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Effect of Repair Material Type and Thermocycling Aging on Repair Bond Strength to Various Artificial Teeth

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ABSTRACT

Objectives: To compare repair bond strength of acrylic and composite resin to different type of artificial teeth with and without thermocycling aging (TMC).
Materials and Methods: A total of 192 specimens were prepared using four different types of artificial teeth (n=48) (Group CA-Conventional polymethylmethacrylate, Group IS-Isosite, Group DCL-Double cross-linked acrylic, Group NC-Nanohybrid composite). All specimens were aged with TMC (5000 cycles, 5◦C/55◦C) and repaired with auto-polymerized acrylic or composite resin. Half of the repaired samples were subjected to the shear bond strength (SBS) test while the other half were subjected to TMC to simulate the aging of the repair material. Then, artificially aged specimens were also subjected to the SBS test. Data were statistically analyzed by three-way analysis of variance (ANOVA). Paired comparisons were made using one-way ANOVA, and multiple comparisons were made using the Tukey HSD test (α=0.05).
Results: The bond strength of both non-aged and artificially aged composite resin and non-aged acrylic resin did not differ according to artificial teeth type (p>0.05). However, artificially aged acrylic resin showed higher bond strength for group CA (9.25±2.96) than for group NC (5.01±3.09) (p<0.05). The bond strength of composite resin was higher than acrylic resin regardless of artificial teeth type and TMC (p<0.05). TMC decreased the bond strength of both acrylic and composite repair materials to all types of artificial teeth (p<0.05)
Conclusions: New-generation artificial teeth used in removable dentures are costly. Therefore, repairing fractured teeth with composite resins instead of replacing them can be both time-efficient and economical.

Keywords: Artificial teeth, shear bond strength, autopolymerizing acrylic resin, composite resin.

Tamir Materyali Tipi ve Yaşlandırmanın Çeşitli Suni Dişlere olan Bağlanma Dayanımı üzerine Etkisi

Süreç

Geliş: 02/01/2023
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ÖZ

Amaç: Akrilik ve kompozit rezinin farklı tipteki yapay dişlere termal yaşlandırma ile ve yaşlandırma olmadan tamir bağlantı dayanımını karşılaştırmaktır.
Gereç ve Yöntemler: Dört farklı yapay diş tipi (n=48) kullanılarak toplam 192 numune hazırlandı (Grup CA-Konvansiyonel polimetilmetakrilat, Grup IS-İzosite, Grup DCL-Çift çapraz bağlı akrilik, Grup NC-Nanohibrit kompozit). Tüm örnekler termal siklus ile yaşlandırıldı (TMC; 5000 döngü, 5◦C/55◦C) ve otopolimerize akrilik rezin veya kompozit rezin ile tamir edildi. Tamir edilen örneklerin yarısı makaslama bağlanma dayanımı (SBS) testine, diğer yarısı ise tamir materyalinin yaşlanmasını taklit etmek için TMC'ye tabi tutuldu. Daha sonra yaşlandırılmış örneklere de SBS testi uygulandı. Veriler, üç yönlü varyans analizi (ANOVA) ile istatistiksel olarak analiz edildi. İkli karşılatırmalar tek yönlü ANOVA kullanılarak, çoklu karşılaştırmalar ise Tukey HSD testi kullanılarak yapıldı.
Bulgular: Hem yapay olarak yaşlandırılmamış hem de yaşlandırılmış kompozit rezinin ve yapay olarak yaşlandırılmış akrilik rezinin bağlanma dayanımı yapay diş tipine bağlı olarak değişiklik göstermedi (p>0,05). Öte yandan yapay olarak yaşlandırılmış akrilik rezin CA grubu (9,25±2,96) için NC grubuna (5,01±3,09) olandan daha yüksek bağlanma gücü gösterdi (p<0,05). Yapay diş çeşidi ve TMC den bağımsız olarak kompozitin bağlanma dayanımı akrilikten daha yüksek bulundu (p<0,05). TMC, hem akrilik hem de kompozit tamir materyalinin bağlanma gücünü tüm yapay diş tiplerinde azalttı (p<0,05)
Sonuçlar: Hareketli bölümlü protezlerde kullanılan yeni nesil suni dişler pahalı olduğu için kırılan dişleri değiştirmek yerine kompozit rezinlerle tamir etmek hem zamandan kazanç sağlar hem de daha ekonomik bir çözüm sunar.

Anahtar Kelimeler: Suni diş, makaslama bağlanma direnci, otopolimerize akrilik rezin, kompozit rezin.

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Introduction

Artificial teeth of complete and partial dentures restore chewing function, phonation, and aesthetics caused by teeth loss and adjacent structures.[1] Polymethyl methacrylate (PMMA) is the most frequently used artificial teeth type due to its advantages including good biocompatibility, dimensional stability, adhesion to denture base, and ease of manipulation.[2] However, PMMA artificial teeth have disadvantages such as low fracture resistance, susceptibility to wear, and color instability.[2-4] To overcome these unsatisfactory features, new generation acrylic teeth with highly cross-linked isosit material, acrylic resin teeth with interpenetrating polymer mesh, and composite resin teeth with different filler size have been developed with the help of advancements in new technologies.[5] As such, by the addition of crosslinking agents, interpenetrating polymer mesh, different monomers, and fillers of various sizes, conventional acrylic resin teeth have been modified to strengthen their physical and mechanical properties.[6, 7]

Fracture of artificial teeth after a certain time of clinical service or due to accidental denture dropping by patients who suffer from motor control impairments is a common problem.[3] Denture tooth fracture and chipping may become a more significant clinical problem with the increased use of implants and the associated increase in forces applied to prosthetic components.[8] The fact that these new generation acrylic artificial teeth are expensive makes it advantageous to repair the teeth instead of replacing them.[9] Immediate in-office repair of fractured denture teeth with composite or auto-polymerized acrylic resins reduces the frequency of appointments and costs, causes minimal discomfort to patients, and eliminates the need for time-consuming procedures.[9, 10]

Previous studies mainly focused on the effect of surface treatments and bonding agents on debonding of artificial teeth from denture base caused by clinical service.[8, 9, 11] However, studies evaluating the repair of new-generation artificial teeth with composite or acrylic resin are lacking in the literature. Therefore, this study aimed to compare the bond strength of auto-polymerized acrylic and composite resin before and after thermocycling aging (TMC) to repair newly developed artificial teeth. The null hypotheses of the study are: 1) The bond strength will not differ according to the repair material used, 2) The bond strength will not differ regarding the type of artificial teeth, 3) The bond strength will not change after TMC.

Materials and Methods

This study evaluated the effect of TMC on repair bond strength of auto-polymerized acrylic and composite resin to 4 different types (conventional polymethylmethacrylate, isosite, double cross-linked acrylic and nanohybrid composite) of artificial teeth (Table 1). The minimum sample size was calculated at 0.25 effect size, 85% power, and α=0.05 error level as n=12 per group (N=192). The design of this research was approved by the Clinical Research Ethics Committee of Lokman Hekim University Faculty of Dentistry, Turkey (2022152; 2022/161). The workflow of the study is shown in Figure 1.

Specimen Preparation

Twenty-four mandibular first molar artificial teeth from each group were sliced vertically by a diamond saw (Microcut 201; Metkon, Turkey) to divide the teeth into two parts. A total of 48 specimens were prepared for each type of artificial teeth and wet-polished with 600- and 800-grit silicon carbide papers. Then, all specimens were artificially aged with TMC (THE-1100; SD Mechatronik, Feldkirchen-Westerham, Germany) in distilled water to simulate intraoral service (5000 cycles, 5°C/ 55°C thermal application, and dwell time of 30 s).

Half of the specimens were treated with acrylic resin and the other half was treated with composite resin to simulate repair. The surface of the specimens repaired with acrylic resin was wetted with methyl methacrylate (MMA) monomer (Meliodent; Heraeus Kulzer Ltd, Newbury, Berkshire, United Kingdom) for 3 minutes and air-dried. Then, auto polymerizing acrylic resin was mixed according to the manufacturer's directions and placed in a polytetrafluorethylene (PTFE) mold (2.5 mm diameter, 4 mm height) which was fixed on the surface of the specimen. After complete polymerization, the PTFE mold was cut and separated carefully from the specimen-resin assembly.

The surface of the specimens repaired with composite resin was treated with Scotchbond Universal Adhesive (3M ESPE, St. Paul, MN, USA) and polymerized with a light curing unit (Bluephase 20i-High power mode; Ivoclar Vivadent, Amherst, NY, USA) for 10 seconds. Then, light curing nanohybrid composite (i-Light N; i-dental, Šiauliai, Lithuania) was placed in the PTFE mold and polymerized with the same light-curing device for 20 seconds. Then, the mold was cut and separated. All repaired specimens were kept in an etuve at 37 °C for 48 hours.

Half of the repaired specimens in each group were immediately subjected to shear bond strength (SBS) test, while the other half were artificially aged with TMC in distilled water (5000 cycles, 5°C/ 55°C thermal application, and dwell time of 30 s) to simulate a period of intraoral service of repaired artificial tooth (n=12). Then, artificially aged specimens were also subjected to the SBS test.

Shear Bond Strength Test

The SBS test was performed using a computer-controlled universal testing machine (Lloyd Instruments Ltd.; Hampshire, United Kingdom) with 1 mm/min crosshead speed. The maximum load at failure was recorded in Newtons (N). This value was divided by the adhesive surface area (mm²) to calculate the SBS value in megapascals (MPa) for each specimen.

Failure Mode Analysis

The surface of all debonded specimens was examined with a stereomicroscope (M3Z; Leica Microsystems, Wetzlar, Germany) under 25x magnification to determine the failure modes. The failure modes were classified as follows: 1) adhesive failure between the repaired acrylic/composite resin and the artificial tooth interface, 2) cohesive failure either within the repaired acrylic/composite resin or the artificial tooth, 3) mixed failure with both adhesive and cohesive failures exhibited (Figure 2).

Statistical Analysis

The Shapiro-Wilk test was used to evaluate the normal distribution of the data. The effects of the artificial teeth (4 levels: CA, IS, DCL, NC), repair material (2 levels: auto-polymerized acrylic resin, composite resin) and TMC condition (2 levels: +, -) on SBS were statistically analyzed by three-way analysis of variance (ANOVA). As the binary and triple interactions were significant, comparisons were analyzed using one-way ANOVA. Multiple comparisons were performed using the post-hoc Tukey HSD test. The statistical significance level of the data was taken as α=0.05. All statistical analyses were performed using IBM SPSS statistical software (v 27.0, Armonk, New York, USA)

Results

Descriptive statistical data are shown in Table 2. Mean bond strengths (MPa) ranged between 5.01± 3.09 (Groups NC-A, with TMC) and 21.34±6.17 MPa (Group CA-C, without TMC).

SBS comparisons for different artificial teeth are shown in Figure 3. Intergroup comparisons revealed no difference in bond strength between different artificial tooth types for composite resin repair material regardless of artificial aging condition ($p>0.05$). Likewise, the bond strength of acrylic resin was similar for all groups without TMC ($p > 0.05$). However, artificially aged acrylic resin repair material showed higher bond strength for group CA (9.25± 2.96) than for group NC (5.01±3.09) ($p<0.05$) (Figure 3). The bond strength of artificially aged acrylic resin to groups IS (6.16± 3.75) and DCL (7.09±2.72) were comparable to each other and the other 2 groups ($p> 0.05$). Considering intra-group comparisons, composite repair material showed better bond strength than acrylic resin for all groups regardless of aging condition ($p < 0.05$) (Table 2). Artificial aging decreased the bond strength of both acrylic and composite repair materials to all types of artificial teeth ($p < 0.05$) (Table 2).

All groups repaired with acrylic resin showed type 1 failure regardless of the artificial aging condition. Failure type distribution for the groups repaired with composite resin is shown in Figure 4. For DCL and CA groups, type 1 failure was dominant, while Type 2 failure mode was more common for groups NC and IS regardless of TMC. All artificially aged CA samples showed type 1 failure, while none of the samples of group NC showed Type 1 failure regardless of artificial aging.

Discussion

This study investigated the repair bond strength of auto-polymerized acrylic and composite resin to artificial teeth with different chemical properties. Also, the effect of artificial aging on bond strength was evaluated with thermal cycling. The bond strength differed according to the repair material used, the type of artificial teeth, and artificial aging condition. Therefore, all 3 null hypotheses were rejected

Table 1: Content details of artificial teeth evaluated

Material	Group abbreviations	Trade name	Manufacturer
Conventional polymethylmethacrylate	CA	Ivostar, Gnathostar	Ivoclar Vivodent AG, Italy
Isosite	IS	SR Orthosit PE	Ivoclar Vivodent AG, Italy
Double cross-linked acrylic	DCL	SR Vivodent DCL	Ivoclar Vivodent AG, Italy
Nanohybrid composite	NC	SR Phonares II	Ivoclar Vivodent AG, Italy

Table 2: Descriptive statistics of the study

Groups	Repair Material	Artificial Aging Condition: Without thermocycling (TMC -) Mean (MPa)± SD**	Artificial Aging Condition: With thermocycling (TMC+) Mean (MPa) ± SD
CA	A	13.01± 6.35	9.25± 2.96
	C*	21.34± 6.17	10.48± 4.97
IS	A	10.46± 4.39	6.16± 3.75
	C*	19.53± 7.45	12.71± 5.69
DCL	A	12.99± 4.48	7.09± 2.72
	C*	15.52± 4.77	12.46± 4.26
NC	A	8.31± 4.8	5.01± 3.09
	C*	15.48± 3.26	13.89± 2.82

† Conventional polymethylmethacrylate (CA), Isosite (IS), Double cross-linked acrylic (DCL), Nanohybrid composite (NC), Acrylic resin (A), Composite resin (C), standard deviation (SD), Thermal cycling (TMC)
* Composite repair material showed better bond strength than acrylic resin regardless of artificial teeth group and aging condition.
**Artificial aging decreased the bond strength of both repair materials for all groups.

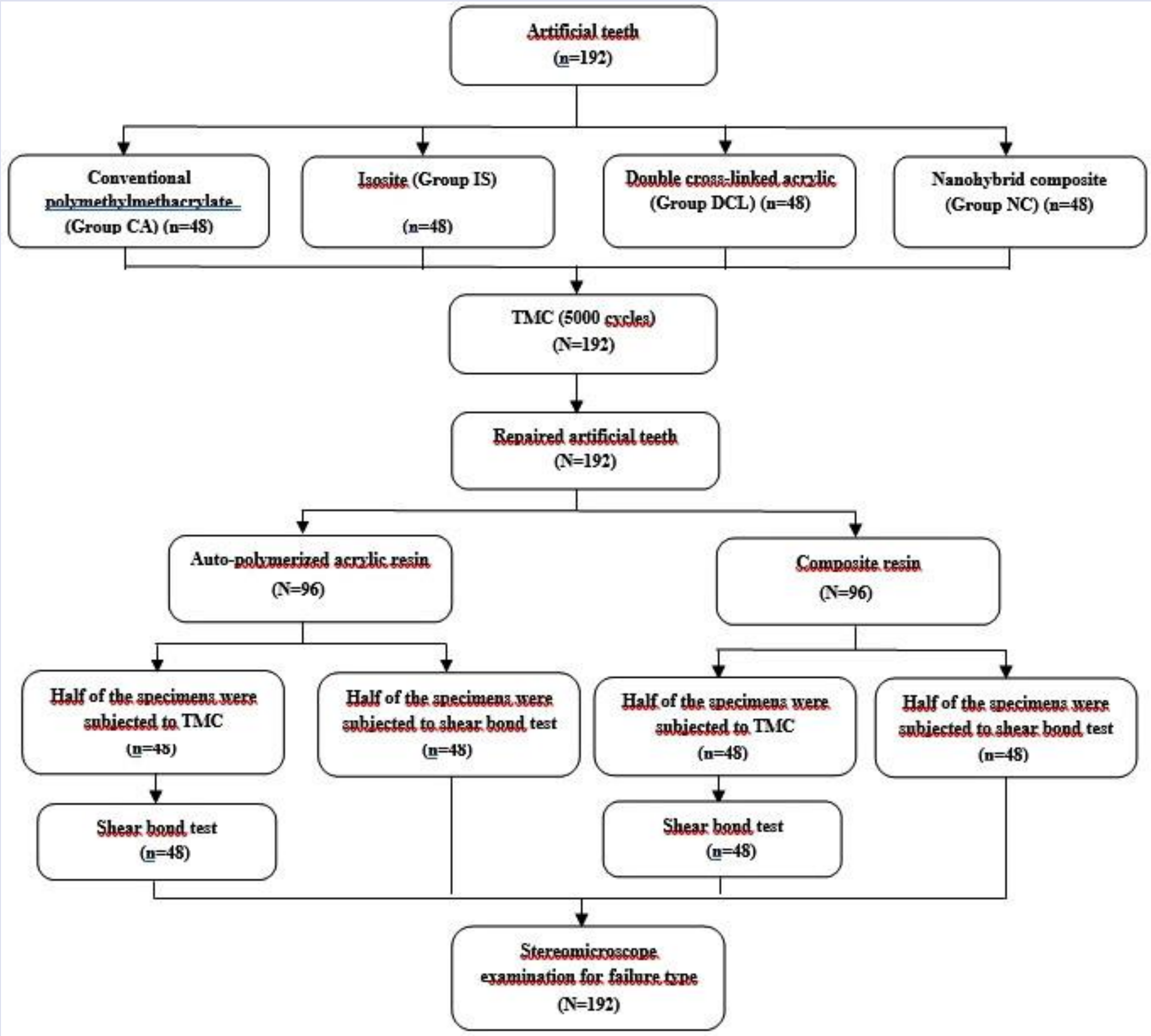

Figure 1. *The schematization of all steps of the study*

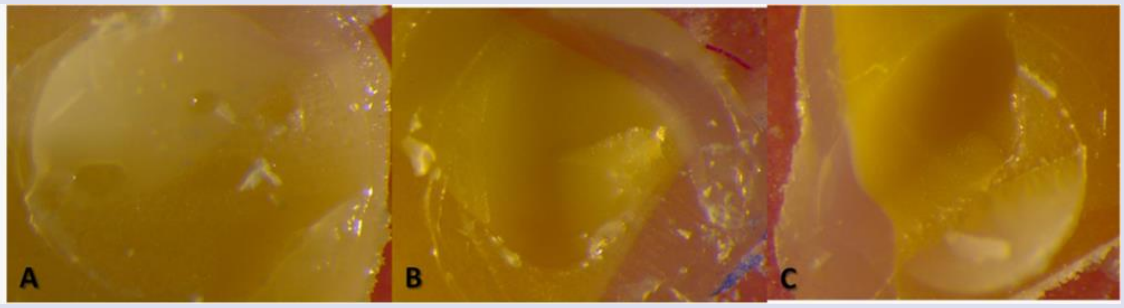

Figure 2. *Demonstrative images of failure modes. A. Adhesive failure B. Cohesive failure C. Mixed failure*

Conventional artificial teeth have a linear polymer structure and PMMA is the main structure.[12] However, mechanical and physical properties are improved with the help of technological advancements.[6] As such, the addition of crosslinks to acrylic teeth increased the physical and mechanical properties.[12] On the other hand, composite artificial teeth contain methacrylate matrix, urethane dimethacrylate (UDMA) based crosslinking agent, and inorganic micro-fillers, which increases the hardness and rigidity.[13] In the present study, the bond strength of acrylic resin repair material was similar for all types of artificial teeth prior to artificial aging. The only significant difference in bond strength regarding different type of artificial teeth was found between conventional polymethylmethacrylate and nanohybrid composite artificial teeth when repaired with acrylic resin and subjected to artificial aging. This condition may have derived from the difference in chemical structures of artificial teeth and the bond of repair materials to them. Acrylic resin presented higher bond strength to conventional PMMA teeth than to nanohybrid composite artificial teeth after TMC. Acrylic resin may have presented better bond strength to PMMA teeth with a similar chemical structure. As nanohybrid teeth consist mainly of composite material, the repair bond strength of acrylic resin to these teeth would have been affected by artificial aging and decreased. Based on this result, clinicians should be aware of the debonding risk in long term when nanohybrid composite artificial teeth are repaired with acrylic resin. On the other hand, this difference in repair bond strength was not present when the teeth were repaired with composite resin, as the bond strength was similar for all artificial tooth types and for both artificial aging conditions. Previous studies noted that the application of bonding agent prior to acrylic resin artificial teeth substantially increases the bond strength of composite resin due to the similarity between the molecules of reactive methacrylate groups and the similar pattens of MMA and bisphenol A diglycidylether methacrylate (BIS GMA) polymerization process.[14,15] According to these considerations, in the present study, a chemical bonding between acrylic resin teeth and composite repair material might have occurred.[15] Papazoglou *et al.*[16] stated that when MMA is applied to acrylic artificial teeth, a swelling effect causes micro irregularities on the surface of acrylic teeth in which composite material penetrates and enhances the mechanical bonding. As a result, a combination of chemical and mechanical bonding between composite and acrylic artificial teeth occurs.[15,16] These reports may also explain the higher repair bond strength of composite than acrylic resin regardless of the artificial teeth type and aging condition. It can be considered that the bonding system applied prior to composite resin provided better wettability and enhanced bonding for all types of artificial teeth.

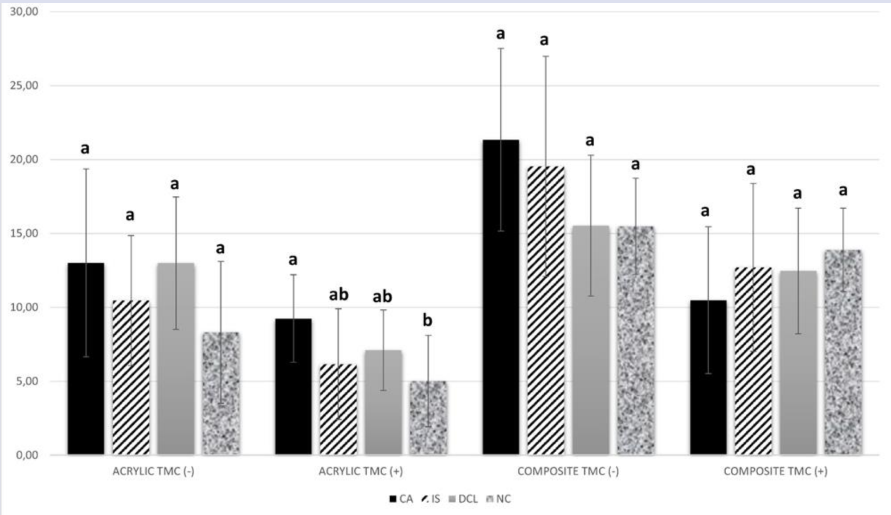

Figure 3. *Statistical differences between the mean bond strengths of groups regarding repair material and TMC.*

*Different superscript letters represent the statistically significant differences (p < 0.05).

† Conventional polymethylmethacrylate (CA), Isosite (IS), Double cross-linked acrylic (DCL), Nanohybrid composite (NC), Acrylic resin (A), Composite resin (C), standard deviation (SD), Thermal cycling (TMC)

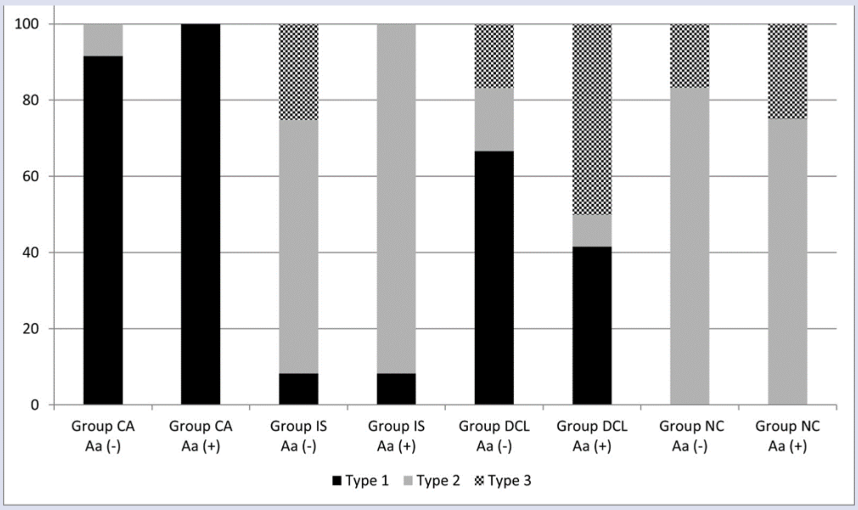

Figure 4. *Distribution of failure modes for each group repaired with composite resin.*

The stability of dental materials is of importance for the long-time service of restoration. The oral environment may cause deterioration in restorative materials, leading to early failures.[17] TMC application is widely used to simulate dental materials' aging of and to evaluate the durability in in vitro studies. The International Organization for Standardization (ISO) recommends a thermal cycling regime between 5°C and 55°C to simulate aging.[18] It was reported that 3000 cycles of thermal cycling application corresponds to 3 years of intraoral service, assuming that the patient consumes an average of 3 meals daily.[19] Based on this information, in the present study, 5000 thermal cycles applied between 5°C and 55°C corresponds to 5 years of clinical service. To simulate five years of oral service, TMC was applied to all specimens and then reapplied to the experimental group of repaired artificial teeth to detect the effect of TMC on the bond strength of repair materials. Artificial aging resulted in a significant reduction in the bond strength of both acrylic and composite repair materials regardless of the artificial teeth type. This finding is in line with previous studies which stated that the bond strength of acrylic and composite resin to various materials decreases significantly by artificial aging.[20-23]

While adhesive failure in the bonding interface indicates poor bond strength, cohesive and mix failures are associated with a strong bond between two materials.[24] All samples repaired with acrylic resin repair material demonstrated lower bond strength than composite resin and showed adhesive-type failure. Therefore, this finding was supported by the analysis via a stereomicroscope. On the other hand, conventional acrylic resin teeth repaired with composite showed adhesive-type failure, yet no difference was found in bond strength between conventional acrylic and other artificial tooth types. This finding can be explained by the weak mechanical bonding between composite repair material and conventional acrylic teeth. However, the failure mode analysis was not in line with the findings of the bond strength test. Further studies are needed to investigate the bonding mechanism between the composite material and newly introduced artificial teeth.

Previous studies investigated the effect of roughening artificial teeth with various methods on the bond strength of acrylic or composite resin to acrylic artificial teeth.[16,25] In the present study, standard methods recommended by the manufacturers were applied and different roughening methods were not evaluated. Future studies may focus on the effect of different surface treatments on the bond strength of acrylic and composite resin to various types of artificial teeth.

As in any in vitro study, the experimental design of this study may not be sufficient to simulate intraoral conditions. The results may vary in the dynamic oral environment. Therefore, the presented results should be supported by future in-vivo studies. Also, types of repair materials and artificial teeth were limited. Future in vitro studies may diversify these and compare different types of materials.

Conclusions

Within the limitations of this study, the following conclusions can be drawn;

1) Repair with composite resin showed similar bond strength for all types of artificial teeth regardless of artificial aging.

2) The bond strength of acrylic resin was similar for all artificial teeth before aging. However, after artificial aging, the bond strength of acrylic resin to conventional PMMA teeth was higher than that of nanohybrid composite teeth.

3) The application of artificial aging reduced the repair bond strength of both acrylic and composite repair materials.

4) Composite repair material exhibited higher bond strength to all artificial tooth types than acrylic resin, regardless of artificial aging condition.

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Conflicts of Interest

The authors of this study declare no conflict of interest.

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