Fracture strength of cusp-replacing fibre-strengthened composite restorations

SADJ June 2014, Vol 69 no 5 p202 - p207

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SUMMARY

Introduction: Fracture of composite restorations, especially when one or more cusps are replaced, is a common reason for failure. Finite element analysis has shown that crack propagation at the tension side of the restoration signals the failure.

Aims and objectives: The strengthening effect of placing a fibre substructure on the tension side was investigated and the results compared with the fracture strengths of a conventional posterior composite without a substructure (control) and of a composite reinforced with fibres incorporated within the composite.

Design: The study was an *in vitro* experimental blind study.

Methods: 75 extracted lower first molars were divided into three groups of 25 teeth each to allow for the comparisons and the restorations were placed. All specimens were thermocycled for 500 cycles between 5°C and 55°C with a dwell time of 30 seconds. Each restoration was subjected to loading on a Universal testing machine at a 30° angle to the long axis of the tooth, until fracture occurred. Maximum force before failure (Fmax in N) was recorded.

Results: The results indicated a significantly higher strength for the composite resin restorations placed on a fibre substructure.

Conclusion: A uni-directional fibre substructure is recommended to achieve greatest strength.

Keywords: glass-fibre reinforcement, posterior composite resin restorations, flexural strength.

INTRODUCTION

Many different treatment modalities exist for restoring a tooth that has lost one or more cusps.[1] Conventional methods to restore teeth with cusp-replacing restorations include direct or indirect metal inlays/overlays, ceramic inlays/overlays and in some cases full-coverage gold/ceramic crowns. Although these methods have a proven track record, they often require removal of additional tooth structure, are expensive, time-consuming and necessitate the skills of a dental technician.[2] In rural areas these services are often not available, resulting in a large section of the population not being treated. This leads to eventual loss of teeth that could have been treated and retained.

An alternative type of restorative material is composite resin. However, fracture of the composite restoration in the posterior region was found to be a common reason for failure, particularly within the first five years.[3] In order to overcome such problems when these materials are used in large stress-bearing applications, significant improvement is needed in their mechanical properties.[4, 5, 6]

Extensive studies have been undertaken on methods of improving and reinforcing these properties of dental composite resin. Examples are ceramic and porous fillers,[2] optimising filler level[7] and the use of micro-scale glass fibres as fillers e.g. Aelite (BISCO, Schaumberg, Illinois, USA).[8,9] Research has also suggested that with the addition of a fibre reinforced composite substructure under a composite resin, the load-bearing capacity of the combination is increased.[5,9]

The use of composite resins in larger posterior restorations which involve cusp replacement is further severely limited by the low flexural strength of the material.[9] SEM analysis of dental restorations confirmed observations that composite resin restorations are prone to bulk fracture with crack propagation rates higher than those occurring in porcelain.[10] Finite element analysis showed that during mastication, the inner side of the restoration can be in maximum tension,[11] leading to fracture initiation.[12] The inclusion of uni-directional glass fibres as reinforcement on the compression side has been found to result in an increased elastic modulus.[13,14] Tension side reinforcement (Figure 1)[15] was found, however, to be the

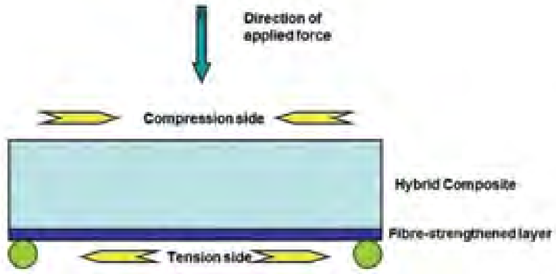

Figure 1

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most effective action in increasing the strength and static load-bearing capacity of dental restorations.[1,13] When reinforcement included both compression and tension sides, the elastic modulus was increased by 150% compared with that of unreinforced material.[15]

The orientation of reinforcement fibres also has a major influence on the strengthening effect.[16] The efficiency of fibre strengthening is mathematically calculated using the Krenchel Factor.[16] Continuous unidirectional fibre orientation, placed at 90º to the applied force, has a Krenchel strengthening factor of 1. Theoretically, this means a strengthening efficiency of 100% (Figure 2) .

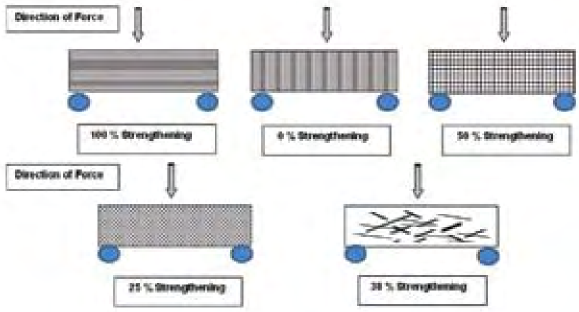

Figure 2: Fibre orientation and strengthening efficiency – Krenchel's Effect based on mathematical calculation.

If the strengthening fibres are aligned in the same direction in which the force is applied there will be no strengthening effect (Krenchel factor 0) because the matrix holding the fibres simply tears apart.

Mathematically, bi-directional (woven) fibres produce a Krenchel strengthening factor of 0.5 (50%) or 0.25 (25%) depending on the orientation and are especially indicated where the direction of load is unknown. For randomly orientated fibres the mechanical properties are the same in all directions. Mathematically the Krenchel factor is calculated as 0.38 (38%).[15, 17, 18]

Oberholzer *et al*[19] concluded in 2007 that research should focus on the on the clinical use of fibre reinforced resins and particularly on the improvement of placement techniques.

In vitro testing is often used to predict the clinical behaviour of dental materials. The main advantage is that methods, specimens and the use of the materials can be standardised.[20, 21, 22]

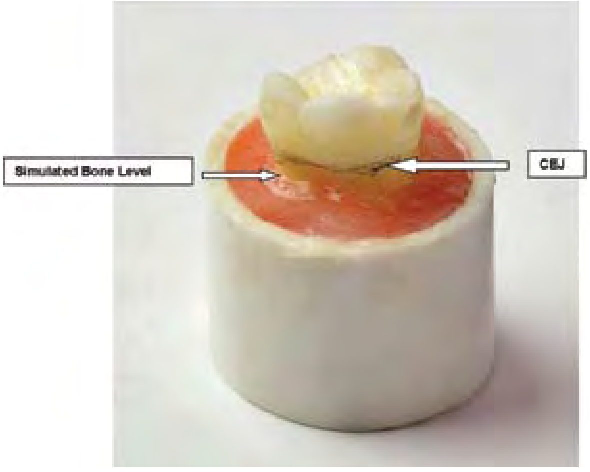

Figure 3: A mounted specimen showing CEJ and simulated bone level.

However, only a few of the different physical properties contributing to the clinical behaviour of a material can be studied in an experiment. One of the disadvantages of using real human teeth in tests is the fact that large variations in fracture resistance can occur due to the anatomical variations.[20, 21, 22, 23] The results of such tests therefore have to be carefully analysed when extrapolated to the clinical environment.[23, 24]

Naumann *et al*[25] concluded that the articles using human teeth, which they reviewed in their 2009 study, were heterogeneous in designs regarding test parameters. Methodological standardization of *in vitro* testing of strength should therefore be investigated. For the purpose of this study it was most practical that test parameters representing an average of the Naumann *et al* data were chosen.[25]

MATERIALS AND METHODS

Specimen selection and preparation

Seventy-five human, non-carious lower first molars were collected and stored in an aqueous solution of 5% chlorhexidine ($C_{22}H_{30}C_{l2}N_{10}$) at +8ºC in a refrigerator.[26] The teeth had been extracted as a result of periodontal disease and the patients were all between 50 and 70 years of age. Informed consent for the research use of the teeth was obtained from all patients. The teeth were selected for the study on an anatomical basis in order that a standardised cavity involving the mesial, occlusal and lingual surfaces (MOL cavity) could be prepared. (Addendum 2 provides relevant data on cavity size specifications). Specimens were severally embedded in acrylic resin cylinders (20mm diameter, height 20mm) with the acrylic surface approximately 1.5mm below the CEJ to simulate bone level (Figure 3).

The preparations were standardised as follows: The Cementum-Enamel Junction (CEJ) was located by visual examination. The mesio-lingual cusp was removed down to 1mm occlusal of the CEJ. A standardised MOL cavity was prepared using a number 142 (size 018) dome-shaped, diamond fissure bur in an air-rotor handpiece with continuous water spray. All internal line angles were rounded. A proximal step with a depth of 1mm was prepared, not exceeding the original 1mm line occlusal of the CEJ. The width of the proximal box was determined by the occlusal anatomy of the specific tooth. The preparations were all done by a single operator and examined for accuracy of the dimensions by a second operator. If the preparation did not conform to the specified dimensions, the preparation was corrected (if possible), otherwise the tooth was removed from the experiment and replaced by another tooth. The dimensions of each preparation were recorded.

The specimens were subsequently randomly divided into three groups:

Group A: (Control) (n=25)

All enamel margins were bevelled to a 1mm wide edge, at 45º to the cavity margin and were then etched with 37% phosphoric acid for 15 seconds. All the exposed dentine (together with the enamel) was etched for an additional 10 seconds. The acid was rinsed off with water, care being taken that all acid was removed. The specimens were then lightly air-dried, ensuring that all dentine surfaces remained slightly moist. A bonding agent (XP Bond, Dentsply, Konstanz, Germany) was applied and light-cured, in accord with the manufacturer's instructions. A Tofflemire matrix band was placed, according to the manufacturer's instructions.

Specimens in Group A were restored with a hybrid composite resin (QuiXfil,B Dentsply, Konstanz, Germany). The restorations were placed using an oblique layering technique with incremental layers, each not exceeding 2mm. and being light-cured for 20 seconds. After the restoration was cured, it was finished and polished using the following protocol: all enamel margins were finished with Dura-White Stones (SHOFU DENTAL GmgH, Ratingen, Germany) using a friction-grip handpiece under continuous water spray. Polishing was done with Sof-Lex TM polishing discs (3M ESPE, Dental Products, St. Paul, Minnesota, USA), from coarse to ultra-fine. Final polishing was performed with Enhance® Polishing Cups (Dentsply, Konstanz, Germany) and Enamel Plus Shiny 1 micron diamond paste (GDF mbH, Rosbach, Germany).

Group B: Posterior composite resin incorporating micro-scale glass fibres (n=25)

The same cavity preparation, etching, bonding and matrix regimes were followed as in Group A, but specimens in Group B were restored with a posterior composite resin which incorporated micro-scale glass-fibres as fillers (Aelite, BISCO, Schaumberg, Illinois, USA). The restoration placement as well as the finishing and polishing were done in exactly the same manner as with Group A.

Group C: Posterior composite resin placed on a fibre sub-structure (n=25)

The same cavity preparation, etching and bonding regimes were used as in Group A.

The interproximal step was restored with a conventionally-filled composite resin (QuiXfil, Dentsply, Konstanz, Germany) and light-cured according to the manufacturer's instructions. In order to maximise the Krenchel factor, an ever-Stick Crown and Bridge uni-directional glass fibre bundle (Stick Tech Ltd, Turku, Finland) was placed at a 45º angle to the mesio-distal axis of the tooth in order to support the mesio-lingual cusp when it was restored (Figure 4). The bundle has fibres embedded in a bis GMA resin and is covered by a sheath of intermediate resins to prevent fraying.

Flowable composite (Esthet X flow, Dentsply, Konstanz, Germany) was used to secure the glass fibre bundle in place. Close contact between the fibre bundle and the floor of the cavity was ensured by means of a placement aid called a Refix, (Stick Tech Ltd, Turku, Finland) in order to prevent the formation of voids.[27] The clear silicone Refix is translucent which allows the curing light to penetrate while it is used to keep the fibre bundle in position (Figure 5). The ever-Stick glass-fibre bundle was light-cured according to the manufacturer's instructions.

As with Group A, a Tofflemire matrix band was placed according to the manufacturer's instructions.

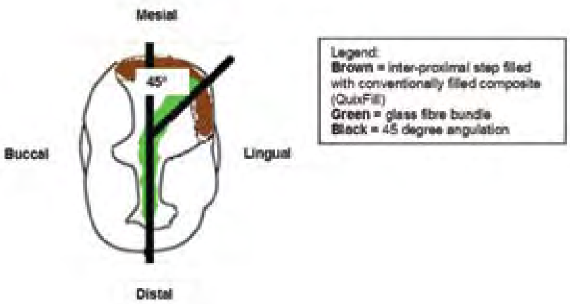

Figure 4: Placement of fibre substructure

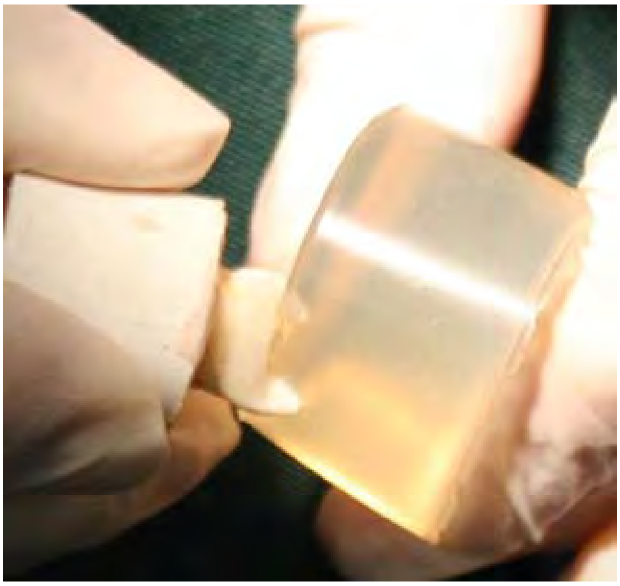

Figure 5: Refix Positioning Aid

Specimens in Group C were restored with a conventionally-filled composite resin (Quixfill, Dentsply, Konstanz, Germany). The restoration was placed using an oblique layering technique with incremental layers, each not exceeding 2mm. The restoration placement, finishing and polishing were done in exactly the same way as with Group A.

All specimens were then stored in saline and subjected to thermocycling in water (500 cycles between 5° and 55° centigrade with a dwell time of 30 seconds).

Testing

Specimens were stored in saline for a minimum of 24 hours before testing. The set up and process of testing adhered to the average data as calculated from the Naumann *et al* review.[25] Each specimen in turn was fixed in a metal holder and positioned under the universal testing machine (TestXpert V 11.02, Zwick 1446, Zwick Roell, Epental, Germany) with the long axis of the roots at an angle of 30 degrees to the direction of the load using a specially made jig (Figure 6).

A stainless steel cylindrical rod (tip diameter of two mm) was used to load the specimens, at a crosshead speed of 0.5mm/min, until fracture occurred. The site of loading was the central fissure of the occlusal surface in the direction of the mesio-lingual cusp. The force needed to fracture the tooth was recorded electronically on a computer. Strength testing

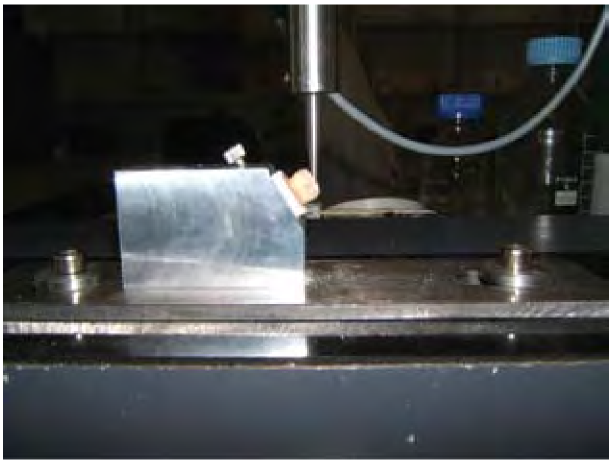

Figure 6: Jig, Rod and Specimen

of specimens was done by an independent operator who did not know to which group each specimen belonged. Tests were done randomly between specimens from Groups A, B and C and numbers were allocated to individual specimens as the tests were being done. That part of the specimen which fractured off was collected, mounted on a transparent sheet and numbered for investigation at a later stage.

Data Management

The raw data from the Universal Testing Machine was stored in the Personal Computer linked to the unit. Specimen numbers were recorded on paper and stored separately. The raw data was exported to a Microsoft Excel Spreadsheet and was collated using the same program. When analysing the data, the same program was used to plot the data. All raw and collated data were backed-up and stored at two separate locations.

RESULTS

Table 1 depicts the range of forces which were required to produce fractures in the three Groups, with minimum (F_{min}), maximum (F_{max}) and average ($F_{average}$) values, together with the standard deviations (SD), being recorded. All measurements are in Newtons. (Complete data records are presented in Appendix 1).

The fracture strengths were compared between the Groups in a one-way analysis of variance (ANOVA) and specific differences were tested by using Fisher's least significant differences (LSD) in pair-wise comparisons.

DISCUSSION

The results of research always have to be interpreted with care, and even more so when biological material is investigated.[24] It is just not possible to control all variables. In this study, specimens had been selected carefully using anatomical criteria, age of the patient and position in the mandible. However, factors that might influence dentine bonding such as sclerotic dentine and dead dentinal tracts could not be controlled. On the other hand, sample size, tooth preparation, placement technique, specimen preparation, testing and analysis of results could easily be standardised.

Fracture strength tests are widely published, although the literature does indicate a need for standardization of a number of controllable influences like cross-head speed of the testing machine, direction of force applied and the cross-section of the testing point. In designing this study, the most commonly-used protocols were followed.[25]

Fracture strength values of the composite resin used as a control varied from 125.78 N to 418.94 N with a mean of 313.008 N and standard deviation of 64.3 N. These results are summarised in Figure 7.

Comparison of the strength values of this study with the data obtained by other researchers in the same field show that results are very similar.[5,18] It can therefore be concluded that the fracture strength values of the composite resin used as the control, fall within acceptable parameters.

Table 1: Collated Fracture Strength Results (N)

	Group A Control n=25)	Group B (n=25)	Group C (n=25)
F_{min}	125.78	205.9	336.55
F_{max}	418.94	636.15	662. 58
$F_{average}$	313.008	393.1944	461.644
SD	± 64.3	± 92.3	± 62

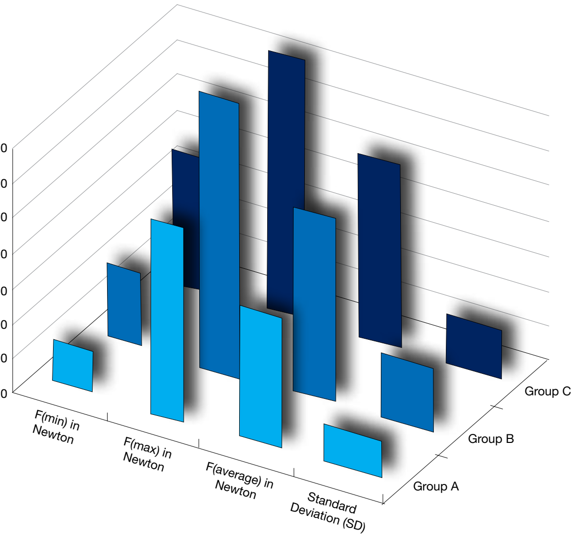

Figure 7: Minimum Force (F_{min}), Maximum Force (F_{max}), Average Force ($F_{average}$) and Standard Deviation (SD)

Fracture strength values of the composite resin reinforced with nano-scale glass fibre reinforcement (Group B – Aelite) varied from 205,9 N to 636.15 N with a mean of 393.19 N and a standard variation of 92.3 N. Other researchers[9, 28] found an average increase of 23% in fracture strength values when nano-scale glass-fibres were incorporated in a composite resin. The slightly higher 25.5% increase in fracture strength

Appendix 1: Collated test results containing individual specimen numbers and fracture strength results

Group A: Quixfill		Group B: Aelite		Group C: Quixfill + everStick	
Specimen number	Fmax Newton	Specimen number	Fmax Newton	Specimen number	Fmax Newton
63	282.21	46	291.58	67	486.76
4	342.27	55	351.45	38	420.77
31	269.31	18	458.19	64	433.48
16	323.59	40	418.94	62	464.46
54	418.94	37	504.17	51	406.31
71	302	32	636.15	57	516.38
47	254.2	69	569.01	75	417.82
43	323.63	70	358.79	35	470.22
74	384.95	59	205.9	56	409.77
27	323.05	66	381.01	41	519.92
39	374.99	13	420.74	17	662.58
8	388.1	25	467.22	19	420.87
33	373.71	12	476.12	53	474.4
30	316.69	34	316.69	65	477.39
5	241.2	58	334.44	28	444.19
26	256.7	23	350.85	60	466.08
7	279.39	42	360.85	45	498.86
2	273.04	15	406.25	20	418.32
9	418.32	22	360.85	50	551.4
11	249.72	10	285.85	29	451.3
36	321.46	73	367.83	61	406.15
3	315.35	48	451.3	21	497.91
49	332.21	72	367.83	44	456.52
52	334.39	1	316.98	68	432.69
14	125.78	24	370.87	6	336.55

values obtained in this study is not statistically significantly different from the 23% increase published by Tian *et al*.[29] It is, however, less than may have been expected had the Krenchal Factor been mathematically applied (a 36% increase would then have been predicted).[16]

Fracture strength values of a composite resin placed on a uni-directional glass-fibre substructure (Group C - Quixfill, Composite placed on ever-Stick) varied from 336.55 N to 662.58 N with a mean of 461.644 N and standard deviation of 62 N. This is an increase of 48% in flexural strength values compared with the control group and of 18 % compared with Group B (Aelite - a composite resin reinforced with nano-scale fibres). Again the increase in flexural strength values is less than would be expected if the Krenchal Factor is applied (100%) but this discrepancy might be explained by the fact that it is impossible to predict exactly where the fracture will occur and therefore exactly where to place the fibre substructure.[16] It is also important to remember that Krenchal values are part of a mathematical calculation which might not consider all the possible variances when biological specimens are evaluated.

The inclusion of fibres, whether placed as a substructure or embedded in the composite resin itself, significantly increased the fracture strength values of the restorative material. This agrees with results found by other researchers.[9, 14, 31]

Fennis *et al* concluded in their 2005 study that unidirectional fibres in cusp-overlaying composite resin restorations not only give higher reinforcement values but also produce less consistent results than reinforcement substructure placed on woven (bi-directional) fibre netting.[18] This differs from results published by Belli[5] and also from the results obtained in this project. Recently published research comparing the strengths of full-cover crowns made out of composite and reinforced by either a fibrous substructure or short multilateral fibres indicated that crowns reinforced with the latter fibres showed a higher load-bearing capacity.[27] These crowns were manufactured in a laboratory and were heat and pressure- cured.[27]

CONCLUSION

This research project clearly shows a significant difference in the fracture strengths of the three different restorations studied, with the strongest being the conventionally-filled composite when placed on a uni-directional fibre substructure.

Declaration: Dr HJ Visser is the scientific consultant of a Dental Company (Stick Bond Dental CC) who is the distributor for Africa for one of the products evaluated in this study.

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