

Two-body Wear and Hardness of New Generation Artificial Resin Teeth

ABSTRACT

The purpose of this study was to evaluate two-body wear and hardness of new generation artificial resin teeth. Ten specimens of four different artificial resin teeth (nanofill composite, nanohybrid composite, microfiller reinforced acrylic and highly modified acrylic) were prepared. Specimens were thermodynamically loaded in a dual-axis chewing simulator (50N, 240,000 cycles, 1.6 Hz, 5/55°C thermocycle). The wear loss was analyzed by using plaster replicas and 3D laser scanner. Vickers hardness was determined before and after thermodynamic loading. Mean Vickers hardness values of highly modified acrylic resin teeth were statistically significantly lower than nanohybrid composite ($p<0.001$), nanofilled composite ($p<0.001$) and microfiller reinforced acrylic resin teeth ($p<0.001$). Mean wear loss of highly modified and microfiller reinforced acrylic resin teeth were statistically significantly lower than nanohybrid composite ($p<0.001$) and nanofilled composite ($p<0.001$) resin teeth. There was a statistically significant difference in wear among the materials. The correlation between hardness and wear was not statistically significant.

INTRODUCTION

In the practice of dentistry, prosthetic restorations are used to enhance the patient's impaired chewing function, phonation, and aesthetic appearance. In recent years, the demand for new dental materials has increased proportionally with the increasing importance of aesthetic dentistry. Artificial teeth are one of the most important factors that enable aesthetics in prosthetic restorations.^{1,2}

Artificial teeth used in prosthetic restorations are expected to have features such as color diversity and stability, smooth surface, and wear resistance. The wear characteristics of artificial teeth are critical in maintaining a proper occlusal relationship.^{3,4}

Excessive wear of occlusal surfaces results in insufficient posterior tooth support and may lead to changes in vertical and horizontal jaw relations, fatigue of masticatory muscles, and loss of masticatory efficiency, thus resulting in functional and aesthetic losses.^{3,5}

To predict wear resistance of many restorative materials, hardness values have been used as a measurement of the mechanical property. Hardness is the resistance of materials against plastic deformation.⁶ Artificial teeth with lower hardness values absorb occlusal impacts better, and artificial teeth with high hardness values may transmit the occlusal forces to the bone, causing bone resorption.⁷ In addition, wear resistance of artificial teeth is considered to be correlated hardness.^{5,8}

Keywords

Hardness
Two-Body Wear
Artificial Teeth
Chewing Simulator

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The rapid advances and the new technologies in the dental material industry offer clinicians a variety of options in aesthetic, mechanical, and physical properties of renewed artificial teeth. Conventional acrylic resin artificial teeth are replaced by a new generation of artificial teeth modified with cross-linking agents, improved monomers or new fillers.³

Further research is needed on the wear and hardness properties of composite resin and acrylic resin artificial teeth that have been introduced into the market in recent years.^{9,10} The aim of this study is to evaluate the two-body wear and hardness of four kinds of artificial resin teeth. The null hypothesis (H_0) has been determined as follows: There is no significant difference between the hardness and wear resistance of composite resin and acrylic resin artificial teeth.

MATERIALS AND METHODS

Nanofill composite (NFC)(Condyloform II NFC⁺), nanohybrid composite (NHC)(SR Phonares II), microfiller reinforced acrylic (MRA)(Vitapan Synoform), and highly modified acrylic (IPNA)(Polystar Selection Edition High Definition) resin teeth were investigated (Table 1). Mandibular first molars were selected as the artificial tooth specimens, as this is the area where chewing occurs most.¹¹ As a result of the Power Analysis performed in G* Power program, when the effect size values of d : 0.576 and SD : 0.007 were taken for hardness and wear values, the number of specimens for Power: 0.80 and α : 0.05 was determined as $n=10$ for each group. Therefore, a total of 40 specimens were prepared, with 10 specimens in each resin artificial tooth group.

Type IV dental plaster (GC Fuji-Rock EP Optiflow) was mixed according to the manufacturer's instructions and poured into the Teflon mold, which is part of the dual-axis chewing simulator (MOY-101). The tubercles of the artificial tooth were placed in the center of the hardened plaster surface, and around it, silicone sealant material (Mucopren) was applied in 3-mm thickness. The other Teflon mold was placed on the Teflon with the specimen on it, and the remaining voids were

filled with autopolymerizing acrylic resin (Takilon Cold Curing Dental Polymer). After the polymerization of the acrylic, the Teflon molds were separated. Parallel straight steps were formed in the Teflon mold with the milling device to superimpose the 3D models and achieve error-free measurements. Central fossa boundaries of all specimens were drawn with a fine-tipped pencil and abraded on the milling device with the occlusal plane parallel to the ground. In order to carry out the wear test in the enamel layer of the artificial tooth, the trace of the pencil in the central fossa was left as a spot. Abraded surfaces were wet polished with 800, 1000, and 2500 grit silicon carbide paper (Buehler) for 15 seconds with 300 rpm using the polishing device (Metaserv 250 Grinder-Polisher) and finally polished using 1 μ m alumina polishing paste (Durodent Diamond Polish) for 1 min. After polishing, Vickers hardness values were determined with a Vickers hardness test device (Innovatest) at a 300-gf load and a dwell time of 15 seconds.^{9,12} Three indentations were measured from the central fossa boundaries on each artificial tooth.⁴

Stainless steel balls with a diameter of 2.5 mm were used as antagonistic specimens and were changed for each artificial tooth specimen.^{13,14} Thermodynamic loading settings in the chewing simulator were adjusted as 1.6 Hz frequency,¹⁵ 240,000 cycles,¹⁶ and 5-55°C thermocycle in distilled water.¹⁵ The masticatory cycle consisted of three phases: contact with a vertical load of 50 N,¹⁷ lateral sliding of 1 mm,¹⁸ and separating the teeth and antagonist. Before the two-body wear process and after 120,000 and 240,000 loading cycles, an impression of each loaded tooth surface was taken using polyether impression material (Express XT Penta Putty/ Ligth Body). Then replica models were made using Type IV dental plaster (Gc Fujirock EP Optixscan).¹⁹ Replica models were scanned by 3D laser scanner (Smart Scan). These models were superimposed on each other in Delcam CopyCAD Pro software to determine the maximum wear loss (vertical and volume loss).²⁰ After thermodynamic loading, the Vickers hardness values were measured by repeating the procedures applied on the central fossa boundaries of the specimens.

Table 1: Materials used in present study

Material	Composition	Manufacturer	Lot Number	Code
Polystar Selection Edition High Definition	H-MPN - Highly modified polymer network H-MPN = IPN (interpenetrating polymer network)	Merz Dental	1983021	IPNA
Vitapan Synoform	MRP - Microfiller reinforced polymer matrix Highly cross-linked acrylate polymer with SiO ₂ microfill material	Vita Zahnfabric	B7	MRA
Condyloform II NFC ⁺	Nanofilled composite resin	Candulor	RP0264	NFC
SR Phonares II	Nanohybrid composite resin	Ivoclar Vivadent	WP0088	NHC

IBM SPSS Statistics 22 program was used for statistical analysis. The Shapiro–Wilk test was used to determine if the measured parameters met the assumptions of normal distribution. The one-way ANOVA test was used to compare the parameters between groups and to determine the groups that caused the difference. If such variances were homogeneous, the Tukey-HSD test was used; if not, then Tamhane’s T2 test was used. Paired sample t-test was used for within-group comparisons of the parameters, and Pearson correlation analysis was used to examine the relationships between the parameters. The level of significance was defined as $p < 0.05$.

RESULTS

HARDNESS VALUES

Before and after thermodynamic loading, statistically significant differences were observed between the mean hardness values of the artificial teeth ($p < 0.05$) (Table 2). Before and after thermodynamic loading, the IPNA group had a statistically significantly lower mean hardness value compared to all other groups ($p < 0.01$). After thermodynamic loading the mean hardness values of the MRA group were statistically significantly lower than the NHC group ($p < 0.01$) and there was no statistically significant difference between the other groups ($p > 0.05$) (Table 2).

VARIATION IN HARDNESS VALUES BEFORE AND AFTER THERMODYNAMIC LOADING

The difference in the change of hardness values of the MRA artificial tooth group before and after thermodynamic loading was statistically significant ($p = 0.006$). The change in hardness values of NHC, NFC and IPNA artificial tooth groups did not yield a statistically significant difference ($p > 0.05$) (Table 2).

VERTICAL AND VOLUME LOSS AFTER 120,000 AND 240,000 CYCLE

A statistically significant difference was observed between the mean vertical and volume loss of artificial tooth groups at the end of 120,000 and 240,000 cycles. The mean wear loss values of the IPNA and MRA groups were lower than the NHC and NFC groups on a very high significance degree ($p < 0.001$) (Table 3, 4) (Figure 1).

VARIATION IN VERTICAL LOSS BETWEEN 120,000 AND 240,000 CYCLES

Within-group comparisons of artificial teeth, the least amount of change in vertical loss values between 120,000 and 240,000 cycles was found in MRA artificial teeth (0.11 ± 0.03). No statistically significant difference was observed between MRA and IPNA artificial tooth groups ($p = 0.099$). The greatest amount of change was found in NHC artificial teeth (0.37 ± 0.04). No statistically significant difference was found between NHC and NFC artificial tooth groups ($p = 0.996$).

VARIATION IN VOLUME LOSS BETWEEN 120,000 AND 240,000 CYCLES

Within-group comparisons of artificial teeth; the least amount of change in volume loss values between 120,000 and 240,000 cycles was found in MRA artificial teeth (0.60 ± 0.12). No statistically significant difference was found between MRA and IPNA artificial tooth groups ($p = 0.130$). The greatest amount of change was found in NFC artificial teeth (2.41 ± 0.20). No statistically significant difference was found between NHC and NFC artificial tooth groups ($p = 1.000$).

Table 2: Mean hardness values of artificial teeth before and after thermodynamic loading (kgf/mm²)

	Mean hardness values Before thermodynamic loading	Mean Hardness Values After Thermodynamic Loading	² p
	Mean (SD)	Mean (SD)	
NHC	24.62 (2.88) ^a	23.49 (1.05) ^a	0.325
NFC	23.26 (1.09) ^a	22.72 (0.58) ^{a,b}	0.211
IPNA	19.75 (0.69) ^b	19.37 (0.97) ^c	0.198
MRA	23.77 (1.04) ^a	22.23 (0.71) ^b	0.006*
¹ p	0.000*	0.000*	

¹Oneway ANOVA Test ²Paired Samples t Test * $p < 0.05$
 Different in superscript letters indicate statistical differences ($p < 0.05$).
 Average values with standard deviations in parentheses

Table 3: Mean vertical loss of artificial teeth (mm)

	Vertical loss after 120,000 cycle	Vertical loss after 240,000 cycle	² p
	Mean (SD)	Mean (SD)	
NHC	0.46 (0.03) ^a	0.83 (0.06) ^a	0.000*
NFC	0.48 (0.05) ^a	0.84 (0.05) ^a	0.000*
IPNA	0.20 (0.06) ^b	0.35 (0.06) ^b	0.000*
MRA	0.26 (0.04) ^b	0.37 (0.04) ^b	0.000*
¹ p	0.000*	0.000*	

¹Oneway ANOVA Test ²Paired Samples t Test *p<0.05
 Different in superscript letters indicate statistical differences (p<0.05)
 Average values with standard deviations in parentheses.

Table 4: Mean volume loss of artificial teeth (mm³)

	Volume loss after 120,000 cycle	Volume loss after 240,000 cycle	² p
	Mean (SD)	Mean (SD)	
NHC	1.55 (0.19) ^a	3.95 (0.37) ^a	0.000*
NFC	1.8 (0.35) ^a	4.21 (0.49) ^a	0.000*
IPNA	0.38 (0.2) ^b	1.1 (0.26) ^b	0.000*
MRA	0.57 (0.1) ^b	1.17 (0.19) ^b	0.000*
¹ p	0.000*	0.000*	

¹Oneway ANOVA Test ²Paired Samples t Test *p<0.05
 Different in superscript letters indicate statistical differences (p<0.05)
 Average values with standard deviations in parentheses.

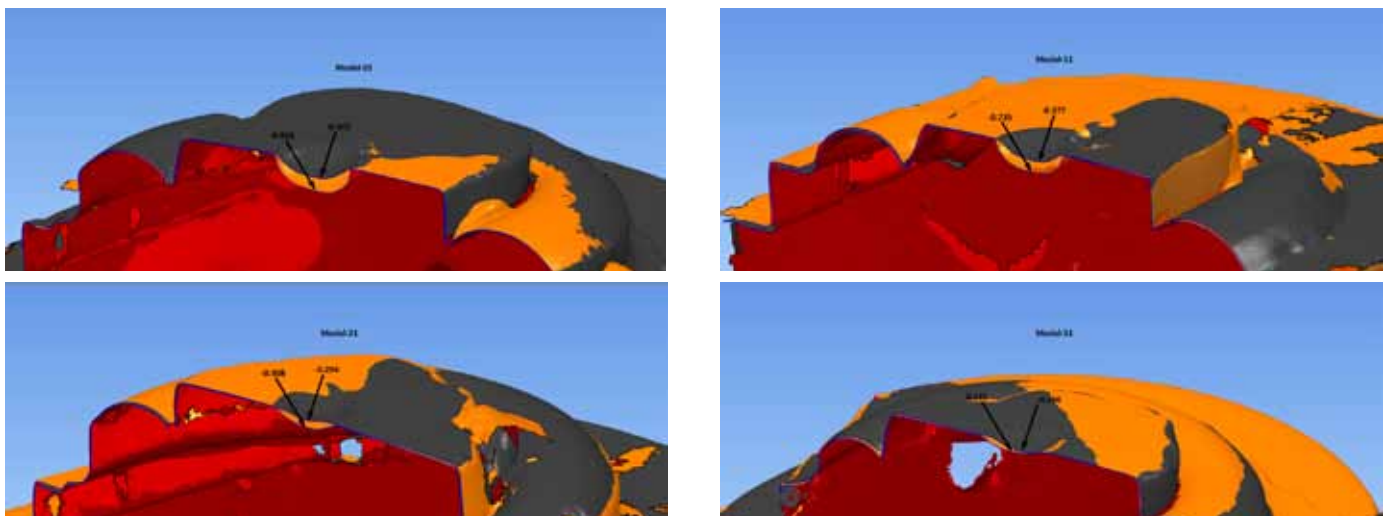


Figure 1: Superimposed 3D Models of Nanohybrid Composite Resin Artificial Tooth Model 01 (vertical loss after 120.000 and 240.000 loading cycle) The grey-coloured areas represent the 3D model obtained after 120,000 cycles, and the orange-coloured areas represent the 3D model obtained after 240,000 cycles. The red colour represents the opposite (negative) surfaces on the 3D model cross-section.

THE EVALUATION OF THE RELATIONSHIP BETWEEN THE MEAN HARDNESS VALUES AND THE MEAN WEAR VALUES

After thermodynamic loading and 240,000 loading cycles, there was no statistically significant relationship between mean hardness values and mean wear values of all artificial tooth groups ($p>0.05$) (Table 5).

Table 5: The evaluation of the relationship between the mean hardness values after thermodynamic loading and the mean wear values after 240,000 cycles

		Hardness After Thermodynamic Loading	
		r	p
NHC	Volume Loss	0.031	0.931
	Vertical Loss	0.158	0.662
NFC	Volume Loss	-0.197	0.586
	Vertical Loss	-0.400	0.252
IPNA	Volume Loss	-0.489	0.151
	Vertical Loss	-0.558	0.094
MRA	Volume Loss	0.461	0.180
	Vertical Loss	0.380	0.265

Pearson Correlation Analysis

DISCUSSION

Since the hardness and wear values of the artificial teeth showed difference, the null hypothesis (H_0) of this study was rejected.

Stober *et al.*¹² reported that nanofill composite resin artificial teeth had more wear than IPN acrylic resin artificial teeth due to their tendency to collect the nanofill particles into clusters in the micrometer range. This is in line with Munshi *et al.*⁹ who also reported that inorganic SiO₂ particles were added to the structure in order to increase the hardness values of the nanofill composite resin artificial teeth, but the wear was accelerated due to the breakage of these particles from the surface during the process. These results agree with the current study in that the highest wear values were identified in NFC artificial teeth. Since wear on artificial teeth may lead to a decrease in occlusal vertical dimension and an increase temporomandibular joint dysfunction,⁷ we recommend performing control sessions of prosthetic restorations with the use of NFC artificial teeth at intervals of no more than 6 months.

In this study, IPNA artificial teeth had the least wear, and MRA artificial teeth had the second least. In parallel with the findings of this study, Munshi *et al.*⁹ and Stober *et al.*²¹ reported that the wear values of double-cross-linked and IPN acrylic resin artificial teeth were lower than those of nano-fill composite resin artificial teeth. According to the results of present study, since the wear values of acrylic resin artificial teeth are lower than those for composite resin artificial teeth, the occlusal relationship can be maintained longer and fewer control sessions will be needed. Additionally, the decrease in the need for replacing the prosthesis due to wear will provide advantages for both clinicians and patients.

When different wear test methods are applied under different antagonists, force, motion, and environmental conditions, the wear values of artificial dental materials may also vary.¹⁰ It has also been reported that, under steady conditions, different wear values were observed in artificial tooth specimens abraded with different antagonist materials.²² Unlike the studies from Ilangkumaran *et al.*²³ and Ghazal *et al.*²⁴, the present study results show that, IPNA artificial teeth have less wear than composite resin artificial teeth. Different findings may be related to different antagonists, composition of the artificial tooth, and wear test methods in those studies.

Medeiros *et al.*²⁵ and Assunção *et al.*²⁶ reported that acrylic resin and composite resin materials have decreased hardness values after water absorption. This result agree with the current study in that, after thermodynamic loading, the hardness values of acrylic and composite resin artificial teeth decreased; however, a statistically significant difference was only found in MRA artificial tooth group. As the wear values between 120,000 and 240,000 cycles also decreased with the decrease in hardness in MRA artificial teeth after thermodynamic loading, it can be inferred that the elasticity modulus of artificial teeth decreases while the flexibility increases.^{7,27} For these reasons, MRA artificial teeth can be used in prosthetic restorations applied to resorbed crests in order to decrease the occlusal forces.

Previous studies found positive^{28,29} or negative^{5,30} correlations between the hardness and wear of artificial denture teeth while the others did not.^{31,32} In our study, there is no correlation between the hardness and wear values of the materials.

Numerous chewing simulators have been developed to determine the wear of artificial teeth *in vitro*.³³ In these simulators, 2-body or 3-body wear methods can be applied to the test specimens. The 2-body wear method is determined by direct contact between the test material and the antagonist. In the 3-body wear method; the wear of the material can vary not only based on the antagonist but also on the abrasive properties and pH of the intermediate material.^{12,34} 2-body wear method was applied in present study since the variables in the 3-body wear method may affect the results of the wear test.

In the literature, there is no consensus on which material should be used as an antagonist in wear tests.³⁵ It has been reported that different materials such as natural teeth, steatite, stainless steel and porcelain are used as antagonist.^{14,36,37} In present study, stainless steel antagonist was preferred, as the micro-structure is standard and the hardness and roughness values are close to the enamel compared to the ceramic materials.^{13,14}

The shape of the antagonist is as important as the material from which it is made. Turssi *et al.*¹³ and Krejci *et al.*³⁸ stated that they drew the specimen surface of the excess load on the edges of the cylindrical antagonists and accelerated the wear by altering the wear mechanism of the material; they also stated these problems do not occur when ball-shaped antagonists are used. Additionally, it was reported that antagonists were used with different diameters of 2.3 mm,³⁴ 2.36 mm,³⁹ 2.4 mm,⁴⁰ and 3 mm.¹⁴ In this study, a ball shaped antagonist with a diameter of 2.5 mm was used.

The average physiological bite force is reported to be 50 N in individuals who do not have bruxism.¹⁷ Therefore, 50 N force was applied to the specimens.

In the literature,^{16,35} it has been reported that 240,000 loading cycles in the chewing simulator correspond to 1 year of chewing. To compare our findings with the 1-year findings of other studies in the literature, the simulator settings were set to 240,000 loading cycles.

The mean lateral sliding movement is specified as 0.9–1.2 mm.¹⁸ However, there are various studies that have different lateral sliding movement values such as 0.3 mm,² 0.7 mm,¹⁷ 1 mm,¹⁴ 2 mm³⁹ and 3 mm³⁴ in chewing simulator. In the present study, 1 mm lateral sliding movement was applied, which falls between these values.

In the literature, there are studies that test wear by forming a flat surface on artificial teeth.^{9,10,41} When using artificial teeth with anatomical surfaces, Heintze *et al.*³⁴ reported that it is not possible to place all specimens in contact with the same occlusal points as the antagonist; the wear patterns may change and thus will not coincide with the clinical results. Artificial teeth can be abraded because of shrinkage during acrylic polymerization, from the maximum intercuspidation with the artificial teeth facing the malposed natural teeth, or by changes in the occlusal relationships through settling of the prosthetic restoration.⁶ Therefore, in the present study, the flat surface was prepared and the polished layer was removed before the wear test.

Wear measurement with 3 dimensional laser scanners is considered to be an accurate and effective technique by the researchers.^{20,42} Therefore, in our study, 3 dimensional laser scanning method was used to determine the wear of artificial teeth.

Incorrect evaluations may occur during the 3-dimensional laser scanning process because laser light penetrates semi-transparent artificial tooth specimens.³⁵ For this reason, the surface may be coated with powder, or a replica model may be obtained. Mehl *et al.*¹⁹ reported that it is not possible to coat specimens with uniform thickness, so replica models should be formed. Researchers^{43,44} recommend the use of plaster as a replica material since it provides the required measurement accuracy due to its good dimensional stability and opacity. Therefore, the replica models were prepared with Type IV dental plaster.

Limitations of this study include that only 2-body wear of 4 materials against 1 stainless steel antagonist was evaluated *in vitro*. Different results might have been obtained with a 3-body wear test or with other antagonistic materials. In addition, as with any *in vitro* study, it remains unclear as to what extend the wear observed clinically may differ. Therefore further research is needed.^{21,45}

Within the limitations of the present study:

- The highest hardness values were determined in nano-hybrid composite resin artificial teeth and the lowest hardness values were determined in highly modified acrylic resin artificial teeth.
- The highest wear values were determined in nanofill composite resin artificial teeth and the lowest wear values were determined in highly modified acrylic resin artificial teeth.
- No significant relationship was found between the hardness and wear values. Therefore, it can be stated that the hardness properties of artificial teeth are not correlated when evaluating their wear properties.
- Since the wear of the highly modified acrylic resin artificial teeth had the lowest values, we believe that the occlusal relationships created in prosthetic restorations can be maintained longer, thus reducing the frequency of control sessions as well as decreasing the need for replacing the prosthesis due to wear, which will have advantages for both clinicians and patients.

MANUFACTURER DETAILS

- Polystar Selection Edition High Definition, Merz Dental, Lütjenburg, Germany
- Vitapan Synoform, Vita Zahnfabric, Bad Säckingen, Germany
- Condyloform II NFC+ , Candulor, Wangen, Switzerland
- SR Phonares II , Ivoclar Vivadent, Schaan, Liechtenstein
- GC Fuji-Rock EP Optiflow, GC America Inc.
- MOY-101, MOD Dental, Esetron Smart Robotechnologies, Ankara, Turkey
- Mucopren, Kettenbach, Germany

- Takilon Cold Curing Dental Polymer, Willmann & Pein GmbH, Hamburg, Germany
- Silicon Carbide Paper, Buehler, ABD
- Metaserv 250 Grinder-Polisher, Buehler, ABD
- Durodent Diamond Polish, Durodent Dental, Australia
- Innovatest, Netherlands, Europe
- Express XT Penta Putty/ Ligth Body, 3M ESPE, Seefeld, Germany
- Gc Fujirock EP Optixscan, GC America Inc.
- Smart Scan, Breuckmann, Germany

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