AN *IN VITRO* STUDY OF COMPOSITE REPAIR

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Key words:

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Bond strength

SUMMARY

The use of direct resin-based composite materials has become an active part of contemporary Operative Dentistry. The clinical diagnosis of secondary caries remains the mean reason for failure of all directly placed restorations. The repair of an existing composite restoration has been considered a viable alternative to complete replacement. A question frequently asked about repair of restorations is whether the repair material bonds adequately to the existing restorations.

AIM: The aim of this study is to investigate the repair bond strength of composite resin following micromechanical and chemical means of retention in improving the repair of composite resin specimens.

MATERIALS AND METHODS: The study investigated a commercially available composite resin that is Z100 (3M) with its respective bonding agent *Adper Scotch Bond*. Seventy five flat specimens, of *Z 100* (3M) were prepared in a custom-made putty silicone mould. The specimens were subjected to the tensile force until fracture. The fractured pieces were returned to the putty silicone and repaired by adding a fresh resin composite. The repaired specimens were once again subjected to the tensile force until fracture. For the tensile bond strength test the Zwik universal testing machine was used.

RESULTS: Use of an intermediary material alone (adhesive) resulted in a significant decrease in the repair bond strength ($P<0.05$). Surface roughening alone (with diamond bur) of a fractured composite surface resulted in a significant decrease in repair bond strength ($P<0.05$). Repair of Z100 by Combining the surface roughening with the intermediary material in the repair procedure significantly improved the repair bond

strength (P<0.05).

CONCLUSION: Within the limitations of this study it is concluded that surface roughening coupled with the application of bonding agent produces the highest repair strength. It seems likely that clinically acceptable bond strengths are possible after repair of composite resins.

DECLARATION

I hereby declare that this minithesis "An *In Vitro* study of Composite Repair" is my own work, that it has not been submitted before for any degree or examination in any university, and that all the sources I have used or quoted have been indicated and acknowledged by complete references.

Hesham Mohammed

September 2007

Signed:……..

The work reported in this minithesis was carried out in the Department of Conservative Dentistry, University of the Western Cape, Tygerberg, South Africa.

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DEDICATIONS

To my mother Mahasin, and my father, Hassan for all their love that they have provided me throughout my education.

To my brothers for all the support that they offered me through my degree.

To my older brother Heythem, without whose constant sacrifice, this project would not have been possible.

Finally, to my wife Wisam. no words can describe her patience with me.

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CHAPTER ONE: INTRODUCTION

The use of direct resin-based composite materials has become an active part of contemporary Operative Dentistry. The esthetic appearance associated with conservative cavity preparations and the constantly improved properties have made these materials the material of choice for all classes of restorations (Roulet, Wilson, and Fuzzi, 2001). However, resin composites in common with the majority of dental materials; undergo deterioration and degradation in the intraoral environment (Söderholm *et al.*, 1984). Also salivary esterase (pseudocholinesterase and cholesterol esterase) can degrade the bisphenylglycidyl dimethacrylate (Bis-GMA) and triethylene glycol dimethacrylate (TEGDMA) monomers that are the basic constituents of all composite resins. The addition of phenylmethylsulfonyl fluoride was found to inhibit such biodegradation (Finer and Santerre, 2004).

Composite resin restorations are technique-sensitive materials; as such failure at the tooth-restoration interface may also occur (Roulet, 1997). Failure of a direct composite restoration as a result of surface discoloration, wear, chipping or bulk fracture, represents a fairly common occurrence in clinical practice (Mjör and Gordan, 2002). As a result, managing of failed composite resin restorations is a common problem encountered in daily practice. For years, the traditional management involved remaking the entire restoration, even in the presence of minor imperfections. In recent times, with more insight into cariology and dental material science, a minimally invasive operative philosophy has prevailed and the advantages of repairing rather than replacing composite restorations has been increasingly emphasized (Tyas *et al.*, 2000, Mjör and Gordan, 2002). Repairing defective resinous restorations is a simple alternative to total replacement; it also preserves healthy tooth structure, and reduces costs and chair-side time involved in the procedure (Blum *et al.,* 2003).

Repair of fractured, worn and discolored restorations is a simple procedure consisting of the addition of a fresh layer of resin composite over the existing material (Boyer, Chan and Torney, 1978). The repair of a partially lost resin-based fissure sealant is a well-accepted technique; the same concept with failed resin-based composite restorations is so far not that well-recognized (Mjör and Gordan, 2002). Besides the clinical doubt of leaving secondary caries underneath a repaired restoration, the possibility of achieving a reliable composite-to-composite bond is one of the major concerns related to this conservative procedure (Mjör, Moorhead, and Dahl, 2000, Blum *et al.*, 2003).

This study examines different aspects of composite repair, namely the chemical, micromechanical, and a combination of chemical and micromechanical repair. The purpose of the study is to investigate the most appropriate method of composite repair. A microtensile bond strength test was used to perform the mechanical trials.

An overview of the literature is provided in order to present the background information existing on composite repair: the longevity of direct resin-based restorations, the reasons of failure as well as the clinical aspects guiding the operative choice between repair and replacement of failed composite resin restorations.

CHAPTER TWO: LITERATURE REVIEW

2.1 Basic formulation of resin composites

By definition a dental composite is a highly cross-linked polymeric material reinforced by a dispersion of amorphous silica, glass, crystalline, or organic resin filler particles and/or short fibres bonded to the matrix by a coupling agent (Anusavice, 2003).

The resin matrix is the chemically active part of the resin composite, based on organic difunctional monomers, such as Bis-GMA (Bisphenol A-diglycidylmethacrylate) and UDMA (Urethane dimethacrylate). Other monomers, for instance TEGDMA (Triethylene glycol dimethacrylate), may be added in various concentrations as resin diluents to lower the viscosity of the composite. Depending on the curing mode, inhibitors, as well as activator or initiator systems may be present (Van Noort, 2002).

The fillers used in resin composite formulations include a variety of materials including quartz, silica and glasses made of lithium, barium, and strontium. Addition of filler particles to the resin matrix improves the overall physical properties of the resin composite: as a general rule, the higher the filler loading by volume (percent filling), the higher the strength of the cured resin-based restoration (Fortin and Vargas, 2000, Albers, 2002). Different classifications have been proposed for resin-based composites including those based on filler size and content (macrofilled, microfilled, small-particle and hybrid composites) (Van Noort, 2002). At present, resin composites commonly used in dental practice are hybrid materials, containing both macrofil and microfil systems to improve mechanical and esthetic properties. A mixture of small particles ranging in size from 0.5 to 3.0 μm are present in most

materials currently in use. Recently composites with even smaller particle size have been introduced, with the purpose of increasing polishability and therefore improving the esthetic result: this is the case with the microhybrid resin composites where the filler particle size ranges from 0.04 to 0.7 μm and the nanohybrid resin composites where the filler particle size ranges from 20 to 75 nm (Albers, 2002).

Silanes represent a large group of compounds that have long been accepted and employed as the basis for promoting surface treatments for the adhesion in the industrial field, both in terms of initial manufacturing and repair of resin composite compounds. The function of silanes is to adhere the resin matrix to the filler particles (Albers, 2002). The most commonly used silane molecule in dental applications is γ-methacryloxypropyltrimethoxysilane (γ-MPTS). This choice is based on the compatibility of the methacrylate group with the dimethacrylates used in composite technology (Hooshmand, van Noort, and Keshvad, 2004).

2.2 Reasons for failure of direct resin composite restorations.

Insufficient wear resistance leading to loss of anatomic form and inter-proximal contacts in addition to general deterioration of the restorative material were the main problems related to direct resin-based restorations (Jordan, 1993). Improvements in filler technology and new resin formulations have minimized wear-related failures with a resultant change in the reasons for restoration replacement (Albers, 2002).

According to Hickel and Manhart (2001), a basic clinical distinction must be made between early and late failures of composite resin restorations. The early failures occur within days, weeks or months, owing to severe dentist-related treatment faults including improper handling of the material, incorrect shade selection in aesthetically demanding areas, insufficient resin polymerization, and

deficiencies in the operative sequence. These failures may lead to postoperative symptoms that may require early re-intervention, and are all possible causes of restoration failure (Hickel and Manhart, 2001).

As regards late failures, clinical data indicates that secondary caries, bulk or marginal fractures, marginal discoloration and tooth fracture are the most frequent reasons of failure of resin-based composites, usually experienced after some years of clinical service (Mjör, Moorhead and Dahl, 2000, Van Nieuwenhuysen *et al.*, 2003, Opdam *et al.*, 2004, Manhart *et al.*, 2004).

2.3 Resin composite repair as a minimally invasive treatment.

Restoring the tooth to a long-term condition of health, function, and esthetic appearance as well as preventing the recurrence of caries are the goals pursued by each restorative treatment in dentistry (Mjör and Gordan, 2002).

An invasive approach to caries management has prevailed in the past decades, and sound tooth structure has often been sacrificed to make up for the limitations of the available operative techniques and filling materials (Simonsen, 2005). The class I amalgam preparation is designed to accommodate the strength deficiencies of amalgam as a restorative material; therefore, tooth preparations are made into the dentinal layer, even if the caries is restricted to the enamel only. The reason is that amalgam is a brittle material and weak in thin sections. Vital tooth structure is removed simply to provide strength through bulk for the restorative material. Similarly, the class I amalgam restoration requires “extension for prevention” which removes adjacent non-carious pits and fissures on the tooth surface in a preventive move to limit the possibility of additional caries attacking on the adjacent surfaces of

the tooth being restored (Simonsen, 2005). As such this preparation is totally excessive for a resin composite restoration.

The synthesis of adhesive resins and the enamel acid-etch technique have marked the start of a major revolution in dentistry. Non-invasive pit and fissure sealing and preventive resin restorations have been the earliest precursors of minimally invasive treatment. The increased understanding of the caries process and the advances in adhesive dentistry have promoted a gradual shift in the operative philosophy from the "extension for prevention" toward "prevention of extension" (Simonsen, 2005).

As a result, the traditional surgical approach to carious lesions has been steadily superseded by a biological approach, focused on the individual caries risk assessment, the disease control, the healing potential of early carious lesions and the selective removal of cavitated lesions. These aspects characterize a refined model of care known in daily practice as "Minimal Intervention Dentistry" (Simonsen, 2005).

Minimal intervention also provides for conservative treatment of failed restorations (Tyas *et al.*, 2000, Murdoch-Kinch and McLean, 2003, Mjör and Gordan, 2002). For many years, it was traditionally considered necessary to completely remake restorations not satisfying strict quality requirements with a result replacement of failed restorations accounted for about 60% of the operative activity in general dental practice (Mjör, 1989).

Laboratory (Krejici, Lieber, and Lutz, 1995) and clinical (Gordan, 2001) studies have shown that replacing a resin-based composite restoration inevitably increases the size of the new cavity preparation, which may extend to areas remote from the original site of failure. Due to the esthetic quality of resin composites, with shade-matching and light-transmitting properties being similar to the surrounding dental tissues, the visual and tactile identification of the bonded resin-tooth interface

may be very difficult to identify (Gordan, Mondragon, and Shen, 2002). Either over- or under-treatment is likely to occur and will finally result in, respectively, an unnecessary loss of tooth structure or in incomplete removal of resin remnants from the substrate (Krejici, Lieber, and Lutz, 1995). As resin residues may prejudice a complete demineralization of the substrate, and presumably affect the bonding potential of the new restoration, the cavity preparation is often extended beyond the resin-impregnated, beveled margins at the time of replacement (Krejici, Lieber, and Lutz, 1995, Gordan, 2001). The use of chemical softening agents selectively dissolving the composite resin matrix has been proposed without much success (Cruickshank and Chadwick, 1998).

Conversely, the optical contrast to the tooth substance and the purely mechanical retention of amalgam restorations, make their removal and replacement more conservative as compared to the removal and replacement of failed resin restorations (Hunter *et al.*, 1995).

There is consensus in the literature that replacement of resin composites is a technically-demanding and time-consuming procedure that is likely to result in weakening of the tooth with a renewed insult to the pulp tissue (Krejici, Lieber, and Lutz, 1995, Tyas *et al.*, 2000, Mjör and Gordan, 2002). The re-restoration cycle may even lead to tooth loss. Considering these concerns, the repair of an existing restoration may be conceived as a viable and minimally invasive alternative to total replacement, providing that the repaired restoration is clinically acceptable.

2.4 Repair versus Replacement: making a clinical choice

A recent literature review of practice-based studies (Sarrett, 2005) indicated that secondary caries is the primary reason given for the replacement of composite restorations, accounting for 30 to 60% of all the operative re-interventions. These

findings are similar to those reported in a previous review based on prospective clinical studies (Brunthaler *et al.*, 2003), even though significantly lower failure rates relating to secondary caries were recorded. Several authors argued that this difference was most likely due to a reflection of the poor sensitivity and specificity for the evaluation of secondary caries in clinical settings (Tyas *et al.*, 2000, Hickel and Manhart, 2001) Improvements in handling properties to ensure void-free placement and complete cure should be investigated to improve the clinical outcome of composite resin restorations. There is a general lack of data that correlates clinical performance with laboratory materials testing. There is a lack of evidence that indicates that polymerization shrinkage is the primary cause of secondary caries. It has been recommended that composite materials be developed with antibacterial properties as a way of reducing failures due to secondary caries (Sarrett, 2005). Post-operative sensitivity appears to be more related to the ability of dentin adhesives to seal open dentinal tubules rather than to the effects of polymerization shrinkage on cuspal deflection and marginal adaptation (Sarrett, 2005). However, the prevention of recurrent lesions by the use of fluoride-releasing restorative materials has not been very successful (Mjör, 2005).

Due to the importance traditionally attributed to microleakage in the occurrence of secondary caries (Kidd, 1976), stains at the margins of tooth-coloured restorations are prone to be misdiagnosed as recurrent carious lesions (Mjör and Gordan, 2002), leading to the preventive replacement of the restoration. Recurrent carious lesions are most often located on the gingival margins of Class II, III, IV, and V restorations (Gordan, 2001). Recurrent caries is rarely diagnosed in Class I restorations. The diagnosis is difficult, and it is important to differentiate recurrent carious lesions from stained margins on resin-based composite restorations. Over-hangs, even minute in size, are predisposed to plaque accumulation and the development of recurrent caries. The development of a recurrent carious lesion in this case is unrelated to microleakage (Mjör, 2005). A correlation between the width of a marginal discrepancy and the presence of recurrent caries only exists when frankly

cavitated lesions are detected at the restoration margins (Frencken *et al.*, 1994, Mjör and Toffenetti, 2000).

As secondary carious lesions are known to be localised and delineated defects, a reconsideration of the conventional treatment approach has recently been recommended. In deciding whether to repair or to replace a defective restoration, a "minimal treatment" should be preferred (Mjör and Gordan, 2002). Simple re-contouring and re-polishing of small marginal defects should be performed as a first option (Mjör and Gordan, 2002), especially in patients with a low caries-risk status (Tyas *et al.*, 2000). Conversely, if any clinical doubt exists in areas prone to plaque accumulation, or in the presence of larger defects and higher caries risk, an exploratory preparation into the composite material at the tooth/resin composite interface may help in diagnosing the existence and the size of the lesion (Mjör and Gordan, 2002, Mount *et al.*, 2006). Since secondary caries is localized in nature, it rarely progresses along the tooth/resin composite interface (Mjör and Toffenetti, 2000). When sound tooth tissue is exposed, the exploratory cavity may be repaired using a conventional restorative technique (Gordan *et al.*, 2003).

In the same way, non-carious, degraded or ditched margins may be successfully restored by re-finishing and re-polishing methods (Mjör, 2005). Based on the same concept, no replacement of any restoration with bulk discoloration in aesthetic areas should be planned without first evaluating whether the unsatisfactory appearance can be treated and improved by resurfacing/veneering procedures. Similarly, clinical reports show that bulk fractures limited to the composite material may be repaired by bonding a new resin composite to the old restoration (Mjör and Gordan, 2002).

If a tooth with a composite filling has cusps, that are not adequately supported by marginal ridges then the restoration should be replaced and the tooth supported by a casting which provides full occlusal coverage (Ettinger, 1990).

Despite composite repair being a conservative option ethically and theoretically valid, and more accepted and practised recently (Blum, Newton and Wilson, 2005), there is little objective evidence available on the increased longevity of the repaired restorations (Gordan *et al.*, 2003). Only recently has composite repair received greater attention. Repair of resin-based composite restorations is a conservative option for the treatment of resin-based composite restorations with inadequate marginal adaptation and marginal staining (Gordan *et al.*, 2006).

Therefore, it has been suggested that in the current absence of evidence-based guidelines, the clinical choice of repair rather than replacement must be based on the individual caries-risk status assessment, the professional evaluation of benefits versus risks, and the conservative principles of cavity preparation (Tyas *et al.*, 2000).

Dental adhesives and restorative materials, new understanding of the caries process and remineralization, and changes in caries prevalance have catalyzed the evolution in caries management from G.V. Black's “extension for prevention” to “minimally invasive” preparations (Murdoch-Kinch and McLean, 2003). The authors describe the scientific basis for early diagnosis based on a modified classification of caries based on site and size of lesion, remineralization, reduction of cariogenic bacteria, and minimally invasive cavity preparation design, techniques and material selection (Murdoch-Kinch and McLean, 2003). The concept of minimally invasive dentistry will provide favorable conditions for the use of composite resin. The quality of the composite resin restoration will not only be affected by the outline form of the preparation but also by the clinician's technique and understanding of the composite resin materials. However, a number of factors must be considered when placing composite resins in conservatively prepared cavities, including: aspects related to the adaptation of the composite resin to the cavity walls; the use of adhesives; and techniques for obtaining adequate proximal contacts. The clinician must also adopt an equally conservative approach when treating failed restorations (Jacobsen, 2004).

However, failed composite resin restorations have their own unique problems. In a study by Krejici, Lieber and Lutz in 1995 it was found that the removal of tooth-colored adhesive posterior composite resin restorations was quite difficult. This difficulty was probably caused by the poor visual and tactile differences between the restorative material and the tooth, and by the total bonding of the remaining restorative material to the enamel and dentin. The attempts at removal of the failed composite resin restoration caused an unnecessary loss of tooth material which was quite significant. These results were supported by Gordan, Mondragon, and Shen (2002) who concluded that the replacement of a class I resin based composite restoration resulted in an increase in the perimeter and area of the new cavity preparation. Similar evidence was also presented in the study by Gordan, 2001 who claimed that the replacement of class V resin based composite restorations resulted in an increased size of the cavity preparation in areas distant from the site of failure of the restoration.

2.5 Factors affecting the composite repair strength

Repair of fractured and/or worn restorations and re-surfacing of discolored restorations is achieved by layering a fresh composite resin layer over the existing material. The coupling effectiveness between the resin composite substrate and the repairing resin composite represents one of the major concerns raised in clinical practice when the repair option is preferred (Gordan *et al.*, 2003). Indeed, the success of this procedure relies on interfacial coupling and long-term retention between the composite surfaces involved in the repair. At present, the minimum bond strength for retention of a composite repair in the intraoral environment is not known (Gordan *et al.*, 2006).

Flaws within the material or at the bonded interface, in the form of voids, phase separations or non-uniform film thickness, may also represent stress concentration

and crack propagation points resulting in failure of the repaired composite resin restoration (Pashley *et al.*, 1995).

The bond strength between increments of composite is known to be equal to the cohesive strength of the composite material (Lloyd, Baigrie and Jeffrey, 1980). However, if the composite surface to be repaired has been contaminated (Eiriksonn *et al.*, 2004) polished (Boyer, Chan and Torney, 1978, Shahdad and Kennedy, 1998) or aged (Boyer, Chan and Reinhardt, 1984), direct bonding of a fresh composite resin may be significantly compromised.

Several chemical and mechanical methods have been studied in an attempt to find an ideal surface treatment for composite resin repair procedures. Repair bond strength values are enhanced by the application of silane primer and unfilled resins to the surface being repaired to facilitate the flow of the repairing resin (Kupiec and Barkmeier, 1996, Shahdad and Kennedy, 1998, Matsumura, Hisamatsu and Atsuta, 1995).

When repairing composite resins the surface treatment of a composite resin surface with a diamond bur results in higher shear bond strength values compared to acid etching the surface only (Bonstein *et al.*, 2005). However, surface treatment with air abrasion and hydrofluoric acid etching offer acceptable bond strengths for laboratory composites repaired with direct repair composite resins (Trajtenberg and Powers, 2004).

The surface preparation of an old composite resin surface has been accomplished by mechanically roughening the surface to remove contaminated material, cleansing with 30% to 50% phosphoric acid to re-energize the surface. Since the brand of pre-existent resin is often unknown when a failed restoration is being repaired, the chemical compatibility between the materials differing in organic matrix and polymerization method has also received some attention in the literature

(Gregory, Pounder and Bakus, 1990). Repairs of composite resin with identical matrix chemistry did not produce bond strength values greater than those of different matrix chemistry (Gregory, Pounder and Bakus, 1990).

The time elapsed after repair is also considered a factor that may have an effect on the composite-to-composite bond strength: besides water, the salivary enzymatic activity has been shown to accelerate the biodegradation of the composite resins and the interfacial couplings (Finer and Santerre, 2004).

It is evident that multiple variables may be involved in the bond at the repair site: various combinations of these factors may exert a different influence on the repair strength. Conflicting results have often been produced when evaluating these variables: this lack of eqivocal information is probably one of the possible explanations for the limited information passed to students and the wide diversity in composite resin repair procedures documented in many European and American dental school curricula (Blum *et al.*, 2003, Gordan *et al.*, 2003). Those dental schools that do not teach composite resin repair procedures apparently replace restorations when localized defects, such as recurrent caries, is diagnosed or misdiagnosed. The consequences are unnecessary loss of tooth tissue, including that from intact areas, and increased cost. An exploratory preparation into the restorative material adjacent to the area where the recurrent lesion was clinically diagnosed will allow a correct diagnosis to be made. Repair then becomes the optimal treatment. How much do repairs enhance the longevity of restorations? No published reports are available. However, the repair procedure is considered an excellent alternative to replacement in many clinical situations even in the absence of long-term clinical data (Gordan *et al.,* 2003). The tooth structure that is preserved with a repair procedure as opposed to a replacement can only be to the advantage of the patient.

2.6 Conclusion

The repair procedure relies on the adhesion of a layer of fresh composite resin material to a pre-existing composite resin restoration. The chemical bonding potential of an aged resinous substrate is affected by the limited amount of residual free-radicals available for reacting with the new resin monomers (Burtscher, 1993). A composite-to-composite bond is mainly based on micro-mechanical retention (Crumpler *et al.,* 1989, Shen *et al.*, 2004, Bonstein *et al.*, 2005, Hanning *et al.*, 2006). Surface roughening of the old composite restoration and coating with an adhesive resin prior to the repair are claimed to increase the surface area available for bonding (Hanning *et al.*, 2006) thus providing new free-radicals (Burtscher, 1993, Shahdad and Kennedy, 1998, Hanning *et al.*, 2003, Hanning *et al.*, 2006). Thus the aim of the study will be to test the tensile bond strength of repaired posterior composite resins using a micromechanical and chemical means of bonding a new layer of composite resin to a fractured specimen of previously set composite resin in a laboratory-based study.

2.7 Null Hypothesis

1. There is no significant difference in the adhesive and cohesive bond strength of composite resin.
2. There is no significant difference in the repair bond strength of composite resin following micromechanical (diamond bur roughening) and chemical (adhesive) preparation of the bonding surface of the material repaired.

2.8 Aims and Objectives

The aim of this study is to measure the tensile bond strength of repaired composite resin restorations and to compare this to the tensile bond strength of a similar specimen of unrepaired composite resin.

The objective of this study is to investigate the repair bond strength of composite resin following micromechanical and chemical means of retention in improving the repair of composite resin specimens.

CHAPTER THREE: REASERCH DESIGN AND METHODS

3.1 Study Design

This was an *in vitro* experimental study.

3.2 Samples

Flat samples measuring 30mm in length, 2mm in width and 1.2mm in thickness, of *Z 100* (3M ESPE, St Paul, MN, USA) restorative material were prepared in a custom-made putty silicone mould according to the manufacturer's recommendations. These measurements of the specimens were determined after a pilot study to investigate the appropriate dimensions of the specimens to avoid fracture of the specimens due to the grip of the jaw of the tensile strength testing machine.

3.3 Sample Size

Seventy five samples were prepared in the custom-made silicone putty mould. Of these forty five samples randomly selected constituted the repair group (fifteen per group). This number was determined according to the data in the literature and after consultation with the statistician.

3.4 Materials to be Tested in the Study

Z100 (3M ESPE, St Paul, MN, USA), a light cured composite resin with its respective bonding agent, Adper Scotch Bond (3M ESPE, St Paul, MN, USA) was investigated (Fig: 3.1). These materials were identified for the study as they are

currently being used in the Faculty of Dentistry; University of the Western Cape as directly placed composite resin restorations.

3.4.1 Z100

Z100 is a visible-light activated, radiopaque, microhybrid composite resin developed by 3M ESPE, St Paul, MN, USA. It can be used for both anterior and posterior restorations.

Z100 is available in a variety of shades.

Composition

Z100 is a microhybrid composite resin with an inorganic filler loading of 72% by weight and 66% by volume. The filler used in Z100 is zirconia/silica with a particle size ranging from 3.5 to 0.01 microns (table 3.1)

The resin matrix contains bisphenol-A glycidylmethacrylate (BIS-GMA) and triethylene glycol dimethacrylate (TEGDMA).

Table 3.1 Restorative material used in the study

Product (Manufacturer)	**Monomer** (matrix)	**Filler (%)**		**Filler**		**Shrinkage (%)**
		Weight	Volume	Composition	Size(μm)	
Z100 3M ESPE USA	Dimethacrylate Triethylene Glycol Dimethacrylate	72	66	Zirconia/Silica	3.4-0.01	2.8

3.5 Sample Preparation

Seventy five specimens measuring 30mm in length, 2mm in width and 1.2mm in thickness, of *Z 100* (3M ESPE, St Paul, MN, USA) restorative material were prepared in a custom-made putty silicone mould according to the manufacturer's recommendations (Fig 3.2 and 3.3).

A notch was created in the middle of the mould to aid in creating a weak point in the specimen where the samples would break (Boyer, Chan, and Torney, 1978, Shahdad and Kennedy, 1998, Shen *et al.,* 2004). All the materials were used according to the manufacturer's instructions (Fig 3.4 and 3.5).

The mould was filled and condensed with the restorative material to avoid air entrapment. The curing time was standardized at 60 seconds. The intensity of the light was checked after the light-curing of each tenth specimen using a lamp checker (Visible Light Cure Meter, Dentsply, Model 644726, Canada). All the specimens were kept for no more than one week before the fracturing process. The tensile strength of the samples was measured using a Zwik 1446 model (Zwik Gmgh and Co., Ulm, Germany) universal material testing machine (Fig 3.6). The measurements obtained represented the control group. All the fractures occurred at the notch created in the mould (weak point).

3.6 Repair Procedure

To simulate the clinical conditions in the laboratory, the fractured specimens were constantly kept in water at 37°C for 24 hours and thermocycled for 250 cycles between 5°C and 55°C with a dwell time of 30 seconds (Lloyd, Baigrie, Jeffrey, 1980) (Fig 3.7).

A dark shade was chosen for the substrate and a lighter shade for the repair material. This was to facilitate distinguishing between the two materials after the specimens were repaired. One half of the broken specimens were returned to the mould and repaired by adding a new layer of fresh composite resin. Repair occurred at the notch (Fig 3.8 and 3.9). All the repaired specimens were kept for no more than one week before the fracturing process.

The fractured specimens were randomly assigned into three groups according to the retention method that was used for the repair of the samples. The three methods of repair were:

1. Micromechanical (diamond bur roughening)

Surface roughening of the fractured composite resin was done using a cavity preparation diamond fissure bur (no: 016, Dentsply-Maillefer instruments, Switzerland) in an air rotor with copius water spray to simulate the clinical removal of a thin layer of old restoration followed by the placement of the repair material. The burs were changed after the roughening of every fifth specimen

2. Chemical, *Adper Scotch Bond* (3M ESPE, St Paul, MN, USA)

A layer of the adhesive was applied to the fractured composite resin surface using a fine brush and then cured for 10 seconds followed by the placement of the repair material.

3. Combination of both micromechanical and chemical

Surface roughening of the fractured composite resin using the diamond fissure bur (no: 016, Dentsply-Maillefer instruments, Switzerland) in an air rotor with copius water spray and a layer of adhesive applied and cured for 10 seconds followed by the placement of the repair material. The burs were changed after the roughening of every fifth specimen

All the repaired specimens were subjected to the Zwik machine once again, and the measurements were recorded in an Excel spread sheet. These measurements were compared to the control measurements.

The specimens were then examined under a Light Microscope for detection of irregularities in the line of fracture.

Fig 3.1: Composite + Adhesive + Composite placement instrument

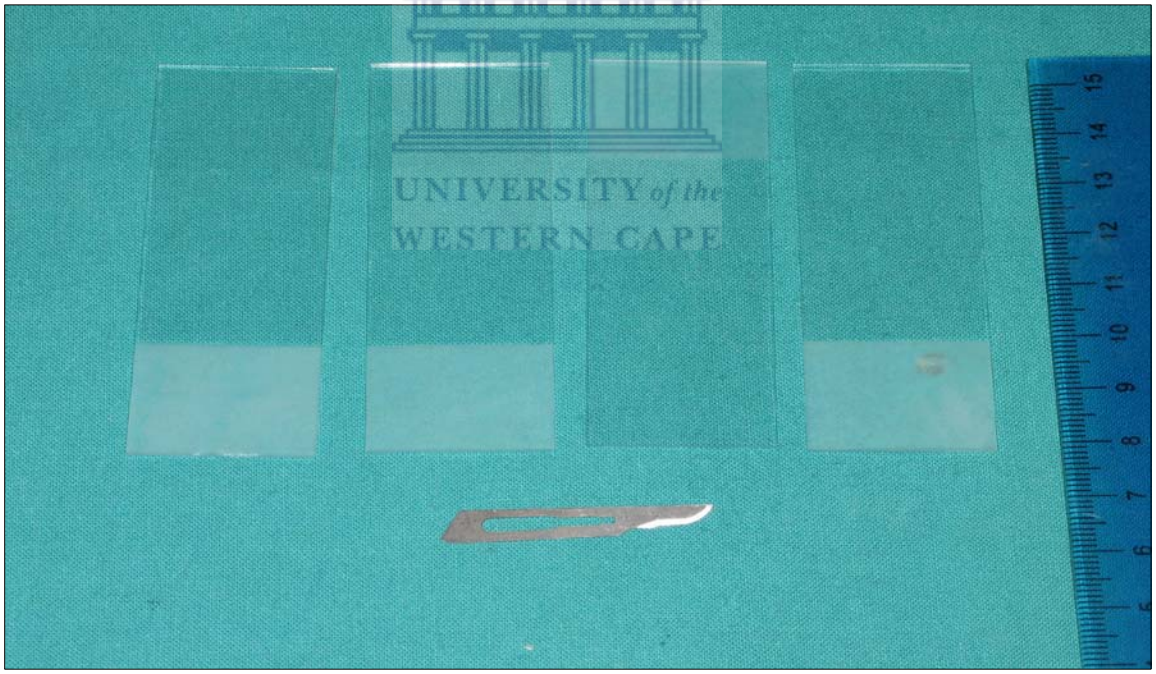

Fig 3.2: Glass Slides + Blade + Ruler

Fig 3.3: Using Silicone Putty to make a customized Silicone Mould

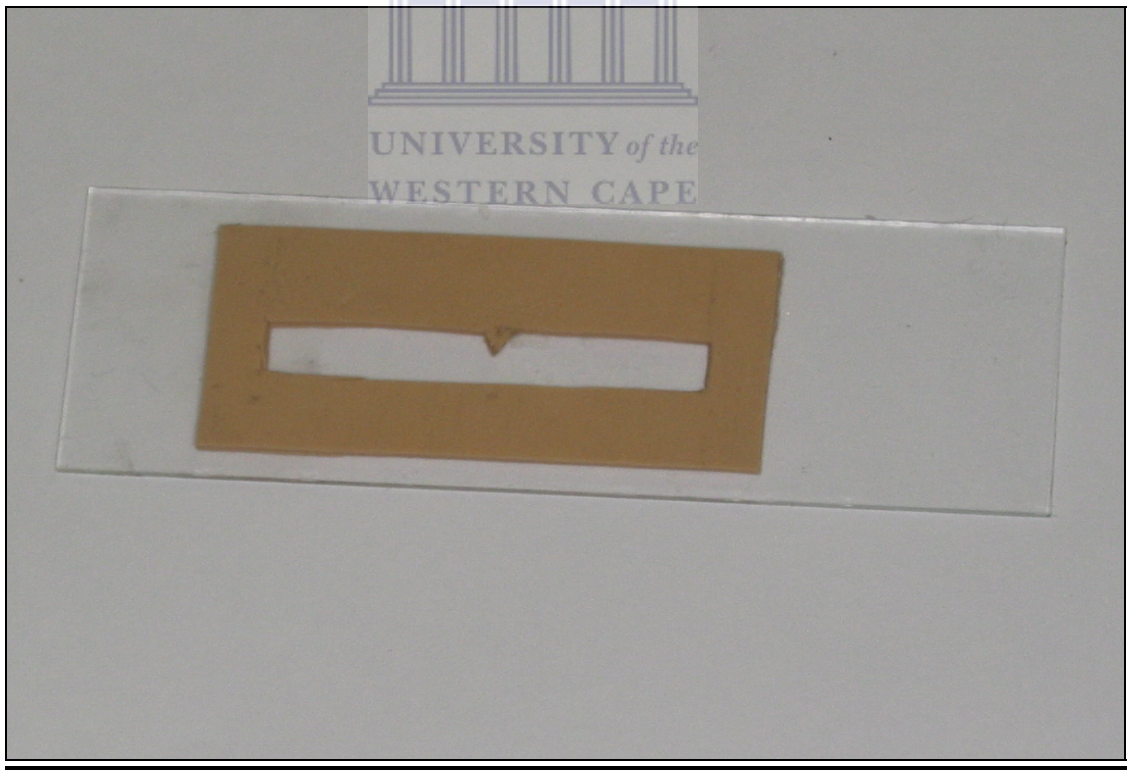

Fig 3.4: Silicone Mould with Notch for Specimen Preparation

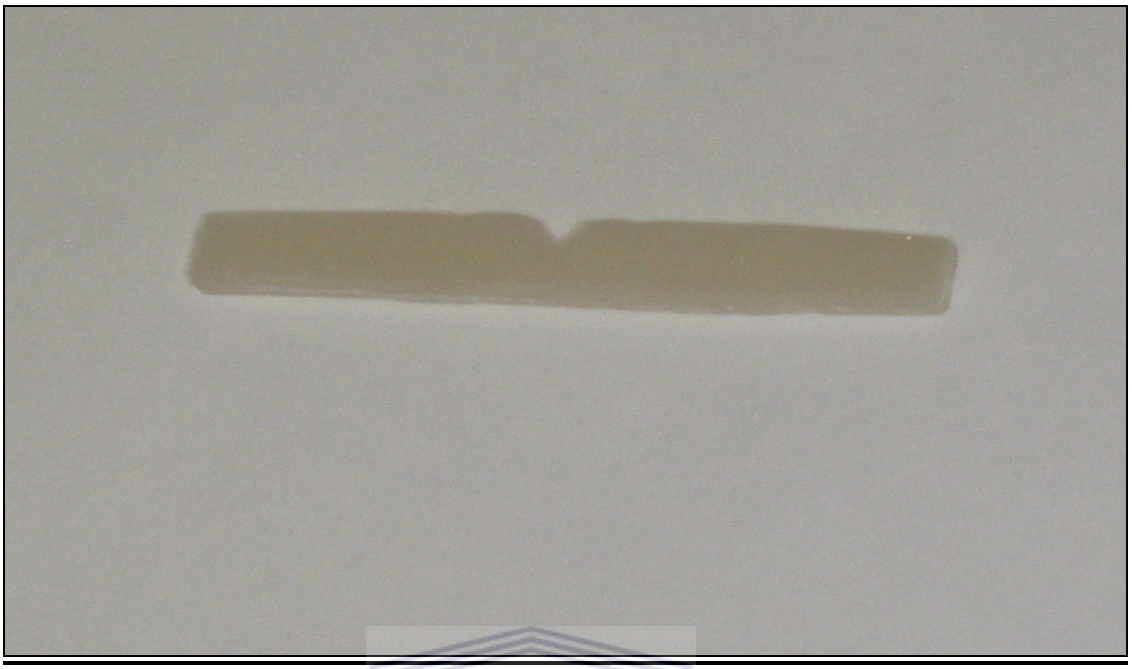

Fig 3.5: Prepared Specimen with Notch

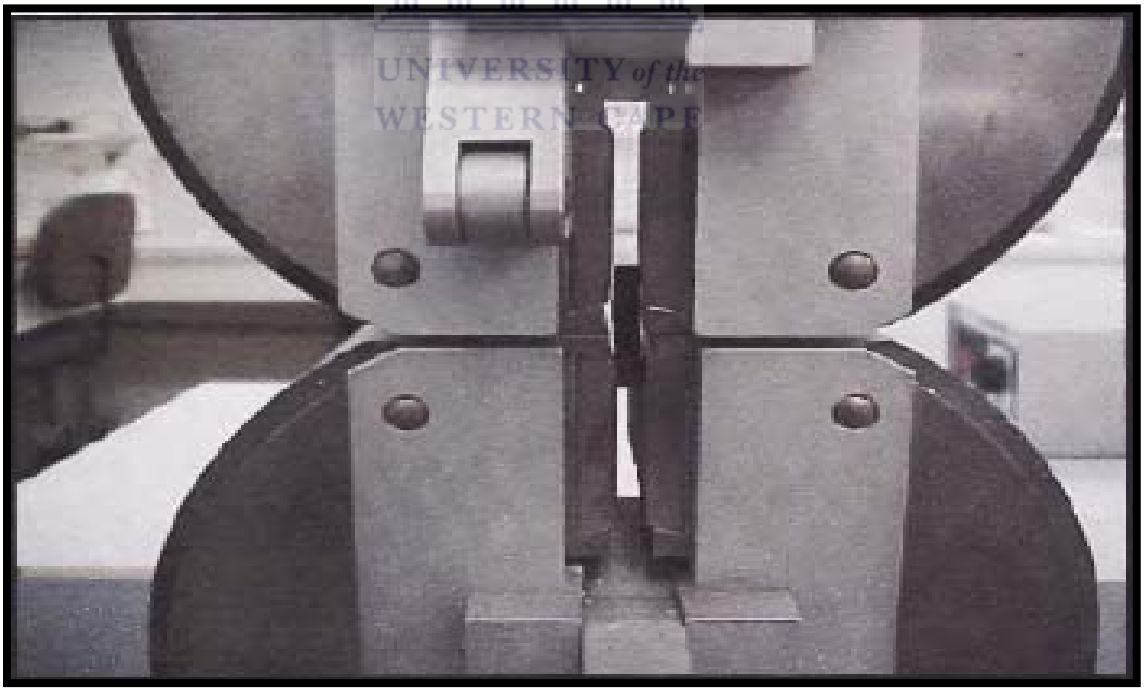

Fig 3.6: Breaking of Specimen Using Zwik Machine

Fig 3.7: Thermocycling Process

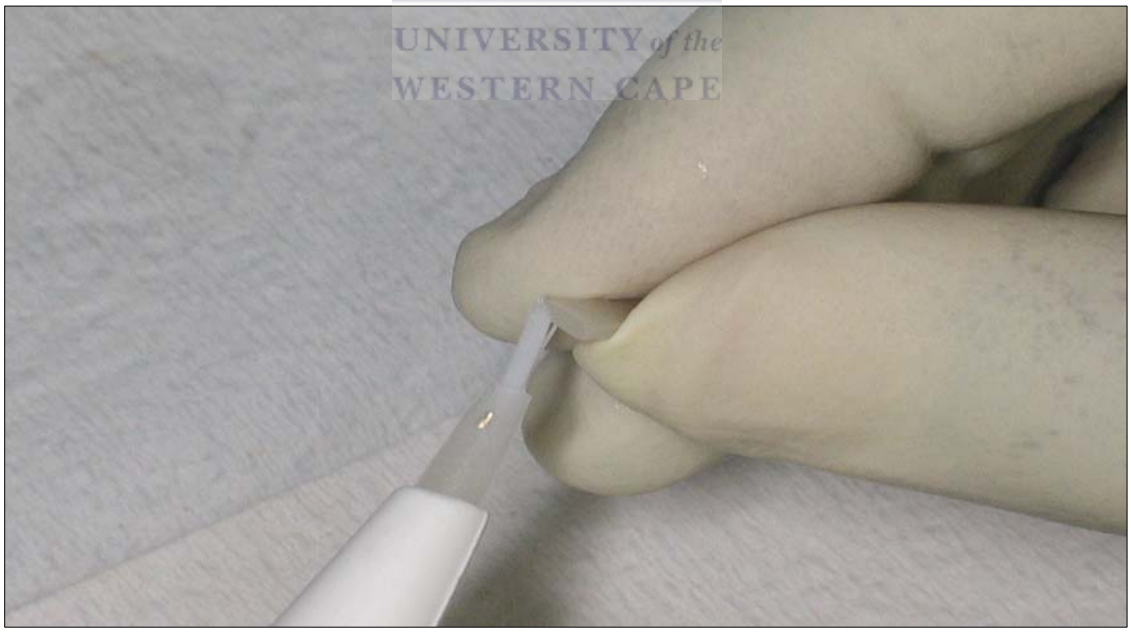

Fig 3.8: Repair by Applying Adhesive to broken sample

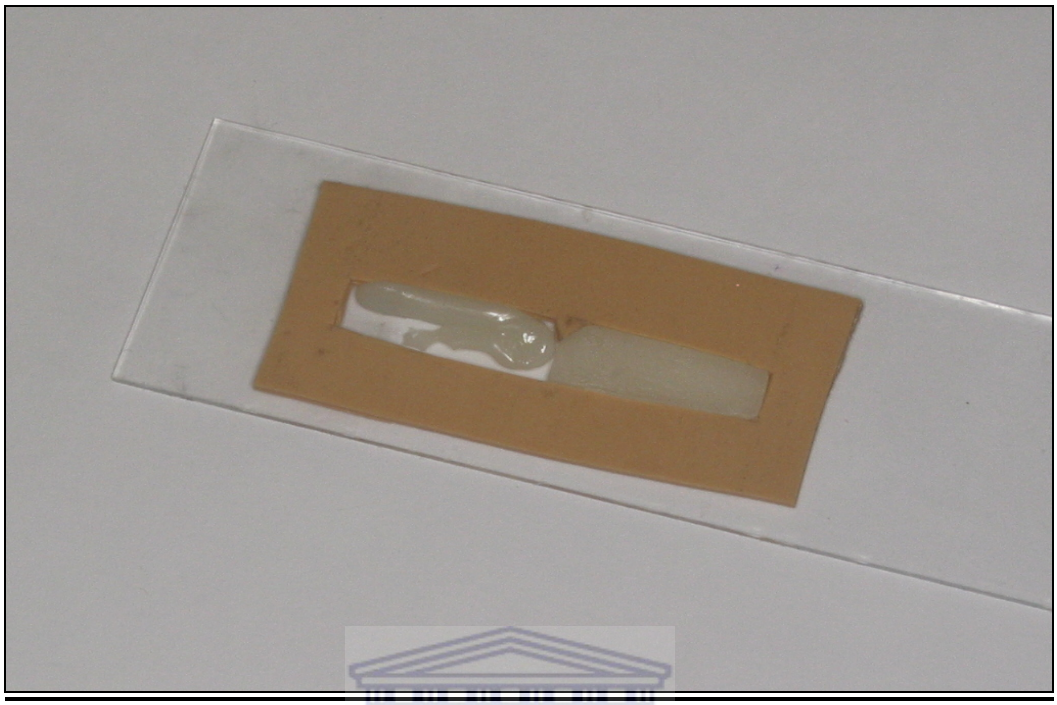

Fig 3.9: Repair by adding New Composite

3.7 Ethical Statement

This was a laboratory-based study that did not involve patients. Samples were disposed after the experiment in accordance with the waste disposal practice at the University of the Western Cape. Conclusions from this study are made without commercial bias.

CHAPTER FOUR: RESULTS

The results of the tensile bond strength tests of the control group are reflected in Table 4.1. These results are recorded in Newtons per square millimeter. Results of the tensile bond strength of the control group display a mean of 21.13 N/mm² and a standard deviation of 7.13 N/mm², with a minimum of 12.01 N/mm² and a maximum of 35.87 N/mm². These values are in accordance with values in the literature for this material (Lloyd, Baigrie, Jeffrey, 1980, Shahdad and Kennedy, 1998, Shen *et al.,* 2004)

Results of the tensile bond strength of group A (samples repaired using a combination of micromechanical in the form of diamond bur roughening and chemical in the form of adhesive) are reflected in Table 4.2. Results of group A display a mean of 20.42 N/mm² and a standard deviation of 9.24 N/mm², with a minimum of 10.85 N/mm² and a maximum of 40.72 N/mm². Although the mean value is similar to that found in the control group the range as reflected by the minimum and the maximum values is greater.

Results of the tensile bond strength of group B (samples repaired using adhesive only i.e., chemical repair) are reflected in Table 4.3. Results of group B display a mean of 15.29 N/mm² and a standard deviation of 5.95 N/mm², with a minimum of 9.02 N/mm² and a maximum of 27.25 N/mm². The mean value in this group is lower than that found in the control group. The minimum and maximum values recorded in this group are also lower than those found in the control group.

Results of the tensile bond strength of group C (samples repaired using diamond bur roughening only) are summarized in Table 4.4. Results of group C display a mean of 15.50 N/mm² and a standard deviation of 3.16 N/mm², with a minimum of 11.87

N/mm² and a maximum of 24.83 N/mm². The mean value in this group is lower than that found in the control group. While the minimum (11.87 N/mm²) of group C was very similar to the minimum of the control group (12.01 N/mm²), the maximum of group C (24.8 N/mm²) was much less than the maximum of the control group (35.87 N/mm²). The mean of this group is very similar to group B.

These data are summarized in Table 4.5 and graphically represented in Figure 4.1.

Sample No.	Sample Thickness (mm)	Sample Width (mm)	Tensile Strength (N/mm^2)
1	1.2	2	14.2
2	1.2	2	15.08
3	1.2	2	29.89
4	1.2	2	19.83
5	1.2	2	17.74
6	1.2	2	24.27
7	1.2	2	33.84
8	1.2	2	13.68
9	1.2	2	16.3
10	1.2	2	28.06
11	1.2	2	24.12
12	1.2	2	14.51
13	1.2	2	13.12
14	1.2	2	13.04
15	1.2	2	29.45
16	1.2	2	20.73
17	1.2	2	21.14
18	1.2	2	35.87
19	1.2	2	26.54
20	1.2	2	16.38
21	1.2	2	24.93
22	1.2	2	12.01
23	1.2	2	17.71
24	1.2	2	16.65
25	1.2	2	16.22
26	1.2	2	19.4
27	1.2	2	15.57
28	1.2	2	17.67
29	1.2	2	31.74
30	1.2	2	34.15
Mean			21.13
Standard Dev.			7.13
Minimum			12.01
Maximun			35.87

Table 4.1: Tensile bond strength of the control group

Sample No.	Sample Thickness (mm)	Sample Width (mm)	Tensile Strength (N/mm²)
1	1.2	2	10.85
2	1.2	2	35.17
3	1.2	2	40.72
4	1.2	2	16.24
5	1.2	2	31.84
6	1.2	2	19.72
7	1.2	2	20.42
8	1.2	2	15.68
9	1.2	2	12.11
10	1.2	2	14.89
11	1.2	2	24.52
12	1.2	2	13.39
13	1.2	2	14.73
14	1.2	2	11.12
15	1.2	2	24.84
Mean			20.42
Std. Deviation			9.24
Minimum			10.85
Maximum			40.72

Table 4.2: Tensile bond strength of group A (Diamond bur + Adhesive)

Sample No.	Sample Thickness (mm)	Sample Width (mm)	Tensile Strength (N/mm²)
1	1.2	2	11.48
2	1.2	2	20.97
3	1.2	2	12.24
4	1.2	2	9.61
5	1.2	2	15.42
6	1.2	2	13.2
7	1.2	2	9.07
8	1.2	2	10.25
9	1.2	2	12.19
10	1.2	2	22.48
11	1.2	2	19.1
12	1.2	2	9.02
13	1.2	2	24.04
14	1.2	2	27.25
15	1.2	2	13.15
Mean			15.29
Std. Deviation			5.95
Minimum			9.02
Maximum			27.25

Table 4.3: Tensile bond strength of group B (Adhesive only)

Sample No.	Sample Thickness (mm)	Sample Width (mm)	Tensile Strength (N/mm²)
1	1.2	2	11.87
2	1.2	2	12.17
3	1.2	2	15.76
4	1.2	2	16.32
5	1.2	2	15.55
6	1.2	2	15.79
7	1.2	2	24.83
8	1.2	2	12.72
9	1.2	2	15.57
10	1.2	2	14.92
11	1.2	2	14.47
12	1.2	2	17.33
13	1.2	2	11.99
14	1.2	2	16.53
15	1.2	2	16.78
Mean			15.50
Std. Deviation			3.16
Minimum			11.87
Maximum			24.83

Table 4.4: Tensile bond strength of group C (Diamond bur only)

	Control group	Group A	Group B	Group C
Minimum	12.01	10.85	9.02	11.87
First Q	15.7	14.1	10.9	13.6
Third Q	26.1	24.7	20	16.4
Maximum	35.9	40.7	27.3	24.8
Average	21.13	20.42	15.3	15.51

Table 4.5: Summary of Statistics of the four groups

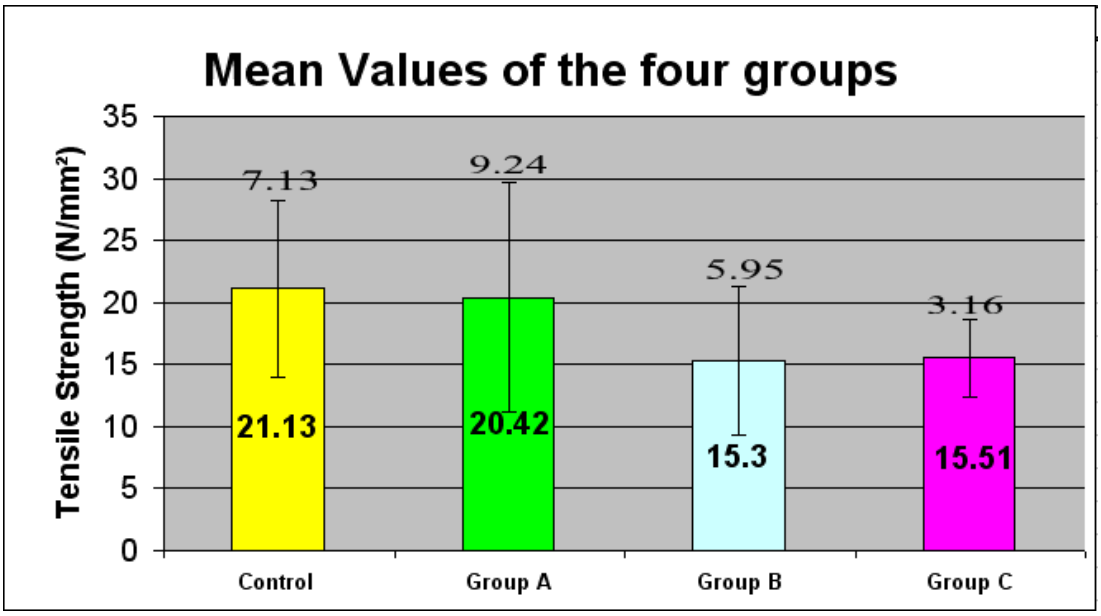

Fig 4.1: Bar graph demonstrating the mean tensile bond strength of the four groups

The data were subjected to a statistical analysis to determine if statistically significant differences existed between the groups. The statistical test used was the Wilcoxon Rank Sum Test (Table 4.6, 4.7, and 4.8).

Table 4.6: Wilcoxon Rank Sum Test comparing group A to the control group

Sample	Rank Sum	Sample Size	
1	721	30	Large Sample Approximation
2	314	15	Test Statistic Z = 0.7464
			P-Value = 0.4554

The Wilcoxon Rank Sum Test comparing the results from group A to those achieved in the control group revealed a P value of 0.4554. This means that the differences between the control group and group A are not statistically significant.

From the bar graph in figure 4.1 it can be seen that there is also not a great difference in the raw data from the two groups.

Table 4.7: Wilcoxon Rank Sum Test comparing group B to the control group

Sample	Rank Sum	Sample Size	
1	806	30	Large Sample Approximation
2	229	15	Test Statistic Z = 2.793
			P-Value = 0.0052

The Wilcoxon Rank Sum Test comparing the results from group B to those achieved in the control group revealed a P value of 0.0052. This means that the differences between the control group and group A are statistically significant.

From the bar graph in figure 4.1 it can be seen that there is a quite big difference in the raw data from the two graphs.

Table 4.8: Wilcoxon Rank Sum Test comparing group C to the control group

Sample	Rank Sum	Sample Size	
1	805.5	30	Large Sample Approximation
2	229.5	15	Test Statistic Z = 2.7809
			P-Value = 0.0054

The Wilcoxon Rank Sum Test comparing the results from group C to those achieved in the control group revealed a P value of 0.0054. This means that the differences between the control group and group A are statistically significant.

From the bar graph in figure 4.1 it can be seen that there is a quite big difference in the raw data from the two graphs.

4.1 The effect of the three variables:

4.1.1 The effect of diamond bur roughening (micromechanical) on the repair bond strength values:

4.1.1.1 With intermediary:

Table 4.2 shows the results of group A. When comparing these results statistically with the control group using a Wilcoxon Rank Sum Test (Table 4.6), it shows that using an adhesive (Scotch Bond) on specimens together with roughening with a diamond bur produced tensile bond strength values that were statistically not significantly different from the control group. The means are very similar and the dispersion around the mean is also similar.

4.1.1.2: With no intermediary:

Table 4.4 shows the results of group C. When comparing these results statistically with the control group using a Wilcoxon Rank Sum Test (Table 4.8), it shows that diamond bur roughening of the specimens without using any intermediary produced tensile bond strength values that were statistically significantly different from the control group. The means are quite different and the range of group C is narrower than that of the control group.

4.1.2 The effect of using an intermediary material (Scotch Bond) on repair bond strength:

4.1.2.1 With no diamond bur Roughening:

Table 4.3 shows the results of group B. When comparing these results statistically with the control group using a Wilcoxon Rank Sum Test (Table 4.7), it shows that using an adhesive (Scotch Bond) to repair specimens which had not been roughened produced tensile bond strength values that were statistically significantly different from the control group. The means are quite different and the range of group B is narrower than that of the control group.

Some specimens recorded high readings signifying high repair bond strength values ranging from 33.37 N/mm² to 38.67 N/mm² with a mean repair bond strength value of 34.05 N/mm². Upon examination under a dissecting microscope at a magnification of 10 times, the repair material was seen to overlap the fracture line. Those specimens were discarded from this study since all the fractures and repairs had to occur at the same area i. e., notch.

Fig 4.2: Graph showing the Distribution of the Results of the Control gorup

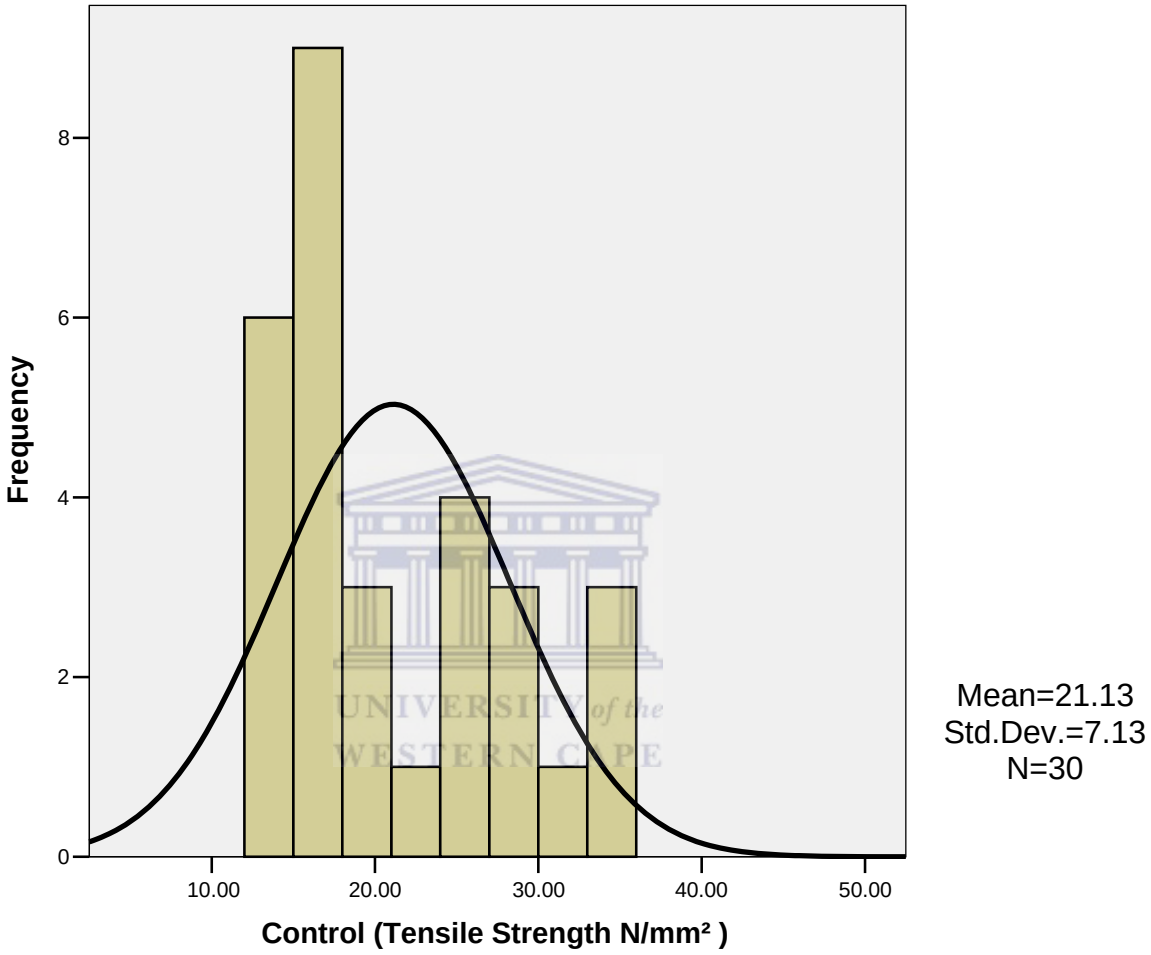

Figure 4.2 graphically illustrates the distribution of the specimens of the control group ranging in the tensile bond strength from 12.01 N/mm² to 35.87 N/mm². The distribution seems like a normal curve with four specimens around the mean. There were four specimens ranging in tensile bond strength from 30 to 35 N/mm² and this may have had an influence on the mean value of 21.13 N/mm².

Fig 4.2: Graph showing the Distribution of the Results of Group A

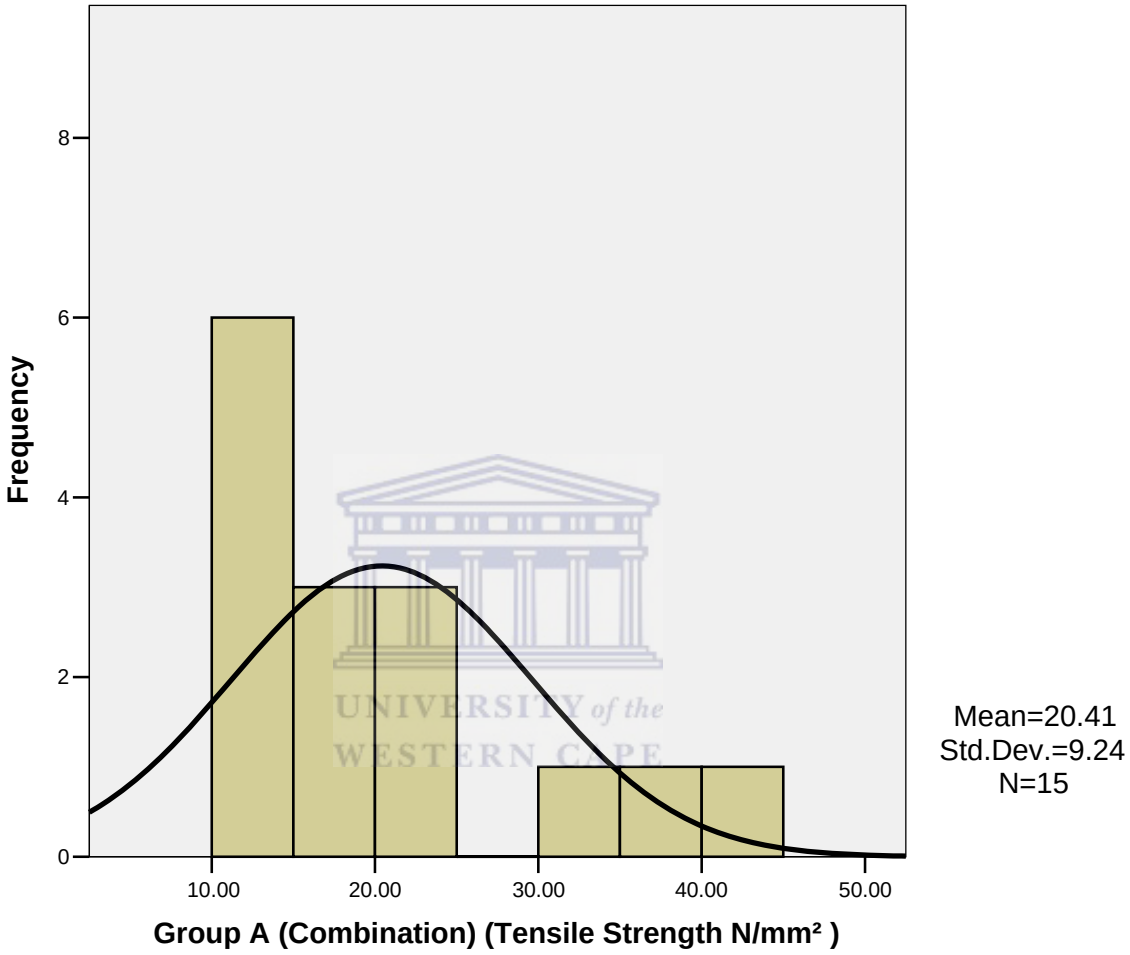

Figure 4.2 graphically illustrates the distribution of the specimens of group A ranging in the tensile bond strength from 10.85 N/mm² to 40.72 N/mm². There were seven specimens ranging in tensile bond strength from 10 to 15 N/mm². It is also noticeable that they were no specimens in the range from 25 to 30 N/mm².

Fig 4.3: Graph showing the Distribution of the Results of Group B

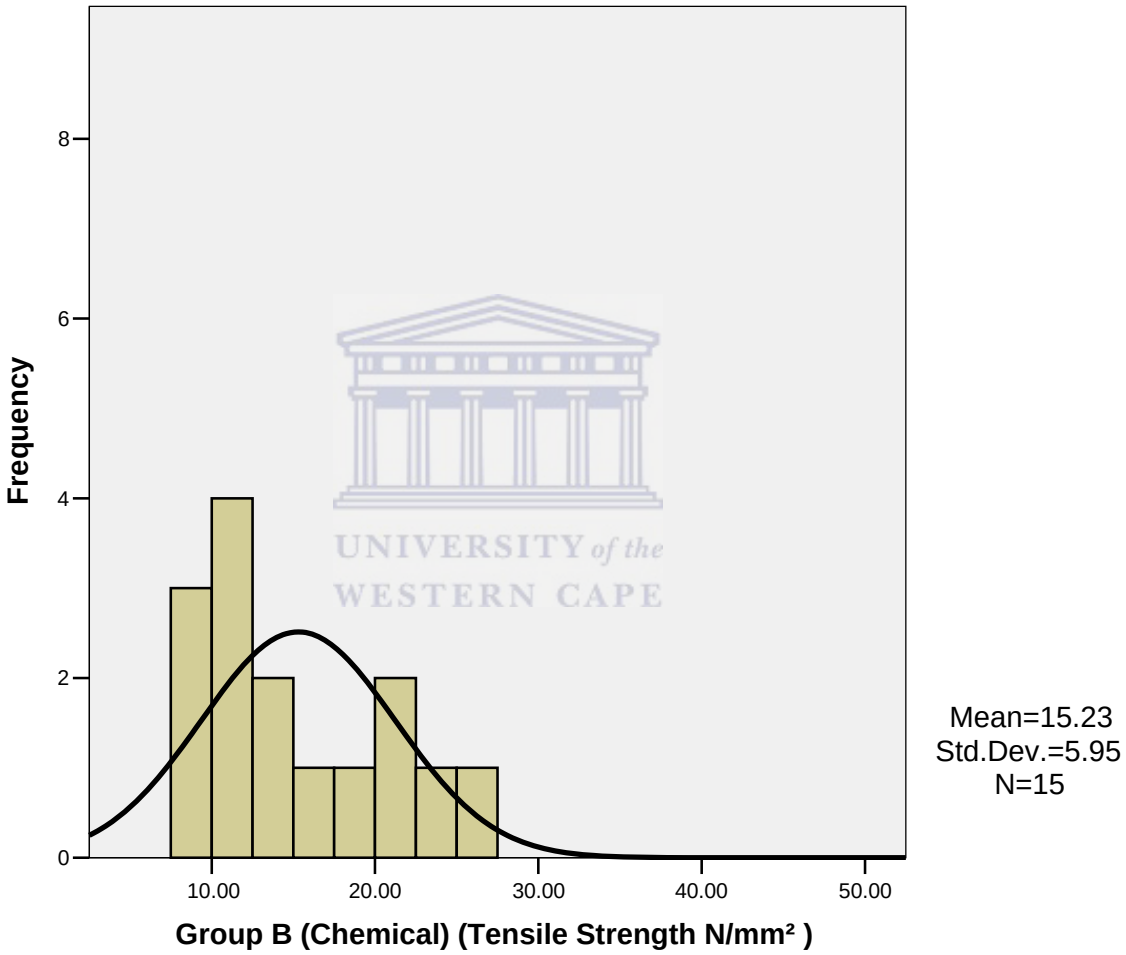

Figure 4.3 graphically illustrates the distribution of the specimens of group B in the tensile bond strength ranging from 9.02 N/mm² to 27.25 N/mm². There were seven specimens ranging in tensile bond strength from 9 to 13 N/mm². There was only one specimen above 25 and this may have had an influence on the mean value of 15.23 N/mm².

Fig 4.4: Graph showing the Distribution of the Results of Group C

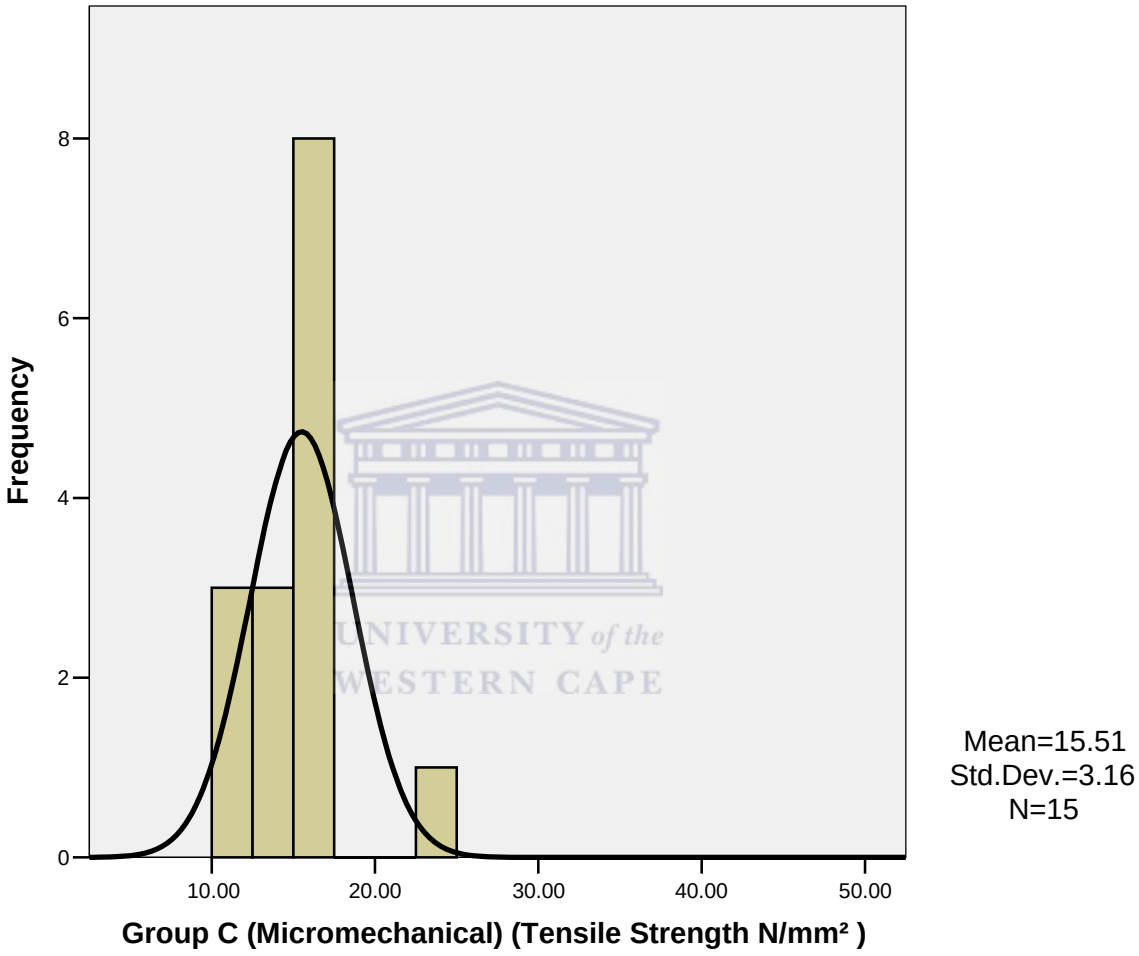

Figure 4.4 graphically illustrates the distribution of the specimens of group C in the tensile bond strength ranging from 11.87 N/mm² to 24.83 N/mm². There were eleven specimens ranging in tensile bond strength from 14 to 17 N/mm². It is noticeable that most of the specimens were dispersed around the mean. There was only one specimen above 20 and none in the gap between 18 N/mm² and the maximum reading, this may have had an influence on the mean value of 15.51 N/mm².

CHAPTER FIVE: DISCUSSION

The objectives of this study were to investigate the repair bond strength of samples of composite resin which had been repaired using three means of repair and to compare this with the tensile bond strength of unrepaired samples as the control group.

It is well known that it is extremely difficult to produce only one type of stress in a specimen (Shen *et al.*, 2004) and it is evident that the method of loading in this study produced elements of shear, tensile and compressive stresses in the specimens prior to failure. All of these stresses are expected to occur *in vivo.* The presence of various types of stresses complicated the situation and the term "repair bond strength" was therefore used in this study to imply the tensile bond strength of the specimens.

Adhesive bond strength values between materials reported in the dental literature often are given in terms of shear bond strength; however, flexure strength, tensile bond strength and diametral tensile strength values are also reported (Shen *et al.,* 2004). The shear test is used more often than any other test method, judging from the literature, but it has been criticized for the test arrangement that produces high stress concentration at the point of contact. The arrangement of the tensile strength test specimen, on the other hand, allows a uniform stress distribution within the interface and is considered a more appropriate approach for evaluating interfacial strength (Shen *et al.,* 2004).

The mean tensile strength of the unrepaired control group was 21.13 N/mm² with a standard deviation of 7.13 N/mm². When compared with the control group, group A, that was the group had specimens repaired using a combination of micromechanical in the form of diamond bur roughening and chemical in the form of adhesive, had the

highest repair strength of all the experimental groups, with a mean value of 20.41 N/mm² and a standard deviation of 9.24 N/mm². The mean and the dispersion around the mean of group A are very similar to those of the control group (21.13 N/mm²). While the minimum of group A (10.87 N/mm²) was less than the minimum of the control group (12.01 N/mm²), the maximum of group A (40.72 N/mm²) was more than the control group (35.87 N/mm²).

Group B, that was the group had specimens repaired using adhesive only, had the lowest repair bond strength with a mean value of 15.29 N/mm² and a standard deviation of 5.96 N/mm². It is noticeable that the means are quite different and the range of group B was narrower range than that of the control group. The minimum (9.02 N/mm²) and the maximum (27.25 N/mm²) of group B were less than the minimum (12.01 N/mm²) and the maximum (35.87 N/mm²) of the control group.

Results of group B were not statistically significantly different from the repair strength of group C which was the group had specimens repaired using a diamond bur roughening only. Group C had an average repair strength of 15.51 N/mm² with a standard deviation of 3.15 N/mm². While the minimum (11.87 N/mm²) of group C was very similar to the minimum of the control group (12.01 N/mm²), the maximum of group C (24.8 N/mm²) was much less than the maximum of the control group (35.87 N/mm²). The range of group C was narrower than that of the control group.

It is evident from the statistical analysis that the specimens in group A did not show a statistically significant difference in repair bond strength compared to the control group with a P value of 0.4554 (Table 4.6). However, group B and C showed statistically significant differences from the control group with a P value of 0.0052 and 0.0054 respectively (Table 4.7 and 4.8).

The results of this study clearly indicate that, when comparing the control group with a mean repair bond strength value of 21.14 N/mm² with the experimental groups, group A (combination of diamond bur roughening and adhesive) produced the strongest repaired specimens with a mean repair bond strength value of 20.42 N/mm². The weakest repaired specimens were in group B where only an adhesive was used, and these had a mean repair bond strength value of 15.30 N/mm².

Interestingly high readings were recorded 33.37 N/mm² to 38.67 N/mm² with a mean repair bond strength value of 34.05 N/mm², when the repair materials overlapped the fracture line. There is no evidence of such findings in the literature. The explanation of this may be due to more surface area being involved in the repair site, yielding a higher bond strength compared to a butt joint for the interface between repair material and fractured specimen.

The repair strength which is required for a satisfactory composite repair *in vivo* has not been thoroughly investigated. In contrast, the bond strength of composite to etched enamel has been extensively investigated and is reported to be of the magnitude of 15 to 30 MPa (Shahdad and Kennedy, 1998). It is well known that composites seldom fail mechanically at the junction with etched enamel and it can therefore be surmised that a repair bond strength which is similar to that of composite to etched enamel would be clinically adequate to sustain a bond between the new composite and the fractured composite resins (Simonsen, 2005). On that basis the results of the present study would suggest that any of the repair methods would produce adequate repair bond strength values; however the combination of diamond bur roughening and adhesive would be the closest to the original bond strength values of the unrepaired composite resin specimens as determined under the conditions of this study.

It is well known that there are many problems with interpreting the results of bond strength studies and it is often difficult to compare the results of studies in this field

as different methods of testing are frequently employed (Shahdad and Kennedy, 1998). In addition, it is generally not possible to use the results of *in vitro* tests to draw conclusions as to how a material will perform *in vivo.* Nevertheless, it seems clear that a stronger repair is preferable to a weaker one and in the present specimens in group A (using a combination of micromechanical and chemical means of repair) showed the highest bond strength of all the repaired specimens.

The results confirmed that bond strength values of the repaired specimens were lower than those of the original specimens and this is in line with the clinical situation where the repaired restorations are not as strong as the original restorations (Shen *et al.,* 2004).

The variables involved in this study revolved around the methods of specimen repair:

1. Diamond bur roughening (micromechanical)
2. Intermediary material (adhesive, chemical)
3. Combination of the two above methods of repair.

5.5 Diamond bur roughening:

The results of this study showed that diamond bur roughening alone without the use of an intermediary material resulted in statistically significant differences in the repair bond strength of the specimens when compared to the control group.

Based on the findings of this study it is not recommended to use diamond bur roughening alone in composite to composite repair.

5.2 Intermediary material:

The intermediary materials are applied using a fine brush, lightly air dried and light-cured for the time recommended by the manufacturers (Albers, 2002).

The results showed that there was a statistically significant difference in the repair bond strength of unroughened specimens using an intermediary material only and therefore, based on the results of this study; it is not recommended for composite to composite repair clinically. This could possibly be due to a contaminated or non-energised or totally reacted layer.

5.3 Combination

Mechanical roughening of the old composite surface with a diamond bur presumably enhanced the ability of the new composite to interlock mechanically onto the surface of the old composite by increasing the surface area available for bonding. Also exposing a subsurface layer that was not contaminated, this subsurface area may also have had greater energy values which made it more receptive to bonding. The diamond bur roughening was chosen because diamond burs are preferred by most clinicians for preparing the enamel for acid etching and preparing composites for the repair procedure (Shen *et al.*, 2004).

The role of using a dental adhesive in the repair procedure is well established in providing a low viscosity material that will flow to cover the roughened surface and also for providing an unreacted surface layer (due to oxygen inhibition) to bond with the new fresh repair resin (Burtscher, 1993).

Despite careful preparation of the specimens the standard deviation of all groups, was relatively large. This is a common finding in comparative studies and may be due to the fact that the repaired interfaces were not all exactly aligned with the direction of the tensile bond strength test structure (Shahdad and Kennedy, 1998) (Shen *et al.,* 2004).

CHAPTER SIX: LIMTATIONS OF THE STUDY

The main limitation of this study relates to the relevance of *in vitro* studies in predicting the clinical performance of the materials tested. Extrapolating the data of *in vitro* observations to the clinical situation is often unreliable and should be done with caution for the following reasons according to Swift, Perdigao, and Heymann, 1995:

1. **Tests of this type do not take into account the three-dimensional nature of tooth preparations, and thus underestimate the effects of polymerization shrinkage.**

2. **The effects of pulpal pressure, dentinal fluid, and tooth dynamics such as flexural phenomena, are not typically taken into account.**

3. **Occlusion especially excursive contacts once they are non-axially directed can be extremely harmful to repaired composite.**

4. **Other factors that contribute to a lack of correlation between laboratory investigations and clinical results include age, storage conditions of specimens, thermocycling procedures, and type and duration of loading forces.**

CHAPTER SEVEN: RECOMMENDATIONS

Conclusions

This *in vitro* study evaluated the effectiveness of three methods of composite repair. Tensile bond strength tests were employed to evaluate the tensile strength of unrepaired composite resin and to directly compare that to the bond strength achieved with three methods of composite resin repair.

Under the conditions set out in this study, several conclusions can be drawn:

1. **Combining the surface roughening with the intermediary material in the repair procedure, produced a repair bond strength that is as good as the control group (unrepaired composite resin restorative material).**

2. **Use of an intermediary material alone (adhesive) resulted in a significant decrease in the repair bond strength when compared to the control group (unrepaired composite resin restorative material).**

3. **Surface roughening alone (with diamond bur) of a fractured composite surface resulted in a significant decrease in repair bond strength when compared to the control group (unrepaired composite resin restorative material).**

4. **Based on an unexpected finding in this study, it is recommended that the interface between the and the fractured specimen be further investigated as results seem to indicate that an overlap produced significantly greater repair bond strength values compared to a butt joint interface.**

Recommendations

1. **All repairs should be done combining the surface roughening with the intermediary material.**

2. **Overlapping of repair material to the repair site should be investigated.**

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