Factors Affecting the Strength of Denture Repairs

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Fracture of dentures is a common clinical finding in daily prosthodontic practice, resulting in great inconvenience to both patient and dentist. A satisfactory repair should be cost-effective, simple to perform, and quick; it should also match the original color and not cause distortion to the existing denture. Different repair materials, surface designs, and mechanical and chemical surface treatments have been recommended in order to obtain stronger repairs. This article reviews some of the available literature with regard to the most important factors that may influence the strength of denture repairs.
J Prosthodont 2007;16:302-310.

INDEX WORDS: surface, treatment, acrylic resin

THE FRACTURE of poly (methyl) methacrylate denture bases is a common clinical occurrence, primarily in the midline of maxillary complete dentures.[1,2] Causes of such fractures are related to poor fit of the denture base,[1,3] poorly balanced occlusion,[1,3] faulty design and fabrication,[1] insufficient strength of repair material,[4,5] and stress on the denture base after years in clinical use.[4-6] Denture failure outside the mouth occurs from impact due to accidents, as a result of expelling the denture from the mouth while coughing, or dropping the denture.[1,4-7]

Common measures to solve the problem of fracture are temporary or definitive repairs, since the construction of a new denture base is expensive and time consuming. A satisfactory repair must have adequate strength[4,7-9] and good color match;[4,5,8,9] be easy,[4,5] quick,[4,5,8,9] and inexpensive;[8,9] and must maintain dimensional stability.[4,5,7,8] Factors affecting adhesion and the mechanical behavior of the repair material may influence the strength of denture repairs. Attempts to improve the bond strength between denture base resin and repair material by mechanical or chemical surface modification[8,10-13] and the transverse strength by metal wire or fiber reinforcements[4,5,13-16] have been described. The choice of denture base resin and repair material combination may also influence the final strength of denture repair.[3,9,17-25] This article reviews some of the current literature with regard to the most important factors that may influence the strength of acrylic denture repairs.

Effect of Repair Material

The repair of a denture base can be performed using several materials, such as autopolymerizing acrylic resin, heat-polymerized acrylic resin, visible light-polymerized resin, and microwave-polymerized acrylic resin. The choice of material depends on the working time, the strength to be obtained with the repair material, and the degree of dimensional stability maintained during and after repair.[7,27]

Most fractured denture repairs are made using a resin, which generally allows a simple and quick repair;[5] however, dentures repaired with autopolymerizing acrylic resin often fracture again at the repaired site. This is attributed to autopolymerizing acrylic resin's insufficient transverse strength, which is lower than heat-polymerized acrylic resin's.[3,24,28] Autopolymerizing acrylic resin's low

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Accepted February 2, 2006.
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1059-941X/07
doi: 10.1111/j.1532-849X.2007.00191.x

transverse strength is related to the low degree of conversion achieved by the use of a chemically activated initiator system.[29] Specimens repaired with autopolymerizing acrylic resin have approximately 60%[3] to 65%[28] of the original strength of the denture, while the strength of heat-polymerized acrylic resin repairs ranges from 75%[28] to 80%[30] of the original bulk material. Repairs using heat-polymerized acrylic resins are seldom performed, because they require a custom split cast gypsum mold, extended polymerization times, and laboratory fees.[31] The patient must also be without the denture during the laboratory repair procedures.

To overcome the limitations of heat-polymerized and autopolymerizing acrylic resins, a visible light-polymerized system was introduced in 1984 and has been used in several applications, including relining and repair of dentures.[21,32] The advantages of visible light-polymerized resin include the reduction of chemical and thermal irritation to the patient,[33,34] good color stability,[34] and good physicomechanical properties. Conversely, the material also presents some limitations, such as increased water sorption,[33] poor adhesion to plastic teeth,[35] and increased brittleness resulting in reduced impact resistance.[34] According to previous studies, the repair of denture bases with different visible light-polymerized resins showed poor properties compared with those repairs with autopolymerizing acrylic resin.[17,21,36]

Dar Odeh et al[21] found that autopolymerizing acrylic resins exhibited higher transverse strength than visible light-polymerized resins when used for the repair of heat-polymerized specimens. This finding is in agreement with a study by Polyzois et al.[5] The adhesion between visible light-polymerized resin to acrylic denture base resin continues to be a serious problem.[23] This limitation was not observed in a study by Razavi et al,[32] who found that the bond strength of Triad VLC material to the tested denture base resins was sufficiently high to suggest its clinical applicability. Likewise, Lewinstein et al[20] reported that all heat-polymerized resin specimens repaired with either autopolymerizing or visible light-polymerized resins have similar bond strengths. The reported differences may be attributed to employing different brands of materials, using different polymerization techniques, or performing the test under dry or wet conditions after different periods of water storage. The development of better bonding methods between denture base resin and visible light-polymerized resin should be further investigated. Alternatively, the use of a microwave system for repairs of complete and removable partial dentures has also been suggested.[5,37,38] The advantages of microwave-polymerized acrylic resins are the lower residual monomer content and superior physical properties.[9] Rached and Del Bel Cury[25] found that the transverse strength of microwave-polymerized acrylic resin was 93% to 106% of the original acrylic resin. Studies have shown that when the fractured heat-polymerized specimens are repaired with microwave-polymerized acrylic resin, the transverse strength and impact resistance of the repaired specimens are superior to those of specimens repaired with autopolymerizing acrylic resin.[4,38] Little literature is available on the use of the microwave system for denture repairs.

Effect of Reinforcement

Reinforcement with metal wires,[26,39] nylon,[15] or fibers (carbon, aramid, ultra-high modulus polyethylene, or glass)[13-16,40] has been used to improve denture repairs.

Some studies have demonstrated that metal wires are difficult to manipulate.[4,41] Hence, modification of the surface by sandblasting was studied by Vallittu and Lassila,[42] who evaluated the effect of surface roughness of different metal wires (Remanium spring hard clasp wire, semicircular wire, and braided wire plate) on the fracture resistance of acrylic resin. The authors found that the best results were achieved by sandblasting, which enhanced retention between the strengthener and the resin by increasing the surface area to promote adhesion. Vallittu[41] showed an improved adhesion between metal and acrylic resin with a silanizing technique. Polyzois et al[39] found that the combination of an autopolymerizing adhesive resin (Meta Fast Sun Medical Co., Ltd., Kyoto, Japan) and metal wires, which were placed perpendicular to the repaired butt joint of denture base resin specimens, increased the fracture load and deflection of specimens tested. The authors reported that the incorporation of metal wires played an important role in the overall mechanical behavior of the repaired specimens. Similarly, Minami et al[26] showed that the 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. Reinforcement with round metal wire or a monolayer glass fiber ribbon has also been recommended by Polyzois et al[5] for improving the strength of autopolymerizing acrylic resin repairs, especially with respect to toughness. John et al[15] compared the transverse strength of conventional poly(methyl) methacrylate resin reinforced with glass, aramid, or nylon fibers. Glass and aramid fibers improved the transverse strength significantly. Keyf and Uzun[14] observed that the reinforcement with glass fiber significantly increased the resistance to deflection and the modulus of elasticity in the repaired denture base resin specimens. Similarly, Nagai et al[13] observed that the reinforcement with glass fiber and methylene chloride pretreatment effectively enhanced the transverse strength and modulus of elasticity of repaired denture base resin specimens. Conversely, some investigators have demonstrated that the reinforcement with woven glass fiber,[26] pure titanium,[26] woven metal wire,[26] and polyaramid[31] did not significantly enhance the strength of the denture base resin specimens repaired with autopolymerizing acrylic resin.

Karacaer et al[16] performed a clinical study in which complete maxillary dentures of patients having a history of midline fractures were reinforced with ultra-high modulus polyethylene fiber in woven form. This fiber was treated with a silane-coupling agent and sandwiched between acrylic dough. The authors observed that at the end of 18 months, all of the dentures were satisfactory and did not exhibit any signs of fracture. In a clinical study, Vallittu[39] used silanized glass fibers to repair complete and partial dentures. After a mean recall period of 1.1 to 1.3 years, there were two additional fractures in previously unrepaired sites. The author concluded that glass fibers incorporated into fractured removable prostheses strengthened the acrylic resin and prevented recurrent fracture.

Effect of Water Storage

It has been demonstrated that the strength of a denture repair may be time dependent. According to Harrison et al,[43] an autopolymerizing acrylic resin repair is relatively weak 1 hour after the laboratory procedure is completed. The authors observed that the mechanical properties of the repaired specimens reached optimum strength after 1 day to 1 week of water immersion. Razavi et al[32] found that the shear bond strength of visible light-polymerized resin to denture base resin significantly increased after 48 hours of immersion in water. The results from the study by Dar-Odeh et al[21] observed that both modulus of rupture and modulus of elasticity for visible light-polymerized resins were weaker at 1 hour than 1 day. The rigidity of specimens repaired with visible light-polymerized resin improved with longer water storage, and the transverse strength reached a maximum after 1 day. From the available literature, it can be assumed that repaired materials generally do not reach their optimum properties until at least the following day, and for this reason repaired dentures ideally should not be returned to the patient for at least 24 hours.[21,43]

Effect of Postpolymerization Treatment

Interestingly, it has been reported that postpolymerization treatment using microwave irradiation can also improve the bond strength between denture base resin and repair material, resulting in stronger repairs. Polyzois et al[5] found that microwave exposure increased the fracture force by 22% and increased the toughness of irradiated specimens over nonirradiated specimens. This finding is in agreement with a study by Yunus et al,[38] who found a reduction of residual monomer in the repair resin after microwave irradiation. It is important to emphasize that although the microwave postpolymerization treatment may produce acceptable physical and mechanical properties, further distortion of the denture base may occur after postpolymerization treatment. In a study by Dyer and Howlett,[27] all acrylic resin bases distorted on initial polymerization and following repair with the microwave-polymerized acrylic resin. Similarly, Al-Hanbali et al[44] observed significant distortion between the first and second polymerization cycles for all polymerization methods tested. Microwave polymerization caused significantly less distortion of the denture base than a short water bath polymerization cycle, mainly in the center of the palate.[44] Although distortion has been verified, further studies should be conducted to determine whether additional heating does not exceed the requirements of the International Standards Organization specification 1567 for denture base polymers.[45]

Effect of Surface Treatment

Chemical Treatment

When a denture base is repaired, the bond strength between denture base resin and the repair material should be as strong as the parent denture base resin. The success of denture repair, however, depends on the adhesion between the repair material and the denture base. Shen et al[11] reported that the fractures of the repaired specimens often occur at the junction of the old and new material rather than through the center of the repair, where the greatest load is applied. According to the authors, this finding clearly indicates that the interface of the old and new material coincides with the site of stress concentration during transverse strength testing, regardless of the technique used. Several factors contribute to differences seen in the bond strength of repaired specimens, including the water permeability of the bonding agent as well the bonding agent's ability to dissolve the denture material, allowing improved bonding by forming an interpenetrating polymer network at the interface. Contamination by saliva,[13] waxes,[12] and thermal stress[46] have also been recognized as causes for decreased bond strength and durability. Unfortunately, contamination by saliva is sometimes inevitable during repair procedures with the patient.

Adhesion between denture base and repair material can be improved by applying appropriate chemicals to the acrylic resin surfaces. Wetting the repair surfaces with methyl methacrylate monomer has been used to soften the poly(methyl) methacrylate, which changes the morphology and chemical properties of the surface promoting improved adhesion.[12] Using the monomer treatment for 180 seconds, Vallittu et al[12] observed that the number of adhesive failures in repaired specimens diminished, compared with shorter wetting time (0.5 and 60 seconds). These favorable results were attributed to the formation of new polymer chains between the heat-polymerized acrylic resin fracture surfaces. Similarly, Olvera and DeRijk[47] observed that monomer treatment for 4 minutes was the optimum treatment for repairing denture base specimens.

Alternatively, chloroform,[11,48] acetone,[25] and methylene chloride[13,46] have been used as softening agents in several situations, including repair of denture bases. According to Shen et al,[11] wetting the denture base resin surface with chloroform for 5 seconds creates a cleaner and more efficient site for bonding, increasing the strength of denture repairs; however, chloroform was identified as a noxious compound with a carcinogenic potential, and precautions are necessary to avoid inhaling chloroform vapor during surface treatment.[11] As a result, chloroform has been replaced by methylene chloride. It has been suggested that the wetting of methylene chloride on the surface causes crazing as well as the formation of numerous pits up to 2 μm in diameter.[49] Nagai et al[13] found that the treatment of a heat-polymerized acrylic resin surface with methylene chloride for 5 seconds improved its transverse strength by 12% when repaired with autopolymerizing acrylic resin. The surface treatment with methylene chloride for 2 minutes associated with monomer has also been recommended to improve the bond strength of visible light-polymerized resin to a heat-polymerized acrylic resin.[47] Nevertheless, current studies have also demonstrated that methylene chloride is a potential occupational carcinogen (OSHA).[50-52] Therefore, surface treatment with acetone for 30 seconds has also been considered as an alternative method for improvement of the bond strength of heat-polymerized resin repaired with microwave-polymerized resin.[25] Finally, it is important to consider that chemical surface dissolution of acrylic resins is affected by the degree of cross-linking of the polymer chains,[11] which will only swell in solvents such as chloroform or acetone.[48]

Mechanical Treatment

As previously discussed, the interface between the heat-polymerized acrylic resin and the repair material is usually the weakest point of the repaired denture bases. In order to overcome this limitation, attempts to improve the bond strength by mechanical surface modification have been described. Different opinions about the appropriate shape of the joint surfaces have been presented. Several studies have indicated different edge profiles, such as a butt joint,[5,8,24,37,53,54] 45° bevel joint,[8,13,31,54,55] 30° bevel joint,[53] 55° bevel joint,[53] rounded,[7,8,10,21,23,54,56] and rabbet joint (Fig 1).[10]

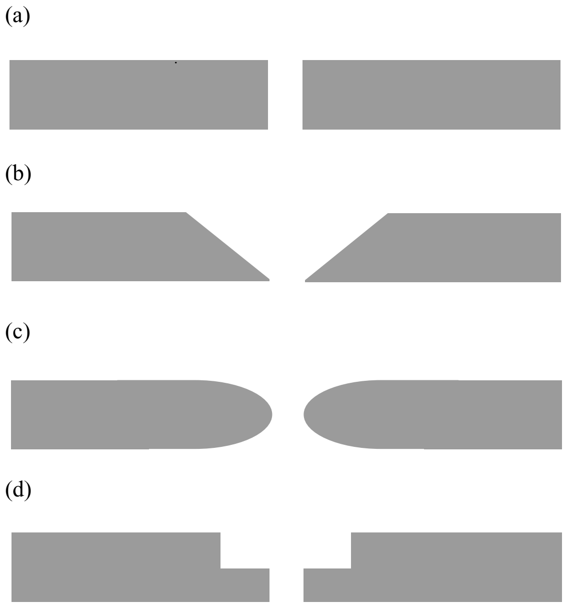

Figure 1. Repair joint surface designs: *(A)* butt joint, *(B)* bevel joint, *(C)* rounded joint, and *(D)* rabbet joint.

In 1970, Harrison and Stansburry[10] analyzed the effect of three repair surface designs on the transverse strength of repaired specimens. They found that the rounded joint surface was superior to the rabbet and butt joints. Ward et al[8] observed that the transverse strength of the butt joint was significantly less than that of the rounded or 45° bevel joints; however, the transverse strength of the round and 45° bevel joints was statistically similar. More recently, Lin et al[54] recommended the rounded joint as the best choice, compared with either the butt or 45° bevel joint designs. According to the authors, the rounded joint is nonlinear and has a greater contact area (78.5 mm^2) with the denture base than either the butt (50 mm^2) or 45° bevel joint (72 mm^2) designs. On the other hand, the 45° bevel joint is preferred clinically, since it is easier to prepare and finish a beveled joint than a rounded joint.[8]

Considering the aspects discussed above, repair width can also be a relevant factor contributing to the distribution of stresses in the repaired specimens. According to many studies, the gap between the parts to be repaired ranged from 1.5 to 3 mm;[3–5,7,11,17,19,21,23,26,29,37,38,56] however, some studies have used a 10-mm gap between the two sections of the specimen.[20,24,25] Leong and Grant[28] reported that a 1.5-mm gap reduced

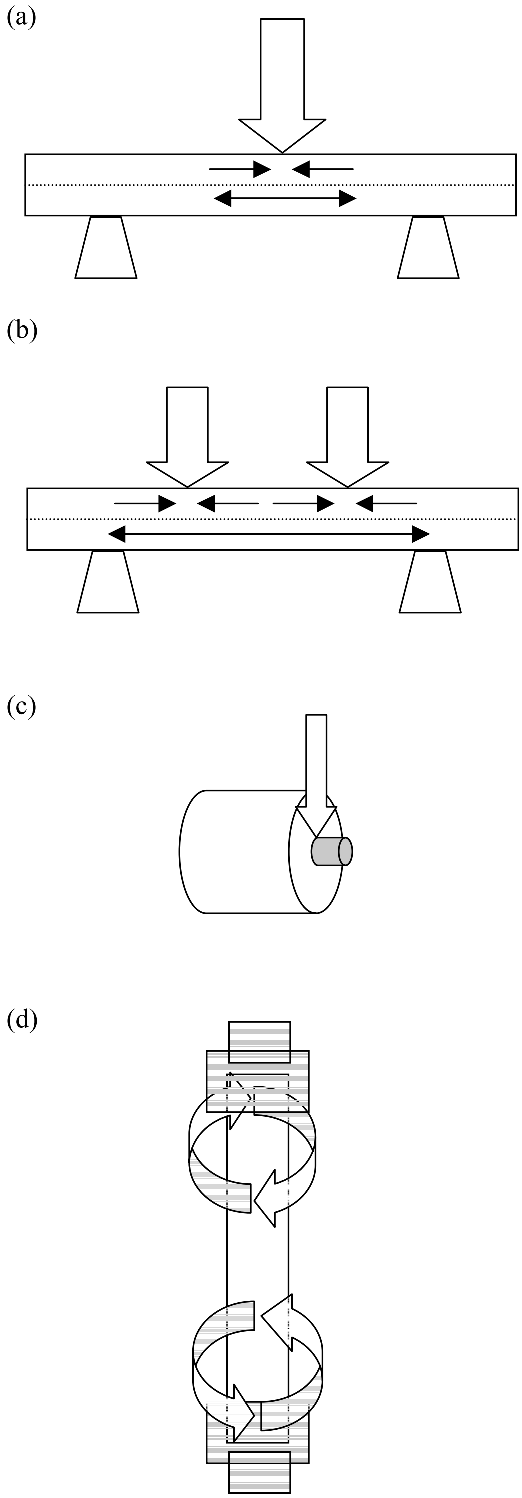

Figure 2. Denture repair test methods: *(A)* three-point bending test, *(B)* four-point bending test, *(C)* shear bond test, and *(D)* torsional test.

Table 1. Repair Strength for the Different Test Methods

Acrylic Denture Base Resin	Repair Material	Mean Minimum	Mean Maximum	Test Method
HP	AP	~62 MPa		3-BT[17]
	VP	~58 MPa		
VP	AP	~50 MPa		
	VP	~32 MPa		
HP	AP	29.92 MPa		3-BT[19]
	VP	7.02 MPa	17.48 MPa	
VP	AP	30.53 MPa		
	VP	6.57 MPa	16.45 MPa	
HP	VP	1.44 kg/mm^2		3-BT[20]
	AP	3.17 kg/mm^2		
MC	MC	34.47 N		3-BT[37]
	AP	12.01 N		
	HP	28.30 N		
HP	MC	36.66 N		
	AP	9.84 N		
	HP	17.64 N		
HP	AP	34.22 MPa	42.06 MPa	TT[22]
HP	AP	53.2 MPa		3-BT[13]
HP	AP	38.21 MPa	41.31 MPa	3-BT[31]
MC		39.83 MPa		
HP	MC	85.82 MPa		3-BT[25]
HP	HP	~30 N		3-BT[5]
	AP	~60 N		
HP	VP	0.0427 MPa		SBT[23]
VP	VP	0.0539 MPa		
HP	AP	1.27 MPa	13.97 MPa	SBT[9]
	MC	14.78 MPa		
HP	MC	63.5 MPa		3-BT[24]
	AP	69.2 MPa		
	HP	70.7 MPa		
MC	MC	67.2 MPa		
	AP	65.0 MPa		
	HP	70.6 MPa		
HP	AP	~90 N		3-BT[26]

HP = heat-polymerized acrylic resin; VP = visible-polymerized acrylic resin; AP = autopolymerizing acrylic resin; MC = microwave-polymerized acrylic resin; 3-BT = three-point bending test; TT = torsional test; SBT = shear bond test.

the deflection of specimens tested by 20% when compared with 3-mm gap specimens. According to Beyli and von Fraunhofer,[57] the use of a maximum of 3-mm gap size decreased the degree of polymerization contraction and reduced any color difference between the denture base and repair material. In addition, if the interface is wider than 3 mm, pure cohesive fracture might occur instead of mixed fracture;[22] however, this behavior was not observed in a study by Rached et al,[24] who showed that the repair methods exhibited a low incidence of purely adhesive rather than cohesive failures.

Test Methods for Denture Repairs

The bond strength of repair materials to denture base resins has been examined by several studies using transverse,[3,5,8,12,17,20,24,25,37,56] shear,[9,17] and torsional[22] tests (Fig 2). The mean values of bond strength according to the type of repair materials used and test methods are listed in Table 1.

To date, bond strength of denture repairs has been commonly evaluated by transverse tests, which can be conducted using three-point or four-point loading. The differences between these test methods are the location of the maximum bending moment and maximum axial fiber stresses. In three-point loading, the maximum stress occurs directly below the loading edge whereas it is spread out over the area between the loading edges in the four-point system. Therefore, flexural properties determined by four-point bending test would appear more appropriate for quality-control and specification purposes[58] as it can better reproduce the distribution of stress and, consequently, the strength of the specimens. However, the validity of the transverse loading method to measure the bond strength of denture repairs is questionable, since the nature of stress presented at the interface between repair material and denture base resin is unknown.

Alternatively, the shear and torsional tests may be considered appropriate bond strength test methods, since the forces to which repairing material is exposed clinically are closely related to shear and tear.[59] The shear bond test applies a shear load directly to the interface between repair material and denture base resins, which allows the results to be easily compared between materials.[60] Similarly, the torsional test also has a significant shear component. The torsion specimen also has a uniform state of stress at any point on the specimen surface, and this state of stress is less dependent on parallelism and specimen shape than in the three-point bending test.[22]

Controversies relating to the effect of surface treatment of the acrylic resin have arisen as a result of research employing different test methods (Table 1). Hence, the standardization of test methods and the conversion of results according to International Unit System for denture repairs studies are required. In Table 1, all results given in MN/m^2 or N/cm^2 were converted to MPa, where MN/m^2 is the same as MPa. The results described in Newtons (N) were not calculated in MPa, since the parent is a measurement of force, and its conversion depends on the area of specimens.

Conclusions

Based on the current literature, it may be concluded that the success of poly(methyl) methacrylate denture repair depends on many variables, such as the combination of denture base resin and repair material applied, repair surface design, repair surface treatments, and use of reinforcements. It is important to consider that few studies simulating clinical conditions of repair dentures have been performed. Future investigations should incorporate more closely simulated clinical conditions, such as the construction of denture-shaped base specimens, thermocycling, and flexural cyclic loading.

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