Original

Wear resistance and microhardness of various interim fixed prosthesis materials

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Abstract: The aim of the present study is to evaluate the wear resistance and microhardness of various interim fixed prosthesis materials with different chemical compositions and curing methods. One heat-cured and four self-cured acrylic resins, and three self-cured, one light-cured, and one dual-cured composite-based materials were tested. For microhardness, samples from each group were tested after storing either at 37°C in artificial saliva for 7 days, followed by thermocycling, or in distilled water solution at 37°C for 24 h. For the evaluation of wear, the remaining samples were evaluated using a 3D scanner and a surface analysis program before loading in the chewing simulator and after every 10,000 cycles. There was a significant difference in wear behavior among the materials tested at both 10,000 and 20,000 cycles ($P < 0.001$). Microhardness and wear resistance were significantly different between acrylic and composite materials.

Keywords: wear resistance; microhardness; interim restoration; provisional restoration; mechanical property.

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Introduction

Interim fixed prostheses are an essential part of fixed prosthodontic treatment. Patients must be provided with an interim restoration from initial tooth preparation until the definitive prosthesis is placed (1). Interim prostheses contribute to prosthodontic treatment in various ways. Their benefits include the following: maintaining dental and periodontal health and preventing abutment teeth from migrating, restoring function and aesthetics during treatment and revealing data to assess hygiene control, guiding soft tissue healing to provide an acceptable exit profile for the definitive prosthesis, and assisting in evaluating maxilla-mandibular relationships and occlusion (2,3).

Prolonged use of interim fixed prosthesis may occasionally be necessary for patients undergoing complex dental treatment. An example is the re-establishment of the occlusal vertical dimension (4) for a patient receiving implant treatment (5). Another indication is soft tissue management using interim fixed prosthesis to provide proper gingival contours for definitive prosthesis (6,7). In such instances, long-term use of interim fixed prosthesis necessitates higher mechanical strength for the restoration, particularly for prostheses between distant abutments and those that are exposed to high functional loads.

Ethyl methacrylates, methyl methacrylates, and dimethacrylate resin composites are the most commonly used materials for both chair-side and laboratory-processed interim fixed prostheses. Dimethacrylate resin composite materials contain di-functional monomers, whereas

Table 1 Materials used in the present study

Material	Type, polymerization	Manufacturer
Dentalon Plus	Polyethyl methacrylate (PEMA)/plymethyl methacrylate (PMMA), self-cured	Heraus Kulzer Gmbh, Hanau, Germany
SR Ivocron	Polymethyl methacrylate (PMMA), heat-cured	Ivoclar Vivadent AG, Schaan, Lilechtenstein
Tab 2000	Polymethyl methacrylate (PMMA), self-cured	Kerr, Orange, CA, USA
EDE Temdent	Polymethyl methacrylate (PMMA), self-cured	Schutz Weil-Dental, Rosbach, Germany
Cool Temp Natural	Bi-functional methacrylate resin, self-cured	Coltene/Whaledent AG, Altstatten, Switzerland
Trim	Vinyl ethyl methacrylate, self-cured	The Harry J. Bosworth Company, Skokie, IL, USA
Telio CS	Multifunctional methacrylate resin, self-cured	Ivoclar Vivadent AG
Revotek LC	Urethane dimethacrylate (UDMA), light-cured	GC Corporation, Tokyo, Japan
Protemp 4 Garant	Multifunctional methacrylate resin, self-cured	3M ESPE AG, Seefeld, Germany
Luxatemp Solar	Multifunctional methacrylate resin, dual-cured	DMG Dental, Hamburg, Germany

methacrylate resins contain mono-functional monomers. The second monomer chain of composite resins provides cross-linking capability to the material and increases strength and durability (8). Previous studies (8,9) have shown that dimethacrylate resin composite-based interim fixed materials were preferred over methacrylate resins because of their more favorable mechanical properties.

Lambrechts et al. (10) defined wear as a complex phenomenon resulting from the overall effect of several interrelated processes. Different forms of wear are known to depend on different mechanisms and forms of interaction between materials. These include adhesive wear, abrasive wear, fatigue wear, and corrosive wear (11). Wear is typically evaluated based on the net loss of material from a surface under operational conditions. Even though there are several published studies about the mechanical properties of interim prostheses (8,9,12-16), little is known about their wear resistance. According to Santing et al. (17), the use of indirect composite resin is preferred over chair-side methacrylate-based materials when the interim restoration must be in service for a long period of time. Simulated wear of dimethacrylate resin materials by dynamic loading has demonstrated higher wear resistance compared to conventional poly (methyl methacrylate) (PMMA) resin (18).

Rapid wear of occlusal contact with interim restorations may lead to some clinical complications. For example, either the antagonist or the abutment teeth or both may erupt to maintain occlusal contact, which eventually results in decreased occlusal clearance. Hence, the final restoration may present premature contacts that would possibly require the adjustment of occlusion. Occasionally, the tooth may even require re-preparation, and the impression procedure must be repeated for a new restoration (19).

The present study was conducted to evaluate and compare wear resistance and microhardness of various interim fixed prosthesis materials having different chemical compositions and curing methods. The null hypothesis of the present study is that no relationship exists between the various interim fixed prosthesis materials in wear rate and microhardness.

Materials and Methods
Specimen preparation and storage
One heat-cured and four self-cured acrylic resins, and three self-cured, one light-cured, and one dual-cured composite-based material were investigated (Table 1). To produce specimens of standard shape and size, 10 disks with 16 mm diameter were cut from a 4-mm thick Teflon block to act as a mold for sample preparation. This Teflon mold was used with two custom-made tempered-glass plates during the fabrication process. The Teflon mold was captured between glass plates using four screws during curing of materials.

The self-cured powder-liquid-type acrylic materials were hand-mixed according to the manufacturers' instructions. The prepared dough of resin was injected in the Teflon mold using a syringe (Ramitec; 3M ESPE, Seefeld, Germany). Specific tips and dispensers were used to fill the mold with cartridge-type materials. Prior to filling the mold, at least one tip full of each material was wasted to ensure a homogeneous mixture. Light-cured composite paste was placed in the mold using a composite spatula. All materials were packed in the mold between glass plates until the end of polymerization. The dual-cured material was light-cured for 40 s, and the light-cured composite was cured for 20 s from both sides of the Teflon mold through glass plates with a chair-side light-curing unit (Elipar II FreeLight, set at 600 mW/cm², 3M ESPE).

To fabricate heat-cured specimens, a light body A-type

silicon impression material (Affinis, Coltene, Altstätten, Switzerland) was cured in the Teflon mold between glass plates to obtain spacers in the exact specimen shape and size. These silicone spacers were flasked in a standard Hanau flask with a type III dental stone (Moldano, Heraeus Kulzer, Hanau, Germany). The heat-cured Sr Ivocron was then mixed, packed in the flask, and polymerized in an automated polymerization unit (Polimer 180, Zhermack, Badia Polesine, Italy) according to the manufacturer's instructions.

A total of 400 disk-shaped specimens were prepared with 10 different resins ($n = 40$ for each material). All specimens were wet-ground with 600, 800, and 1,200 grit silicon carbide papers for 15 s each on a 300 r/min grinding machine (Buehler Metaserv, Buehler, Germany). Specimens were finished with rag wheel and slurry fine pumice, followed by the application of a universal polishing paste (Ivoclar Vivadent AG, Schaan, Liechtenstein). Each disk was then checked for precise dimensions of 16-mm diameter and 3-mm thickness using a screw-type micrometer (Mitutoyo, Kawasaki, Japan; accuracy 0.001 mm) and adjusted if necessary. Disks that did not match the standard shape and size were eliminated.

Prepared disks were divided into four groups, with 20 disks spared for dynamic wear test and the remaining 20 tested for microhardness. Prior to microhardness testing, a group of 10 disks was stored in distilled water at 37°C for 24 h, and the other 10 were stored in artificial saliva (12) that was refreshed every 24 h for 7 days. The latter were subjected to thermocycling of 500 cycles between 5°C and 55°C with a dwell time of 45 s and transfer time of 2 s (Salubris Technica, Dentester, Turkey).

Microhardness test

Knoop hardness test is a surface hardness test that uses a diamond stylus. This test is suitable for most classes of materials, including brittle and elastomeric materials. It is used for harder materials and characterized by the diamond- or rhomboid-shaped indentation made using a rhombic-based pyramidal diamond indenter. The long diagonal of the resulting indentation is measured to determine the hardness. Knoop hardness number (KHN) is a measure of hardness obtained using a diamond pyramid indenter and rhombic base with included angles of 172.5° and 130°. KHN is the ratio of the applied load to the area of the indentation (1).

A microhardness tester (HMV-II; Shimadzu, Japan) was used for KHN measurements. This tester forced the diamond indenter, under a test load of 100 g, into the surface of the test material for a dwell time of 20 s. The long diagonals of indentations were optically measured at 40× magnification. Three readings were taken from each disk, and the averages were calculated. KHN values (in kg/mm^2) were obtained using the universal formula KHN = L/l2Cp, where "L" is the load applied (kgf), "l" is the length of the long diagonal of the indentation (mm), and "Cp" is a constant related to the projected area of the indentation.

Wear test

Dynamic occlusal loading was simulated in an artificial oral environment sliding wear tester (Chewing Simulator; University of Selcuk, Research Laboratory Centre, Konya, Turkey). Disks (20 for each group) were mounted in simulator chambers that were filled with artificial saliva in occlusal contact similar to the physiological conditions. The simulator constantly kept the saliva at 37°C during the test interval. Dynamic loading was carried out in a pin-on-block design with 0.5-mm eccentric sliding at a frequency of 1.2 Hz. A stainless-steel ball antagonist with 4-mm diameter was in continuous contact with the tested disks under a constant load of 50 N. A total of 20,000 dynamic cycles were applied, and surface analyses were made before loading and after every 10,000 cycles.

For surface analysis, three reference marks were created on each disk before mechanical loading, and wear test surfaces were digitized using a 3D scanner (3Shape D700, Copenhagen, Denmark). The data were processed in surface analysis software (SAS; ScanItOrthodontics V2010-2 p3, Copenhagen, Denmark). Disks were scanned before dynamic loading, after 10,000 cycles, and finally at 20,000 cycles. The three shell images created in the SAS represented different stages of the wear test. They were converted to STL files and superimposed in data preparation/editing software (Magics, v9.54). Maximum, minimum, and mean wear values were determined from the superimposed images. The volumetric loss due to the wear process was calculated as follows: mean vertical wear (mm) × contact area (mm^2) = volume (mm^3).

Statistical analyses

IBM SPSS v16.0 software (IBM, Armonk, NY, USA) was used for statistical analysis. Shapiro-Wilk test was used to determine if the measured parameters met the assumptions of normal distribution. Because the distribution of the data did not meet the requirements for normality and homogeneity of variances assumptions, the non-parametric Kruskal-Wallis one-way analysis of variance by ranks and Bonferroni correction tests were used for the multiple comparisons. Mann-Whitney U test was used to compare differences between time intervals

Table 2 Mean Knoop hardness (KHN) of the tested interim materials at 24 h and after 7 days

Materials	Microhardness (KHN)-24 h Mean ± SD	Microhardness (KHN)-7 days Mean ± SD
Trim	9.6 ± 0.5[Aa]	9.8 ± 0.4[Aa]
EDE Temdent	6.4 ± 1.5[Ab]	6.8 ± 0.44[Ab]
Dentalon Plus	10.6 ± 0.4[Aa]	11.6 ± 0.54[Ac]
Telio CS	18 ± 0.7[Ac]	19 ± 0.1[Ad]
Luxatemp Solar	25.4 ± 0.8[Ad]	29.2 ± 1.3[Be]
Protemp 4 Garant	19 ± 0.7[Ac]	20.4 ± 0.5[Ad]
Tab 2000	10.4 ± 0.5[Aa]	10 ± 0.7[Ba]
SR İvocron	39.2 ± 2.4[Ae]	37.6 ± 0.5[Af]
Revotek	18.4 ± 1.4[Ac]	19 ± 0.7[Ad]
Cool Temp Natural	14.4 ± 0.5[Af]	14.8 ± 0.4[Ag]

Different superscripted letters in columns represent a statistically significant difference ($P < 0.05$).
Different superscripted capital letters in rows represent a statistically significant difference ($P < 0.05$).

Table 3 Mean values of wear depending on the number of cycles and materials used

Materials	Wear-10,000 cycles Mean ± SD (mm^3)	Wear-20,000 cycles Mean ± SD (mm^3)
Trim	0.25 ± 0.04[Aa]	0.36 ± 0.07[Ba]
EDE Temdent	0.32 ± 0.08[Ab]	0.41 ± 0.09[Bb]
Dentalon Plus	0.30 ± 0.08[Ab]	0.37 ± 0.08[Ba]
Telio CS	0.18 ± 0.06[Ac]	0.21 ± 0.05[Ac]
Luxatemp Solar	0.13 ± 0.03[Ad]	0.15 ± 0.02[Ad]
Protemp 4 Garant	0.18 ± 0.02[Ac]	0.20 ± 0.03[Ac]
Tab 2000	0.20 ± 0.05[Ac]	0.24 ± 0.06[Be]
SR İvocron	0.11 ± 0.02[Ad]	0.13 ± 0.02[Ad]
Revotek	0.17 ± 0.03[Ac]	0.23 ± 0.04[Be]
Cool Temp Natural	0.26 ± 0.05[Aa]	0.32 ± 0.08[Bf]

Different superscripted letters in columns represent a statistically significant difference ($P < 0.05$).
Different superscripted capital letters in rows represent a statistically significant difference ($P < 0.05$).
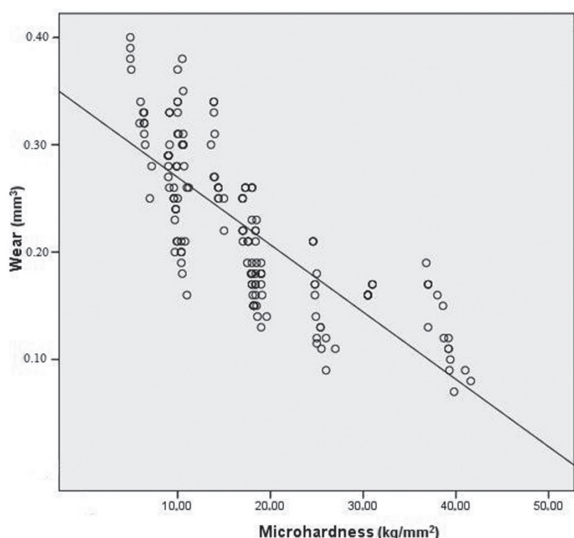

Fig. 1 Scatterplot of microhardness and wear.

and both cycles. Spearman's rank correlation coefficient was used to find any relationship between microhardness and wear resistance of interim materials. Results were at a 95% confidence interval, and a significant level of $\alpha = 0.05$ was used for all statistical analysis.

Results

The results are presented in Tables 2 and 3. The methacrylate-type resins, except the heat-cured polymerized SR Ivocron material, exhibited significantly lower microhardness than the dimethacrylate resin composites at both time intervals (Table 2). Except for the dual-cured Luxatemp Solar materials, all other materials showed a statistically insignificant change in microhardness over time. There was a significant difference in wear behavior among the materials tested at both 10,000 and 20,000 cycles ($P < 0.001$; Table 3). Of the 10 interim prosthesis materials, EDE Temdent and Dentalon Plus showed the highest degree of volume loss, and SR Ivocron showed the lowest degree of loss in all cycles. The correlation between microhardness and wear was significant (Fig. 1), with a correlation coefficient of r = −0.89 ($P < 0.01$) demonstrating a relatively strong relationship between the variables. This showed that higher surface micro-

hardness was associated with less wear.

Discussion

The wear resistance and microhardness of 10 different types of interim prosthesis materials were evaluated *in vitro* in the current study by measuring the volume loss due to friction with a stainless-steel ball antagonist and Knoop microhardness test. Because several types of materials may be used as interim prosthesis in routine clinical practice, the present study aimed to evaluate the chemically different acrylic and composite materials that had different polymerization methods, such as dual-, light-, or self-cure. The results support the research hypothesis and show that different materials exhibit different wear characteristics and microhardness.

Diaz-Arnold et al. (12) stated that the hardness of most provisional fixed prosthodontic materials decreases over time. However, according to Savabi et al. (20), who evaluated the hardness and wear resistance of different interim restorative materials, there was no significant change in the microhardness of the tested interim materials after one week of conditioning in saliva. The results of the present study demonstrated that, although all acrylic-based materials showed no significant difference according to time, the dual-cured composite-based materials showed a significant increase in hardness from 24 h to 7 days. The dual-cured nature may have allowed for more continual cross-linking to take place between 24 h and 7 days, contributing to the significant increase in microhardness during that time interval in Luxatemp Solar. Furthermore, a 14-day storage time was chosen by Diaz-Arnold et al. for their study. This may be the reason why the hardness of most provisional fixed prosthodontic materials decreased over time, unlike in the current study.

Regarding hardness, the study by Oliveira et al. (21) found that composite resin showed higher values than self-cured acrylic resins stored in water and thermo-cycling groups. These results agree with the current study showing that composite-based materials display higher microhardness than self-cured. However, unlike in their study, a heat-polymerized Sr Ivocron material was used in the present study and showed the highest microhardness values for all materials in both the 24-h and seven-day measurements. This is in agreement with Jo et al. (22), who also found that heat-polymerized acrylic interim materials showed the highest microhardness values. Although more laboratory and chair time is necessary to produce heat-polymerized materials, Jo et al. recommended heat-polymerized interim materials for long-term provisionalization when there was a history of frequent breakage, long-span restorations were needed, in areas of heavy occlusal loads, and/or in cases of parafunction.

During polymerization of acrylic resins, the polymerization of the monomer was not totally complete. The free and unreacted monomer, in various amounts, remained in the polymerized resin (23). This residual monomer acted as a plasticizer and negatively affected the physical and mechanical properties of acrylic resins. Because the amount of chemical activator in heat-polymerized acrylic resins was more than the chemical activators in the self-polymerized acrylic, the amount of residual monomer in the heat-polymerized acrylic resins was less than that of the acrylic resins (24). This phenomenon could be the reason why the heat-polymerized SR Ivocron material showed the highest wear resistance value and microhardness.

The difference between the microhardness and wear behavior of the auto-polymerized PMMA and polyethyl methacrylate (PEMA)-based resins and the dimethacrylate-based and light-curing composite-based resins may be their different monomer compositions. Resistance increased because of the cross-linking of multifunctional monomers (such as Bis-GMA: bisphenol A glycidyl methacrylate or TEGDMA: triethylene glycol dimethacrylate;) with other monomers contained in the dimethacrylate resins. Auto-polymerized conventional methacrylate resins may exhibit lower wear resistance and microhardness because they contain mono-functional, low molecular weight, and linear molecular monomers (22,25).

Because the dimethacrylate-based composite resins are applied using a special applicator that works with their cartridge system, they may be more accurately and appropriately mixed than acrylic resins, which are hand-mixed as powder and liquid. The homogeneity of the powder-liquid ratio may vary each time it is mixed depending on the clinician (26). More precise mixing that activates the mechanical properties of materials may be another reason why dimethacrylate-based composite resins generally exhibit higher wear resistance and microhardness than auto-polymerized acrylic resins.

If the indenter overlaps with the filler particles, significant differences may occur when measuring the hardness values of interim materials. For this reason, it is recommended that more than one measurement be made for samples when measuring surface hardness (12,27). In the current study, three measurements were made from each sample and averaged. When a very high value was observed during measurement, that value was not included in the average because the indenter was thought to have overlapped with the filler particles.

Regarding the devices used in the wear simulation, loading/force application variations ranging from 1 to 100 N were possible (28). A previous study showed that the chewing force of molars varied between 20 and 120 N (29). Therefore, a 50 N occlusal load was applied in this study. Moreover, when the results of various studies were examined, the number of cycles varied. Studies evaluated anywhere from 5,000, 10,000, 25,000, 50,000, 100,000, and up to 120,000 cycles (10,30-32). In the wear device used in the current study, the samples were continuously in contact with the antagonist with occlusal and lateral forces. Wear was significantly affected by loading type and the contact time between specimens and antagonists (33), so the number of cycles used in the present study was purposely low. According to the literature, the wear produced by 240,000-250,000 masticatory cycles in a chewing simulator corresponded to the wear measured after one year of clinical service (34). Therefore, to simulate a service time of one month, about 20,000 masticatory cycles had to be performed in a chewing simulator.

To compare the wear results of the present study with previous studies that evaluated the wear resistance of interim prosthesis materials was difficult because previous studies used different chewing simulators and methods to determine wear. To the best of the author's knowledge, only three studies have been published. In the first, Santig et al. (17) evaluated the three-body wear of three indirect laboratory composite resins, five chair-side dimethacrylate resin-based materials, and two chair-side methacrylate-based materials. They used a wear machine developed by the Academic Centre for Dentistry Amsterdam (ACTA) to determine the loss of material using a profilometer via millimeter by area measurements. In the second, Takamizawa et al. (18) evaluated erosive wear behavior of three dimethacrylate-based provisional resins, a conventional PMM, and a resin composite. They used a Leinfelder-Suzuki wear simulation device and a noncontact profilometer. In the third study, Savabi et al. (20) evaluated the wear resistance of seven interim restorative materials using a custom-made wear machine. They studied the wear behavior of the specimens through the determination of surface roughness.

Taking into consideration the limitations of an *in vitro* study, the following conclusions may be drawn:
1. There is a relationship between microhardness and wear resistance of the interim materials in this study.
2. All dimethacrylate resin composite materials exhibit superior microhardness over the methacrylate resins, except the heat-cured polymerized acrylic, after both 24 h and 7 days.
3. Among the materials tested, SR Ivocron and Luxatemp Solar are significantly harder and more resistant to wear than the others.
4. Microhardness and wear resistance are significantly dependent on the chemical nature and curing mechanism of the interim prosthesis material.

Conflict of interest
None.

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