Wear Resistance of Hybrid Composite Resin for Crown Material by the Two-body Sliding Test

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Comparative studies on two-body sliding wear resistance were performed between a hybrid composite resin and conventional light-curing composite veneering materials. This study investigated the wear resistance of hybrid composite resins compared with three composite resin veneering materials for 12%Au-Ag-Pd alloy, the wear resistance of four restorative materials opposed to hybrid composite resin, and the influence of surface characteristics on hybrid composite resins. Hybrid composite resin without heat-curing, which was compared with other composite resin materials exhibited inferior wear resistance, but hybrid composite resin mechanically polished after heat-curing exhibited the most superior wear resistance.

Key words : Wear resistance, Composite material, Crown

INTRODUCTION

Esthetic restorative materials are broadly divided into two categories: resinous materials and inorganic materials, with the latter including porcelain and castable glass ceramics. Both types of materials have their own advantages and disadvantages. From a material point of view, it has been noted that resinous materials are softer than natural tooth structure, while inorganic materials are too hard for biocompatibility with natural teeth. Hard resins continue to play an important role for jacket crowns and veneering crowns, but a number of clinical problems associated with their use persist. While most of these problems have been investigated extensively, most progress has been achieved in the area of wear resistance¹⁾. Composite resin veneering materials have become more common because of the improved wear resistance of newer materials^{2–4)}. Recently, new composite resin materials for posterior full crowns were developed, and the mechanical properties were improved by resin and filler technology, including heat curing in addition to visible-light curing. With its ultrahigh concentration of fine ceramic filler particles, these hybrid composite resins offer exceptional physical properties.

The purpose of this study was to evaluate the wear resistance of a new hybrid composite resin crown material and several conventional veneering light-curing composite materials using the two-body sliding wear testing method.

MATERIALS AND METHODS

In this investigation, a new hybrid composite resin (HC) and three kinds of light-curing composite resin materials (SD, LC, CS) designed for fixed restorative veneering procedures were examined using a two-body sliding wear device (Table 1). Each test specimen had a uniform size 10 mm $\times$ 10 mm in length and width, and 3 mm in thickness. The surfaces of the specimens were prepared flat in order to press them against a glass plane, and polymerized by light-curing. In addition, the surfaces of the HC were ground flat using a conventional, mechanical polishing technique after heat-curing. As opposing specimens, balls of 6 mm in diameter were fabricated using 12% Au-Ag-Pd alloy, mechanically polishing HC and castable glass ceramics, and enamels of an extracted mandibular premolar were prepared. The wear resistance of pairs of materials are given in Table 2. The opposing specimens were centrally positioned on each sliding test specimen. They were vertically loaded and tested at 1.0 kgf. The test was conducted at a rate of 120 cycles per minute and a stroke of 5 mm each. The cycling procedure was carried out 10,000, 50,000, 100,000 and 200,000 cycles under running water (Fig. 1 and Fig. 2). The wear track was defined as the distance from the surface of the specimens to the base of the deepest and widest defect generated by a wear testing device after 200,000 cycles. The surfaces of the worn specimens were observed with a scanning electron microscope. The area of contact of the worn alloy ball, enamel, HC and castable glass ceramic (CPCC) after each cycle was also measured by the silicone replica method. The ratio

Table 1 Materials investigated in this study

Material type	Products	Manufacturer	code
Hybrid composite resin	Estenia	Kuraray, Osaka, Japan	HC
Veneering light-curing composite resin	Solidex	Shofu, Kyoto, Japan	SD
	Thermoresin LC	GC, Tokyo, Japan	LC
	Cesead II	Kuraray, Osaka, Japan	CS
12% Au-Ag-Pd alloy	Castwell M.C.	GC, Tokyo, Japan	Pd
Castable glass ceramic	Cry-cera	Kyutai dentceram	CPCC
Enamel	Extracted mandibular premolar		Enamel

Table 2 Material couples of wear resistance for each experiment

Experiment 1			
	HC vs	12% Au-Ag-Pd alloy ball	
	SD vs	12% Au-Ag-Pd alloy ball	
	LC vs	12% Au-Ag-Pd alloy ball	
	CS vs	12% Au-Ag-Pd alloy ball	
Experiment 2			
	HC pressed to glass plane vs	12% Au-Ag-Pd alloy ball	
	HC polished mechanically vs	12% Au-Ag-Pd alloy ball	
Experiment 3			
	HC polished mechanically vs	12% Au-Ag-Pd alloy ball	
	HC polished mechanically vs	Natural tooth enamel	
	HC polished mechanically vs	HC ball polished mechanically	
	HC polished mechanically vs	Castable glass ceramic ball

Fig. 1 Two-body sliding wear testing machine.

Fig. 2 Schematic of the sliding wear apparatus.

of the worn area after each sliding number of times for the original contact area of each material ball was calculated as the changing ratio. The surface hardness values (Vickers hardness number) of the hybrid composite resin, three composite resins, 12% Au-Ag-Pd alloy and castable glass ceramics were measured prior to the sliding wear test.

The results were statistically analysed by means of one-way analysis of variance (ANOVA) followed by Fisher's *t* test.

Fig. 3 Maximal depth and width of the wear tracks of each composite resin.
(Significant difference *: $p < 0.05$, **: $p < 0.01$)

Fig. 4 SEMs of the wear tracks of each composite resin opposed by 12%Au-Ag-Pd alloy.

RESULTS

Figure 3 shows the maximal depth and width of wear of HC and three veneering

Fig. 5 SEMs of 12% Au-Ag-Pd alloy balls worn by HC and SD.

Fig. 6 Maximal depth and width of the wear tracks of HC with two differently prepared surfaces.

pressed HC: press to a flat glass plane, and polymerized by light-curing

polished HC: mechanical polishing after heat-curing pressed HC

(Significant difference *: $p < 0.05$, **: $p < 0.01$)

composite resins (SD, LC and CS) when opposed by 12% Au-Ag-Pd alloy balls after 200,000 cycles. The depth values of HC averaged $40.8 \mu\text{m}$, whereas other composite resins were $2.7 \mu\text{m}$ to $18.3 \mu\text{m}$. One-way ANOVA and the t test showed that HC possessed significantly larger depth values than SD, LC or CS ($P < 0.05$). The wear width values of HC averaged $1,980 \mu\text{m}$, whereas other composite resins were $460 \mu\text{m}$ to $1,380 \mu\text{m}$. One-way ANOVA and the t test showed that HC possessed significantly

larger width values than SD, LC or CS ($P < 0.001$). Scanning electron micrographs of various composite resin veneering materials and each worn ball observed on completion of the wear testing are presented in Figs. 4 and 5. The SEMs of wear tracks of SD (top-left), LC (top-right), CS (bottom-left) and HC (bottom-right) opposed by 12% Au-Ag-Pd alloy balls after 200,000 cycles are shown in Fig. 4. The SEM of HC material showed the submicron-sized filler particles protruding from the surface. The SEMs of the alloy ball worn by HC and SD are shown in Fig. 5. In the case of HC material, the worn alloy ball surface showed well-defined margins and wear tracks generated by hard micro-filler, whereas in the SD material, there was an irregular margin and no wear tracks. Figure 6 shows the maximum depth and width of wear of HC with two different surfaces when opposed by 12% Au-Ag-Pd alloy balls after 200,000 cycles. HC ground flat using conventional mechanically polishing after heat-curing was more wear resistant than HC prepared flat in order to press against a glass plane with light-curing. A significant difference ($P < 0.01$) was noted between the two differently prepared surfaces (Fig. 6). The changing ratio of worn 12% Au-Ag-Pd alloy balls of mechanically polished HC specimens was half that of

Fig. 7 Changing ratio of worn areas of alloy balls against two differently prepared HC surfaces.

Fig. 8 SEM of the wear tracks of mechanically polished HC opposed by 12% Au-Ag-Pd alloy.

Fig. 9 Maximal depth and width of the wear tracks of HC opposed by alloy, enamel, HC and castable glass ceramic.
(Significant differences *: $p < 0.05$, **: $p < 0.01$)

Fig. 10 Changing ratio of worn areas of an alloy ball, enamel, an HC ball and a castable glass ceramic ball against mechanically polished HC.

Fig. 11 Vickers hardness values of each material.
(Value of enamel refers to reference number 19)

those pressed to a flat glass plane with light-curing only (Fig. 7). Figure 8 shows the SEM of the worn surface of a mechanically polished HC specimen opposed by 12% Au-Ag-Pd alloy balls. It illustrates a narrow wear track and a little protruding micro-filler compared with as shown in Fig. 4. Figure 9 shows the maximal depth and width of wear of HC opposed by 12% Au-Ag-Pd alloy balls, enamel, mechanically polished HC and castable glass ceramic after 200,000 cycles. HC opposed by mechanically polished HC was the least wear resistant, whereas when opposed by castable glass ceramic, it was the most wear resistant.

Figure 10 shows the changing ratio of the contract areas of the worn alloy ball, enamel, mechanically polishing HC ball and castable glass ceramic ball for mechanically polished HC planes after 10,000, 50,000, 100,000 and 200,000 cycles. The changing ratio of worn enamel was greater in value, in the following the ratio of the worn HC ball, and the ratio of the worn castable glass ceramic ball were similar to that of the worn alloy ball.

Vickers hardness values for the surfaces of each material are presented in Fig. 11. Hybrid composite resin mechanically polished after heat-curing showed 180 Hv, markedly harder than conventional light-curing composite resin materials.

DISCUSSION

A number of studies were conducted to investigate wear characteristics of composite resin veneering materials *in vivo* and *in vitro*⁵⁻⁷⁾. Composite resin materials have demonstrated occlusal wear in the oral environment⁸⁾ and have had limited usage in occlusal reconstructions. Composite resins have most often been reported excessively worn by enamel and other restorative materials⁹⁻¹¹⁾. The amount of wear depends on such factors as neuromuscular force, lubricants, foreign objects, habits and the restorative materials¹²⁾. Two methods are commonly used to report the wear of restorative materials, 1) the volume of the material removed (volume loss), and 2) loss of vertical height (height loss). With a sufficient volume loss from the occlusal surface, an opposing tooth or teeth could elongate or change position. The latter is

more relevant clinically, because it correlates with the diminished vertical dimension of occlusion⁹⁾.

A distinction is made between two-body and three-body abrasive wear. Three-body abrasive wear occurs when a freely moving abrasive medium is placed between two independently moving surfaces, whereas two-body abrasive wear occurs when the abrasive particles are attached to one of the surfaces¹²⁾. Tranter *et al*¹³⁾ suggested that the two-body wear device used in their investigation had the ability to rank materials with a three-body wear device ($r=0.94$), and pooled clinical data with a high degree of correlation ($r=1.0$)¹⁴⁾.

Wear resistance of composite resin materials is presented as two main clinical components: occlusal-contact wear and contact-free wear. Occlusal-contact wear is a localized process that has been primarily based on theories of microfracture and degradation of a silane coupling agent by hydrolysis and chemical absorption¹⁵⁾.

Hybrid composite resin is a new type of composite material, produced by adding a large quantity of ceramic fillers to a resin matrix which is greatly reinforced by a high concentration of ultra-fine ceramic particles.

The present study consisted of 1) wear resistance of HC material when compared with three composite resin veneering materials, 2) wear resistance of four materials opposed to HC materials, and 3) the influence of surface characteristics of the HC specimens.

In the SEM findings, SD and LC with less wear contained low amounts of round ultra-micro fillers. In the worn HC, submicron fillers were raised. The wear and the consistency of the HC containing high amounts of micro fillers was increased by an ultrafine-particle matrix. SD, LC and CS contained inorganic fillers of 50% to 60% and soft organic complex fillers. On the wear sliding test of the 12% Au-Ag-Pd alloy balls, SD and LC were hard to wear because of the soft fillers and matrix. HC possessed significantly larger depth and width of wear than other materials (Fig. 3), because this was the HC specimen fabricated to press at a flat glass plane and polymerized by light-curing only. There was a monomer rich layer without inorganic fine glass ceramic fillers in the HC surface layer of the pressed glass side, the thickness of this layer was about $30\mu\text{m}$. This layer began to wear by the alloy ball first, the amount of wear increased during the sliding wear test. A monomer rich layer was worn, and angular fine glass ceramic fillers protruded. Further, when this surface was smoothed by repeated wearing, it was determined to be maximum (Fig. 12). SEM observations of the worn surface of HC specimen showed the protruded ultrafine and fine glass ceramic fillers of particle size of $0.02\text{--}1.5\mu\text{m}$ (Fig. 4). The area of the worn alloy ball opposed to HC as shown in Fig. 7 is smaller and smoother than that opposed to SD, and its boundary is definite as for the worn side of the alloy ball. This was compared in the degree that the hardness of the alloy ball made by 12% Au-Ag-Pd alloy was similar to that of HC, and it was suggested to be significantly larger than that of SD. The polymerization of a monomer rich layer was promoted by heat-curing. Further, the mechanically polished HC surface was smoothed by pre-cutting fillers, because it was not damaged by protruding

fillers. The matrix portion of HC was reinforced by loading ultrafine alumina filler, and remained at the same level as glass particles. HC resulted from the reduction of the differences in the physical properties between fine glass ceramic filler and matrix reinforced by ultrafine filler and reduction in the particle size and increase in the content of the fine glass ceramic filler. The type and content of fillers and the resin matrix influence the localized wear resistance of composite resin⁵⁾. Decreasing the particle size resulted in a greater incidence of marginal fracture and localized wear. Increasing the particle size tended to result in a more generalized wear pattern⁶⁾. Hybrid composite resins contain much finer fillers than conventional restorative veneering materials. The smaller the particle diameter, the shorter the distance between the adjacent particles becomes. The matrix in hybrid composite resins has been greatly reinforced by using multi-functional monomers. In addition, a large quantity of ultrafine ceramic filler particles was used. The matrix itself, reinforced by hybridization with ultra-fine particles, takes a further step toward ceramic char-

Fig. 12 Changing phase of the HC surface pressed to a glass plane during the sliding wear testing
top: immediately after being polymerized by light-curing.
middle: monomer rich layer was worn, and angular fine glass fillers protruded
bottom: smooth surface by repeated sliding wear

acteristics because the difference in physical properties between the matrix and the filler is significantly reduced. This results in a more uniform material in which the fillers are very evenly dispersed in the matrix. Robert suggested¹⁶⁾ that the abraders opposing the hybrid composites showed much heavier wear than those opposing the microfills or amalgam. The heavy wear of the steatite abraders opposing the hybrids was associated with a release of wear particles from the abraded which may have contributed to the higher rate of specimen wear than seen with enamel. On the hybrid composite resin used in this study, the bonding mechanism between the matrix resin and glass ceramic filler was improved by a special surface treatment technique of glass ceramic filler, and fine fillers never release from the matrix resin. Nishino demonstrated¹⁷⁾ using the impacting-sliding test that the largest wear was found in the combination of porcelain and hybrid composite resin, he suggested that the resultant sharp surface irregularities as well as the small broken and isolated ceramic filler particles of hybrid composite resin might in turn act as a severe abrasive against the two bodies during the sliding process. Therefore, as for the combination with HC and a harder material than HC, the fine glass ceramic filler of HC promotes wear due to surface texture. Furthermore, Nishino suggested¹⁷⁾ the second largest amount if wear on the combination of hybrid composite resin and Au-Ag-Pd alloy, showed a deep concave abrasion in the alloy at the impact region in the alloy. He stated that it was surrounded by a slight bank-like periphery, suggesting that it might partly involve plastic deformation by the repeated dropping of hybrid composite resin against ductile alloy. These findings show the characteristic aspects of the impact-sliding test, and the present study found that the isolated fine glass ceramic filler in the matrix influences the wear of each material in a similar manner.

Although the hardness of material is often used as an index of wear resistance, the process of wear is associated with complex mechanisms which influence many factors, and it can not be judged by hardness alone. Some studies suggested to a negative correlation between hardness and wear resistance. Hara suggested¹⁸⁾ that the relative wear might not always be affected by the hardness but by other physical and mechanical properties such as configuration, surface aspect, elasticity, plasticity and the impact strength of the materials. On the other hand, Craig suggested¹⁹⁾ that wear is a function of a number of material and environmental factors, including the nature of wear surfaces; the microscopic contact; interaction between sliding surfaces (*i.e.*, elevated stress, temperature, and flow at contact points, leading to localized yielding, melting, and hardening); lubrication; and different material combinations. In general, wear is a function of both opposing materials and the interface between them. The presence of a lubricating film, such as saliva, separates surfaces during relative motion and reduces frictional forces and wear. It is markedly different for wear resistance in experimental methods. In the present study, the Vickers hardness number of veneering light-curing composite resins (SD, LC and CS) showed 40-60 Hv and about 30% of HC hardness, but the wear resistance of these materials opposed to 12% Au-Ag-Pd alloy were greater larger than that of HC. Although in this experiment the Vickers hardness of HC was 150 Hv, its surface had a

monomer rich layer and the fine glass ceramic filler was not less than other veneering composite resin materials. The Vickers hardness number of the mechanical polished HC and 12% Au-Ag-Pd alloy, and that of enamel and CPCC showed similar values, but a positive correlation between wear resistance and hardness of materials was not always recognized because their surface textures, submicron structures, frictional coefficients, elasticity and so on were different. The newly developed hybrid composite resin is useful as an esthetic posterior restorative material that has advantages of both resinous and inorganic materials. For clinical applications, heat-curing (110°C, 15min) and mechanical polishing of the hybrid composite resin are essential for all restorations, and hybrid composite resin restorations may work well without excessive wear and help maintain surface gloss.

CONCLUSION

The wear resistance of a new hybrid composite resin for posterior restoration was investigated in vitro using a two-body sliding wear device. The hybrid composite resin which was compared with other composite resin veneering materials exhibited inferior wear resistance. Scanning electron micrographs made after the wear testing showed protruded micro-fillers of various size on the HC surface pattern. However, after heat-curing, the mechanically polished hybrid composite resin exhibited superior wear resistance. The findings of the present investigation suggested that the wear resistance of the hybrid composite resin was influenced by heat-curing and mechanical polishing of its surface.

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