Curriculum Vitae

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2011	Bisphosphonates
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2012	Functionally Generated Path
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Nov 2012 "Various Methods of Repairing Fractured Denture Bases and Their Effect on Fracture Strengths"
Table Clinic Presentation at American College of Prosthodontists 42st Annual Session
Baltimore, Maryland

Oct 2012 “Immediate Loading in the Completely Edentulous Patient: A Clinical Report”
Oral Presentation at 18th Annual Northeast Postgraduate Implant Symposium
Farmington, Connecticut

Feb 2012 “Prosthodontic Treatment Difficulties in Myotonic Muscular Dystrophy (MMD) Patient”
Table Clinic Presentation at American Academy of Fixed Prosthodontics meeting 2012
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D. Professional Licensure

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Abstract

Statement of problem: Denture fracture is a frequent clinical problem faced by the dentist. Denture repair should be simple to perform, cost-effective and quick. Unfortunately, the current methods of repair do not meet all of these requirements. Cyanoacrylate is a conveniently available adhesive material and it has been used by some patients to temporarily repair dentures before they get new ones. It is easy to use and relatively inexpensive. However, there is no literature that lists cyanoacrylate as a type of denture repair material.

Purpose: This study investigated the transverse fracture strength of denture bases repaired with cyanoacrylates (Loctite Superglue Liquid, Loctite Superglue Liquid Professional). This was compared with denture bases repaired with auto-polymerizing acrylic resin (Lucitone 199 Repair Material).

Material and methods: Thirty maxillary denture specimens were prepared and tested. They were divided into 3 different groups. Each of them was prepared with a clean midline fracture, repaired with Loctite Superglue Liquid, Loctite Superglue Liquid Professional or Lucitone 199 Repair Material and tested using the Universal Testing Machine. Data were analyzed using 1-way ANOVA and Tukey's HSD test, $\alpha=0.05$.

Results: There was a significant difference among the 3 types of repair materials. There was no significant difference in transverse fracture

strength between Loctite Superglue Liquid Professional (107.16 ± 20.57 MPa) and Lucitone 199 Repair Material (128.90 ± 22.08 MPa). Loctite Superglue Liquid (53.79 ± 19.05 MPa) had significant less transverse fracture strength than the other 2 types of material.

Conclusion: Within the limitations of this study, cyanoacrylate containing methyl methacrylate polymer (Loctite Superglue Liquid Professional) is an inexpensive and readily available material which can be used as a temporary measure to repair dentures with a clean fracture. However, further studies are required to investigate the long term cytotoxicity and intraoral stability of the material.

Fracture Strength of Repaired Midline Fractures of Maxillary Denture

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Dissertation submitted to the Faculty of the Graduate School of the

University of Maryland, Baltimore in partial fulfillment

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Introduction

Denture fracture is one of the most frequent clinical problems faced by the dentist [1-4]. It commonly presents as detachment of denture teeth and midline fractures of the maxillary denture. A survey done by Darbar et al.[2] in 1994 showed that 122 out of 195 repairs were due to fracture of the denture, the remaining were repairs involving detachment of acrylic resin saddles from the metal in metal based dentures and the fractures of connectors in the all-acrylic resin partial dentures. Thirty-three percent of repairs carried out were due to debonding or fracture of teeth from the denture base resin. Midline fracture represented 29% of the total denture repairs carried out; of which 68% were seen in upper complete dentures, 28% were seen in the lower complete dentures and 4 % were seen in partial upper dentures [2].

Damage to the denture can occur either intra-orally or extra-orally. Extra-oral causes are usually due to the patients' careless handling of dentures. The sudden impact from accidental dropping of the dentures can lead to fractures[1]. Midline fracture in the maxillary denture is a flexural fatigue failure. This is mainly due, over a period of time, to the cyclic deformation of the base during function[5]. It has been estimated that a person bites on an average of 500,000 times per year [6]. Hence, fatigue failure of the prosthesis is highly possible. This was supported by Hargreaves'1969 study[7], where she stated that maxillary complete dentures were most liable to lose a tooth or sustain a mid-line fracture during eating after 2 to 3 years of use. This was also re-established in 1993 by Vallittu et al[8]. They showed a relationship between damaged maxillary complete dentures and age of the denture ($\chi^2 = 10.41$, $\rho < 0.005$). In their study, 94% of the damaged maxillary complete dentures with porcelain teeth had been in use for more than 3 years. Of the fractured upper complete dentures with acrylic teeth, 74% were more than 3 years old. Most of the other types of damaged dentures had also been in use that long.

Debonding/ fracture of teeth from the denture base may be caused by excessive stress, fatigue or failure of the tooth to bond with the denture base. The denture-tooth bond is dependent on the composition of the denture base material or denture tooth and the presence of contamination at the joining surfaces [9]. When incompatible surface conditions exist at the denture tooth-base interface, the denture teeth are not able to bond with the denture base completely, thus resulting in detachment[10] .

Types of denture base resins

Polymethylmethacrylate (PMMA) is a transparent resin of remarkable clarity. It is rigid with a Knoop hardness number of 18 to 20 and a tensile strength of approximately 60 MPa. It has a density of 1.19g/cm^3 and its modulus of elasticity is approximately 2400 MPa. The resin is extremely stable and does not discolor in ultraviolet light. Also, PMMA is a popular selection for denture base material due to the relative ease with which it may be processed[2, 11]. Some resin materials used for denture base resins include heat-activated acrylic resin, pourable auto or chemically activated acrylic resins, visible light activated resins, and microwave-activated acrylic resins (see Table 1).

Table 1 : Common uses and properties of different types of PMMA denture resins

Denture base material	**Properties**	**Common uses**
Heat-activated	Good mechanical properties, poor adaptation	Denture base
Chemical-activated	Poor mechanical properties, good adaptation	Repair material
Visible-light activated	Poor mechanical properties, good adaptation	Record base, repair material
Microwave-activated	Excellent mechanical properties, good adaptation	Denture base, repair material

Heat activated acrylic resins

Heat activated acrylic resins are the most often used in denture fabrication. The resins are shaped via compression molding or injection–molding and polymerized in a heated water bath. Heat is required to decompose the benzoyl peroxide, which yields free radicals necessary for polymerization. In heat-activated acrylic resin, heat is the activator and benzoyl peroxide is the initiator. Good physical properties are achieved by the high degree of polymerization [12] but the adaptation to the tissues is poor due to polymerization contraction, thermal contraction and the strain accompanying stress release during deflasking [11]. Although heat activated acrylic resins have certain flaws, they are still one of the most common used material for denture fabrication [12].

Chemically activated acrylic resins

In chemically activated acrylic resins, a chemical activator like tertiary amine (dimethyl-para-toluidine) is used to split the benzoyl peroxide into radicals. Polymerization takes place at room temperature but the exothermic autopolymerizing reaction can increase the temperature to more than $100^{o}C$[12].

When using chemically activated resins to fabricate a denture, the fluid resin technique may be employed. This technique was developed in 1955[13]. Its main advantage, compared to the heat-processing technique, is that it makes processing of dentures less time consuming and improves adaptability to the associated tissues[13, 14]. However, the pour resin denture base seems to have relatively poorer mechanical properties, which results in easier dislodgment of teeth from the denture base, more fractures of the denture base, and increased wear of the polished surfaces [12]. Hence, chemical activated acrylic resins are mostly used as repair material for denture bases [14].

Visible-light activated acrylic resins

Visible-light activated acrylic resin is a composite of a matrix of urethane dimethyacrylate, microfine silica, and high-molecular-weight acrylic resin monomers. Acrylic beads are included as organic fillers. Visible light is the activator and camphoroquinone serves as the initiator for polymerization. Denture base fabrication using light-activated resin is different as it is not flasked in a conventional manner. It is exposed to a high-intensity visible light source for an appropriate period [12]. Visible-light activated acrylic resins provide dentures that have an accurate fit and superior strength. They allow for complete polymerization without residual compounds, ease of fabrication and manipulation ability to bond with other denture base resins and low bacterial adherence [15]. However, visible–light activated acrylic resin is more brittle than PMMA denture resin. Therefore, it is commonly used for relines and repairs rather than for laboratory fabrication of the entire denture base [16].

In recent years, a new type of visible light polymerized denture resin (Eclipse, Dentsply, York, PA) was introduced. In this system, the baseplate resin is used to fabricate the record base, which later becomes the definitive denture base. It was proposed that Eclipse may prove to be a useful alternative to conventional denture base resins[17] but this has yet to materialize.

Microwave activated acrylic resins

Microwave activated acrylic resin uses microwave energy to activate the polymerization process. Thus metallic flasks cannot be used as microwaves do not pass through them. Specially designed plastic flasks and special microwave machines are needed for this procedure[18] and the cost of repair will subsequently increase as well. Microwave polymerization allows a more uniform curing process resulting in a lower residual monomer-to-polymer ratio and better adaptation to the ridges[19]. Its physical properties are comparable to the conventional polymerized resin[18]. Therefore, microwave activated resin can be used for denture base fabrication[20] and repairing of a fractured denture[21].

Table 2 and 3 shows that heat and microwave polymerized acrylic resins are suitable materials for denture bases, but these acrylic resins do have a certain degree of brittleness according to the study on fracture morphology by Faot et al.[20]; hence, fractures in dentures are likely to occur when the other contributing factors are present to reduce the material's resistance to breaking apart.

<u>Table 2: Summary of studies comparing mechanical properties of different types of denture base materials (1991-1992)</u>

Study	**Denture Base Materials**	**Results**
Dixon et al.,1991[22]	2 Heat polymerized (Lucitone 199, Accelar 20) and 1 Visible Light polymerized (Triad)	Transverse strength of Triad was significantly lower than both heat polymerized resin.
Smith et al.,1992[23]	Heat polymerized (Accelar 20, Compak 20, Perma-cryl 20, PERform, Lucitone 199), Microwave polymerized (Acron MC), Visible Light (Triad)	1) Lucitone 199 had the greatest impact strength. 2) Triad had the greatest Knoop hardness, least Rockwell indentation, and greatest modulus of elasticity. 3) Acron MC had the greatest transverse strength. 4) All the resins were generally harder and less flexible but had lower impact strength than Lucitone 199.

Table 3: Summary of studies comparing mechanical properties of different types of denture base materials (2004-2008)

Study	**Denture Base Materials**	**Results**
Rached et al.,2004[24]	1 Heat polymerized (Lucitone 199) ,1 Microwave polymerized (Acron MC) and 1 Auto polymerized (Acron MC/R)	Microwave polymerized (Acron MC) had the highest transverse strength.
Faot et al. ,2006[20]	1 Heat polymerized (Lucitone 550) and 3 Microwave polymerized (Onda Cryl, Acron MC, Vipi Wave)	Impact Strength of Lucitone 550 and Onda Cryl is greater than Acron MC and Vipi Wave.
Machado et al.,2007[17]	1 Heat polymerized (Lucitone 199) and 2 Visible Light polymerized (Triad VLC and Eclipse)	Eclipse had greatest transverse strength, followed by Lucitone 199 and Triad VLC which showed the lowest value.
Diaz-Arnold et al.,2008[16]	4 Heat polymerized (Diamond D, Lucitone 199, HI-I , Nature-Cryl Hi-Plus) and 1 Visible Light polymerized(Eclipse)	Visible Light polymerized (Eclipse) had greater flexure strength than all heat polymerized but comparatively more brittle.
Ali et al. ,2008[25]	1 Visible Light polymerized (Eclipse), 1 Heat polymerized (Meliodent) and 1 Auto polymerized (Probase Cold)	Visible Light polymerized (Eclipse) had highest surface hardness, flexural strength, and flexural modulus followed by heat polymerized (Meliodent) and Auto polymerized (Probase Cold) which demonstrated lowest values.

Factors causing midline fractures in maxillary dentures

Stress within the dentures

The stress fields in the dentures have been widely studied to define the stress concentration areas due to external loading. It is known that fracture occurs as a result of crack initiation and propagation from areas of high stress concentration. Crack initiation and propagation in a complete denture can occur in 3 modes:

- The crack opening mode, which is due to tensile loads
- Shearing mode due to in-plane shear load
- Tearing mode due to out-of-plane shear loads[26]

In a study by Anthony et al.[26], rosette strain gauges were used to determine the principal stresses on a maxillary denture. It was demonstrated that the anterior stress field, the area palatal to the central incisors, was dominated by a principal tensile stress and a smaller compressive stress [26]. The tensile principal stress was approximately perpendicular to the midline and was greater in magnitude than the other principal compressive stress. This was different in the mandibular complete denture where the midline stress field was characterized by two compressive principal stresses and a low shear stress. The rate of stress increase was seven times higher in the maxillary denture than in the mandibular denture and the maximum shear stress was four times higher in the maxillary denture when external load was applied. This indicates that for the same increase in loading, the stress on the maxillary denture was much higher than that of the mandibular denture [26]. Brittle materials normally used to fabricate dentures, such as (PMMA), exhibit greater strength in compression (76 MPa) than in tension (48-62.5MPa)[27]. The greater strength of PMMA in compression than in tension suggests that regions of an acrylic resin base subject to tensile stresses will be more prone to failure than the regions under compressive stresses. Therefore, cracks will readily initiate and propagate in a maxillary anterior region since it is characterized by a high tensile principal stress and a high maximum shear stress. This is the reason why midline fracture occurs more commonly in the upper denture after a long time in function.

"Notch-effect"

It is a common experience that many brittle materials may be broken more easily if a fine notch is cut in the surface. Sharp changes in contour, pinholes, inclusions, deep scratches, and residual processing stresses may cause stress intensification[1]. When the notch is sufficiently sharp, the local stress concentration may exceed the breaking strength of the material and a crack will form which will run right through to complete failure under constant load[28]. This supports the finding by Hargreaves[7] in 1969 that a deep incisal notch was one of the causative factors in midline fracture and that cracks initiated at the tip of the notch, where high local stress concentration was located.

Occlusion

For complete dentures, the bilateral balanced occlusal scheme is ideal as it provides stability of the denture during function. If this is not achieved, heavy contact at the anterior teeth will result as there are inadequate posterior stops during centric occlusion. This increases the probability of fracture in the anterior region[29]. Hence, Ellinger et al.[30] recommended recontouring the natural opposing teeth to obtain an occlusal plane favorable to a maxillary denture with a balanced occlusal scheme.

Another consideration in occlusion is occlusal force. DiPietro and Moergeli[31] stated that patients with a low Frankfort-mandibular plane angle (FMA) have increased biting forces, resulting in more stress to the residual ridge. They further stated that shallow ridges, flat palates and decreased inter-ridge space occur more frequently in low FMA patients resulting in poor retention and support in their dentures. Hence, with the increased occlusal force and inadequate stability from the denture-supporting area, the possibility of denture base fracture also increases in these patients.

Biodegradation of dentures

Oral environment affects the denture both biochemically and mechanically. This is related mainly to the composition of the saliva. Water in saliva is absorbed into the polymer denture base and weakens it by plasticizing the material over a period of time. Saliva also chemically degrades the material through hydrolysis and enzymatic reaction. The salivary enzymes can degrade the polymers through the attacks on the side chains, producing both potentially harmful by-products as well as a deterioration of the physical properties of the material, such as surface hardness and wear resistance [32].

Two other sources of biodegradation are thermal and chemical dietary changes. Intraoral temperature changes may be induced by routine eating and drinking. These temperature changes produce a hostile environment for the materials as they have different coefficients of thermal expansion. Thermal fluctuations encountered in vivo can induce surface stresses due to the steep thermal gradients near the surface. Mechanical stresses brought about by different thermal changes can directly induce crack propagation through bonded interfaces [32].

Chewing force is also a cause of the biodegradation of the denture material. The relative low repetitive occlusal loads induce fatigue in the material which can lead to progressive degradation and crack initiation and growth, resulting in catastrophic failure of the resins [32]. Factors affecting the bond strength of denture teeth to denture base

Factors affecting the bond strength of denture teeth to denture bases

Impurities at the tooth-denture base interface

Schoonover et al.[33] did an experiment to investigate how wax and separating medium affected the bond strength between acrylic teeth and heat-activated acrylic denture base resin. Four different groups of denture teeth were tested; namely:

i) Teeth had no contact with wax

ii) Wax eliminated with boiling water only

iii) Wax eliminator used subsequent to application of boiling water

iv) Unwaxed teeth were contaminated with separating medium

The results showed that teeth with no prior wax contact had an average bond strength of 35.36 MN/m^2, teeth which were de-waxed with boiling water only reached 14.28 MN/m^2. The teeth treated with a solvent (wax eliminator) had bond strength statistically equal to unwaxed teeth. Contamination of wax-free tooth surfaces with alginate mould seal reduced the bond strength to 10.20 MN/m^2. This study showed that impurities will affect the bonding of denture teeth to the denture base [33].

Later, Darbar et al.[2] investigated the effect of impurities on the stress distribution at the tooth-denture base resin interface. With the finite element analysis technique, they discovered that the presence of an impurity at the interface had a significant effect on the stress magnitude of the bond between the teeth and the denture base resin. The impurity lowered the stress threshold for the crack to propagate, thereby increasing the risk of tooth detachment and fracture.

Types of denture base resin

Heat activated resins produce a higher bond strength to denture teeth than the microwave activated, visible light cured, pour-type or self-cure acrylic resins. This has been demonstrated in various research experiments where investigators compared bond strength of denture teeth to conventional heat-polymerized denture resin and other newer types of denture base resins [4, 10, 34-36]. However, the study by Geerts and Jooste[37] found that bond strength of denture teeth was higher in microwave activated resin than the traditional heat activated ones.

Types of denture teeth

Suzuki et al.[38] used a dye penetration technique to indirectly test the bonding between conventional acrylic resin teeth and cross-linked resin teeth to heat-polymerized denture base resin using porcelain teeth as a control. Greater dye penetration reflected lower bond strength. The results showed that porcelain teeth experienced the most dye penetration, followed by cross-linked teeth, with conventional resin teeth experiencing the least dye penetration. It was then concluded that, as the hardness of the tooth increased, the bonding between the tooth and the denture base decreased[38]. In another study that investigated the bond strength of conventional and cross-linked acrylic teeth, results demonstrated that conventional resin teeth possessed higher bond strength than cross-linked acrylic teeth[10]. Cross-linking in denture teeth reduces chemical bonding with the denture base resin. This is the reason why most prosthetic teeth are fabricated with less cross-linking at the cervical portion[12].

However, Chai et al.[39] found no significant difference in bond strength between the conventional resin teeth and cross-linked acrylic teeth comparing bond strength of conventional resinous and highly cross-linked acrylic teeth to a pour type denture base resin. They concluded that it was actually thermal cycling that significantly decreased the bond strength [39].

Polymerization temperature

The effect of polymerization temperatures on bond strength between denture teeth and denture bases was studied by Buyukyilmaz and Ruyter[36]. They concluded that by increasing the polymerization temperature of the denture base polymer, the bond strength between the teeth and denture base polymer was increased. The greatest bond strength was achieved with heat polymerized denture base resin. Autopolymerizing denture base polymers showed lower bond strengths. With increasing temperatures, the bond strengths of autopolymerizing systems increased and the bonding characteristics changed from adhesive to cohesive failure particularly at temperatures above 50^{o}C[36]. This is explained by the swelling phenomenon of the acrylic resin polymer teeth which was investigated by Vallittu et al[40]. When a solvent comes in contact with a polymer, the surface of the polymer swells because of diffusion of the solvent into the polymer. As the temperature increases, the polymer beads of the tooth swells. Therefore, by increasing the polymerization temperature, monomers can diffuse more effectively into the denture teeth, resulting in an increase in bond strength between the denture base and the teeth [41].

Factors affecting the strength of repair

Denture repair must fulfill several factors. It has to be simple to perform, cost-effective, reinforce the denture with adequate strength, maintain dimensional stability and possess satisfactory esthetic properties. The repair can be temporary or definitive depending on the extent of fracture and the patient's expectations. Usually, a new denture should be recommended if the fracture of the denture is too large or has recurred frequently.

Types of repair material

It is always advisable to select a repair material that is compatible with the denture base being repaired. There are many types of repair materials and each exhibits different properties.

Repair using heat-polymerized acrylic resin

Repair of dentures with heat-polymerized acrylic resin yielded satisfactory strengths ranging from 75% to 80% of the original bulk material[14, 42]. However, the procedure involved in the repair is time-consuming and tedious. Impression making and extended polymerization time are required. The patient must also do without the denture during the laboratory repair stage.

Repair using autopolymerizing acrylic resin

This is commonly used due to its ease of manipulation and lowered amount of time required for repair. However, many studies have shown that autopolymerizing resin is inferior to heat-polymerized acrylic resin in terms of transverse strength and hence results in frequent re-fractures [24, 42, 43]. This is caused by the low degree of conversion achieved by the chemically activated initiator system[44]. Specimens repaired with auto-polymerizing acrylic resin have approximately 60% to 65% of the original strength of the denture[42, 43].

Repair using light-polymerized acrylic resin

In 1984, a visible light-polymerized system was introduced and was used for repair and reline of dentures[45, 46]. The advantages included reduction of chemical and thermal irritation [4, 15], good color stability [15], and good physico-mechanical properties [15]. However, it has limitations as well: increased water sorption[4], poor adhesion to denture teeth and increased brittleness resulting in reduced impact resistance [15]. According to studies, the repair of denture bases with different visible light-polymerized resins showed poor properties compared with those repaired with autopolymerizing acrylic resin and is not recommended [45, 47, 48].

Repair using microwave-polymerized acrylic resin

This type of resin is quite new in the market and little research is available on the use of the microwave-system resin in denture repair. Microwave-polymerized resin has superior physical properties and lower residual monomer content [49]. Its transverse strength was reported to be 93% to 106% of the original acrylic resin [21]. Studies have shown that when the fractured heat-polymerized specimens were repaired with microwave-polymerized acrylic resin, the transverse strength and impact resistance of the repaired specimens were superior to those of specimens repaired with autopolymerizing acrylic resin [50, 51] .

Use of reinforcement to repair dentures

Reinforcement such as metal wires or fibers can be used to improve on the strength of the denture repair. Polyzois et al.[52] found that the use of autopolymerizing resin with metal wires placed perpendicular to the repaired butt joint of the denture base resin specimens yielded good results in terms of fracture load and deflection force. Minami et al[3] showed that specimens reinforced with 1.2 mm diameter stainless steel wires or Co-Cr-Ni wires had significantly higher transverse strength than the specimens without reinforcement[3]. Vallittu[41] used partial glass fibers to repair complete and partial dentures. These dentures were reviewed after an average of 13 months. Of the 20 complete dentures and 10 partial dentures, 1 complete denture and 1 partial denture fractured in the region of reinforcement during the examination period. In six dentures, new fractures occurred in regions without the fiber reinforcement. The result of this experiment was promising and partial fiberglass can be considered as an alternative reinforcement to total fiber reinforcement.

However, the high cost of these materials and their processing characteristics restrict their use in the denture market [53].

Chemical surface treatment

The failure of the repaired joint usually occurs at the junction between the repair material and the denture base and not on the repair material itself. Thus, chemical surface treatment is advocated in most studies to improve the adhesion between the denture base and the repair materials. Vallittu et al.[54] observed that the number of adhesive failures in repaired specimens were lower after 180 seconds of wetting period as compared with those wetted for a shorter duration. It had been suggested that wetting the repair surfaces with methyl methacrylate monomer (MMA) dissolved the polymethyl methacrylate (PMMA) at the repaired site. This allowed the formation of new polymer chains between the repaired material and the denture base.

Alternatively, chloroform, acetone and methylene chloride can be used to treat the surface before repair. According to Shen et al.[55], wetting the denture base resin surface with chloroform for 5 seconds created a cleaner and more efficient site for bonding, increasing the strength of repairs. But chloroform was seldom used as it was identified as a solvent with carcinogenic potential and inhaling of the vapor during treatment could cause health problems.

Hence, chloroform has been replaced by methylene chloride or acetone. Both products have been shown to improve the bond strength of the repaired material to denture base resin. Another way to improve surface wettability is to use plasma irradiation. Plasma irradiation, a process whereby an electrically neutral highly ionized gas made of ions, electrons and neutral particles are used to clean, degrease, roughen and activate the surface simultaneously. It has been shown that the hydroxyl group is brought to the surface of the product with irradiation of the plasma, thus improving wettability. Nishigawa et al.[56], revealed that plasma treatment is effective in increasing the shear bond strength between heat-polymerized acrylic base resin and self-polymerizing acrylic repair resin. However, plasma surface treatment is still fairly new in denture repair and more clinical tests are required to evaluate its safety.

Joint surface contours

The interface between the repair material and denture base resin is usually the weakest area and mechanical surface modification is required to reduce this weakness and improve the adhesion between them. In 1970, Harrison and Stanbury[57] studied the effect of different types of joint contours on the transverse strength of the repair. The common joints investigated were butt, round and rabbet. They found that the round joint was clearly superior to the rabbet and the butt joint. This was due to the fact that the round joint has a large surface area for bonding compared to butt and rabbet joints.

The other consideration was the distance between the fractured parts. According to Beyli and von Fraunhofer[1], the gap size should be 3mm or less to minimize the bulk of repair material used. This then decreases the degree of setting shrinkage. A smaller gap size would also reduce any color difference between the denture base and the repair material.

Summary of the literature review

Dentures usually fracture after prolonged usage in the mouth. This is due to fatigue failure and seldom caused by a sudden impact force from biting. The masticatory force of the denture wearer is actually reduced as compared to patients with natural dentition and the large force required to split the denture in the mouth rarely occurs. Therefore, the most likely reason for denture fracture is fatigue failure from the low cyclic force of mastication. This commonly presents as detachment of denture teeth and midline fractures of the maxillary denture.

Denture repair should be simple to perform, cost-effective and quick. Unfortunately, the current methods of repair do not meet all of these requirements. An effective repair usually involves several steps including chemical and mechanical treatment of surfaces of the fractured denture base. Subsequently, much time has to be spent to polymerize the repaired denture. In certain cases, the denture has to be sent to the laboratory for repair, which may be unacceptable to the patient.

Cyanoacrylate is a conveniently available adhesive material. It has been used by some patients temporarily to mend their dentures before they get new ones. It is easy to use and relatively inexpensive. However, there is nothing in the literature that reports the use cyanoacrylate as a type of denture repair material.

Purpose

This study investigated the various methods of repairing fractured denture bases and their effect on fracture strength. Specifically, denture bases repaired with cyanoacrylate were compared with denture bases repaired using auto-polymerizing acrylic resin. Their fracture strengths were compared after 24-hour.

Hypothesis

Null Hypothesis

There is no significant difference in fracture strength between denture bases repaired by two different types of cyanoacrylate and auto-polymerizing acrylic resin.

Research Hypothesis

There is a significant difference in fracture strength between denture bases repaired with two different types of cyanoacrylate and autpolymerizing resin.

Materials and Methods

The list of materials used in this study is shown in Table 4. Denture bases were made from Lucitone 199, a heat-polymerizing acrylic resin. Three different repair materials were used. They were Lucitone 199 Repair Material, an auto-polymerizing acrylic resin; Loctite Superglue Liquid Professional, a liquid-type cyanoacrylate; and Loctite Superglue Liquid, another liquid-type cyanoacrylate.

Table 4: Materials used

Use	Product	Manufacturer	Description	Content
Denture Base	Lucitone 199	Dentsply	Heat-polymerizing acrylic resin	Powder : Polymethylmethacrylate Liquid : Methyl Methacrylate , ethylene Glycol Dimethacrylate
Repair Material	Lucitone 199 Repair Material	Dentsply	Auto-polymerizing acrylic resin	Powder : Polymethylmethacrylate Liquid : Methyl methacrylate, ethylene dimethacrylate
Repair Material	Loctite Superglue Liquid Professional	Henkel	Liquid-type cyanoacrylate	Ethyl 2-cyanoacrylate, Methyl methacrylate polymer
Repair Material	Loctite Superglue Liquid	Henkel	Liquid-type cyanoacrylate	Ethyl 2-cyanoacrylate

Preparation of the specimens

A stone cast of an average maxillary edentulous ridge was fabricated using Type III stone (Heraeus Kulzer, South Bend, IN). On the stone, a point 1.5mm posterior to the hamular notch was marked on the left and right sides and a postdam area was prepared. The postdam was created with a no. 8 round bur (SS White Burs Inc, Lakewood, NJ) and smoothed with a plaster knife #6 (J&J Instruments, Linden, NJ). The stone cast was then duplicated 30 times using reversible hydrocolloid (Instaloid Duplicating Material, CMP Industries Inc, Albany, NY). On the stone cast, a thin layer of petroleum jelly (Vaseline, Unilever, Greenwich, CT) was applied and a vacuum-formed 3mm thick dual laminate (Pro-form, Keystone Industries, Cherry Hill, NJ) was adapted to ensure uniformity of denture base thickness. The excess laminate at the vestibular regions was removed with a carbon steel non-sterile blade no.11 (Bard-Parker, Franklin Lakes, NJ) and the posterior extension was determined by the distal end of the postdam.

The casts were invested in the drag of the denture processing flasks (Teledyne Hanau, Buffalo, NY) using Type II dental plaster (Heraeus Kulzer, South Bend, IN). The undercuts in the investment were removed and the investment was allowed to set. A thin layer of separating medium (Liqui-foil, American Dental Supply Inc, Allentown, PA) was applied to the surface of the investment. The cope was positioned in place and a second mix of Type II plaster (Whip Mix) was poured into the flask until the ring was filled completely. The flasks were then placed in the boil-out tank (Nevin Laboratories, Chicago, IL) for eight minutes and the cope and drag were separated.

The vacuum-formed baseplates were then discarded. Heat polymerized polymethylmethacrylate (PMMA) resin (Lucitone 199, Densply, York, PA) was mixed according to the manufacturer's instructions. The resin was then packed into the flask during the doughy stage at 1500 psi for 3 trial packs using 4×4 clear separating sheets (Densilk, Reliance Dental Mfg. Co., Worth, Il) soaked in water as a separator, and at 3000 psi for one final pack. The flasks were clamped and polymerized at 165 degrees F (74 degrees C) for nine hours from the time of initial placement into the tank.

After allowing enough time for bench cooling, the two parts of the flask were separated and the denture base was retrieved. Minimal finishing of the denture base was done with double-cut carbide burs (C.T.I. Carbide Tools for Industries Inc, Santa Ana, CA) and 100 to 600 grits silicon carbide abrasive papers (Imperial Wetordry, 3M, St Paul, MN) under running tap water. The dentures were then stored in room temperature tap water for 24 hours before testing.

Preparation of the specimens was performed by one individual (YHT). Using the results of the power analysis, an n of 30 maxillary dentures were made and labeled from 1 to 30 together with their corresponding master casts. Each denture had a line of weakness scored through the midline using a carbon steel non-sterile blade no.11 (Bard-Parker, Franklin Lakes, NJ) and deepened with a plaster knife #6 (J&J Instruments, Linden, NJ). Then, they were fractured by hand so as to achieve a clean midline fracture.

Assignment of the specimens to various repair treatments

The fractured dentures were randomly assigned to the three different types of treatments (see Table 5). This random assignment was done using the computer program "Research Randomizer" (http://www.randomizer.org/).

Table 5: Repair Groups

Group	Number of Specimens	Repair Materials
A	10	Lucitone 199 Repair Material (Auto-polymerizing resin)
B	10	Loctite Superglue Liquid Professional (Cyanoacrylate)
C	10	Loctite Superglue Liquid (Cyanoacrylate)

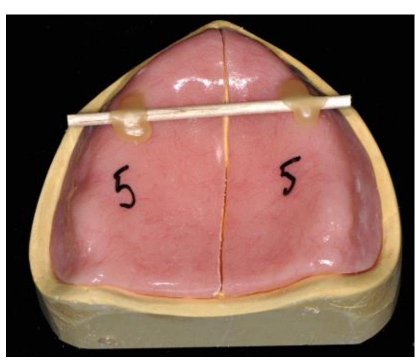
Repair Method

Group A: Repair with Lucitone 199 Repair Material

First, the edges of the broken pieces were beveled with a double-cut carbide bur (Carbide Tools for Industries Inc,) and repositioned together on the master cast which was preserved after deflasking. Both the master cast and the fractured denture were matched together according to the number labeled during the preparation.

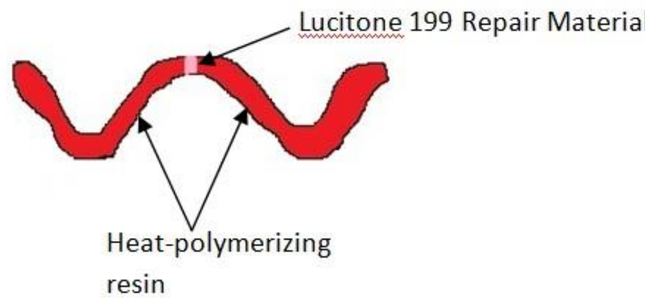
The edges were primed for 15 seconds with a drop of resin monomer of the repair material. Next, a thin layer of separating medium (Liqui-foil, American Dental Supply Inc, Allentown, PA) was coated on the master cast and the broken pieces were fitted together on it. One wooden Q tip (Q-Tips, Unilever, Greenwich, CT) and sticky wax (Dentsply, York, PA) were used to secure the pieces together. The wooden Q tips were placed across the arch and affixed onto the ridge with sticky wax (see Figure 1).

Figure 1 : Repositioning and Securing the Fractured Denture Bases



When the broken pieces were in the correct position and immobilized, the repair material (Luctione 199 Repair Material, Dentsply, York, PA) was applied onto the fracture area as shown in Figure 2.

<u>Figure 2 : Schematic Diagram of Repair with Lucitone 199 Repair Material</u>



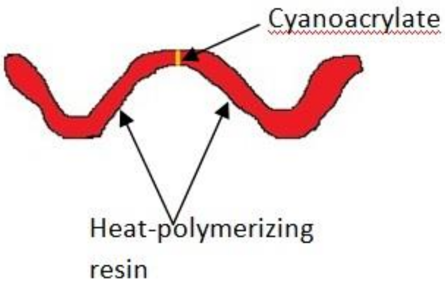
The powder was dusted in successive thin layers and each layer was moistened with the monomer component of Lucitone 199 Repair Material [58]. The repair was slightly overcontoured. Then the material was allowed to bench cure for one to two minutes before it was placed in a pneumatic curing unit (Acri-Dense VI, GC Lab Technologies Inc., Alsip, IL) containing warm water (110 ^{o}F) under 15 psi pressure for ten minutes, according to the manufacturer's guidelines. This improved the bond strength of the auto-polymerizing repair material[36]. A photograph of the denture base repaired with Lucitone 199 Repair Material is shown in Figure 3.

Figure 3 : Denture Base Repaired with Lucitone 199 Repair Material

Group B and C: Repair with Loctite Superglue Liquid Professional/Loctite Superglue Liquid

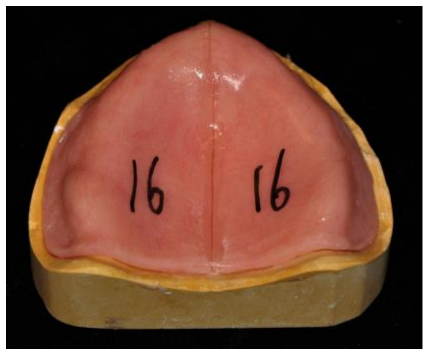
The denture bases repaired with cyanoacrylate were not treated. The edges of the broken pieces were aligned and placed on the cast, without modification, with a thin layer of cyanoacrylate (Loctite Superglue Professional; Loctite Superglue Liquid, Henkel, Avon, Ohio) as shown in Figure 4.

Figure 4: Schematic Diagram of Repair with Loctite Superglue Liquid Professional/Loctite Superglue Liquid



The fractured denture and the cast were matched together according to the number labeled during the preparation. The repaired denture base was allowed to set for five minutes before removal from the master cast for polishing. A photograph of the denture base repaired with Loctite Superglue Professional is shown in Figure 5.

Figure 5 : Denture Base Repaired with Loctite Superglue Liquid Professional/Loctite Superglue Liquid

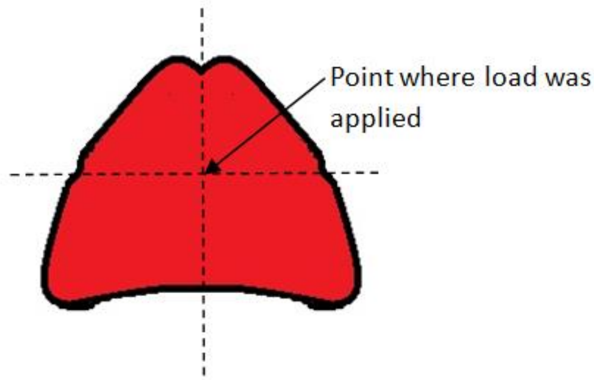


Once the repair with auto-polymerizing resin or cyanoacrylate was completed, the excess was removed with double-cut carbide burs (Carbide Tools for Industries Inc) and polished with 100 to 600 grits silicon carbide abrasive papers (Imperial Wetordr,) under running tap water. Finally, the repaired denture base was polished with fine grain pumice (Pumice Fine, Miltex Inc, York, PA) on a buffing machine (Esmadent Electropolisher, CMP Industries Inc, Albany, NY). The repaired denture bases were stored in room temperature tap water for 24 hours before the fracture test. This was because, according to the literature, repaired materials generally do not reach their optimum properties until at least the day following repair[45, 59].

Fracture of specimens

Two lines were drawn on the tissue side of the denture base, as shown in Figure 6, to determine the location of force application.

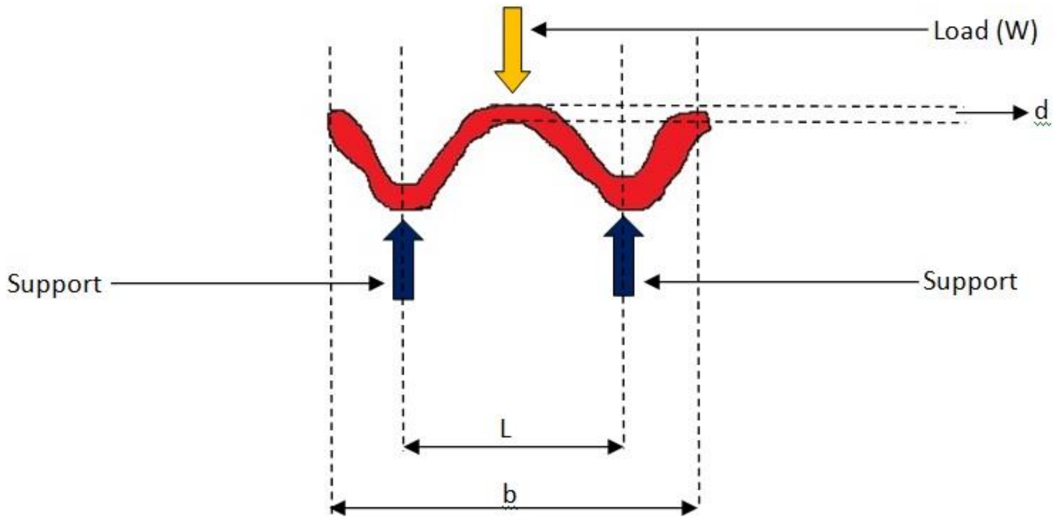
Figure 6 : Schematic diagram of the location of the applied load on the fitting surface of the denture



The first line connected the buccal frenum notches on the left and right; the second line was perpendicular to the first line and drawn from the labial frenum notch. The intersection of these lines was the location where the load was applied.

Denture bases were tested using a 3-point flexure test (ISO1567: Specifications for denture base polymer, see Figure 7). Each denture was secured onto the pneumatic grip of the Universal Testing Machine (EnduraTEC ELF 3300, BOSE, Eden Prairie, MN) and a 2 kN load cell, at a crosshead speed of 0.05mm/min, was applied until the denture base fractured[16]. This downward loading was designed to be equivalent to an upward loading on both sides combined with an unyielding support in the center of the palate. The load required to fracture the specimen was recorded.

Figure 7: Schematic representation of 3-point flexure test



The transverse fracture strength, S (Pa) of each specimen, was determined using the following formula:

$$\mathbf{S = \frac{3WL}{2bd^2}}$$

Where:

W = the fracture load (N)
L = the distance between the supports (0.045m)
b = the specimen width (0.060m)
d = the specimen thickness (0.003m)

Statistical Analysis

A power analysis was performed using the data from Seo et al.[60]. With an n of 10, an effect size of 12.25, a $p \leq 0.05$, and a difference of 15 MPa between the groups; the power was 1.00. Therefore it was decided to use 10 subjects per group (see Appendix Table I, II).

One-way ANOVA was used to detect a difference in the mean fracture transverse strength among the groups. Tukey's Honestly Significant Difference (HSD) Test was then used to detect significant differences between the groups. A $\rho \leq 0.05$ was considered significant.

Results

This study compared the transverse fracture strength between Loctite Superglue Liquid, Loctite Superglue Liquid Professional and Lucitone 199 Repair Material. Thirty maxillary denture specimens were prepared (see Figure 8) and repaired with three different repaired materials mentioned in Materials and Methods (see Figure 9). Each denture was fractured at the midline using a Universal Testing Machine (EnduraTEC ELF 3300, BOSE, Eden Prairie, MN, see Figure 10). The load to fracture for each specimen was recorded (see tables 6-8).

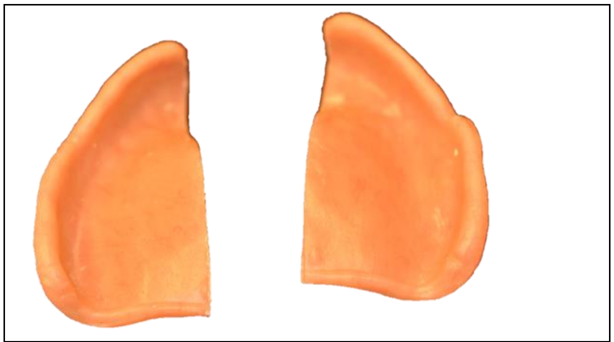


Figure 8 : Photographs of the fractured specimen

Figure 9 : Photographs of the repaired specimen

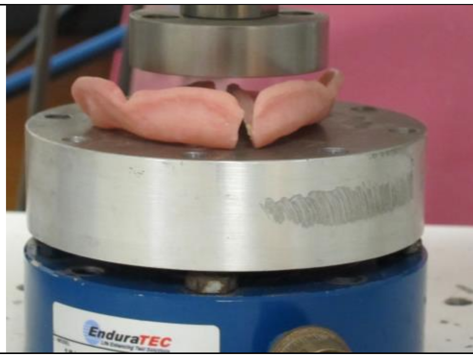


Figure 10 : Photographs of the testing of the repaired specimen

Loctite Superglue Liquid required a smaller load to fracture (430±152.4 N, see Table 6) when compared to Loctite Superglue Professional (857.2 ± 164.7 N, see Table 7) and Lucitone 199 Repair Material (1031.1 ± 176.8 N, see Table 8). The Loctite Superglue Liquid mean load to fracture was about half of the other two repair materials.

Table 6: Specimens Repaired by Loctite Superglue Liquid

Specimen Number	Load to Fracture (N)	Transverse Fracture Strength(MPa)
1	180.0.	22.5
2	583.0	72.9
4	420.5	52.3
10	583.7	73.0
13	397.3	49.7
15	551.3	68.9
18	599.1	74.9
24	384.5	48.1
26	201.5	25.2
30	403.6	50.4
Total Mean±SD	430.4± 152.4	53.8± 19.1

Table 7: Specimens Repaired by Loctite Superglue Liquid Professional

Specimens	Load to Fracture (N)	Transverse Fracture Strength(MPa)
3	1064.7	133.1
6	724.6	90.6
7	645.2	80.7
8	615.9	77.0
9	1036.3	129.5
16	780.2	97.6
19	976.3	122.0
20	806.7	100.8
23	916.7	114.6
25	1005.7	125.7
Total Mean±SD	857.2± 164.7	107.2± 20.6

Table 8: Specimens Repaired by Lucitone 199 Repair Material

Specimens	Load to Fracture(N)	Transverse Fracture Strength(MPa)
5	797.2	99.7
11	999.2	124.9
12	986.5	123.3
14	1371.3	171.4
17	800.5	100.1
21	1028.5	128.6
22	1023.4	127.9
27	1263.9	158.0
28	1013.6	126.7
29	1027.0	128.4
Total Mean±SD	1031.1±176.8	128.9± 22.1

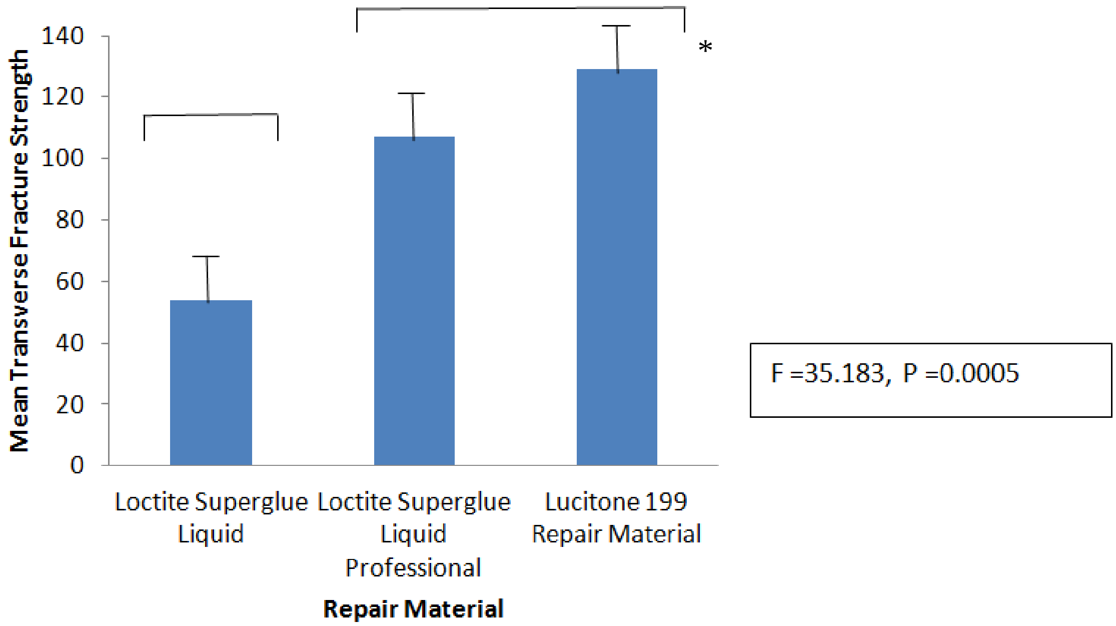
One-way ANOVA was used to detect a difference in the mean fracture transverse strength among the groups. Tukey Honestly Significant Difference Test was then used to detect significant differences between the groups. Statistical analysis revealed that there was a significant difference in the mean transverse fracture strength among the three types of repair materials ($F = 35.183$, $\rho=0.0005$). Loctite Superglue Liquid (53.8 ± 19.1 MPa) had significantly less transverse fracture strength than the other two types of materials. There was no significant difference in transverse fracture strength between Loctite Superglue Liquid Professional (107.2 ± 20.6 MPa) and Lucitone 199 Repair Material (128.9 ± 22.1 MPa, see Table 9 and Figure 11).

Table 9: Table Showing the Significant Difference Between the Mean ±SD of the Repair Material

Repair Material	**Number of Specimens**	**Mean±SD Transverse Fracture Strength (MPa)**	**F**	**p**
Loctite Superglue Liquid	10	53.8 ± 19.1[a] *	35.183	0.0005
Loctite Superglue Liquid Professional	10	107.2 ± 20.6[b]		
Lucitone 199 Repair Material	10	128.9 ± 22.1[b]		

**Means with the same letter are not significantly different.*

Figure 11: Bar Graph Showing Significant Differences Between the Mean Transverse Fracture Strength of the Repair Materials



** Materials under the same bracket are not significantly different.*

Discussion

The purpose of this study was to compare the transverse fracture strength of specimens with two different types of cyanoacrylates (Loctite Superglue Professional; Loctite Superglue Liquid, Henkel, Avon, Ohio) and auto-polymerizing acrylic resin (Luctione 199 Repair Material,Dentsply, York, PA). The results of this study support the research hypothesis that there is a significant difference among the three types of repair materials. The transverse fracture strengths were higher than those stated in the literature by Seo et al[60]. The dimensions of the specimens used in this study were different from those reported in the literature. In this study, the specimens had a larger surface area for repair and that could have contributed to more force required to break the specimens.

The ultimate goal of denture repair is to restore or reinforce the denture's strength in order to avoid recurrent fractures. The transverse fracture force of dentures, according to the ISO standard (1567:1988)[61] should be higher than 55 N[62]. In this study, the transverse fracture force for Loctite Superglue Liquid (430±152.4 N, see Table 6), Loctite Superglue Professional (857.2 ± 164.7 N, see Table 7) and Luctione 199 Repair Material (1031.1 ± 176.8 N, see Table 8) were all above the ISO standard.

The fracture strength, reported in the literature, of a 2.5mm thick maxillary complete denture made with Lucitone 199 ranged from 836 ± 162N[63] to 909

± 195N[64]. The thickness of the maxillary complete dentures made in the current study was 3mm; and hence the fracture strength of the repaired materials was higher due to their greater thickness, which allowed more surface area for bonding.

In this study, the group of denture bases repaired with auto-polymerizing acrylic resin (Lucitone 199 Repair Material) served as the control. Compared to this control, the transverse fracture strength of Loctite Superglue Professional and Loctite Superglue Liquid was 83.2% and 41.7% of the control group, respectively.

The results also demonstrated that the transverse fracture strength of Loctite Superglue Professional was not found to be significantly different from the Lucitone 199 Repair Material. This could be due to the presence of methylmethacrylate polymer in Loctite Superglue Professional, which is the same polymer in the denture base specimens (see Tables 4 and 9). The Loctite Superglue Liquid does not contain methyl methacrylate polymer. It had a weaker fracture strength than Loctite Superglue Professional and Luctione 199 Repair Material. In addition, Loctite Superglue Liquid required only half the mean load to fracture when compared with the other two repair materials.

Cyanoacrylate is a conveniently available adhesive material. It usually contains methyl 2-cyanoacrylate or ethyl-2-cyanoacrylate (commonly sold under trade names like SuperGlue and Krazy Glue). Generally, cyanoacrylate is an acrylic resin which rapidly polymerizes in the presence of water (specifically hydroxideions), forming long, strong chains, joining the bonded surfaces together. It sets quickly, often in less than a minute. A normal bond can reach full strength in two hours [65]. When cyanoacrylate is applied onto the denture base surface, it penetrates into the pores of the crystalline structure and forms a thin layer between the bonded segments, thus not affecting the fit of the repaired denture base[66].

In this in-vitro study, the specimens were fabricated to replicate a maxillary complete denture. A midline fracture mode was replicated as this is the most common type of fracture seen in dentures[2]. The specimens were also fractured in such a way as to achieve minimum to no gap between the two fractured pieces. This allowed testing of the fracture strength of the bond between the heat-polymerized denture base and the repaired material. Currently, the various cyanoacrylate products on the market do not have filler particles incorporated that fill up the space between the broken pieces. Hence, if the denture does not have a clean fracture or a part of it needs to be re-constructed, cyanoacrylate may not be suitable to repair the denture.

One limitation of this study was that the specimens were not tested in an environment similar to the oral cavity. The constant thermal changes, presence of saliva, and chewing force were not taken into consideration. Temperature changes induced by the daily intake of food and drinks, continuous pounding during eating, and the hydrolytic effect from the wet environment in the mouth may weaken the repair strength.

Furthermore, the solubility of cyanoacrylate in the oral environment is another potential problem. The released by-products from biodegradation of the material could be cytotoxic. One study [67] showed that methyl- and isobutyl-2-cyanoacrylate adhesives may contribute to the thrombotic events associated with the necrosis observed on application of these adhesives to tissues *in vivo* . Another study mentioned that the toxicity was associated with the heat of polymerization and presence of not reacted monomers[68]. However, others have found that as the alkyl group on the cyanoacrylate becomes longer, the tissue reaction decreases[69]. Further studies need to be conducted to find out the stability of cyanoacrylate in the oral environment and whether it can withstand repeated impact during mastication.

Clinical Implications

Cyanoacrylate containing methyl methacrylate polymer (Loctite Superglue Liquid Professional) is an inexpensive and readily available material. Patients may use it as a temporary measure to repair dentures with a clean fracture. However, further studies are required to investigate the long term cytotoxicity and intraoral stability of cyanoacrylate.

Conclusion

Within the limitations of this study, the results suggest that there is a significant difference between the three types of repair materials. Loctite Superglue Liquid had less fracture strength than the other two repair materials and there was no significant difference in fracture strength between Loctite Superglue Professional and Luctione 199 Repair Material.

Appendix

Power Analysis

Table I : Mean fracture strength values of heat polymerizing denture bases using auto-polymerizing acrylic resin[60]

Acrylic Denture Base Resin	Repair Material	Mean(MPa)	Test Method
Heat-polymerizing acrylic resin	Auto-polymerizing acrylic resin	62	3-point flexure test
		29.92	
		53.2	
		38.21	
		41.31	
		69.2	

A review article [60] provided the values shown in Table 5 for the fracture strengths of heat-polymerized denture base repaired with auto-polymerizing resin using the 3-point flexure test. It was estimated that the average fracture strength mean was 49.0.

Next we performed a power analysis using the statistics program, Power and Precision [70]. Data from the Seo et al study was used for the power analysis. It was determined that a difference in fracture strength of 49±15 MPa would indicate an important clinical difference.

Table II : Results of Power Analysis

Factor Name	Number of Levels	Cases per level	Effect size f	Power
Fracture strength of the repair	3	10	12.25	1.00

Within Cell SD = 1.00, Variance =1.00
Cases per cell = 10, Total N of cases =30
Alpha (2-tailed) = 0.05
Power Computations: Non-central F

With an n of 10, an effect size of 12.25, a p = 0.05 and a difference of 15 MPa between the groups; power was equal to 1.00. Therefore it was decided to use 10 subjects per group (see Table II).

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