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Effect of Dry and Wet Cyclic Loading on the Longevity of Dental Composites

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Abstract

Resin based dental composites are widely used for both anterior and posterior restorations. They have comparable mechanical properties to dentin, ability to bond to tooth tissues and superior aesthetics make them more favourable than other restorative materials. However, failures of dental restorations occur in clinical service. One of the reasons for failure is the small repeated masticatory forces (cyclic loads) that form an initial crack and accelerate the crack growth which may eventually fracture the material. Fatigue failure of resin composites is also induced by water attack (oral environment) over a period of time. The aim of the study is to determine the effects of cyclic loading (dry and wet conditions) on the longevity of the dental composites. A total number of 60 cylindrical specimens were prepared from three different types of composites (microhybrid, nanohybrid and bulkfill. half of the specimens were stored in distilled water for 4weeks and the rest specimens were stored dry. The specimens were subjected to cyclic loading at 150N at 2Hz frequency until failure. the number of cycles were recorded and subjected to statistical analysis. It was concluded that the cyclic loading significantly ($p<0.05$) reduced the longevity of the composite under wet conditions. The bulkfill composites showed significantly ($p<0.05$) higher number of cycles when compared with other types of composites depicting longer clinical service.

Keywords: Bulkfill composites, Cyclic loading, Fatigue failure.

Introduction

In the past few decades, several new dental composites for aesthetic posterior restorations have emerged. Overcoming few drawbacks like reduced strength, increased polymerisation shrinkage, these materials have been improved over time to meet the critical needs of reliability, durability, and longevity.[1] Manufacturers have made the improvements by modifying the composite resin composition by incorporating higher filler loading with glass fibers, porous filler particles, irregular filler particles, glass filler particles, and viscosity modifiers.[2] These material properties in turn provide useful guidelines for designing and selecting materials with a higher likelihood of clinical success. With the introduction of nanohybrid technology, the composites are suitable for both anterior and posterior restorations as they provide adequate resistance in high stress bearing areas and superior esthetics than microhybrids. Nowadays, bulkfill composites are most commonly used in posterior restorations and have to provide lower cusp strain, shrinkage stress and higher fracture resistance. [3]

However, the resin based composites over a period of time fail in their clinical service and requires replacement. The replacement of failed restorations consumes the majority of a dentist's daily activities. In fact, replacing failed restorations accounts for 50–70% of all clinical work performed. [4]

The two major reasons for restored tooth failure are recurrent caries and fractures.[5] Restorative materials are subjected to cyclic loading (fatigue) during mastication, and evidence exists pointing to fatigue being responsible for the wear, chipping, and generalized failure of dental restorative materials. [6]

Fatigue is regarded as the reduction in load-carrying capacity of a material subjected to cyclic stresses and results from an accumulation and growth of damage. As such, conditions that involve repetitive loads warrant consideration of fatigue-related material failures. The cyclic nature of mastication, and the delayed failure of restorations after a period of oral function, clearly suggest that an understanding of fatigue is relevant to the success of restorative dentistry. [2] The naturally occurring loading of a filling was estimated at between 5 and 20MPa.[7]

Fatigue failure in dental composites is induced by corrosive water attack and cyclic masticatory forces. The presence of water exposure brings about a host of weakening effects on resin composites that serve to accelerate slow crack growth: degradation of filler-matrix interface, elution, and swelling or viscoelastic effect on the matrix.[8] The failure of structural materials that are designed to withstand mechanical loading can result from a variety of causes. While failures associated with overloads are generally considered first, fatigue is more often the primary mode of failure of load-bearing structures [9]

Fracture mechanics provides a basis for estimating component lifetime clinical service. Most of the studies perform testing by subjecting the material to static loading and thereby determining the compressive strength. In oral environment or *in vivo* conditions, there is an ongoing cyclic loading by masticatory forces which can determine the clinical success of the restoration.

Thus, the aim of the study was to determine the effects of cyclic fatigue loading on three different types of commonly used resin composite materials under dry and wet conditions simulating the clinical situations

Materials and Methods

For the study, three light cured composites were chosen based on different filler size and distribution namely, microhybrid, nanohybrid and bulkfill composites. Table 1 list the three types of commercially available dental composites used in this study together with their compositions. For this study, a total of 60 cylindrical specimens (n=20 per group) measuring 8mm diameter and

4mm height were fabricated using a polyethylene mould (Fig 1).

The materials were packed incrementally for micro and nanohybrid whereas for bulkfill a direct 4mm material was placed. Each increment was cured for 20 seconds with LED lamp (LEDition, Ivoclar Vivadent; wavelength 430 – 490 nm, energy source 600 mW/cm^2). The last increment of composite was covered with a mylar strip and a glass slab to provide a flat, smooth surface and to extrude excess material.

Table 1: Characteristics of dental composite materials used in this study

Brand Name	Manufacturer	Type	Composition
Te-Econom Plus (Group A)	Ivoclar Vivadent	Microhybrid	**Matrix:** dimethacrylate and TEGDMA (22 wt%). **Fillers:** barium glass, ytterbium trifluoride, silicon dioxide and mixed oxide (76 wt% or 60 vol%). Additives, initiators, stabilizers and pigments (2 wt%).
Tetric N-Ceram (Group B)	Ivoclar Vivadent	Nano-hybrid	**Matrix:** UDMA, Bis-GMA, Ethoxylated Bis-EMA, TEGDMA **Fillers:** Barium Glass, Yitterbium Triflouride, Silicon dioxide
Tetric N-Ceram Bulk Fill (Group C)	Ivoclar Vivadent	Nano-hybrid Bulkfill	**Matrix:** Bis-GMA, Bis-EMA and UDMA (20-21% weight) **Fillers:** barium glass, ytterbium trifluoride, mixed oxide, and prepolymer (78%–81% by weight, additives, catalysts, stabilizers, and pigments (<1.0% weight).

Figure 1: Cylindrical specimen of composite for testing

Following polymerization, the specimens were removed from the mould and were polished with Super Snap (Shofu, Inc. Kyoto, Japan) to remove any surface defects

Fig 2: Digital caliper was used to check the specimen dimensions.

Figure 2: Finishing and polishing of the composites

The specimens with voids, defects or incorrect dimensions were discarded. From each group 10 samples were stored in distilled water at room temperature (37ºC) for 4weeks to simulate oral environment and rest 10 were stored dry. The lifetime tests were carried out by submitting the samples to a sinusoidal cyclic load and recording the time required for specimen failure.

Cyclic loading was applied with a metallic sphere with 4-mm diameter in an alternating mode at a frequency of

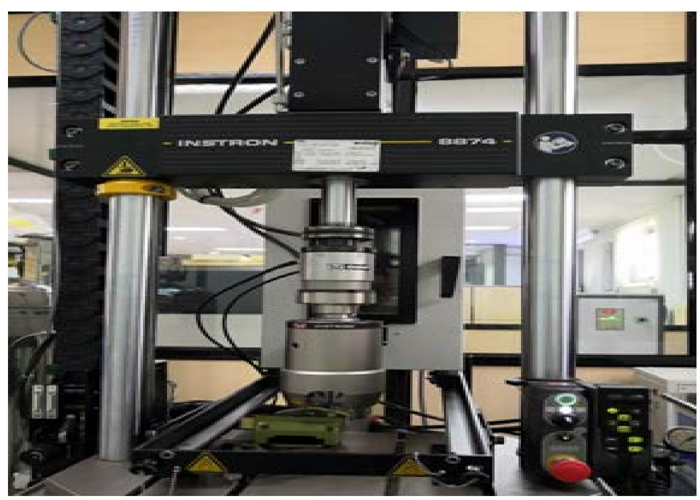

Figure 3 (a): Servo-hydraulic fatigue testing machine

Figure 3 (b): Metallic sphere contacting the specimen surface for cyclic loading

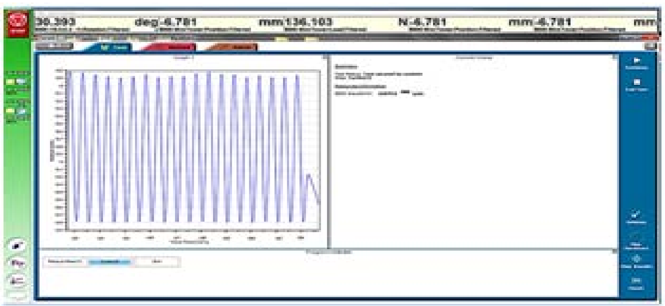

Figure 4: Graph depicting number of cycles until failure

Results

Table 2 represents the descriptive analysis of all the three groups showing the mean number of cycles until fracture. It was observed that the number of cycles was highest for group C i.e bulkfill composites both under wet and dry conditions. The cyclic loading under wet conditions significantly ($p<0.05$) reduced the lifecycle 2 Hz, keeping a constant maximum/minimum stress of 150N on the specimen surface.The samples were subjected under cyclic loading in a servo-hydraulic fatigue testing machine (Instron 8874, Instron Corp, Canton, MA, USA) (Fig 3. a,b). The time required to fracture the specimen determines the clinical service and longevity of the restoration under different conditions (Fig 4). of the all the three composites when compared with dry environment as described in Table 3.

On inter group comparison using post Hoc Tukey's test it was observed that Group C was significantly ($p<0.05$) superior in terms number of cycles until fracture when compared with both group A and B under both conditions (Table 4).

The amount of cycles determines the clinical service of the material. The cyclic loading under wet conditions simulate the clinical masticatory condition. The number of cycles for 1 year of clinical service is approximately 2.5 x 10^5 cycles and the tested materials showed no failure under 2.5 x 10^5 cycles.

Discussion

The composite resin materials undergo frequent loading and unloading during mastication in a hostile oral environment and result in posterior restorations undergoing fatigue and eventually fracture. The success of such materials will, therefore, depend partly on the ability of the resin matrix, the ceramic filler, and the effectiveness of the silanation to resist stress corrosion and fatigue. [10]

This study used a more clinically relevant approach, which investigated the effect of cyclic loading in determining the number of cycles until failure. An excellent review of fatigue of restorative materials has been done by Baran et al listing the different methodologies and response of the numerous dental restorative materials. [11]

Table 2: Data Descriptive Statistics, Mean & S.D analysis of the specimens

		N	Mean	Standard Deviation	Standard Error	95% Confidence Interval for Mean		Minimum	Maximum
						Lower Bound	Upper Bound		
Dry conditions	Group A	10	260499.700	31.5350	9.9722	260477.141	260522.259	260451.0	260551.0
	Group B	10	310081.100	65.7917	20.8052	310034.035	310128.165	310012.0	310200.0
	Group C	10	324118.500	1438.5073	454.8960	323089.454	325147.546	320068.0	324879.0
	Total	30	298233.100	27768.1638	5069.7499	287864.297	308601.903	260451.0	324879.0
Wet conditions	Group A	10	250073.100	38.1996	12.0798	250045.774	250100.426	250028.0	250154.0
	Group B	10	300357.100	199.5998	63.1190	300214.315	300499.885	300003.0	300689.0
	Group C	10	311083.500	30.0786	9.5117	311061.983	311105.017	311040.0	311150.0
	Total	30	287171.233	27050.2282	4938.6734	277070.512	297271.955	250028.0	311150.0

Table 3: One Way ANOVA analysis

		Sum of Squares	Degree of freedom	Mean Square	F	Significance (P value)
Dry conditions	Between Groups	22342385127.2	2.0	11171192563.6	16154.030	.0005
	Within Groups	18671637.5	27.0	691542.1		
	Total	22361056764.7	29.0			
Wet conditions	Between Groups	21219350737.1	2.0	10609675368.5	754170.244	.0005
	Within Groups	379836.3	27.0	14068.0		
	Total	21219730573.4	29.0			

Table 4: Post Hoc Tukey test analysis

Dependent Variable			Mean Difference (I-J)	Standard Error	Significance (P value)	95% Confidence Interval	
						Lower Bound	Upper Bound
Dry conditions	Group A	Group B	-49581.4000*	371.8984	.0005	-50503.491	-48659.309
		Group C	-63618.8000*	371.8984	.0005	-64540.891	-62696.709
	Group B	Group A	49581.4000*	371.8984	.000	48659.309	50503.491
		Group C	-14037.4000*	371.8984	.0005	-14959.491	-13115.309
	Group C	Group A	63618.8000*	371.8984	.000	62696.709	64540.891
		Group B	14037.4000*	371.8984	.000	13115.309	14959.491
Wet conditions	Group A	Group B	-50284.0000*	53.0434	.0005	-50415.517	-50152.483
		Group C	-61010.4000*	53.0434	.0005	-61141.917	-60878.883
	Group B	Group A	50284.0000*	53.0434	.000	50152.483	50415.517
		Group C	-10726.4000*	53.0434	.0005	-10857.917	-10594.883
	Group C	Group A	61010.4000*	53.0434	.000	60878.883	61141.917
		Group B	10726.4000*	53.0434	.000	10594.883	10857.917

*. The mean difference is significant at the 0.05 level.

One method is the establishment of fatigue limits for resin- composite materials and has been completed by many authors. This technique commonly uses the staircase approach where a number of cycles to be completed is predetermined and the load is varied depending on whether the sample fails or does not fail before the number of cycles are completed.[12] A second method is the fatigue behaviour of a material with respect to stress amplitude or stress mean and the number of cycles to failure.[13] McCool et al. investigated the differences between cyclic and dynamic fatigue (which uses a range of constant stressing rates) and concluded that cyclic fatigue was a more conservative means of predicting lifetimes of resin-based composites.[14]

Other studies used different devices with only a vertical movement to perform a static fatigue test on the specimens. Moreover, the fatigue process used in most of these studies was based on performing 40% to 60% of the initial static compressive force of a given material (ranges from 1000 to 2000 N roughly). For instance, the 50% fatigue force for a composite will be on average about 1200 N, which is far higher than the mean physiological chewing force (49-150 N).[15] Thus, cyclic loading uses a repeated constant stress on a surface of a material rather than continuous load. In this study the cyclic load was provided with the help of servo-hydraulic fatigue testing machine. Other methods to determine the cyclic fatigue include computerized masticatory simulator (chewing simulator), biaxial flexural test with a ball-on-ring jig, three-point bend test.

Another parameter which was taken into consideration was the effect of wet conditions on composites. Moisture can assist in failure of a material in several ways: (i) corrosion of the surface which leads to surface flaws; (ii) condensation into a crack tip exerting considerable capillary pressure acting to open the flaw; (iii) enbrittling the material around the crack tip; and (iv) reduction of the surface energy necessary to form the new surfaces (Bascom, 1974). Stress corrosion by water occurs in three general areas: (i) the oxide surface of the filler; (ii) the resin immediately adjacent to the filler; and (iii) the bulk resin distant from the interface. Moisture-induced failure of the composites requires a distinction between the effect water can have on the resin alone, and the water attack on the resin-filler interface.[10]

The attack of water on composites has been shown to be enhanced when fatigue occurs through cycling rather than static loading. This observation was in accordance to the above results, depicting a significant reduction in the number of cycles of the specimen in wet conditions when compared with dry conditions. [16]

The number of cycles were significantly higher ($p<0.05$) for bulkfill composites when compared with micro-hybrid and nanohybrid composites. Bulkfill composites have higher filler loading and can be cured to greater depths. Since, they can be cured in a single increment, there is reduction in number of voids during packing of the restoration. The mode of fracture for dental composites with low filler content has been suggested to be that of a crack front which intersects the random particles and is required to move between them.[17] As the filler content increases, or correspondingly the interparticle distance decreases, a point is reached where the energy required to pass around the particles is equal to the energy required to pass through the particles. Once such a point is reached, then particle shearing or decohesion of the particles at or ahead of the crack tip occurs due to the high localized stress in this region. This point will be dependent on the fracture toughness of the matrix in combination with the filler fracture toughness and the volume percentage packing and size of the filler particles. [10]

Yu et al stated that the mean shrinkage of bulk-fill composite resins ranges from 1.5% to 3.4%, while this range is 2.1% to 4.3% for conventional composites. [18] The lower polymerisation shrinkage causes less water sorption and elution of resin in the oral environment thereby increasing the mechanical integrity and clinical longevity of the restoration.

The sinusoidal cyclic loading was at 150 N which is the average force required in chewing. The frequency was 2Hz which corresponds to the duration of masticatory cycle (repetition frequency per second), thus stimulating masticatory conditions. All the specimens exceeded $2.5x10^5$ cycles (i.e) one-year chewing cycle or one year of clinical service.

One of the limitation of this study was the specimens were not subjected in a chewing simulator where the specimens can be stored in wet conditions while cyclic loading. In the present study, radiometer was not used which may have influenced the results as there might be variation in the polymerization among different specimens.

Conclusions

Within the limitations of the present in-vitro study, it was concluded that the longevity of the composites were affected under wet and dry conditions with decrease in the number of cycles in wet conditions. The highest number of cycles were observed in bulkfill composites describing increased longevity of the restoration in clinical service.

Abbreviations

UDMA- Urethane Dimethacrylate

Bis-GMA- Bisphenol A Glycol Dimethacrylate

Ethoxylated Bis-EMA- Ethoxylated Bisphenol A Glycol Dimethacrylate

TEGDMA- Triethylene Glycol Dimethacrylate

LED- Light Emitting Diode

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