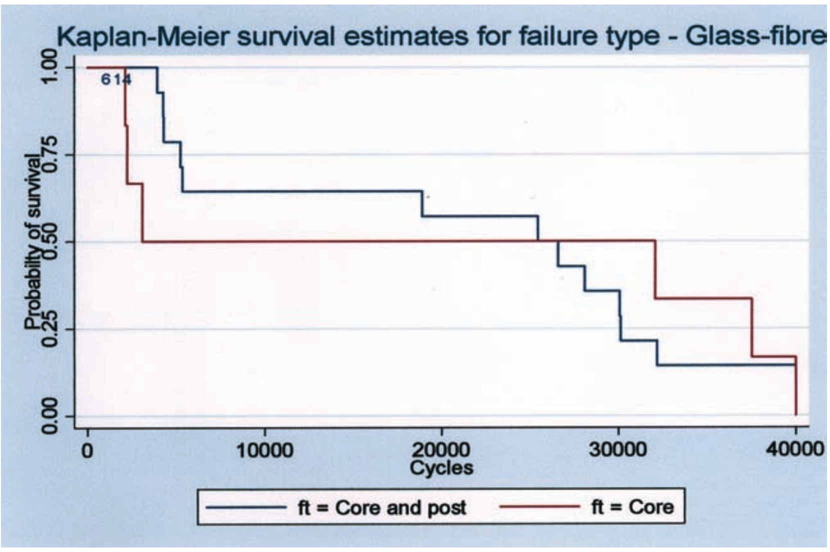

Figure 3. *Kaplan-Meier survival estimates showing modes of failure of glass fibre reinforced posts*

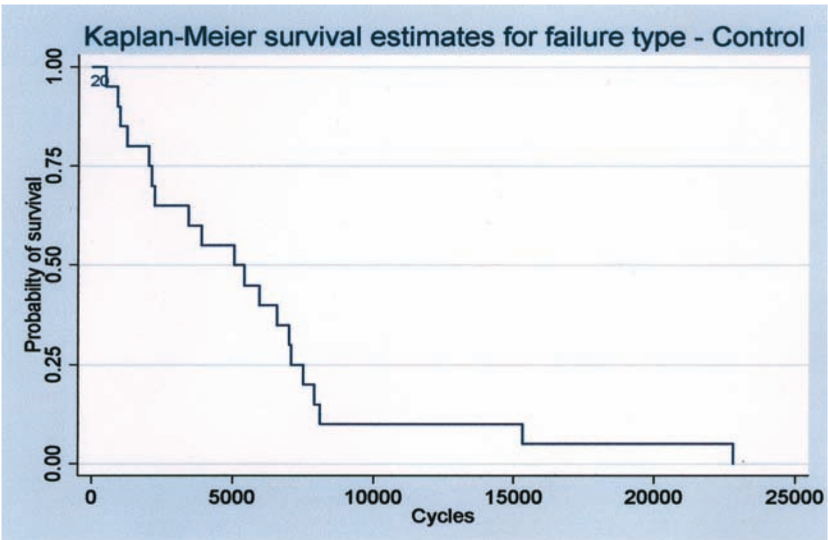

Figure 4. *Kaplan-Meier survival estimates showing modes of failure of control group (without post.)*

Direct comparisons of the findings from the present study with previous studies on fracture resistance of endodontically treated teeth restored with posts and cores are difficult. This may be attributable to normal variations among teeth such as their different sizes, different positions of the root canals or distance between the remaining coronal surface and the dentinoenamel junction[16] or the variations introduced during extraction[26] or storage of the teeth. In addition, the variations may also involve the type of teeth used e.g. human or bovine teeth[27], the post types examined, the length, width, shape and surface texture of the posts, the type of load applied such as static loading[10,12] or cyclic loading[20,27] and lastly, the direction of testing as well as the type of definitive restorations employed.

The variations observed within this study could be attributable to factors such as the condition and age of the original tooth samples, size of the teeth, the quality of the endodontic therapy and post cementation and finally the placement of the composite resin core build-ups. Several previous in-vitro studies[28,16] and retrospective clinical studies[29] proved that, in the restoration of endodontically treated teeth, crown coverage results in increased fracture resistance of premolars and molars. However, no prospective clinical study has confirmed these reports. A recent prospective clinical study demonstrated that, in endodontically treated premolars with limited loss of tooth structure and restored with adhesive techniques and fibre posts, full-crown coverage may not be necessary in 3 years after treatment[30]. The pulpless tooth has usually lost significant amount of coronal and radicular tooth structure from pre-existing restorations, dental caries and access cavity preparation. This must be considered when a complete crown is planned, because the tooth reduction for an artificial crown is considerable[28] particularly when the teeth are prepared for metal ceramic crowns, that are, for aesthetic and functional reasons, the most common method for crown coverage of premolars. The evaluation of the effect of crown coverage on the survival of endodontically treated teeth was not included in this study. In this study, two different post systems with the same shape (parallel-sided-serrated) and diameter (1.14mm), produced by the same manufacturer were evaluated. Comparisons with other types of fibre-reinforced posts (e.g. quartz-fibre or carbon-fibre) were not accomplished for several reasons. Firstly, the quartz-fibre and carbon-fibre posts are produced by another manufacturer with different specifications in their products. Secondly, it was not possible to obtain these posts systems with the same dimensions. Maintaining the same size of post was important in order to maintain the thickness of remaining radicular dentine. Moreover, the post space was prepared to the same shape using the post drills of identical size thus ensuring the shape and length were identical in both experimental groups. Finally, prefabricated posts come in different shapes. Both of the post systems tested in this study were passive, parallel posts. Parallel metal posts[31,32] and fibre posts[33] are more retentive than tapered posts. Parallel posts induce less stress into the root because they produce a minimal wedging effect. They have been reported to be less likely to cause catastrophic root fractures than tapered posts[10,34,27]. In a retrospective clinical study, Sorensen and Martinoff[29] reported a higher success rate with parallel posts than with tapered posts. In this study, both post systems used were parallel so the comparison between the different designs was eliminated. The mode of failure demonstrated could have been more catastrophic if tapered posts had been used instead.

Within the limitations of the present in-vitro study, it can be concluded that:

1. The resistance to fracture of both experimental groups was not statistically different under the present experimental conditions.

2. Glass fibre-reinforced post reduced the risk of irretrievable root fractures

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MANUFACTURER'S DETAILS

- Fibre White ParaPost; Coltene, Whaledent, Sussex, UK
- Para Post XP; Coltene, Whaledent, Sussex, UK
- Size 2 round end tapered diamond burs; Dentsply, Surrey, UK
- Barbed Broach; (Micro Mega, Besancon, France).
- Colorinox Hedstroem files 25mm; Maillefer, Baillagues, Switzerland
- Milton sterilising fluid; Milton Pharmaceutical UK Ltd, Dorset, UK
- Absorbent paper points; Coltene, Whaledent, Sussex, UK
- Finger spreaders; Maillefer, Baillagues, Switzerland
- Sealapex root canal sealer; Kerr, Scafati, Italy
- Gates glidden drills sizes 2,3,4; Maillefer, Baillagues, Switzerland
- RelyX Unicem Maxicap dual resin luting cement; 3M ESPE AG, Seefeld, Germany
- Adhesive conditioner A; Coltene, Whaledent, Sussex, UK
- Adhesive Conditioner B; Coltene, Whaledent, Sussex, UK
- ParaForm core formers; Coltene, Whaledent, Sussex, UK
- ParaCore Automix; Coltene, Whaledent, Sussex, UK
- Soft silicon putty; Aquasil, Dentsply, Konstanz, Germany
- SMAC testing machine; SMAC Europe Ltd, Horsham, West Sussex, UK

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