



YEDITEPE UNIVERSITY

INSTITUTE OF HEALTH SCIENCES

DEPARTMENT OF PEDIATRIC DENTISTRY

**THE EFFECT OF SURFACE COATING AND
ARTIFICIAL AGING ON THE SURFACE
ROUGHNESS AND MICROHARDNESS OF GLASS
IONOMER-BASED RESTORATIVE MATERIALS
*IN-VITRO***

DOCTOR OF PHILOSOPHY THESIS

YAĞMUR YILDIRIM, DDS

İstanbul – 2023



YEDITEPE UNIVERSITY

INSTITUTE OF HEALTH SCIENCES

DEPARTMENT OF PEDIATRIC DENTISTRY

**THE EFFECT OF SURFACE COATING AND
ARTIFICIAL AGING ON THE SURFACE
ROUGHNESS AND MICROHARDNESS OF
GLASS IONOMER-BASED RESTORATIVE
MATERIALS *IN-VITRO***

DOCTOR OF PHILOSOPHY THESIS

YAĞMUR YILDIRIM, DDS

SUPERVISOR
ASSOC. PROF. DR. ELİF SUNGURTEKİN EKÇİ

İstanbul – 2023

THESIS APPROVAL FORM

Institute : Yeditepe University Institute of Health Sciences
Programme : PhD Program in Pediatric Dentistry
Title of the Thesis : The Effect of Various Surface Coating Agents and Artificial Aging on the Surface Roughness and Microhardness of Glass Ionomer Based Restorative Materials *In Vitro*
Owner of the Thesis : Yağmur Yıldırım
Examination Date : 01.03.2023

This study have approved as a Master Thesis in regard to content and quality by the Jury.

	Title, Name-Surname (Institution)
Chair of the Jury:	Prof. Dr. Senem SELVİ KUVVETLİ Yeditepe University
Supervisor:	Doç. Dr. Elif SUNGURTEKİN EKÇİ Yeditepe University
Member/Examiner:	Prof. Dr. Didem ÖZDEMİR ÖZENEN Yeditepe University
Member/Examiner:	Prof. Dr. Serap Hatice AKYÜZ Marmara University
Member/Examiner:	Doç. Dr. Bahar Başak KIZILTAN ELİAÇIK Hamidiye University

APPROVAL

This thesis has been deemed by the jury in accordance with the relevant articles of Yeditepe University Graduate Education and Examinations Regulation and has been approved by Administrative Board of Institute with decision dated and numbered

Prof. Dr. Bayram YILMAZ
Director of Institute of Health Sciences

DECLARATION

I hereby declare that this thesis is my own work and that, to the best of my knowledge and belief, it contains no material previously published or written by another person nor material which has been accepted for the award of any other degree except where due acknowledgment has been made in the text.

Yağmur Yıldırım

ACKNOWLEDGEMENTS

I would like to express my acknowledgements to my dear teacher and thesis consultant **Assoc. Prof. Dr. Elif SUNGURTEKİN EKÇİ**, who always shares her knowledge and experience with me during my doctorate study and never spared her support and tolerance, and whom I take as an example in all aspects;

to my dear teacher **Prof. Dr. Senem SELVİ KUVVETLİ**, Head of the Department of Pediatric Dentistry of Yeditepe University Faculty of Dentistry, who never spared her support, knowledge, and experience and always guided me during my doctorate study;

to my dear teacher **Prof. Dr. Didem ÖZDEMİR ÖZENEN**, who never spared her knowledge and experience throughout my doctorate study and always reminded us that we are a family as a department, and to all other valuable academic members of our department;

to Dilek Öztürk, who have always been with me since I started my doctorate, and all my teammates;

to my dear mother Nurgül Yıldırım, my father Haydar Yıldırım and my brother Umit İlkan Yıldırım, whose love I always feel and who helped me come to these days, guided me in every period of my life, and supported me in every respect;

Thank you very much.

THESIS APPROVAL FORM.....	ii
DECLARATION.....	iii
ACKNOWLEDGEMENTS.....	iv
TABLE OF CONTENTS.....	v
LIST OF TABLES.....	viii
LIST OF GRAPHICS.....	ix
LIST OF IMAGES.....	x
LIST OF SYMBOLS AND ABBREVIATIONS.....	xi
ABSTRACT.....	xiv
1. INTRODUCTION AND PURPOSE.....	1
2. GENERAL INFORMATION (LITERATURE REVIEW).....	2
2.1. Glass Ionomer Cements.....	2
2.1.1. History of Glass Ionomer Cements.....	2
2.1.2. Classification of Glass Ionomer Cements by Areas of Use.....	3

2.1.3. Classification of Glass Ionomer Cements by Content.....	3
2.1.3.1. Conventional Glass Ionomer Cements	4
2.1.3.2. Resin-Modified Glass Ionomer Cements (RMGICs)	8
2.1.3.3. High-Viscosity Glass Ionomer Cements.....	10
2.1.3.4. Polyacid-Modified Composite Resins (Compomer)	11
2.1.3.5. Giomer.....	13
2.1.3.6. Glass Carbomer.....	13
2.2. Surface Coating Agents.....	14
2.2.1. Petroleum Jelly (Vaseline).....	15
2.2.2. Cocoa Butter.....	15
2.2.3. Light-Cured Surface Sealants.....	16
2.3. Artificial Aging Methods	17
2.3.1. Aging by Thermal Cycling Test.....	17
2.3.2. Aging by Water Resorption.....	18
2.3.3. Aging by Occlusal Loading.....	19
2.4. Evaluation of Surface Roughness.....	19
2.5. Evaluation of Surface Microhardness.....	20

3. MATERIALS AND METHODS.....	22
3.1. Tested Materials.....	22
3.2. Sample Preparation for Surface Roughness Test and Microhardness Test.....	27
3.3. Surface Roughness Test.....	34
3.3.1. Measurement of Surface Roughness.....	34
3.4. Surface Microhardness Test.....	36
3.4.1. Measurement of Microhardness.....	36
3.5. Statistical Analysis.....	39
4. RESULTS.....	40
4.1. Surface Roughness Test Results.....	40
4.2. Surface Microhardness Test Results.....	45
5. DISCUSSION.....	50
5.1 Discussion of Surface Roughness Test Results.....	54
5.2 Discussion of Surface Microhardness Test Results.....	57
6. CONCLUSION.....	62
7. REFERENCES.....	65
8. CURRICULUM VITAE.....	77

LISTS OF TABLES

Table 1. Light-cured surface sealants used in dental applications.

Table 2. General properties of materials used in the study.

Table 3. Preparation method of samples used in the study.

Table 4. Tested material groups.

Table 5. Comparison of surface roughness values of ACTIVA™ kids BioACTIVE-RESTORATIVE™ before and after thermal aging.

Table 6. Comparison of surface roughness values of EQUIA® Forte Fil before and after thermal aging.

Table 7. Comparison of surface roughness values of ChemFil® Rock before and after thermal aging.

Table 8. Comparison of surface roughness values of all tested materials without coating application.

Table 9. Comparison of surface roughness values of all tested materials after coating application.

Table 10. Comparison of surface microhardness values of ACTIVA™ kids BioACTIVE-RESTORATIVE™ before and after thermal aging.

Table 11. Comparison of surface microhardness values EQUIA® Forte Fil before and after thermal aging.

Table 12. Comparison of surface microhardness values of ChemFil® Rock before and after thermal aging.

Table 13. Comparison of surface microhardness values of all tested materials.

Table 14. Comparison of surface microhardness values of all tested materials after coating application.



LIST OF GRAPHICS

Graphic 1. Comparison of Surface Roughness Values of ACTIVA™ kids BioACTIVE-RESTORATIVE™ before and after thermal aging.

Graphic 2. Comparison of surface roughness values of EQUIA® Forte Fil before and after thermal aging.

Graphic 3. Comparison of surface roughness values of ChemFil® Rock before and after thermal aging.

Graphic 4. Comparison of surface roughness values of all tested materials without coating application.

Graphic 5. Comparison of surface roughness values of all tested materials after coating application.

Graphic 6. Comparison of surface microhardness values of the ACTIVA™ kids BioACTIVE-RESTORATIVE™ and the ACTIVA™ kids BioACTIVE-RESTORATIVE™ + coating before and after thermal aging.

Graphic 7. Comparison of Surface Microhardness values of test EQUIA® Forte Fil before and after thermal aging.

Graphic 8. Comparison of surface microhardness values of ChemFil® Rock before and after thermal aging.

Graphic 9. Comparison of surface microhardness values of all tested materials without coating application.

Graphic 10. Comparison of surface microhardness of all tested materials after coating application.

LIST OF IMAGES

Image 1. ACTIVA™ kids BioACTIVE-RESTORATIVE™ (PULPDENT®, Watertown, USA).

Image 2. EQUIA® Forte Fil (GC Corporation, Tokyo, Japan).

Image 3. ChemFil® Rock (Dentsply Sirona, Konstanz, Germany).

Image 4. EQUIA Forte™ Coat (GC Corporation, Tokyo, Japan).

Image 5. Plexiglass molds.

Image 6. Elipar® S 10 (3M ESPE, USA).

Image 7. a.max, AM-1 Capsule mixer (Monitex, Taiwan).

Image 8. Capsule Applier III (GC Corporation, Tokyo, Japan).

Image 9. Phonenix Beta Twin Wheel (Buehler®, USA).

Image 10. Polishing the samples with sandpaper.

Image 11. Profilometer (MarSurf M 1, Germany).

Image 12. The surface roughness measurement of the specimens using the profilometer.

Image 13. Thermocycler (Salubris-Technica, Turkey).

Image 14. Buehler Micromet 5114D digital microhardness tester (Buehler, Dusseldorf, Germany).

Image 15. Vickers microhardness (VMH) measurements using the microhardness tester.

LIST OF SYMBOLS AND ABBREVIATIONS

A⁺³ : Aluminum

ADA : American Dental Association

Al₂O₃ : Aluminum Oxide

ART : Atraumatic Restorative Treatment

ASPA : Aluminosilicate Polyacrylic Acid

Bis-GMA : Bisphenol-A Glycidyl Methacrylate

°C : Celsius Degree

Ca⁺² : Calcium

CaF₂ : Calcium Fluoride

CGIC : Conventional Glass Ionomer Cement

d : Specimen Diameter

F : Force

FDA : The American Food and Drug Administration

F-PRG : Fully pre-reacted glass

GIC : Glass Ionomer Cement

HEMA : 2-Hydroxyethyl methacrylate

ISO : International Standards Organization

ITR : Interim Therapeutic Restoration

K⁺ : Potassium

La⁺³ : Lanthanum

LED : Laser Emission Diode

MPa : Megapascal

MMA : Methyl methacrylate

mm : Millimeter

mm/s : Millimeters Per Second

Na₂O : Sodium Oxide

Na⁺ : Sodium

P₂O₅ : Phosphorus Pentoxide

pH : Power of Hydrogen

PRG : Pre-reacted Glass

Ra : Arithmetic Roughness

RMGIC : Resin-Modified Glass Ionomer Cement

Sr⁺² : Strontium

SiO₂ : Silicon Dioxide

S-PRG : Surface pre-reacted glass

SPSS. : Statistical Package for the Social Sciences

TEGDMA : Triethylene Glycol Dimethacrylate

UDMA : Urethane Dimethacrylate

VMH : Vickers Microhardness

VHN : Vickers Hardness Number

Zn⁺² : Zinc

% : Percent

μm : Micrometer

ABSTRACT

Yıldırım Y. 2023. The Effect of Surface Coating and Artificial Aging on the Surface Roughness and Microhardness of Glass Ionomer-Based Restorative Materials *In-Vitro*. Yeditepe University Institute of Health Sciences, Ph.D. Thesis, Istanbul.

Glass Ionomer Cements (GIC), due to their chemical bonding to dental tissues with minimal preparation and their fluoride-releasing properties, have become popular in pediatric dentistry. Until the secondary hardening of restorations made using GIC is completed, surface coatings are applied to the restoration surface to reduce its negative physical properties. When applied to glass ionomer restorations, surface coatings improve the properties of materials, such as surface roughness and microhardness. A bioactive restorative material ACTIVA™ kids BioACTIVE-RESTORATIVE™ (PULPDENT®, Watertown, USA), high-viscosity glass ionomer cement materials EQUIA® Forte Fil (GC Corporation, Tokyo, Japan) and ChemFil® Rock (Dentsply Sirona, Konstanz, Germany) were used within the scope of the study. EQUIA Forte™ Coat (GC Corporation, Tokyo, Japan) was used as a surface coating agent. Thirty-four samples were prepared from each material group, and Equia Forte Coat was applied to half of them. Plexiglass molds (10±0.1 mm in diameter and 2±0.1 mm in depth) were used for surface roughness and microhardness tests. Before and after the thermal cycling procedure, surface roughness and microhardness measurements were performed for all samples. Statistical Package for the Social Sciences (SPSS) 24.0 program was used for statistical analysis. Significance was evaluated at $p<0.01$ and $p<0.05$ levels. In the intragroup comparison where the effect of the surface coating application was evaluated, the surface roughness values of all tested materials showed a statistically significant decrease ($p<0.05$). Surface roughness values in all other tested materials showed a statistically significant decrease after artificial aging ($p<0.05$). In the intragroup comparison where the effect of the surface coating application was evaluated, the surface hardness value of all tested materials showed a statistically significant decrease ($p<0.05$). The microhardness value of all other tested materials showed a statistically significant decrease after artificial aging ($p<0.05$).

Keywords: Surface roughness, surface microhardness, thermal aging, glass ionomer cement, artificial aging, *in vitro*, surface coating.

ÖZET

Yıldırım Y. 2023. Yüzey Örtücü Uygulamasının ve Yapay Yaşlandırmanın Cam İyonomer Esash Restoratif Materyallerin Yüzey Pürüzlülüğü ve Mikrosertliğine Etkilerinin *In Vitro* Değerlendirilmesi. Yeditepe Üniversitesi Sağlık Bilimleri Enstitüsü, Doktora Tezi, İstanbul.

Cam İyonomer Simanlar (CIS); minimal preparasyonla diş dokularına kimyasal bağlanmaları ve florid salma özellikleri nedeniyle özellikle çocuk diş hekimliğinde yaygın şekilde kullanılmaktadır. Cam iyonomer siman restorasyonların sekonder sertleşmesi tamamlanana kadar olumsuz fiziksel özelliklerini azaltmak için yüzey örtücü ajanlarının kullanılması giderek yaygınlaşmaktadır. Yüzey örtücü ajanlar, cam iyonomer restorasyonlara uygulandığında restorasyonun yüzey pürüzlülüğü ve mikrosertlik gibi fiziksel özelliklerini iyileştirir. Çalışmamızda biyoaktif bir restoratif materyal olan ACTIVA™ kids BioACTIVE-RESTORATIVE™ (PULPDENT®, Watertown, USA), yüksek viskoziteli cam iyonomer siman materyalleri; EQUIA® Forte Fil (GC Corporation, Tokyo, Japonya) ve ChemFil® Rock (Dentsply Sirona, Konstanz, Almanya) kullanılmıştır. Yüzey örtücü ajan olarak EQUIA Forte™ Coat (GC Corporation, Tokyo, Japonya) kullanılmıştır. Mikrosertlik ve yüzey pürüzlülük testleri için pleksi cam kalıplar (10±0.1 mm çapında ve 2±0.1 mm derinliğinde) kullanılmıştır. Termal döngü işleminden önce ve sonra örneklerin yüzey pürüzlülüğü ve mikrosertlik ölçümleri yapılmıştır. İstatistiksel analizler için SPSS (Statistical Package for the Social Sciences) 24.0 programı kullanılmıştır. Anlamlılık $p<0,01$ ve $p<0,05$ seviyelerinde değerlendirilmiştir. Yüzey örtücü uygulamasının etkisinin değerlendirildiği grup içi karşılaştırmada, test edilen tüm malzemelerin yüzey pürüzlülük değeri istatistiksel olarak anlamlı düşüş göstermiştir ($p<0,05$). Test edilen diğer tüm materyallerde yüzey pürüzlülük değerleri yapay yaşlandırma sonrası istatistiksel olarak anlamlı düşüş göstermiştir ($p<0,05$). Yüzey örtücü uygulamasının etkisinin değerlendirildiği grup içi karşılaştırmada, test edilen tüm malzemelerin yüzey sertlik değeri istatistiksel olarak anlamlı düşüş göstermiştir ($p<0,05$). Test edilen diğer tüm materyallerim mikrosertlik değeri yapay yaşlandırma sonrası istatistiksel olarak anlamlı düşüş göstermiştir ($p<0,05$).

Anahtar Kelimeler: Yüzey pürüzlülüğü, yüzey mikrosertliği, termosiklus, cam iyonomer siman, yapay yaşlandırma, *in vitro*, yüzey örtücü.

1. INTRODUCTION AND PURPOSE

Restoration of decayed primary and permanent teeth is one of the most essential treatment needs in pediatric dentistry. Materials and treatment methods used in dentistry are changing, and new materials and treatment alternatives are emerging today. In pediatric dentistry, the search for the ideal material for restoration continues. Supporting the remaining tooth tissue and restoring the lost form and strength of the tooth are the main features that an ideal restorative material should have.

Glass ionomer cements (GIC) are frequently preferred as restorative materials due to their chemical bonding properties to enamel and dentin tissues. In addition to these properties, other advantages of GIC can be listed as their ability to release fluoride, be biocompatible, have a similar coefficient of thermal expansion to the tooth structure, and have the potential to heal the pulp in teeth with caries progression below the enamel-cementum boundary (1). However, they also have disadvantages such as sensitivity to moisture in the early period, low resistance to chewing forces and low abrasion resistance, not being translucent and aesthetic, and short working times (2). To reduce the negative properties of GICs and increase their success in clinical use, the components in their structures have been changed, and different types of GICs, such as compomer and resin-modified glass ionomer cements, have been produced (3).

Until the secondary hardening of restorations made using GIC is completed, surface coatings are applied to the restoration surface. Their use is tried to be expanded to eliminate the contact of the restoration with moisture, reduce its negative physical properties and protect the material. It has been reported that surface coatings improve the properties of materials, including surface roughness and surface microhardness when applied to glass ionomer restorations (4).

This study aims to evaluate the effect of surface coating and artificial aging on the surface roughness and microhardness of three different glass ionomer-based materials. A bioactive restorative material ACTIVA™ kids BioACTIVE-RESTORATIVE™ (PULPDENT®, Watertown, USA), and high-viscosity glass ionomer cement materials; EQUIA® Forte Fil (GC Corporation, Tokyo, Japan) and ChemFil® Rock (Dentsply Sirona, Konstanz, Germany) were used as glass ionomer-based materials. There are few

studies about this subject in the literature. The tested null hypothesis was that there is no difference within both the surface roughness and microhardness values of three different glass ionomer-based restorative materials regardless of surface coating and artificial aging. H₁ hypothesis was that coating application improved the roughness and hardness of all tested materials.

2. GENERAL INFORMATION (LITERATURE REVIEW)

2.1. Glass Ionomer Cements

GICs were first introduced by Wilson and Kent in 1971 under the name of aluminosilicate polyacrylic acid (ASPA). GICs contain silicate and zinc polycarboxylate in their structures. GICs are made with a combination of silicate cement, which is capable of releasing fluoride, and polyacrylic acid, which is capable of binding to hydroxyapatite in enamel and dentin (5).

2.1.1 History of Glass Ionomer Cements

GIC was first developed due to the acid-base reaction between fluoro-aluminosilicate glass and polyacrylic acid in the aqueous medium. This cement was named ASPA. GIC powder called "G 200" consists of fluoro-aluminosilicate particles and liquid aqueous polyacrylic acid. In addition, the powder contains high levels of calcium and fluoride and low amounts of sodium and phosphate. Different versions of homo and copolymers of alkenoic acids in the acid part have been used to produce different types of ASPA (6).

In 1971, ASPA I was not suitable for widespread use in clinical use due to its long curing time, difficulties experienced during operation, and disadvantages such as opacity in its color. On the other hand, ASPA II was obtained by Wilson and Crisp by adding some tartaric acid to this content, and it was reported that it contains polyacid. ASPA II contains polyacid, and it has been observed that the bonds formed between hydrogen molecules after a specific time cause the liquid to turn into a gel. It has been reported that the hydrogel structure formed because of this gelation reaction has a negative effect on the aesthetic and mechanical properties of the material. To prevent this, ASPA III was

developed by adding methyl alcohol to the solution in 1974 by Wilson and Crisp. ASPA IV was created by adding itaconic acid to the liquid of ASPA III. Due to its fine granule structure, it was suggested to be used as a cementation agent. ASPA V is formed by adding dried acid to glass powder, which has been reported to increase its durability and shorten the setting time of the material (7).

The properties of ASPA result from the combination of the properties of dental silicate cements and polycarboxylate cements. A similar feature with polycarboxylate cement is adhesion, and the transparency feature of GICs creates a significant advantage regarding aesthetics. Dental silicate cements and GIC have many common features despite their different chemical structures. Their durability is similar; however, GICs show a higher resistance to acid attacks but have a more negligible effect on the pulp (7).

2.1.2 Classification of Glass Ionomer Cements by Areas of Use

According to their usage areas, GICs are divided into four types. The chemical structures of the classes are the same, but due to various changes in powder/liquid ratios, and particle sizes, they can gain the necessary function.

Type I: GIC used as luting cements

Type II: GIC used as restorative materials

- a) Aesthetic restorative cements
- b) Reinforced restorative cements

Type III: GIC used as a fast-setting base material and fissure sealant

Type IV: GIC used as root canal sealant (8).

2.1.3. Classification of Glass Ionomer Cements by Content

According to the contents of GIC:

- Conventional Glass Ionomer Cements
- Glass Ionomer Cermet Cements
- Resin-Modified Glass Ionomer Cements
- High-Viscosity Glass Ionomer

- Polyacid-Modified Resins (Compomers)
- Giomers
- Glass Carbomers (9).

Areas of use of GICs in pediatric dentistry are; Class I, II, III, IV, and V primary tooth restorations, fissure sealants, Class III and V permanent tooth restorations, bonding of brackets and bands used in orthodontics, atraumatic restorative treatment (ART), and interim therapeutic restorations (ITR) (10).

2.1.3.1. Conventional Glass Ionomer Cements

The powder part of conventional glass ionomer cements (CGIC) consists of fluoro-aluminosilicate particles; the liquid part consists of polyacrylic acid and contains calcium, fluoride, phosphate, and sodium in the powder part (3). GICs harden by the acid-base reaction. The acid-forming liquid part (pH:1) dissolves the silicate glass particles and releases calcium, ammonium, fluoride, and strontium ions. It has been stated that the ionized carboxyl groups of acids are bonded to calcium ions by deflation. As a result of this reaction, hydrogen salt, which plays the role of the binding matrix, is formed. The main structure remains intact while the surface part of the glass particles reacts. The hydraulic stabilization of the cross-ionic bonding network is formed after hardening. Hydrogen continues to exist even after the hardening reaction, providing ion exchange and creating strong cross-links by replacing calcium ions with aluminum ions in 24-72 hours, thus gaining a more durable structure (3,11).

Hydrate silicate incorporates silicon ions and unbound water into inorganic matrix formation during maturation involving cross-linking of aluminum ions. As a result of the problems in clinical applications at this stage, both water absorption and water loss can occur with the contamination and dehydration of the cement with water; therefore, it is crucial to maintain the water balance in the first 24 hours (12).

Powder Structure of Conventional Glass Ionomer Cements

The glass powder is formed by the preparation of molten aluminum oxide (Al_2O_3), silicon dioxide (SiO_2), aluminum phosphate, and aluminum fluoride at a temperature of 1100°C - 1300°C . It has been stated that calcium fluoride (CaF_2) is included in the structure

to act as a fluoride reservoir. In addition, sodium oxide (Na_2O) and phosphorus pentoxide (P_2O_5) in the powder structure, aluminum (Al^{+3}), and calcium (Ca^{+2}) as metal ions. Potassium (K^+), lanthanum (La^{+3}), zinc (Zn^{+2}), and strontium (Sr^{+2}) are present (13).

Al_2O_3 and SiO_2 form the skeletal structure of the glass, while lanthanum oxide and strontium oxide provide radiopacity. (14). It has been stated that phosphate and fluoride are added to the glass composition, which lowers the melting temperature and modifies the hardening properties. Barium sulfate, titanium oxide, strontium oxide, and zinc oxide can be added to the glass powder, provided that they are not in the glass composition.

Liquid Structure of Conventional Glass Ionomer Cements

It has been reported that the polyacid in the glass ionomer cement is a polycarboxylic acid and reacts with fluoro-aluminosilicate glass. The elements added to the glass ionomer cement are polyacrylic acid, poly maleic acid, acrylic acid-itaconic acid copolymer, acrylic acid-maleic acid copolymer, acrylic acid, acrylic acid-maleic acid-2butene dicarboxylic acid copolymer, and polyvinyl phosphoric acid. It has been reported that the molecular weight, concentration, and content of the copolymer are the factors that affect the reactivity of the polyacid, and an increased viscosity problem will occur because of increasing the molecular weight or concentration. To prevent this, water as liquid or diluted tartaric acid is added to the powder using the dehydrated form of polyacrylic acid (14).

Setting Reaction of Conventional Glass Ionomer Cements

The hardening of GIC occurs by an acid-base reaction due to mixing powder and liquid in the presence of water. The reactions of GICs are,

1. Contact of powder and liquid
2. Acid attack on glass particles
3. Chelation of matrix
4. Hardening, respectively (15).

An acid-base reaction occurs between the aqueous solution of polyalkenoic acid and soluble alumina silicate glass. The acid dissolves the alumina-silicate glass structure

and releases calcium, sodium, and aluminum cations (Ca^{+2} , Na^{+} , A^{+3}). Later, these cations were chelated by carboxylate groups and cross-linked to the polyalkenoic acid chain (16,17).

The hardening phase of glass ionomer cements occurs in two stages (18). It has been reported that the first stage is the first 10-minute clinical hardening process after mixing the GIC. The second stage is the slow and long-lasting stage that starts with releasing Ca^{+2} , Sr^{+2} , and A^{+3} ions due to the hydrogen ions of the acid sticking to the glass particles in the presence of water. GIC polymerization was completed after 24 hours. If the cement surface comes into contact with water before the cement setting reaction is completed, the Ca^{+2} and A^{+3} ions move away from the surface and prevent the cement from hardening, which causes the cement to lose its translucent property and weaken the surface and become easily eroded. It takes one week for GICs to reach optimal physical properties, so finishing processes should be completed at least one week later (14,19).

Adhesion of Conventional Glass Ionomer Cements to Dental Structures

Glass ionomer restoration materials bind to dental tissues physically and chemically. It has been reported that physical bonding occurs due to the micro-mechanical adhesion of the material to the tooth surface irregularities. An ion exchange begins immediately between the GIC and dentin with the removal of the smear layer from the surface. The silica particles in the GIC are small enough to enter the dentinal tubules. The possible mechanism of adhesion can be explained by both diffusion and absorption.

While polyalkenoic acid penetrates the tooth structure, phosphorus ions are released, and they cause electrical neutrality by releasing calcium ions from the tooth surface (20,21). This phenomenon is defined as "diffusion-induced adhesion". It was stated that this adhesion is formed by the replacement of polyacrylic ions in the GIC with phosphate ions of hydroxyapatite and the formation of hydrogen bonds between the amino and carboxylic groups of the glass ionomer. Meanwhile, metallic ions emerging from hydroxyapatite and glass ionomer have been reported to contribute to adhesion by deflating free carboxyl groups on the surface (22).

Advantages of Conventional Glass Ionomer Cements

- Chemically binding to calcified tissues such as enamel and dentin by forming cross-links with calcium and metal ions,
- They can release fluoride, be able to be reloaded with fluoride, and, accordingly, show anti-cariogenic properties,
- Being biocompatible,
- They have similar thermal expansion coefficients to dental tissues.
- Thermal compatibility to enamel and dentin,
- Low cytotoxicity due to their low monomer content,
- Easy to apply,
- Low solubility in oral fluids after hardening,
- Being more successful compared to resin-based materials regarding secondary caries formation (2,23).

Disadvantages of Conventional Glass Ionomer Cements

- Short working times and long hardening times,
- Moisture contamination during application and hardening.
- High susceptibility to dehydration,
- Abrasion resistance, compressive strength, elasticity coefficient, and breaking point to be low,
- Requires high technical precision,
- Due to their low color stability, they are not aesthetic as composite resin restorations (23,24).

Mechanical Properties of Conventional Glass Ionomer Cements

Both tooth and restorative materials are exposed to tensile and compression forces during chewing. Therefore, it is necessary to know the mechanical properties of restorative materials well to evaluate clinical success. The modulus of elasticity of glass ionomer cements varies between 1-10 MPa, depending on the test conditions applied. It is stated that the excessive moisture contamination that GICs are exposed to, especially

during the initial curing, causes a decrease in the cement's modulus of elasticity and fracture resistance (18).

After the restorations with GICs are completed, the water absorption of the restoration is 5% in the first six months. The high water absorption indicates that the expansion of GICs is higher than that of composite resins (25).

Occlusal wear of GICs is three times greater than that of composite resin and five times that of amalgam. Due to mechanical fatigue, restorative materials with low surface wear resistance may exhibit negative effects such as particle breakage, crack propagation, and cavity formation. The compressive strength of glass ionomer restorations is lower than composite resins (2).

2.1.3.2. Resin-Modified Glass Ionomer Cements

Resin-modified glass ionomer cements (RMGIC) were introduced to the market in 1991 to increase the mechanical properties of CGIC. In the structure of RMGIC, in addition to glass powder, water, and polyacid in CGIC, there is a resin monomer and related initiator system.

It is known that the content of RMGIC consists of 80% glass ionomer cement and 20% resin. It has been stated that hydroxyethyl methacrylate (HEMA), methacrylate groups, tartaric acid, polyacrylic acid, and water form the liquid part, whereas fluoro-aluminosilicate particles form the powder part (26,27).

Setting Reaction of Resin-Modified Glass Ionomer Cements

The hardening mechanism of RMGIC takes place in three different stages. These stages are neutralization (acid-base reaction), light polymerization, and chemical activation. An acid-base reaction has been reported to start when powder and liquid are mixed, and HEMA polymerization occurs if chemical initiators are present. In light curing, it has been reported that only HEMA polymerization occurs with blue light activation. In both cases, it has been stated that the initiation is with HEMA polymerization, and a matrix is formed, which is strengthened by a slower acid-base

reaction (28,29). RMGICs are classified as RMGICs that perform a dual-cure reaction when light-cure is used alone and a triple-cure reaction when both chemical and light-polymerization are used (30).

Adhesion of Resin-Modified Glass Ionomer Cements

RMGICs bind to dental tissues both micro-mechanically and chemically. It has been reported that the wettability of HEMA contained in RMGIC and the increased penetration of the material into the tooth supports the formation of chemical bonding by the acid-base reaction. The micro-mechanical bonding of RMGIC is due to the demineralization of the dentin tissue by the polyacrylic acid contained in the material. The adhesion of RMGIC to the tooth surface is better than CGIC (31).

Mechanical Properties of Resin-Modified Glass Ionomer Cements

The resin content of RMGICs increases their resistance to contamination and mechanical strength. The compressive strength of these cements is lower than hybrid composites and higher than conventional glass ionomers (30). Fluoride, sodium, aluminum, phosphate, and calcium releases of RMGICs are similar to CGICs (27).

Advantages and Disadvantages of Resin-Modified Glass Ionomer Cements

Since the filler particles in the structure of RMGICs are smaller, it has been stated that RMGIC is more aesthetic than CGIC. Longer working times, easy manipulation, low intraoral solubility, and more color options are among the other advantages of RMGIC. The biocompatibility of RMGICs is less than that of CGICs, due to the HEMA monomers in the material. The amount of HEMA released from the material depends on the light-curing time, and it has been reported that it can have a cytotoxic effect on the pulp (32). In addition, microleakage resulting from polymerization shrinkage during curing and postoperative sensitivity and discoloration are shown among the negative features of RMGIC (33).

2.1.3.3. High-Viscosity Glass Ionomer Cements

The use of high-viscosity glass ionomer cements increased with the spread of ART in the 1990s. Particle sizes and distributions were changed to reduce moisture sensitivity and increase abrasion resistance. GICs were strengthened by adding polyacrylic acid to the high-viscosity powder, and high-viscosity glass GICs were introduced to the market. While the powder: liquid ratio is 3:1 or 4:1 in GCIS, it is stated that this ratio is 6:1 or 7:1 in high-viscosity GICs. It has been reported that the curing mechanisms of high-viscosity GICs occur with an acid-base reaction, as in CGIC. It has been reported that fluoride release of high-viscosity glass ionomer cements is similar to CGICs, but their abrasion, wear, and tensile strengths are higher than GCISs (34,35). It has been stated that since high-viscosity GICs complete their hardening reaction quickly, their physical properties are not adversely affected in contact with water in the early period. However, it is known that the application of high-viscosity GIC together with surface protective resins is recommended by the manufacturers (36).

It has been reported that the reason for the higher viscosity of these materials is the change in the particle distribution and size in the powder fractions and the addition of polyacrylic acid to its content. High-viscosity GICs, whose condensation in the cavity is likened to amalgam due to their high viscosity, were developed as an alternative to amalgam restorations in the teeth in the posterior region. The aesthetics obtained in restorations made with these materials are acceptable (24).

ACTIVA™ kids BioACTIVE-RESTORATIVE™ (PULPDENT®, Watertown, USA) was introduced to dentistry practice in 2013 as a material that combines the advantages of RMGIC and composite resins. ACTIVA™ kids BioACTIVE-RESTORATIVE™ has abrasion and fracture resistance close to composite resins and can be used as an alternative to composite resins in anterior and posterior teeth due to its advantages, such as fluoride release and low polymerization shrinkage (37).

The manufacturer has reported ACTIVA™ kids BioACTIVE-RESTORATIVE™ as the first bioactive-based material with a shock-absorbing resin component that mimics the chemical and physical properties of teeth. This new material contains the acid-base reacting glass particles and the polyacid component that all GICs have. They have a

formula that is a 'bioactive ionic resin matrix' with light and chemical polymerization capability. This product has three light-curing mechanisms and cures per layer with low-intensity light for 20 seconds. It has an acid-base reaction (glass ionomer reaction) and composite self-cure setting reactions. The self-cure setting time is 3 minutes. It is also advisable to allow the material to self-cure for 15–20 s before light curing (38). ACTIVA™ kids BioACTIVE-RESTORATIVE™ can be used as a restorative material, base/lining material, and luting cement (37). The bioactive properties of ACTIVA™ kids BioACTIVE-RESTORATIVE™ are based on a mechanism whereby the material responds to pH cycles and plays a role in calcium, phosphate, and fluoride-releasing and recharging.

2.1.3.4. Polyacid-Modified Composite Resins (Compomers)

Polyacid-modified composite resins (Compomers) were first introduced in 1994 by the Dentsply company under the name Dyract. It is known that because they contain both the aesthetic properties of composites and the fluoride release feature of GIC, they are briefly named "Compomer" by the manufacturers to include the names of both materials. It has been reported that 30% of its structure consists of glass ionomers and 70% composite resin (10,39).

The chemical content of compomers contains strontium fluorosilicate glass particles, which can exchange ions (ion-leachable) as in composites. Since salt matrix and hydrogen are not formed in compomers, fluoride ions cannot be recharged, and therefore fluoride ion releases are reported to be limited. The mechanical and physical properties of compomers are between composite resins and glass ionomer cements and closer to composites and contain small-diameter fillers such as composite resins (40,41). Although compomers are resin-based materials, it has been reported that they do not contain water (42). After the light polymerization, an acid-base reaction occurs between the saliva (water) absorbed by the material from the oral environment and the acidic monomer and basic glass particles. The absorbed saliva also initiates the release of fluoride.

Definition confusion arises in the classification of compomers due to their structure and properties. It is known that names such as "Hybrid glass ionomers," "Light-cured GIC," and "Resin-modified GIC" were used at the beginning (10). Since

compomers cannot bind to dental hard tissues alone, a special primer-adhesive system has been developed to ensure the adhesion of the material to the tissues. In addition, since the material contains resin monomers, it has been reported that its hardening occurs with light activation (42).

Advantages and Disadvantages of Polyacid-Modified Composite Resins

The mechanical, physical, and aesthetic properties of polyacid-modified composite resins are more substantial than conventional and RMGICs. It has been stated that it provides the advantage of not requiring acid during application and is biocompatible with dental tissues.

Fluoride release of compomers is lower than GICs (43). Being able to release fluoride, setting with light, and being easy to apply to the cavity are shown among the favorable properties of compomers (11). The disadvantages of compomers have been stated as the inability of the curing reaction to occur in areas where light cannot reach, polymerization shrinkage, lower physical properties than composites, and lower fluoride release compared to CGIC and RMGIC (44). Compomers are recommended for use in Black Class V restorations of permanent teeth and Black Class I and II restorations of primary teeth (11).

2.1.3.5. Gionomers

It is known that a search for new materials has been started due to the wear of CGIC and RMGIC materials over time. Accordingly, the physical restoration wear of the surface leads to an increase in bacterial colonization. Gionomer has been launched as a new "fluoride-releasing resin-based restorative material" (45).

Unlike other fluoride-releasing materials, gionomers have been reported to contain pre-reacted glass (PRG) fillers. It has been stated that PRG fillers are produced by hydrogen formed due to an acid-base reaction between fluoride-containing glass and polyacrylic acid. After freeze-drying, the dehumidified gel is ground and silanized to create PRG fillers. It has been stated that PRG fillers allow the material to release long-term fluoride and recharge with fluoride (46).

PRG particles are divided into:

1. Fully pre-reacted glass (F-PRG)
2. Surface pre-reacted glass (S-PRG) (46).

The resin part of the giomers is the same as the conventional composite component. The monomers bisphenol A glycidyl methacrylate (Bis-GMA) and triethylene glycol dimethacrylate (TEGDMA) bind to PRG fillers and form a stable distribution (46). The most apparent advantages of giomers are that they can release fluoride, be recharged with fluoride, resist abrasion, have good long-term clinical stability, cause minimal pulp damage, and neutralize the acid. There are many F-PRG and S-PRG particles (46,47).

2.1.3.6. Glass Carbomers

Glass carbomers have been introduced as a new generation of restorative material which contains nano-sized glass particles and fluorapatite crystals as a secondary filler. Crystals provide tooth remineralization and formation of fluorapatite (48). The liquid part of the glass carbomers consists of polyacrylic acid. Since it contains nanoparticles in its structure, the material's physical properties, such as compressive strength and abrasion resistance, are high (49). Glass carbomer also contains resin, monomer, metal, and bisphenol-A. When applying glass carbomers, it is recommended to use the manufacturer's surface sealant. It has been stated that the purpose of the silicone-based surface sealant is to protect the surface from moisture in the first stage of curing and prevent dehydration and microcrack formation. Application of heat is recommended during the curing process of glass carbomers. It is recommended to perform this application with a laser emission diode (LED) device (1400mw/cm² wavelength and 60°C) for 60-90 seconds on each surface of the restoration and in a way that creates a right angle to the restoration. Heat application shortens the setting time, thus increasing the adhesion of the material to the dental tissues and its physical properties. Glass carbomers are recommended for use in Class I, II, and V restorations of posterior teeth as a core material and fissure sealant and crown/bridge cementation (50).

2.2. Surface Coating Agents

GICs have a long setting time (24 hours). The material is sensitive to moisture and dehydration in this process. If dehydration occurs during the hardening reaction, size change, loss of resistance, adhesion problems, and cracks may occur in GICs. As a result of the early contact of the material with water, the loss of calcium and aluminum ions, surface erosion, and a decrease in translucency can be observed (51). Some surface coatings are recommended to avoid these problems and protect GIC restorations. Another advantage of surface coatings is preserving the restoration's original color by filling small gaps and defects on the surface and preventing discoloration (7).

Softeners (cocoa butter, petroleum jelly), varnishes (nitrocellulose-based), resins (methyl methacrylate and amide resins, light-cured bonding agents), and nail polish are shown as alternatives to surface sealants (52). Vaseline, cocoa butter, liquid-proof surface sealers, and nail polishes have been used as surface coating agents in the past. As a result of wear due to chewing, these surface sealants were moving away from the restoration surface in a short time. However, during this time, the cements became more resistant to changes as they reached the fluid balance after setting. With the developments in surface coating systems, light-cured surface coatings have emerged as the optimal surface protection agents. Light-cured surface coatings restricted water contact with the restoration surface during curing (52). Resin-containing surface coating agents that reduce water absorption also slow down the rate of polymerization shrinkage. In addition, the American Dental Association (ADA) declared the importance of light-cured surface coatings for GIC in 1990 (53).

2.2.1. Petroleum Jelly (Vaseline)

Petroleum jelly has been reported to be used in many areas of pharmacology due to its viscoelastic structure. It has been reported that the chemical structure of petroleum, which is obtained by distilling crude oil and passing it through a coal filter, consists of 2 different solid hydrocarbon waxes (paraffin wax and microcrystalline wax) and a liquid hydrocarbon part. Different ratios of these hydrocarbons determine the characteristic features of petroleum jelly. Petroleum jelly is recommended as a surface protector for

GICs because of its advantages, such as ease of application, patient safety, more effectiveness than copal varnish and adhesive systems, and low cost (54,55).

2.2.2. Cocoa Butter

The American Food and Drug Administration (FDA) defined cocoa butter as the oil obtained from *Theobroma cacao* or its close species before or after the roasting process. It has been reported that the chemical structure of cocoa butter contains 98% glyceride, 1% free fatty acids, 0.3-0.5% diglyceride, 0.1% monoglyceride, 0.2% sterol, and 150-200 ppm tocopherol. While cocoa butter is solid at room temperature, it takes a slippery and fluid form in the mouth (55).

2.2.3. Light-Cured Surface Coating Agents

The manufacturers recommend using light-cured surface coatings to ensure the edge harmony of glass ionomer restorations, prevent discoloration and facilitate polishing processes. Surface coatings also resist intraoral forces in GIC in the first months when their maturation is not completed. There are adhesive monomers and nanofiller particles in the structure of light-cured surface coatings (56).

Light-cured surface coatings provide excellent coverage on the glass ionomer cement surface with their high hydrophilic properties and low viscosities. Shear and compressive strength of high-viscosity glass ionomer cements with light-cured surface coatings were reported to increase after four to eight weeks (57). Light-cured surface coatings have a positive effect on edge sealing (58). Light-cured surface sealants may or may not be used depending on the chewing force, occlusion, chewing habits, and diet of the person to whom the restoration is applied. It was observed that the chipping remained on the restoration surface for six months (57). At the end of six months, the maturation of the high-viscosity glass ionomer cement has been completed, so there is no need to repeat the surface coating application. In addition, light-cured surface coatings, when used in combination with GIC, give better clinical results (58). Sample products and manufacturers of light-cured surface coatings used in dental applications are shown in Table 1.

Table 1. Light-cured surface coating agents used in dental applications.

Light-Cured Surface Coatings	Manufacturer
EQUIA Forte Coat	GC, Tokyo, Japan
Riva Coat	SDI Bayswater, VIC, Australia
Easy Glaze	VOCO, Cuxhaven Germany
Ketac Glaze	3M ESPE, St Paul, MN, United States
Perfect Gloss	UMSDENTAL, Cairo, Egypt

2.3. Artificial Aging Methods

It is not always possible to conduct experiments on the materials used in dentistry in the oral environment. However, in laboratory conditions to predict the prognosis of the materials in the mouth, aging techniques mimic the oral environment, such as thermal cycling, occlusal loading, pH cycling, and water resorption. In bonding tests, the pre-experimental storage conditions of the teeth are as important as the procedures performed after the experimental materials are applied and before the rupture test.

Dental materials are exposed to many factors in the mouth. They are exposed to chemical, mechanical, and thermal factors for life. Due to these factors, their mechanical properties weaken over time. Structural changes and the weakening of mechanical properties due to thermal, physical, and chemical effects are called aging. By examining the aging resistance of restorative materials with *in vitro* studies, the necessary factors for high long-term success can be determined. For this purpose, artificial aging processes are applied to restorative materials. Artificial aging processes can be done using thermal, chemical, and physical factors.

The chemical structure deteriorates due to the water absorption with the thermal cycle aging method. In addition, thermal contraction and expansion happen within the material due to temperature changes. For this reason, it is thought that crack formation increases and mechanical properties weaken in restorative materials (59).

2.3.1. Aging by Thermal Cycling Test

The average intraoral temperature is $35.2 \pm 2.1^{\circ}\text{C}$ without any thermal effect and mouth breathing. Oral temperature is constantly changing due to eating, drinking, and breathing in the oral environment. The thermal cycling test applies heat exchange to the test materials to mimic the oral environment *in vitro*. It is designed to adapt the oral environment to *in vitro* conditions. The aging method with thermal cycling test; is frequently used in microleakage, shear bond strength, and tension bond strength tests.

According to the International Standards Organization of 2003 (ISO TR 11405-2003), in a study that will measure the bonding value of adhesives used in dentistry, it has been determined that 500 thermal cycles in water where the upper and lower temperature values are between 5 and 55°C are appropriate for artificial aging when applying the thermal cycle test. In thermal cycle test applications, residence time (immersion time), the number of cycles, and waiting time vary. There is no clear information in the literature regarding the number of cycles per unit of time required to simulate *in vivo* conditions. If the daily intraoral temperature change is 20-50 times, 10,000 cycles correspond to approximately one year of aging (60).

The mechanism of action of this test occurs in two ways; the first is by accelerating the hydrolysis (water uptake) of the interface components of hot water, the formation of degradation products or incompletely polymerized resin oligomers, and the other is the coefficient of thermal contraction and expansion. As a result of the difference between tooth and material, it is aimed to age by creating repetitive shrinkage and expansion stresses. In evaluating restorative materials, clinical studies are the most accepted studies. However, since clinical and long-term studies are complex, laboratory tests with easier standardization are preferred (61).

2.3.2. Aging by Water Resorption

The most commonly used artificial aging technique is leaving the samples in water for a long time. The samples are kept in water at 37°C for a certain period. This period may be several months, 4-5 years, or more extended. Most studies have shown a reduction in bond strength even after a short waiting period (62).

After leaving the in water for one year, water tree formation is observed in the adhesive layer. Interfacial aging occurs with water uptake and porous areas increase in the hybrid layer (63). The decrease in bond strength is due to the degradation of resin or collagen by hydrolysis. In addition, water infiltrates the polymerized matrix, causing a decrease in its mechanical properties. Residual monomers also weaken the linkage (64).

Artificial saliva solutions can also approximate the clinical situation to *in vivo* conditions. The decrease in bonding values obtained from samples stored in artificial saliva was similar to degradation in samples stored in pure water for the same material (65).

2.3.2 Aging by Occlusal Loading

Teeth are under constant load and stress in the oral environment. These stresses are chewing forces, parafunctional habits, bruxism, and forces during swallowing, threatening the long-term durability of restorations (66). To simulate the *in vivo* environment with *in vitro* conditions with occlusal loading, it is aimed to measure the bonding efficiency by applying occlusal forces to the restorations. For this purpose, the bonding efficiency is calculated after the samples are aged in chewing simulators.

Studies have reported that mechanical loading can be performed in 1000 to 100,000 cycles. However, it has been reported that up to 100,000 cycles, this application does not affect bond strength values when done alone. For this reason, the mechanical cycle is usually applied together with the thermocycling process (67,68).

2.4. Evaluation of Surface Roughness

Irregularities on the surface of materials are defined as “surface roughness”. Recesses and protrusions in molecular dimensions are responsible for this rough structure on the surface (69). Inadequate finishing and polishing processes are directly related to surface roughness and essential to plaque accumulation. Surface roughness measurement can be determined with the help of a “mechanical profilometer”, in which the sensor scanning the surface is in contact with the surface during the scanning, and an “optical

profilometer,” where the sensor scanning the surface is not in contact with the surface during scanning. Mechanical profilometers work on the two-dimensional surface profile measurement principle by passing a diamond-sharp tip with a radius of 5 μm over the indentations and protrusions on the sample surface (70). In optical profilometers, by scanning the sample surface with optical rays, the surface topography can be transferred three-dimensionally to determine the surface morphology. Although the "Ra" parameter is the most commonly used in the profilometric evaluation of surfaces, it is defined as the average roughness value (69,70).

Cilli et al. (2009) stated that surface roughness, an important physical property of restorative materials, directly affects the surface properties of materials such as gloss, color, and surface hardness (71). *Ersöz et al. (2012)* have reported that the mean surface roughness threshold value in plaque accumulation is approximately 0.2 μm (72). *Gürdoğan et al. (2017)* have stated that surface roughness values (Ra) above 0.2 μm cause an increase in plaque accumulation, periodontal inflammation, and a higher risk for caries (73).

2.5. Evaluation of Surface Microhardness

Surface hardness tests are defined as the resistance of materials to plastic deformation and are one of the most widely used surface characterization and analysis methods. Surface hardness is related to the other mechanical properties of the material. Surface hardness evaluation is based on measuring the resistance that occurs in the material by immersing a standardized and non-deforming penetrating tip into the material. The surface hardness value is determined by measuring the dimensions of the permanent traces formed on the sample by the cone, pyramid, or pyramid-shaped penetrating tips immersed in the material at a certain time interval and under a certain load. For this purpose, microhardness methods, which are suitable for measuring the hardness of small and thin material samples, are "Vickers" and "Knoop" microhardness measurement methods, and the difference between these methods is the shape of the tips of the devices used to create traces (74).

In the method developed in England in 1925, values are evaluated by applying pyramid-shaped diamond tips with an apex angle of 136° and a square base to the surface

of the material with a certain load, then removing the load and measuring the diagonals of the trace formed on the material surface (75). The two parallel lines on the microscope inside the device are set tangentially to the corner regions of the pyramid formed on the material's surface. The measurement values of the lower and upper corners, the right and left corners, are determined separately in the microscope, and the device automatically records the average of the obtained values, and "Vicker's surface hardness value (VHN)" is obtained (75,76). As the resulting scar area gets smaller, the Vicker's hardness value increases and a high Vicker's hardness value indicates that the hardness ratio of the material is high (75). The diamond tip used for the hardness measurement test does not deteriorate with time and use. The values are accurate and reliable. However, it is essential to adjust the thickness of the material correctly so that the pyramid tip applied to one surface of the test sample does not form a protrusion on the other side of the sample. It is also essential that the test specimens' lower and upper surfaces are prepared flat to prevent the test specimen from moving and slipping when the load is applied (77).

Kanık et al. (2011) used two different GICs (Fuji IX GP Extra and Riva Self Cure) and two different surface sealers (G-Coat Plus and Fuji Varnish) to measure microhardness after keeping the samples in artificial saliva for one day, one week, and one month. It is reported that the microhardness values of all glass ionomer cement groups increased over time (78).

This study aims to evaluate the effect of surface coating and artificial aging on the surface roughness and microhardness of three different glass ionomer-based restorative materials. A bioactive restorative material ACTIVA™ kids BioACTIVE-RESTORATIVE™ (PULPDENT®, Watertown, USA), and two high-viscosity glass ionomer cement materials, EQUIA® Forte Fil (GC, Tokyo, Japan) and ChemFil® Rock (Dentsply Sirona, Konstanz, Germany) were used as glass ionomer-based restorative materials. The tested null hypothesis was that there is no difference within both the surface roughness and microhardness values of three different glass ionomer-based restorative materials regardless of surface coating and artificial aging. H₁ hypothesis was that coating application improved the roughness and hardness of all tested materials.

3. MATERIALS and METHODS

All *in vitro* tests carried out within the scope of this thesis study were performed in Yeditepe University Faculty of Dentistry Hard Tissue Laboratories.

3.1. Tested Materials

A bioactive restorative material ACTIVA™ kids BioACTIVE-RESTORATIVE™ (PULPDENT®, Watertown, USA), and two high-viscosity glass ionomer cement materials, EQUIA® Forte Fil (GC, Tokyo, Japan) and ChemFil® Rock (Dentsply Sirona, Konstanz, Germany) were used in this study (**Images 1, 2, 3**). As a surface coating agent, EQUIA Forte™ Coat (GC, Tokyo, Japan) was used (**Image 4**).

The general properties and handling methods of the materials used in the study are shown in **Tables 2** and **3**. Study groups are shown in **Table 4**.



Image 1. ACTIVA™ kids BioACTIVE-RESTORATIVE™ (PULPDENT®, Watertown, USA).



Image 2. EQUIA® Forte Fil (GC, Tokyo, Japan).



Image 3. ChemFil® Rock (Dentsply Sirona, Kontstanz, Germany).



Image 4. EQUIA Forte™ Coat (GC, Tokyo, Japan).

Table 2. General properties of materials used in the study.

Material Name	Manufacturer	Material Type	Lot Number	Content
ACTIVA™ kids BioACTIVE- RESTORATIVE™	PULPDENT®, Watertown, MA, USA	Bioactive Restorative Material	191007	A blend of diurethane and other methacrylates with modified polyacrylic acid (44.6%), Amorphous silica (6.7%), Sodium fluoride (0.75%)
EQUIA® Forte Fil	GC, Tokyo, Japan	High-viscosity Glass Ionomer Cement	1903161	Fluoro alumino silicate glass, UDMA, MMA
ChemFil® Rock	Dentsply Sirona, Kontstanz, Germany	High-viscosity Glass Ionomer Cement	1903000819	Calcium-aluminum-zinc- fluoro-phosphorus silicate glass, polycarboxylic acid, iron oxide pigments, titanium oxide pigments, tartaric acid, water
EQUIA Forte™ Coat	GC, Tokyo, Japan	Nano-filled Resin	190423A	Camphorquinone, phosphoric ester monomer

Table 3. Handling methods of samples used in the study.

Material Name	Preparation Method	Setting Time
ACTIVA™ kids BioACTIVE-RESTORATIVE™	Application of the material with an automix syringe.	20 seconds of light-cure
EQUIA® Forte Fil	Mixing the capsule in the mixing device for 10 seconds and applying it with a capsule applier.	2 minutes and 30 seconds of self-cure
ChemFil® Rock	Mixing the capsule in the mixing device for 10 seconds and applying it with a capsule applier.	6 minutes of self-cure
EQUIA Forte™ Coat	Application of the material to the surfaces of restoration with an applicator.	20 seconds of light-cure

3.2. Sample Preparation for Surface Roughness and Microhardness Tests

The power analysis by G*Power software version 3.1 revealed that the effect size between the study groups was 0.4 (alpha error probability=0.05). In the sample size analysis performed by taking the power value as 0,8, the total number of samples required was 15 per group. In this study, 17 samples were prepared from each material group.

Plexiglass molds with a diameter of 10 ± 0.1 mm and a depth of 2 ± 0.1 mm were used for microhardness and surface roughness tests (**Image 5**) (79).

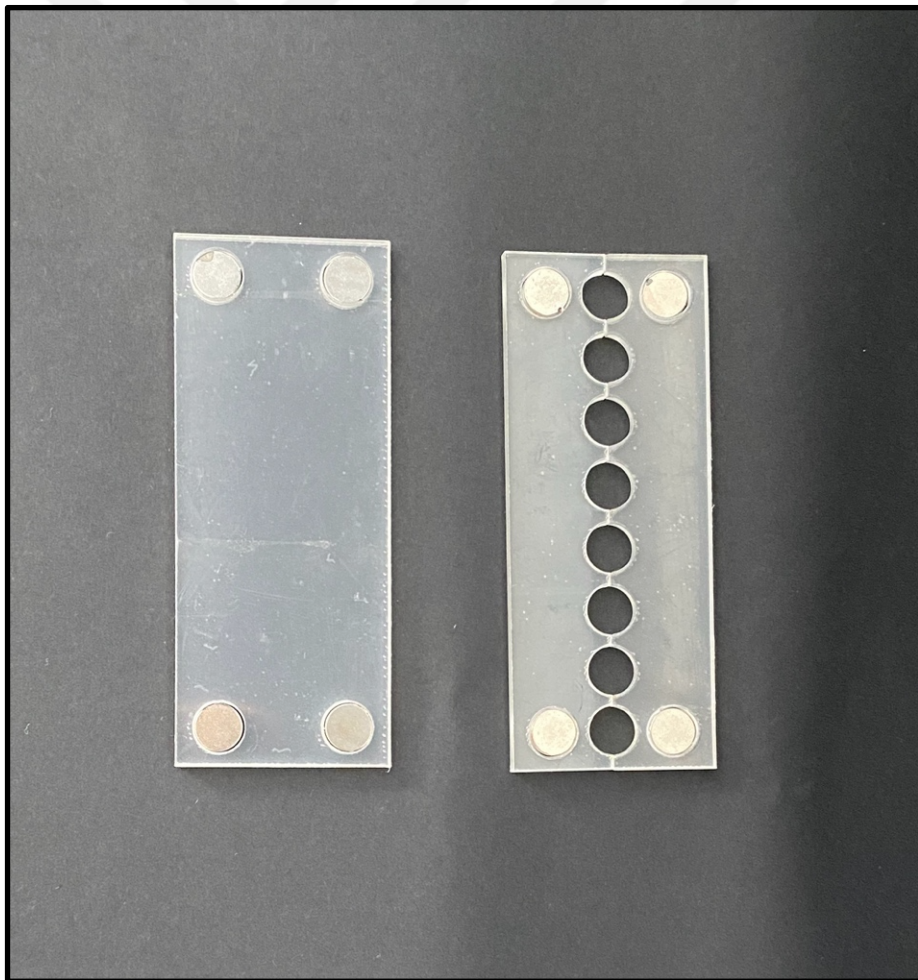


Image 5. Plexiglass molds.

Table 4. The tested material groups.

Group 1	ACTIVA™ kids BioACTIVE
Group 2	ACTIVA™ kids BioACTIVE + EQUIA Forte™ Coat
Group 3	EQUIA® Forte Fil
Group 4	EQUIA® Forte Fil + EQUIA Forte™ Coat
Group 5	ChemFil® Rock
Group 6	ChemFil® Rock + EQUIA Forte™ Coat

The materials used in the study were prepared as described in **Table 3**, following the manufacturers' instructions. For each tested material, cylindrical specimens were prepared using plexiglass molds. The interior of the molds was insulated using petroleum jelly to prevent the materials from sticking to the plexiglass molds. Then all tested materials were placed in plexiglass molds taking care to avoid incorporating air bubbles and were immediately covered with a Mylar strip. A glass slab was laid over the top and held under hand pressure for proper placement. Excess material was extruded laterally, ensuring that the lower surface of the specimen remained flat.

Groups 1 and 2 samples were polymerized using a halogen light device for 20 seconds (Elipar™ S10, 3M ESPE, USA) (**image 6**). After the setting process of the materials was completed, the specimens were removed from their molds.



Image 6. Elipar™ S10 (3M ESPE, USA).

For Groups 3-6, a mixing device (a.max, AM-1 Capsule mixer, Monitex, Taiwan) was used (**Image 7**).



Image 7. a.max, AM-1 Capsule mixer (Monitex, Taiwan).

EQUIA[®] Forte Fil and ChemFil[®] Rock were overflowed into the plexiglass molds according to the manufacturers' instructions with Capsule Applier III (GC, Tokyo, Japan (**Image 8**)). Materials were left in the molds for 6 minutes at room temperature to ensure the chemical setting. After the setting reaction was completed, the specimens were removed from their molds.



Image 8. Capsule Applier III (GC, Tokyo, Japan).

After the removal of samples, the top and bottom surfaces of all specimens were polished with 600, 800, and 1200 grit sandpaper with a polishing device (Phoenix Beta Twin Wheel, Buehler®, USA) (**Images 9 and 10**).



Image 9. Phoenix Beta Twin Wheel (Buehler®, USA).

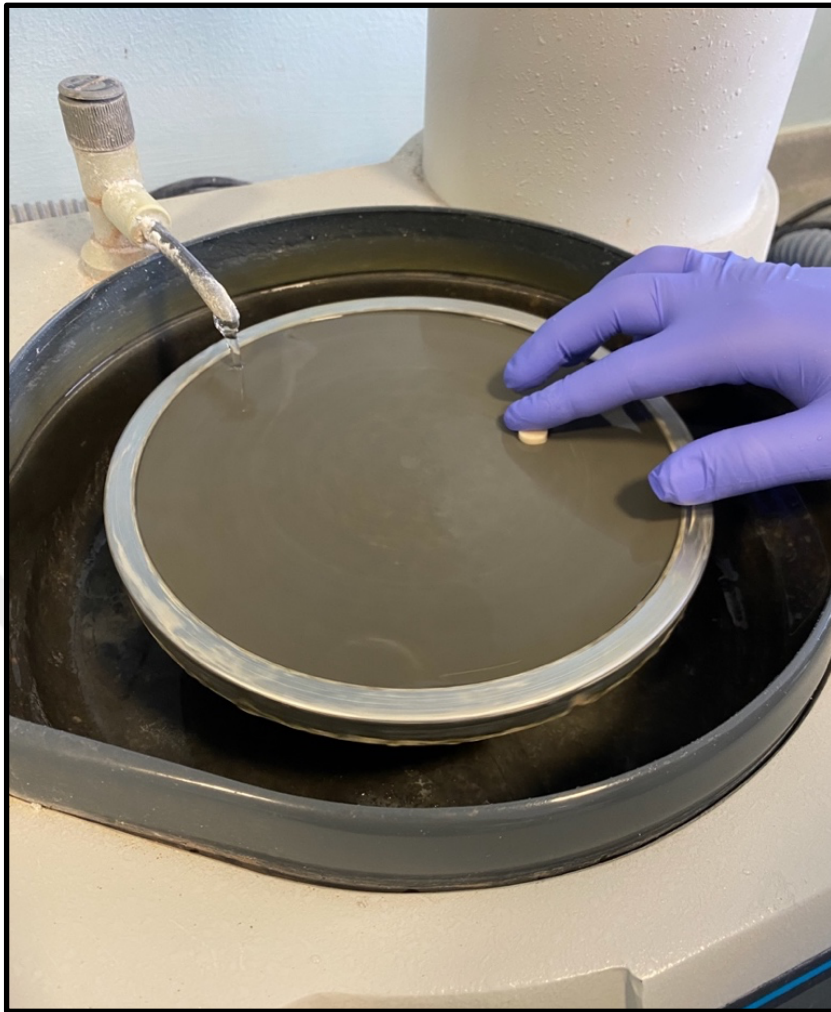


Image 10. Polishing the samples with sandpaper.

After polishing all specimens, half of them in each group were left uncoated (n=17), while the remaining half was covered with one layer of EQUIA Forte™ Coat (n=17) (GC, Tokyo, Japan). EQUIA Forte™ Coat was applied with a micro brush, then gently air blown for 5 seconds, and all surfaces were light-cured for 20 seconds. Then all specimens were stored in distilled water at 37°C for 24 h.

3.3. Surface Roughness Test

3.3.1. Measurement of Surface Roughness

The surface roughness of the specimens was measured two times (baseline and after-aging) using a profilometer (Mahr Perthometer M1, Germany) with a 5.6 mm tracing length and a 0.8 mm cut-off value (**Image 11**). A reading was obtained by a diamond stylus moved at 0.5 mm/s, and then the arithmetic roughness (R_a) was recorded. This procedure was repeated at three positions on the same specimen, and the average value was calculated using these values (**Image 12**).

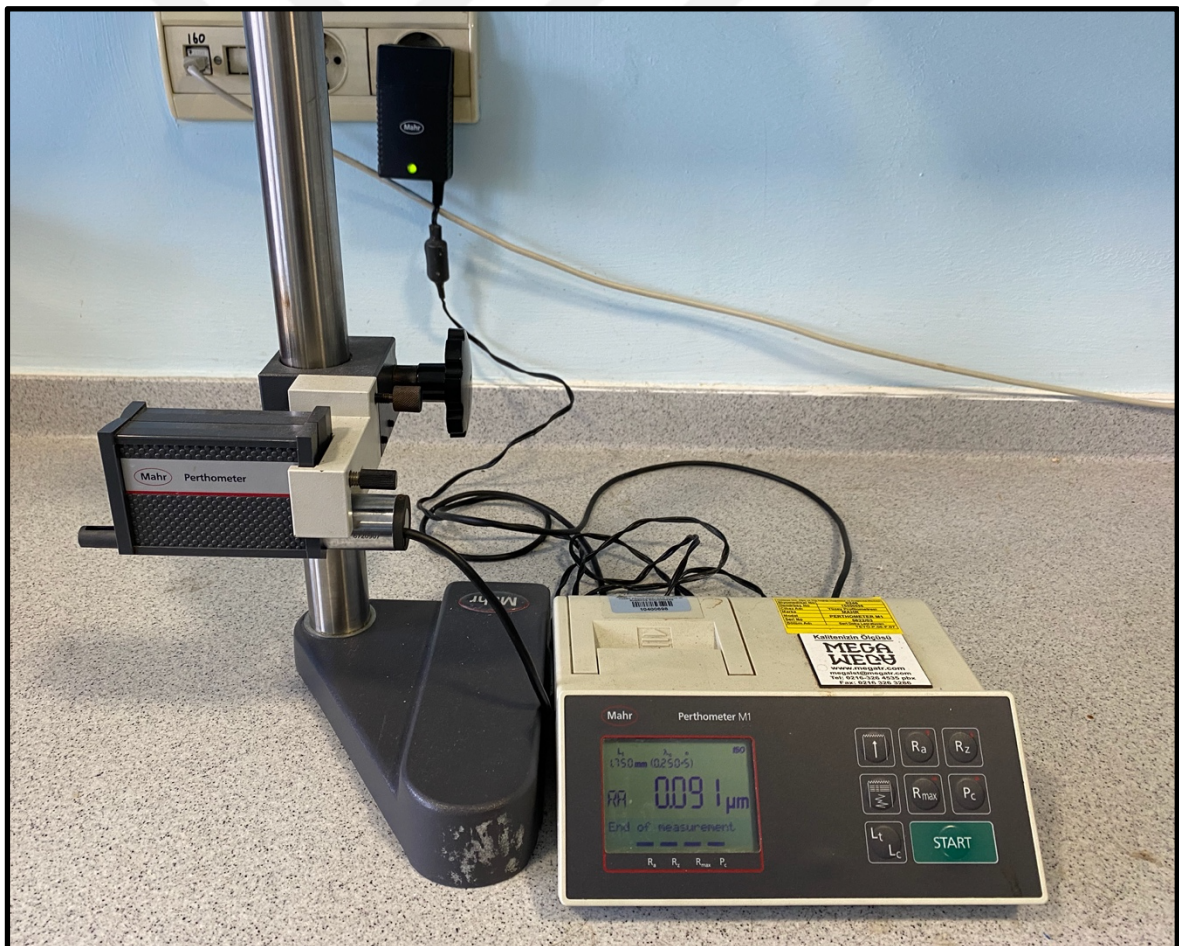


Image 11. Surface Profilometer (Mahr Perthometer M1, Germany).



Image 12. The surface roughness measurement of the specimens using the profilometer.

The thermal aging procedure was performed According to ISO TR 11450 (1994) standards within 10,000 cycles simulating an average of 1 year under *in vivo* conditions.

Following the baseline measurements, all specimens were thermocycled in distilled water for 10,000 cycles between 5 and $55^{\circ}\text{C} \pm 2^{\circ}\text{C}$ with a dwelling time of 30 sec. (Salibus Technica, Turkey) (**Image 13**). After the thermal cycling procedure, final surface roughness measurements of the same specimens were performed.



Image 13. Thermocycler (Salibrus Technica, Turkey).

3.4. Surface Microhardness Test

3.4.1. Surface Microhardness Measurement

Vickers microhardness (VMH) measurements were performed two times (baseline and after-aging) using a Buehler Micromet 5114D digital microhardness tester (Buehler, Dusseldorf, Germany) at a load of 200 g for 10 seconds on top of the surfaces of each sample from three different areas (**Images 14** and **15**). The VMH measurement of each specimen was recorded as the average of these three measurements.

The Vickers hardness number (VHN) was calculated according to the following formula:

$$\text{VHN} = 1.854(\text{F}/\text{d}^2)$$

F: The applied load (measured in kilograms-force).

d²: The area of the indentation (measured in square millimeters).



Image 14. Buehler Micromet 5114D digital microhardness tester (Buehler, Dusseldorf, Germany).



Image 15. Vickers microhardness (VMH) measurements using the microhardness tester.

Following the baseline measurements, all specimens were thermocycled with 10,000 cycles between 5 and 55°C±2°C with a dwelling time of 30 sec. (Thermocycler, Salibrus Technica, Turkey). After the thermal cycling procedure, final microhardness measurements of the same specimens were performed from the bottom surfaces.

3.5. Statistical Analysis

SPSS (Statistical Package for the Social Sciences) 24.0 program was used for statistical analysis. While evaluating the study data, the Wilcoxon Signed Rank test was used to compare the changes seen over time according to positions, and descriptive statistical methods (Mean, Standard Deviation, Median, Frequency, Ratio, Minimum, and Maximum) were used. Mann Whitney U Test was used for comparisons of two groups, whereas Kruskal Wallis Test was used for comparisons of groups of three or more. Significance was evaluated at $p<0.05$ level.

5. RESULTS

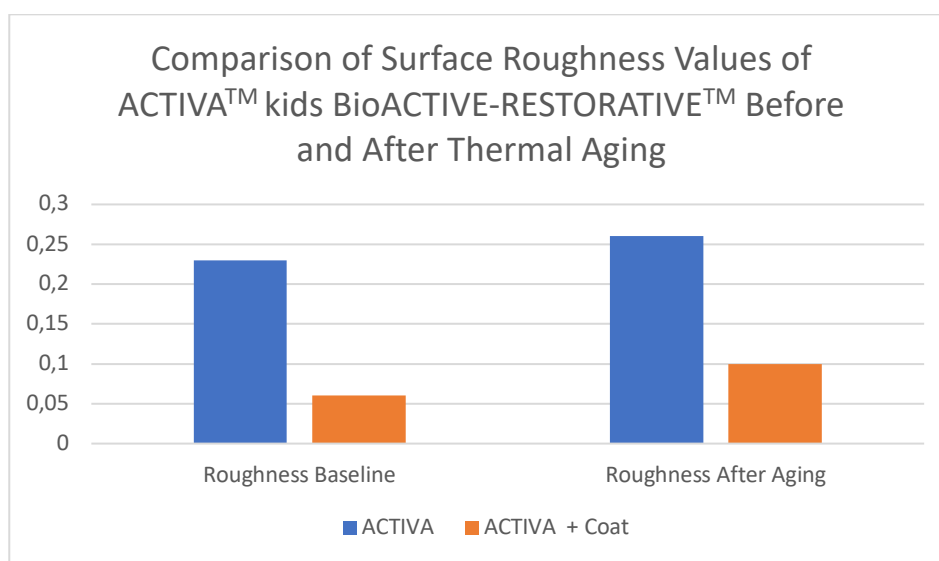
5.1. Surface Roughness

Table 5. Comparison of surface roughness values of ACTIVA™ kids BioACTIVE-RESTORATIVE™ before and after thermal aging.

	Baseline	After-aging	p ^a
	Mean±SD*	Mean±SD*	
ACTIVA™ kids	0.23±0.05	0.26±0.04	0.055
ACTIVA™ kids + Coating	0.06±0.02	0.10±0.02	0.001**
p ^a	0.001**	0.001**	
^a Wilcoxon Signed Rank Test	*Standard deviation	**p<0.01	

No statistically significant difference between the baseline and after-aging surface roughness values was found within the ACTIVA™ kids BioACTIVE-RESTORATIVE™ group (p=0.055), whereas a statistically significant difference was found within the ACTIVA™ kids BioACTIVE-RESTORATIVE™ + coating group (p=0.001; p<0.01). In ACTIVA™ kids BioACTIVE-RESTORATIVE™ + coating group, thermal aging revealed statistically higher surface roughness values than the baseline (p=0.001; p<0.01) (**Table 5** and **Graphic 1**).

There was a statistically significant difference between the baseline surface roughness values of the ACTIVA™ kids BioACTIVE-RESTORATIVE™ and ACTIVA™ kids BioACTIVE-RESTORATIVE™ + coating groups and between the after-aging values of both groups (p=0.001; p<0.01). Accordingly, coating application significantly decreased the surface roughness values at baseline and after thermal aging (p=0.001; p<0.01) (**Table 5** and **Graphic 1**).



Graphic 1. Comparison of surface roughness values of the ACTIVA™ kids BioACTIVE-RESTORATIVE™ and the ACTIVA™ kids BioACTIVE-RESTORATIVE™ + coating groups before and after thermal aging.

Table 6. Comparison of surface roughness values of EQUIA® Forte Fil before and after thermal aging.

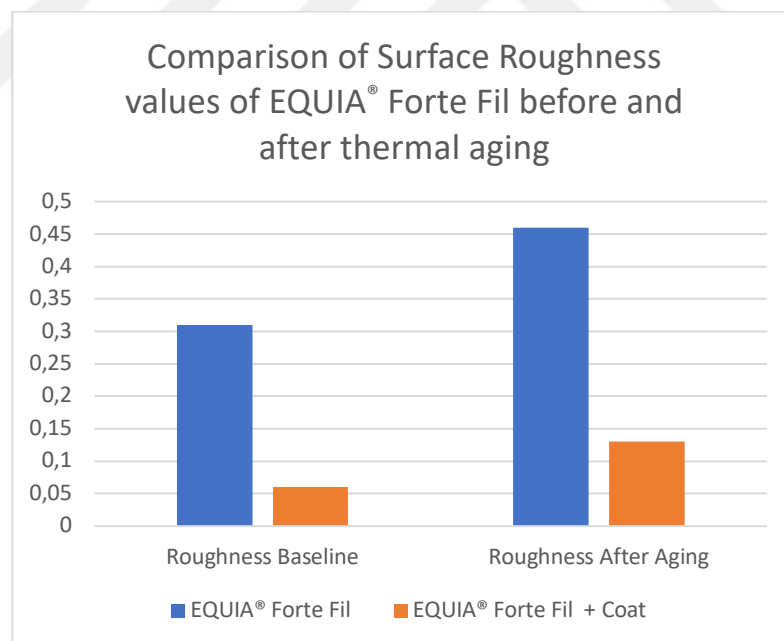
	Baseline	After-aging	p ^a
	Mean±SD*	Mean±SD*	
EQUIA® Forte Fil	0.31±0.04	0.46±0.08	0.003**
EQUIA® Forte Fil + Coating	0.06±0.01	0.13±0.03	0.001**
p ^a	0.001**	0.001**	

^aWilcoxon Signed Rank Test *Standard deviation

**p<0.01

A statistically significant difference was found between the baseline and after-aging surface roughness values within the EQUIA[®] Forte Fil and the EQUIA[®] Forte Fil + coating groups ($p < 0.01$). Accordingly, the aged group showed statistically higher surface roughness values than the baseline in both groups ($p < 0.01$) (**Table 6** and **Graphic 2**).

There was a statistically significant difference between the baseline surface roughness values of the EQUIA[®] Forte Fil and the EQUIA[®] Forte Fil + coating groups and between the after-aging values of both groups ($p = 0.001$; $p < 0.01$). Accordingly, coating application significantly decreased the surface roughness values at baseline and after thermal aging ($p = 0.001$; $p < 0.01$) (**Table 6** and **Graphic 2**).



Graphic 2. Comparison of surface roughness values of the EQUIA[®] Forte Fil and the EQUIA[®] Forte Fil + coating groups before and after thermal aging.

Table 7. Comparison of surface roughness values of ChemFil® Rock before and after thermal aging.

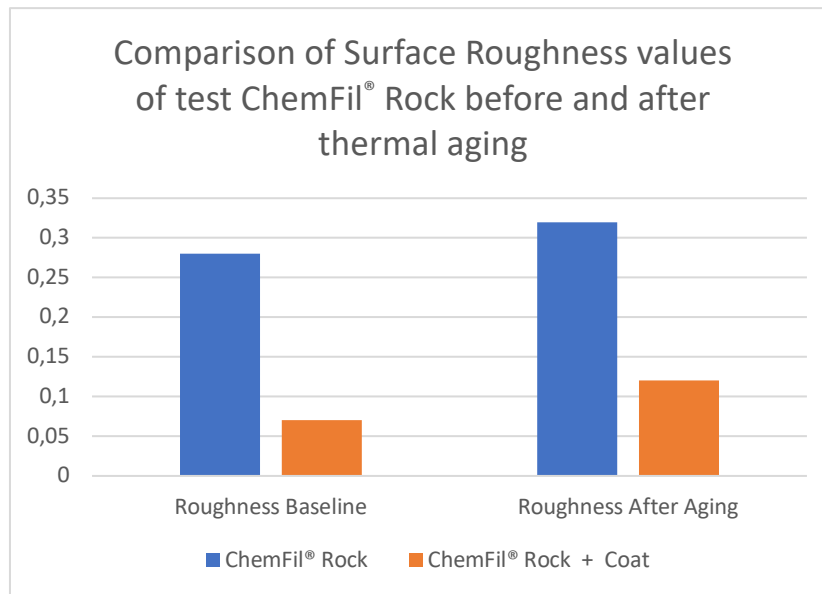
	Baseline	After-aging	p ^a
	Mean±SD*	Mean±SD*	
ChemFil® Rock	0.28±0.05	0.32±0.04	0.001**
ChemFil® Rock + Equia Forte Coating	0.07±0.01	0.12±0.02	0.001**
p^a	0.001**	0.001**	

^aWilcoxon Signed Rank Test *Standard deviation

**p<0.01

A statistically significant difference was found between the baseline and after-aging surface roughness values within ChemFil® Rock and ChemFil® Rock + coating groups (p=0.001; p<0.01). Accordingly, the aged group showed statistically higher surface roughness values than the baseline in both groups (p=0.001; p<0.01) (**Table 7** and **Graphic 3**).

There was a statistically significant difference between the baseline surface roughness values of the ChemFil® Rock and the ChemFil® Rock + coating groups and between the after-aging values of both groups (p=0.001; p<0.01). Accordingly, coating application significantly decreased the surface roughness values at baseline and after thermal aging (p=0.001; p<0.01) (**Table 7** and **Graphic 3**).



Graphic 3. Comparison of surface roughness values of the ChemFil® Rock and the ChemFil® Rock + coating before and after thermal aging.

Table 8. Comparison of surface roughness values of all tested materials without coating application.

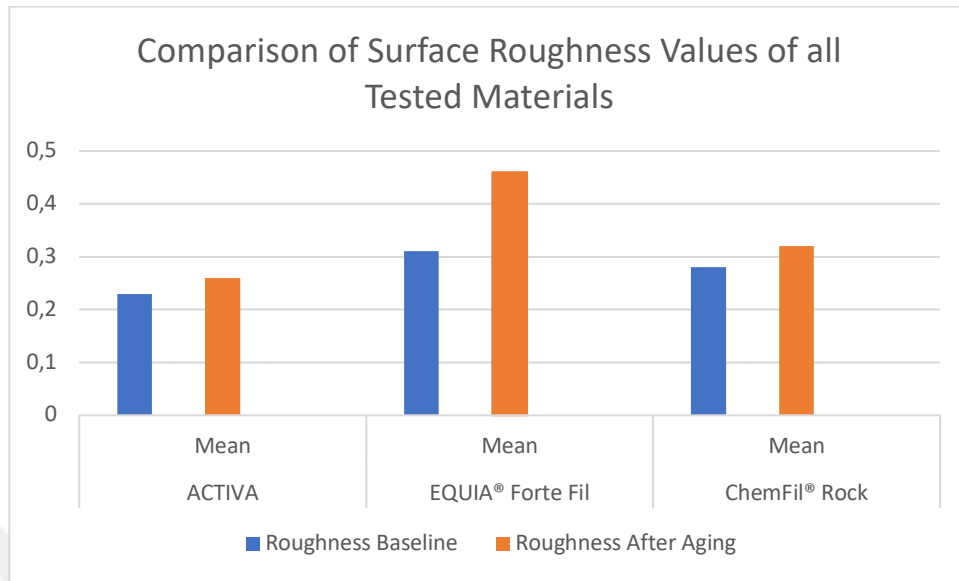
	ACTIVA™ kids	EQUIA® Forte Fil	ChemFil® Rock	p ^a
	Mean±SD	Mean±SD	Mean±SD	
Roughness baseline	0.23±0.05 ^{ab}	0.31±0.04 ^a	0.28±0.05 ^b	0.001**
Roughness after-aging	0.26±0.04 ^{cd}	0.46±0.08 ^c	0.32±0.04 ^d	0.001**

^aKruskal Wallis Test

*Standard deviation

**p<0.01

***Groups with the same superscript letter have statistically significant difference



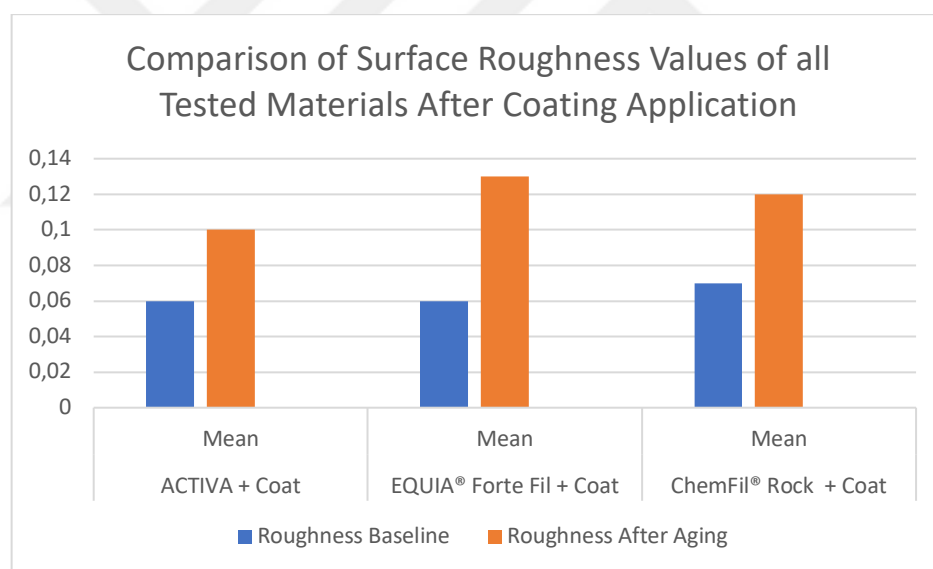
Graphic 4. Comparison of surface roughness values of all tested materials without coating application.

In the surface roughness test performed in the study, for the baseline groups, the highest surface roughness value was found in EQUIA® Forte Fil, followed by ChemFil® Rock and ACTIVA™ kids BioACTIVE-RESTORATIVE™ groups, respectively ($p=0.001$; $p<0.01$). All groups' differences were statistically significant except for EQUIA® Forte Fil and ChemFil® Rock. The highest surface roughness value for the aged groups was found in EQUIA® Forte Fil, followed by ChemFil® Rock and ACTIVA BioACTIVE groups. The difference between all groups was statistically significant ($p=0.001$; $p<0.01$) (**Table 8** and **Graphic 4**).

Table 9. Comparison of surface roughness values of all tested materials after coating application.

	ACTIVA™ kids + Coating	EQUIA® Forte Fil + Coating	ChemFil® Rock + Coating	p ^a
	Mean±SD	Mean±SD	Mean±SD	
Roughness baseline	0.06±0.02	0,06±0,01	0,07±0,01	0,193
Roughness after-aging	0.1±0.02 ^{ab}	0,13±0,03 ^a	0,12±0,02 ^b	0,002**

^aKruskal Wallis Test *Standard deviation **p<0.01
***Groups with the same superscript letter have statistically significant difference



Graphic 5. Comparison of surface roughness values of all tested materials after coating application

Regarding the surface roughness of the baseline groups after coating application, the highest surface roughness value was found in ChemFil® Rock, followed by ACTIVA™ kids BioACTIVE-RESTORATIVE™ and EQUIA® Forte Fil, respectively. There was no statistically significant difference between the groups ($p>0.05$). In the aged groups, the highest surface roughness was found in EQUIA® Forte Fil, followed by

ChemFil® Rock and ACTIVA™ kids BioACTIVE-RESTORATIVE™ groups, respectively. All groups' differences were statistically significant except for EQUIA® Forte Fil and ChemFil® Rock ($p<0.01$) (Table 9 and Graphic 5).

5.2. Surface Microhardness

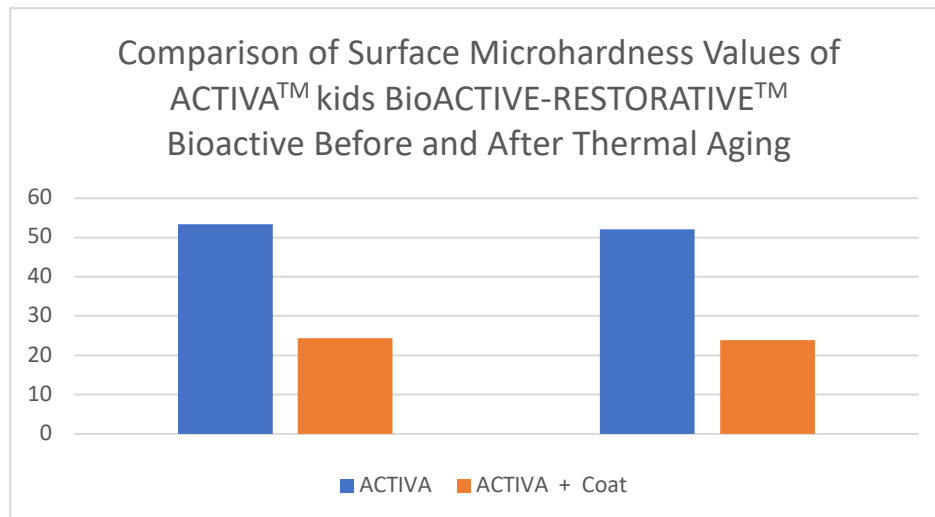
Table 10. Comparison of surface microhardness values of ACTIVA™ kids BioACTIVE-RESTORATIVE™ before and after thermal aging.

	Baseline	After-aging	p ^a
	Mean±SD	Mean±SD	
ACTIVA™ kids	53.47±2.18	52.14±1.83	0.001**
ACTIVA™ kids + Coating	24.35±0.95	23.82±0.92	0.017*
p ^a	0.001**	0.001**	

^aWilcoxon Signed Rank Test *Standard deviation ** $p<0.01$ * $p<0.05$

A statistically significant difference was found between the baseline and after-aging surface microhardness values within ACTIVA™ kids BioACTIVE-RESTORATIVE™ and ACTIVA™ kids BioACTIVE-RESTORATIVE™ + coating groups ($p=0.001$; $p<0.01$). In both groups, thermal aging revealed statistically lower surface microhardness values than the baseline ($p=0.001$; $p<0.01$).

There was a statistically significant difference between the baseline surface microhardness values of the ACTIVA™ kids BioACTIVE-RESTORATIVE™ and ACTIVA™ kids BioACTIVE-RESTORATIVE™ + coating groups and between the after-aging values of both groups ($p=0.001$; $p<0.01$). Accordingly, coating application significantly decreased the surface microhardness values at baseline and after thermal aging ($p=0.001$; $p<0.01$).



Graphic 6. Comparison of surface microhardness values of the ACTIVA™ kids BioACTIVE-RESTORATIVE™ and the ACTIVA™ kids BioACTIVE-RESTORATIVE™ + coating before and after thermal aging.

Table 11. Comparison of surface microhardness values of EQUIA® Forte Fil (GC, Tokyo, Japan) before and after thermal aging

	Baseline	After-aging	p ^a
	Mean±SD	Mean±SD	
EQUIA® Forte Fil	86.47±1.62	70.62±2.42	0.001**
EQUIA® Forte Fil + Coating	36.45±1.00	35.11±1.08	0.005**
p^a	0.001**	0.001**	

^aWilcoxon Signed Rank Test

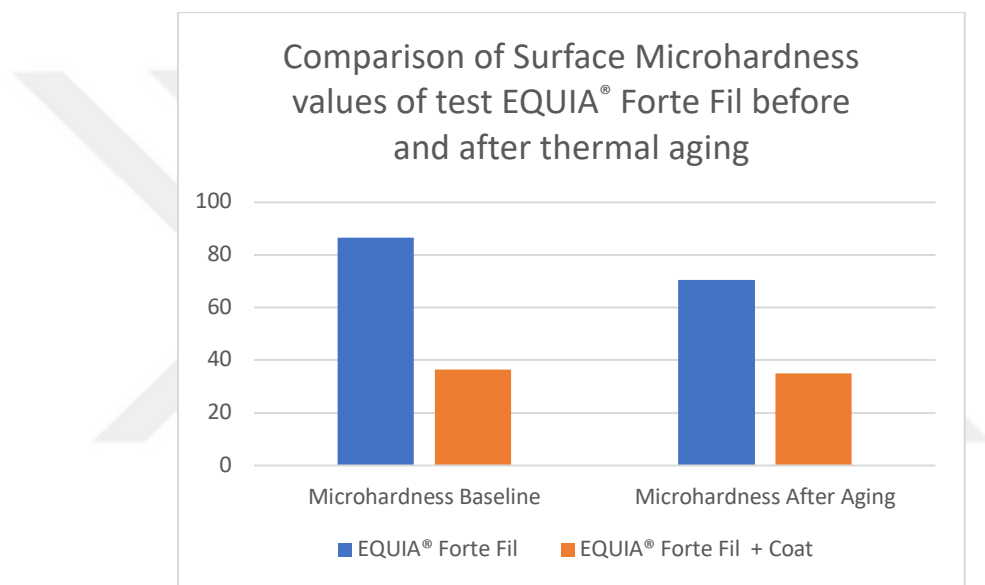
*Standard deviation

**p<0.01

A statistically significant difference was found between the baseline and after-aging surface microhardness values within the EQUIA® Forte Fil (GC, Tokyo, Japan) and the EQUIA® Forte Fil (GC, Tokyo, Japan) + coating groups (p<0.01). Accordingly, the

aged group showed statistically lower surface microhardness values than the baseline in both groups ($p<0.01$).

There was a statistically significant difference between the baseline surface microhardness values of the EQUIA® Forte Fil (GC, Tokyo, Japan) and the EQUIA® Forte Fil (GC, Tokyo, Japan) + coating groups and between the after-aging values of both groups ($p=0.001$; $p<0.01$). Accordingly, coating application significantly decreased the surface microhardness values at baseline and after thermal aging ($p=0.001$; $p<0.01$).



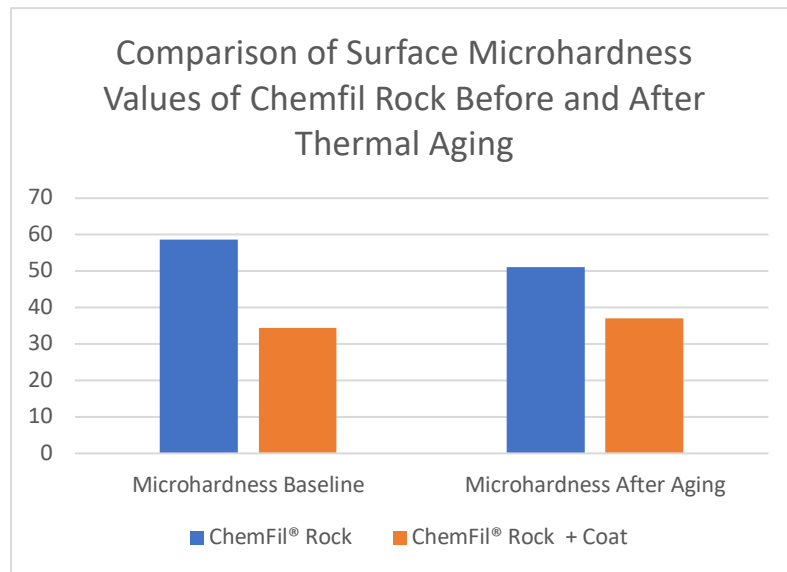
Graphic 7. Comparison of Surface Microhardness values of EQUIA® Forte Fil (GC, Tokyo, Japan) and EQUIA® Forte Fil (GC, Tokyo, Japan) + coating before and after thermal aging.

Table 12. Comparison of surface microhardness values of ChemFil® Rock before and after thermal aging

	Baseline	After Aging	p ^a
	Mean±SD	Mean±SD	
ChemFil® Rock	58.67±0.73	51.02±1.69	0.001**
ChemFil® Rock + Equia Forte Coat	34.42±1.01	36.98±1.45	0.001**
p^a	0.001**	0.001**	
^a Wilcoxon Signed Rank Test	*Standard deviation	**p<0.001	

A statistically significant difference was found between the baseline and after-aging surface microhardness values within ChemFil® Rock and ChemFil® Rock + coating groups (p=0.001; p<0.01). Accordingly, the aged group showed statistically lower surface microhardness values than the baseline in the ChemFil® Rock group, whereas it was statistically higher than the baseline in ChemFil® Rock + coating group (p=0.001; p<0.01).

There was a statistically significant difference between the baseline surface microhardness values of the ChemFil® Rock and the ChemFil® Rock + coating groups and between the after-aging values of both groups (p=0.001; p<0.01). Accordingly, coating application significantly decreased the surface microhardness values at baseline and after thermal aging (p=0.001; p<0.01).



Graphic 8. Comparison of surface microhardness values of ChemFil® Rock before and after thermal aging

Table 13. Comparison of surface microhardness values of all tested materials

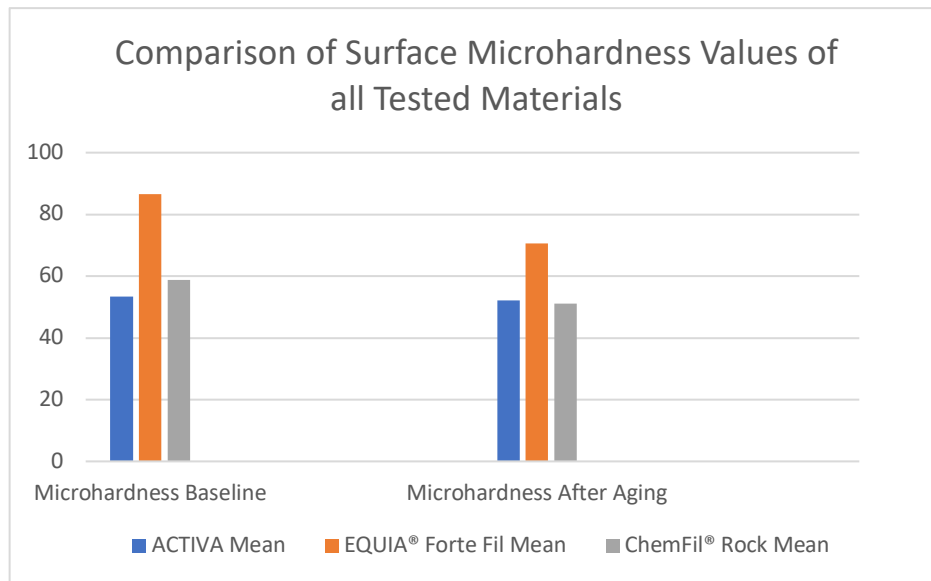
	ACTIVA™ kids	EQUIA® Forte Fil	ChemFil® Rock	p ^a
	Mean±SD	Mean±SD	Mean±SD	
Microhardness Baseline	53.47±2.18 ^a	86.47±1.62 ^a	58.67±0.73 ^a	0.001**
Microhardness After-Aging	52.14±1.83 ^b	70.62±2.42 ^{bc}	51.02±1.69 ^c	0.001**

^aWilcoxon Signed Rank Test

*Standard deviation

**p<0.001

***Groups with the same superscript letter have statistically significant difference



Graphic 9. Comparison of surface microhardness values of all tested materials without coating application

In the surface microhardness test performed in the study for the baseline groups, the highest microhardness values were found in EQUIA® Forte Fil, followed by ChemFil® Rock and ACTIVA™ kids BioACTIVE-RESTORATIVE™ groups, respectively. All groups' differences were statistically significant ($p=0.001$; $p<0.01$). The highest surface microhardness value for the aged groups was found in EQUIA® Forte Fil, followed by ACTIVA™ kids BioACTIVE-RESTORATIVE™ and ChemFil® Rock, respectively. All groups' differences were statistically significant except for ACTIVA™ kids BioACTIVE-RESTORATIVE™ and ChemFil® Rock ($p<0.05$).

Table 14. Comparison of surface microhardness values of all tested materials after coating application

	ACTIVA™ kids + Coating	EQUIA® Forte Fil + Coating	ChemFil® Rock + Coating	p ^a
	Mean±SD	Mean±SD	Mean±SD	
Microhardness Baseline	24.35±0.95 ^a	36.45±1.00 ^a	34.42±1.01 ^a	0.001**
Microhardness After-Aging	23.82±0.92 ^a	35.11±1.08 ^a	36.98±1.45 ^a	0.001**

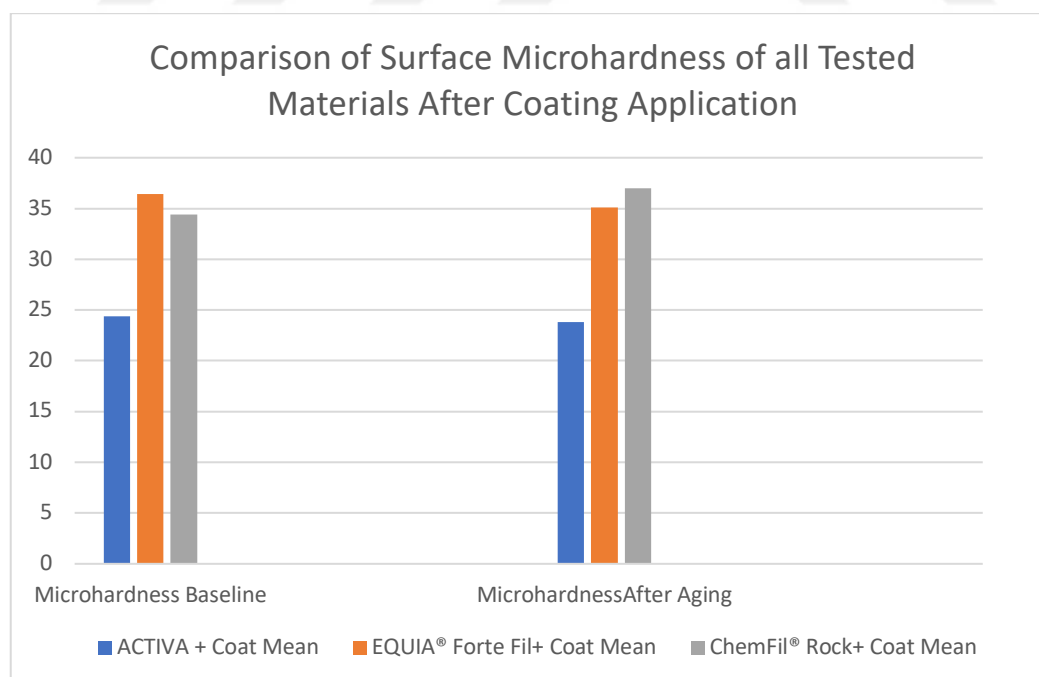
^aWilcoxon Signed Rank Test

*Standard deviation

**p<0.001

***Groups with the same superscript letter have statistically significant difference

Graphic 10. Comparison of surface microhardness of all tested materials after coating application



In the surface microhardness tests performed for the baseline groups with coating application, the highest surface microhardness value was found in EQUIA® Forte Fil, followed by ChemFil® Rock and ACTIVA™ kids BioACTIVE-RESTORATIVE™ groups, respectively. All groups' differences were statistically significant ($p=0.001$; $p<0.01$). In the aged groups, the highest surface microhardness was found in ChemFil® Rock and EQUIA® Forte Fil, followed by ACTIVA™ kids BioACTIVE-RESTORATIVE™ groups, respectively. The difference between all groups was statistically significant ($p=0.001$; $p<0.01$).



5. DISCUSSION

Surface roughness and surface hardness are important properties that need to be addressed to achieve a proper dental restoration. Surface hardness increases resistance to abrasion and roughness and positively affects clinical success by preventing the material from deforming against the forces it is exposed to in the mouth (80).

Surface roughness can determine the quality and clinical behavior of the restoration material. A smooth surface is not only a requirement for the desired aesthetic appearance but also prevents the formation of a coloring film layer and plaque retention. Surface smoothness can also reduce the coefficient of friction, which can reduce the wear rate. As a result, surface roughness is an important criterion affecting the restoration's aesthetic, friction, abrasion, bacterial adhesion, and optical properties. Surface roughness and surface microhardness are important parameters used in the evaluation of dental materials *in vitro* and affect the success of restorative materials, as well as an essential factor influencing the long-term success of dental restorative materials by reducing the durability and surface quality of the restoration (81).

Glass ionomer restorative materials, due to their chemical bonding to dental tissues with minimal preparation and their fluoride-releasing properties, have become increasingly popular in routine dental practice (82,83). The flexibility in their clinical use and the fact that they are expandable materials have led to the frequent use of GICs in dental practice. International organizations support using glass GICs, especially in low-income regions, due to their positive clinical performance (84). Other than some advantages, such as biocompatibility, good adhesion to dental hard tissues, and fluoride release, it also has disadvantages, such as poor resistance to abrasion and compression-tensile strength. For this purpose, studies are carried out to develop new glass ionomer cement formulations (85,86).

Knowing the physical, biological, and mechanical properties of the dental materials to be used provides an idea about the clinical conditions in which they should be used. Using appropriate dental materials in pediatric patients with poor cooperation is advantageous for the dentist and the patient. Therefore, using glass ionomer cements in pediatric dentistry is very beneficial in terms of easy application of these materials, direct bonding to dental tissues, and releasing fluoride (87,88). In this study, a bioactive

restorative material ACTIVA™ kids BioACTIVE-RESTORATIVE™ (PULPDENT®, Watertown, USA), and two high-viscosity glass ionomer cement materials, EQUIA® Forte Fil (GC, Tokyo, Japan) and ChemFil® Rock (Dentsply Sirona, Konstanz, Germany) were used.

In vivo tests used to evaluate a new material introduced in dentistry are time-consuming, costly, and difficult to standardize. For this reason, researchers prefer *in vitro* tests that are effective and give rapid results, parameters can be changed, and results can be compared. Therefore, in this study, *in vitro* test methods were also used. **Van Meerbeek et al. (2009)** stated that there is a parallelism between bond strength tests (*in vitro* tests) and clinical tests (*in vivo* tests) and that aging tests approximate laboratory test results to clinical test results (89). Dental restorative materials are constantly exposed to temperature and pH changes in the oral environment. The constant change in intraoral temperature has a negative effect on restorative materials *in vivo*.

The thermal cycling test aims to transfer the intraoral temperature changes to *in vitro* conditions (90). The temperature values to which thermal cycling will be applied should mimic the oral environment. The American Dental Association (ADA, Acceptance Program Guidelines 2001) recommended temperature values for bond strength and microleakage tests of adhesive materials used on dentin and enamel are between 5 and 55°C. In addition, according to ISO Standards (ISO TR 11405, 2003), in the case of measuring the bond strength of adhesives used in dentistry, it is recommended that the lower and upper-temperature values be between 5 and 55°C. In the literature, there is no standard for applying the thermal cycling test. However, 500 to 10,000 cycles are considered significant. It has been reported that 10,000 cycles are equivalent to mean aging of one year. For this reason, 10,000 cycles were applied in this study to mimic aging for one year in the oral cavity.

Restorative materials properties such as surface roughness, microhardness, and wear resistance are important in clinical aesthetics, longevity, and resistance to dental plaque (89). Surface roughness, an important physical property of restorative materials, directly affects the surface properties of materials, such as gloss, color, and surface hardness (71,91).

Studies have reported that the lowest roughness value is achieved using a transparent mylar strip after polymerizing composite resin materials (91). However, due to the presence of an oxygen inhibition layer on the top layer of the restorations finished using transparent tape, this layer reduces the surface hardness of the material, deforms its mechanical properties, and causes discoloration in the restorations; it should be removed from the environment (92). Finishing and polishing processes are required to remove this layer from the oral environment. In this study, the materials were finished with a mylar strip and polished with sandpapers after setting reaction to mimic the clinical procedure.

During the initial setting stages, fluid contamination and dehydration weaken the physical properties of the GIC (93). It is recommended to use surface coatings to prevent the early exposure of CGIC to moisture. It has been suggested that coating the material with resin is necessary to ensure water balance and that this application improves physical and aesthetic properties. Many coating materials have been developed for this purpose. In studies examining the surface coating applications of glass ionomer restorations, different surface coating agents were tested, such as; vaseline, cocoa butter, light-cured surface sealants, nail polish, and petroleum jelly (94,95).

Gemalmaz et al. (1998) stated that early moisture contamination negatively affects the mechanical durability of glass ionomer restorations and reduces the wear resistance of the surface due to erosion and abrasion (96). To prevent these disadvantages, restorations are strongly recommended to be protected from moisture contamination for at least 1 to 2 weeks after placement (52,97).

Although it is known that the protective resin improves the physical properties of CGIC, limited studies have been conducted on its effect on the physical properties of high-viscosity GICs. **Leirskar et al. (2003)** reported that coating high-viscosity glass ionomer cement with a light-cured protective resin reduces the shear puncture resistance of this material. These researchers suggested that the increase in the drilling resistance of GICs is related to the water absorption of the material from the external environment and that covering the material with protective resin reduces the water absorption (98).

In their clinical study, **Klinke et al. (2016)** evaluated the 48-month clinical performance of surface-coated glass ionomer restorations. Researchers have stated that

applying surface sealant increases the wear resistance of GICs at a level close to composite resins (99).

Lohbauer (2010) stated that applying the surface sealant increases the impermeability of the material by coating the porosity and cracks on the material surface (18). This study evaluated surface roughness and microhardness values of glass ionomer materials with surface coating. The light-cured surface coating gives the surface a slippery and shiny appearance in glass ionomer cements with low polishing properties and makes the color more acceptable. It has been observed with the naked eye that most or all of the light-cured surface coating is removed from the restoration surface in the sixth month due to occlusal contacts during the chewing function, foods, and using a toothbrush (18). Since the maturation of glass ionomer cements is completed in this process, it is not necessary to repeat the surface coating application. In the present study, a light-curing coating material (EQUIA Forte™ Coat (GC, Tokyo, Japan) was used as a surface cover to mimic the clinical use and standardize the testing procedure.

5.1.Discussion of Surface Roughness Test Results

Surface roughness is a critical parameter in evaluating dental materials *in vitro*. It affects the long-term success of dental restorative materials by reducing the durability and surface quality of the restoration (100). The surface roughness of restorative materials has various clinical implications. Changes in surface topography and surface roughness are often used to determine the wear of a material. Increased roughness can increase microbial colonization and cause oral diseases, secondary caries, gingival irritation, and inflammation (101). In addition, the increase in surface roughness causes discoloration and deterioration of restorative materials. In this way, it shortens the life of restorative materials and limits their use (102).

Many external effects will affect the surface roughness of the materials used in dental restorations. Of these, occlusal forces that occur during chewing, abrasions that may arise according to tooth brushing and the paste used, temperature changes that may occur in the mouth with consumed foods, and acid erosions are of prime importance (103). The roughness may be related to a combination of factors, including the cement matrix, the proportion and size of inorganic glass particles, and air bubbles formed during material preparation (104).

The roughness of the restoration surfaces can cause discoloration, plaque accumulation, gingival irritation, and secondary caries formation. In addition, the surface roughness of the restoration is a factor that directly affects the patient's comfort. The tongue can feel a rough area of 0.3 μm on the surface (105). It has been reported that the optimum surface roughness value in materials should be below 0.2 μm (105,106). In addition, studies have stated that surface roughness values (Ra) above 0.2 μm cause a plaque accumulation increase and a higher risk for caries and periodontal inflammation (69).

Surface roughness is a 2-dimensional parameter. Measurements can be made with a device called a profilometer. This device calculates the surface roughness measurement data numerically (107). Profilometer numerically gives the average surface roughness value (Ra), is easy to use, can carry out surface roughness measurements effectively and accurately, is suitable for statistical analysis, and is one of the most frequently used traditional methods. Considering these advantages, using a surface profilometer was preferred to evaluate the surface roughness in this study (107,108).

The most commonly used method to characterize the surface roughness is taking the arithmetic average of the roughness values taken from five points along a line on the sample surface. This average is stated as Ra (roughness average), and its unit is micrometer (μm). Many studies were based on the Ra value (101,109,110). The parameters needed to measure the surface roughness are the measurement area of the profilometer device and the sample size. Accordingly, samples with a diameter of 10 mm and a thickness of 2 mm were prepared (111).

In surface roughness measurements, some studies used polishing or blasting on the measured surfaces after the samples were prepared, while in others, only mylar strip was used. Studies also show that very smooth surfaces are obtained using silicon carbide discs (112). However, many studies report a smoother texture in samples prepared using only mylar strips (95,109,113). In this study, a mylar strip was used to obtain a smoother sample surface, and all samples were polished with sandpaper.

Baldağ et al. (2014) evaluated the surface roughness of CGIC cement GC Fuji IX GP® and zinc-containing glass ionomer cement (ChemFil® Rock) after 24 hours and 168 hours with or without using a surface coating. While there was no statistically

significant difference between the GC Fuji IX GP® and ChemFil® Rock groups, it was observed that the surface roughness values significantly reduced when the surface coating was applied to both groups. In the measurements made after 168 hours, there were statistically significant differences between the groups with and without the application of surface coating. While the surface roughness of the groups with the surface coating was lower, the surface roughness value of the GC Fuji IX GP® group without the surface coating was higher than that of the ChemFil® Rock group (114). Similar to the above-mentioned study, the surface roughness values of all surface coating groups were found to be statistically significantly lower when compared to the groups without a surface coating, regardless of the aging protocol. Hence, the surface coating application decreased the roughness values in the present study.

Pacifici et al. (2013) aimed to determine the surface roughness of different GIC groups with and without surface coating. It was concluded that a surface coating did not significantly improve the surface roughness of glass ionomer cements in specimens mimicking the standard clinical procedures. Although similar surface roughness values were observed between the coated and uncoated surfaces of glass ionomer cements, it was observed that coated GICs were more successful in terms of marginal sealing. In addition, compared to resin-modified glass ionomer cements, the surface coating application gave more successful results when used in high-viscosity glass ionomer cements (60). In this study, surface coating application decreased the surface roughness values of all glass ionomer materials.

Hotta et al. (1992) applied different surface coatings (3M™ Ketac™ Glaze Light-Cured Varnish Refill, bonding agent, and Bellfeel brightener) to CGICs (GC Fuji II®, Chemfil II, and Chelon-fil). In the SEM images, cracks were observed on the surface of all CGICs without surface coating after water absorption and after air drying, while the surface of the surface-coated specimens was smooth. As a result, it was stated that applying a surface coating is necessary for the clinical success of CGIC (52). Similar to the above-mentioned study, the surface roughness values of all surface coating groups were found to be lower when compared to the groups without a surface coating.

Al-Angari et al. (2014) conducted a study comparing the surface roughness of conventional (GC Fuji IX GP® Extra), condensable (Ketac™ Molar), resin-added (EQUIA® Forte Fil), and zinc-added (ChemFil® Rock) GICs. When the surface

roughness of these materials, on which surface protection was applied, was evaluated after the samples were prepared, it was found that GC Fuji IX GP® Extra had the lowest roughness value. In contrast, ChemFil® Rock, a zinc-containing glass ionomer cement, had the highest roughness value (115). In line with this result, the highest baseline surface roughness value was found in the ChemFil® Rock + EQUIA Forte™ Coat group in the present study. The second highest surface roughness value was found in EQUIA® Forte Fil.

Korkut et al. (2018) evaluated the surface roughness of glass ionomer-based fissure sealants combined with 10% and 30% bioactive glass. When the results obtained in this study were examined, no statistically significant difference was observed in the surface roughness values of the groups to which bioactive glass was added at the rates of 10% and 30%. In contrast, the control group's surface roughness value was statistically significantly lower than the other groups (116). Unlike the study mentioned above, the ACTIVA™ kids BioACTIVE-RESTORATIVE™ showed lower surface roughness results than the other materials. The surface roughness of GICs is affected by the shape, distribution, filler size, and the number of particles in the matrix.

In the present study, when baseline the surface roughness was evaluated, the statistically highest values were found in Equia Forte Fil, and the lowest roughness was found in ACTIVA™ kids BioACTIVE-RESTORATIVE™. The measurements after aging revealed that the surface roughness increased significantly in all groups except the ACTIVA™ kids BioACTIVE-RESTORATIVE™ group without coating. This increase is thought to be due to the increase in the contact time of the materials with water. When the literature was reviewed, it was seen that different results were obtained in studies with zinc-containing glass ionomer cements. It is thought that these differences may be due to the way the samples were prepared and the tests performed. In the present study, when the after-aging surface roughness was evaluated, the statistically highest values were found in EQUIA® Forte Fil, and the lowest roughness was found in ACTIVA™ kids BioACTIVE-RESTORATIVE™.

5.2. Discussion of Surface Microhardness Results

One of the most critical factors contributing to the clinical success of restorative materials is the structural properties of the materials. The structural properties of the materials also affect their performance in the oral environment (117). Microhardness, one of the criteria for evaluating the structural properties of materials, is specified as the material's resistance against indentations (117,118). Hardness is also defined as the resistance of any material to continuous deformation against a hard object. Restorative materials used in dentistry are exposed to many different effects in the mouth, and they must have high surface hardness values to resist these effects. Hardness increases the material's mechanical strength and resistance to fracture and wear and ensures the preservation of the original shape against forces (119).

Surface hardness tests are test methods used to evaluate the deterioration and durability of dental materials, examine the surface properties in the environments they are stored, determine their abrasion resistance, and monitor the hardening processes of cements (119,120). Brinell, Knoop, Rockwell, and Vickers test methods are used to measure the surface hardness of the materials. Among these, Knoop and Vickers hardness measurements are the most commonly used tests for dental materials (119,121,122).

Surface hardness measurements evaluate the surface hardness of restorative materials used in dentistry under *in vitro* conditions. In the studies, surface hardness measurements are made by applying loads of different weights to the material's surface at different times using a Vickers or Knoop tip. The hardness measurements of the materials tested in the present study were carried out using a Vickers tip. Restorative materials are under intense chewing forces in the mouth, and their hardness values must be high to withstand the stresses created by these forces. Materials with low surface hardness values may have higher wear rates (123). However, it should be noted that the microhardness measurements made on the surfaces of restorative materials only examine the outer surfaces, and the changes in the deeper regions cannot be evaluated.

In the Vickers hardness test, the hardness is calculated by measuring the amount of trace created by applying force on the material to be reckoned with a square-bottomed, pyramid-shaped diamond tip with an apex angle of 136°. Vickers hardness test is commonly used in dentistry in microhardness studies because it can produce accurate

values after measurement, the diamond tip does not deteriorate with time and use, and it can be used for the surfaces of all materials. It is suitable for measuring the hardness values of highly brittle materials. The load and time adjustments employed in the Vickers hardness test were preferred since the most precise image was obtained when a force of 200 grams was applied to the samples for 10 seconds (124). For the surface microhardness measurements of the glass ionomer cements used, samples were prepared using standard metal molds with a diameter of 10 mm and a thickness of 2 mm with the help of a mylar strip (57,119,121).

Kanık (2011) investigated the effect of a nano-filled surface coating on the physical and mechanical properties of different GICs with a long-term *in-vivo* study and various *in-vitro* tests. While it was not found significant, the composite resin group showed significantly higher abrasion resistance than glass ionomer cement groups. Applying a light-cured surface coating has increased the wear resistance of glass ionomer cements. The composite resin group gave significantly higher strength values in the three-point bending and compression strength tests. Differences in 24-hour and 30-day data were statistically insignificant in all groups. In the Vickers test, the microhardness of glass ionomer cement groups increased significantly over time (78).

Çelik and Ermiş (2008) evaluated the effect of protective resin application on the microhardness of HVGIC and CGIC. A protective resin was applied to half of the HVGIC samples according to the manufacturer's instructions. The samples were kept in distilled water for one month, and microhardness values were measured after 24 hours, two weeks, and one month. They prepared the 2 mm thick and 5 mm diameter samples with and without a surface coat using GC Fuji IX GP® extra and G-Coat PLUS, and the samples were then kept in distilled water at 37°C for one month. In the microhardness measurements, 200 grams of force was applied for 15 seconds. The microhardness value in the group without protective resin increased significantly over time. It was reported that there was no time-dependent difference in the group in which the coating application was made. It has been concluded that exposure to water in the early period positively affects the hardness value of HVGIC and that the protective resin application creates lower hardness values on the surface of the samples. When the groups were compared, the microhardness of the unsealed group was higher in all time periods. Therefore, applying self-adhesive protective resin containing light-curing nano-fillers to the surface

of high-viscosity glass ionomer cement did not provide an advantage to the material in terms of hardness (78). In this study, in line with the above-mentioned study, the microhardness value was statistically significantly decreased after the surface coating application in all sample groups. Therefore, it can be considered that the surface microhardness of the material can be reduced with coating application. However, a statistically significant increase was observed in the microhardness value only in the ChemFil® Rock group with surface coating after aging.

On the other hand, in the EQUIA® Forte Fil and ACTIVA™ kids BioACTIVE-RESTORATIVE™ groups with surface coating, the microhardness values were statistically significantly decreased after aging. According to the manufacturer, ChemFil® Rock should present enhanced durability due to a zinc-containing glass with an accelerated ion release pattern compared to conventional GICs. Besides changes in the chemical composition of the glass particle, a novel acrylic acid copolymer with a high molecular weight was also incorporated into the material (78).

Al-Angari et al. (2014) compared the surface microhardness of zinc-containing glass ionomer cement (ChemFil® Rock) and different glass ionomer cements (GC Fuji IX GP® Extra, Ketac™ Molar Quick Aplicap, and EQUIA® Forte Fil) it was found that GC Fuji IX GP® Extra was the material with the highest surface hardness value. In the present study, unlike the study mentioned above, the highest microhardness value was found in the EQUIA® Forte Fil group before aging and without coating application (115).

Brito et al. (2009) compared the effect of different surface coating materials on the hardness of glass ionomer restorative material (Ketac™ Molar Easy Mix) in their *in-vitro* study. As a result of the study, the researchers stated that nail polish showed the highest success in protecting the material surface. It has been noted that nail polish is more successful because it adheres quickly to the surface and forms a thick film when it comes into contact with the surface. However, it has been reported that nail polish is not clinically indicated because it contains toluene in its structure and is not suitable for the oral environment (51).

Zoergiebel and Ilie (2013) compared the surface microhardness of three different conventional GICs (Riva Self Cure, GC Fuji IX GP® Fast, and GC Fuji IX GP® Extra) and zinc-containing glass ionomer cement (ChemFil® Rock). It was concluded that Fuji

IX GP Fast has the highest microhardness value. The microhardness value of ChemFil® Rock was significantly lower (125).

Bagheri et al. (2013) measured the microhardness values of glass ionomer materials before and after the coating application. Measurements of the materials kept in distilled water were made in the 4th and 8th weeks. In the measurements made in the 4th week, the microhardness values of all the materials were found to be significantly lower than the first measurements (57). Similar to the above-mentioned study, the surface microhardness values of all surface coating groups were statistically significantly lower when compared to the groups without coating in both baseline and after-aging groups.

Shimada et al. (2015) used EQUIA® Forte Fil + EQUIA Forte™ Coat, Fuji IX GP Extra + G-COAT PLUS™, Ketac™ Molar Quick Aplicap + Scotchbond Universal + Ketac Glaze, and Riva Self Cure + Riva Coat in their study. The samples were exposed to 10,000 cycles (under 200 grams load) in the toothbrushing simulator in the presence of toothpaste. The wear depth of the samples was measured by scanning electron microscopy. The microhardness values of samples were measured with a Vickers hardness device. Regarding wear resistance and surface hardness, EQUIA® Forte Fil + EQUIA Forte™ Coat and Fuji IX GP Extra + G-COAT PLUS™ have higher values than other groups. Because it has been observed that there is no unpolymerized layer in these two materials, EQUIA® Forte Fil + Equia Forte Coat showed higher abrasion resistance than other materials. It can be said that the above-mentioned study overlaps with this present study in terms of the high microhardness values of EQUIA® Forte Fil. In the present study, the highest microhardness values before the thermal aging procedure are found both in the uncoated and coated EQUIA® Forte Fil groups (126).

Ryu et al. (2019) evaluated the microhardness and wear resistance of a nano-filled surface coating. The samples were prepared from GIC and RMCIS and divided into three groups according to the surface coating: (1) no coating, (2) EQUIA Forte™ Coat, and (3) a filler-free adhesive coating. All samples were then kept in distilled water for 24 hours. Surface hardness was evaluated on a Vickers hardness testing machine. Using a chewing simulator, the abrasion resistance was evaluated after a sample was thermally cycled for 10,000 cycles. Surface hardness was highest in uncoated groups, followed by EQUIA Forte™ Coat and adhesive sealant groups (127). This study also found that uncoated groups showed higher microhardness results.

6. CONCLUSION

1. In the ACTIVA™ kids BioACTIVE-RESTORATIVE™ group, no statistically significant difference between the baseline and after-aging surface roughness values was found within the uncoated subgroup ($p=0.055$), whereas thermal aging revealed statistically higher surface roughness values than the baseline in the coated subgroup ($p=0.001$; $p<0.01$). Coating application significantly decreased the surface roughness values at baseline and after thermal aging in the ACTIVA™ kids BioACTIVE-RESTORATIVE™ group ($p=0.001$; $p<0.01$).
2. In the EQUIA® Forte Fil group, thermal aging revealed statistically higher surface roughness values than the baseline in both coated and uncoated subgroups ($p<0.01$). Coating application significantly decreased the surface roughness values at baseline and after thermal aging in the EQUIA® Forte Fil group ($p=0.001$; $p<0.01$).
3. In the ChemFil® Rock group, thermal aging revealed statistically higher surface roughness values than the baseline in both coated and uncoated subgroups ($p=0.001$; $p<0.01$). Coating application significantly decreased the surface roughness values at baseline and after thermal aging in the ChemFil® Rock group ($p=0.001$; $p<0.01$).
4. In the surface roughness test performed in the study, for the uncoated baseline groups, the highest surface roughness value was found in EQUIA® Forte Fil, followed by ChemFil® Rock and ACTIVA™ kids BioACTIVE-RESTORATIVE™, respectively. All groups' differences were statistically significant except for EQUIA® Forte Fil and ChemFil® Rock ($p<0.01$).

5. The highest surface roughness value for the uncoated aged groups was found in EQUIA® Forte Fil, followed by ChemFil® Rock and ACTIVA BioACTIVE. The difference between all groups was statistically significant ($p=0.001$; $p<0.01$).
6. Regarding the surface roughness of the baseline groups after the coating application, the highest surface roughness value was found in the ChemFil® Rock, followed by ACTIVA™ kids BioACTIVE-RESTORATIVE™ and EQUIA® Forte Fil. There was no statistically significant difference between the groups ($p>0.05$).
7. The highest surface roughness in the coated aged groups was found in EQUIA® Forte Fil, followed by ChemFil® Rock and ACTIVA™ kids BioACTIVE-RESTORATIVE™, respectively. All groups' differences were statistically significant except for EQUIA® Forte Fil and ChemFil® Rock ($p<0.01$).
8. In the ACTIVA™ kids BioACTIVE-RESTORATIVE™ group, thermal aging revealed statistically lower surface microhardness values than the baseline in both coated and uncoated subgroups ($p=0.001$; $p<0.01$). Coating application significantly decreased the surface microhardness values at baseline and after thermal aging in the ACTIVA™ kids BioACTIVE-RESTORATIVE™ group ($p=0.001$; $p<0.01$).
9. In the EQUIA® Forte Fil group, thermal aging revealed statistically lower surface microhardness values than the baseline in both coated and uncoated subgroups ($p<0.01$). Coating application significantly decreased the surface microhardness values at baseline and after thermal aging in the EQUIA® Forte Fil group ($p=0.001$; $p<0.01$).

10. In the ChemFil® Rock group, thermal aging revealed statistically lower surface microhardness values than the baseline in the uncoated subgroup, whereas it was statistically higher than the baseline in the coated subgroup ($p=0.001$; $p<0.01$). Coating application significantly decreased the surface microhardness values at baseline and after thermal aging in the ChemFil® Rock group ($p=0.001$; $p<0.01$).
11. In the surface microhardness test performed in the study for the uncoated baseline groups, the highest microhardness values were found in EQUIA® Forte Fil, followed by ChemFil® Rock and ACTIVA™ kids BioACTIVE-RESTORATIVE™ groups, respectively. The difference between all groups is statistically significant ($p<0.01$).
12. The highest surface microhardness value for the uncoated aged groups was found in EQUIA® Forte Fil, followed by ACTIVA™ kids BioACTIVE-RESTORATIVE™ and ChemFil® Rock, respectively. All groups' differences were statistically significant except for ACTIVA™ kids BioACTIVE-RESTORATIVE™ and ChemFil® Rock ($p<0.05$).
13. In the surface microhardness tests performed for the baseline groups with coating application, the highest surface microhardness value was found in EQUIA® Forte Fil, followed by ChemFil® Rock and ACTIVA™ kids BioACTIVE-RESTORATIVE™, respectively. All groups' differences were statistically significant ($p=0.001$; $p<0.01$).
14. In the coated aged groups, the highest surface microhardness was found in ChemFil® Rock and EQUIA® Forte Fil, followed by ACTIVA™ kids BioACTIVE-RESTORATIVE™, respectively. The difference between all groups was statistically significant ($p=0.001$; $p<0.01$).

Limitations of the Study;

- The use of thermocycling as an artificial aging method does not mimic the possible effects of the actual oral environment, such as the presence of saliva, pH changes, chewing pressure, tooth brushing, etc.
- Preparation of the samples was achieved under ideal *in vitro* conditions which did not necessarily reveal the challenges faced in the clinical setting.
- The same coating was applied to all glass ionomer cements regardless of their manufacturer. Different coating materials would possibly reveal different results.

In conclusion, the thermal aging procedure affected all materials' surface roughness and hardness. Therefore, the tested null hypothesis was rejected. When all the tested materials were evaluated in terms of surface roughness and microhardness, EQUIA® Forte Fil showed the highest surface roughness and microhardness values. All tested materials' surface roughness and hardness values decreased after coating application and thermal aging. Therefore, the tested H_1 hypothesis was partially rejected. Further *in vivo* and *in vitro* studies are needed to evaluate the long-term effects of surface coating materials and aging on the clinical success of glass ionomer-based dental restorative materials.

7. REFERENCES

1. Cho SY, Cheng AC. A review of glass ionomer restorations in the primary dentition. *J Can Dent Assoc.* 1999;65(9):491-495.
2. Croll T, Nicholson J. Glass ionomer cements in pediatric dentistry: Review of the literature. *Pediatr Dent.* 2002;24(5):423-429.
3. McLean JW. The clinical use of glass-ionomer cements. *Dent Clin North Am.* 1992;36(3):693-711.
4. Berg JH, Croll TP. Glass ionomer restorative cement systems: an update. *Pediatr Dent.* 2015;37(2):116-124.
5. Raju V, Venumbaka N, Mungara J, Vijayakumar P, Rajendran S, Elangovan A. Comparative evaluation of shear bond strength and microleakage of tricalcium silicate-based restorative material and radioopaque posterior glass ionomer restorative cement in primary and permanent teeth: an in vitro study. *J Indian Soc Pedod Prev Dent.* 2014;32(4):304-310.
6. Francisconi L, Scaffa P, de Barros V, Coutinho M, Francisconi P. Glass ionomer cements and their role in the restoration of non-cariou cervical lesions. *J Appl Oral Sci.* 2009;17(5):364-369.
7. Sidhu S, Sherriff M, Watson T. The effects of maturity and dehydration shrinkage on resin-modified glass-ionomer restorations. *J Dent Res.* 1997;76(8):1495-1501.
8. Socransky S, Haffajee A. Dental biofilms: difficult therapeutic targets. *Periodontol 2000.* 2002;28(1):12-55.
9. Marsh P. Dental plaque as a microbial biofilm. *Caries Res.* 2004;38(3):204-211.
10. Hse K, Leung S, Wei S. Resin-ionomer restorative materials for children: a review. *Aust Dent J.* 1999;44(1):1-11.
11. Lin A, McIntyre N, Davidson R. Studies on the adhesion of glass-ionomer cements to dentin. *J Dent Res.* 1992;71(11):1836-1841.
12. Bresciani E, Barata Tde J, Fagundes T, Adachi A, Terrin M, Navarro M. Compressive and diametral tensile strength of glass ionomer cements. *J Appl Oral Sci.* 2004;12(4):344-348.
13. Williams J, Billington R, Pearson G. Effect of moisture protective coatings on the strength of a modern metal-reinforced glass-ionomer cement. *J Oral Rehabil.* 1998;25(7):535-540.
14. Davidson C. Advances in glass-ionomer cements. *J Appl Oral Sci.* 2006;14

Suppl(SPEC. ISS.):3-9.

15. Hatton P, Brook I. Characterisation of the ultrastructure of glass-ionomer (poly-alkenoate) cement. *Br Dent J*. 1992;173(8):275-277.
16. Matsuya S, Maeda T, Ohta M. IR and NMR analyses of hardening and maturation of glass-ionomer cement. *J Dent Res*. 1996;75(12):1920-1927.
17. Wasson E, Nicholson J. New aspects of the setting of glass-ionomer cements. *J Dent Res*. 1993;72(2):481-483.
18. Lohbauer U. Dental Glass Ionomer Cements as Permanent Filling Materials? Properties, Limitations Future Trends. *Materials (Basel)*. 2010;3(1):76.
19. Kleverlaan C, van Duinen R, Feilzer A. Mechanical properties of glass ionomer cements affected by curing methods. *Dent Mater*. 2004;20(1):45-50.
20. Retief D, Bradley E, Denton J, Switzer P. Enamel and cementum fluoride uptake from a glass ionomer cement. *Caries Res*. 1984;18(3):250-257.
21. Pitt Ford T. The leakage of root fillings using glass ionomer cement and other materials. *Br Dent J*. 1979;146(9):273-278.
22. Wilson A, Prosser H, Powis D. Mechanism of adhesion of polyelectrolyte cements to hydroxyapatite. *J Dent Res*. 1983;62(5):590-592.
23. Kaya T, Tirali R. Cam İyonomer Simanlardaki Gelişmeler. *Atatürk Üniversitesi Diş Hekim Fakültesi Derg*. 2013;23:-.
24. Hume W, Mount G. In vitro studies on the potential for pulpal cytotoxicity of glass-ionomer cements. *J Dent Res*. 1988;67(6):915-918.
25. Small I, Watson T, Chadwick A, Sidhu S. Water sorption in resin-modified glass-ionomer cements: an in vitro comparison with other materials. *Biomaterials*. 1998;19(6):545-550.
26. Mitra S. Adhesion to dentin and physical properties of a light-cured glass-ionomer liner/base. *J Dent Res*. 1991;70(1):72-74.
27. Koroğlu A, Ekren O, Kurtoğlu C. Geleneksel Ve Adeziv Dental Simanlar Hakkında Bir Derleme Çalışması. *Atatürk Üniversitesi Diş Hekim Fakültesi Derg*. 2012;2012(2):205-216.
28. Burgess J, Norling B, Summitt J. Resin ionomer restorative materials: the new generation. *J Esthet Dent*. 1994;6(5):207-215.
29. Cattani-Lorente M, Dupuis V, Moya F, Payan J, Meyer J. Comparative study of the physical properties of a polyacid-modified composite resin and a resin-modified glass ionomer cement. *Dent Mater*. 1999;15(1):21-32.

30. Miyazaki M, Iwasaki K, Soyamura T, Onose H, Moore B. Resin-modified glass ionomers: Dentin bond strength versus time. *Oper Dent*. 1998;23(3):144-149.
31. Almuammar M, Schulman A, Salama F. Shear bond strength of six restorative materials. *J Clin Pediatr Dent*. 2001;25(3):221-225.
32. Berzins D, Abey S, Costache M, Wilkie C, Roberts H. Resin-modified glass-ionomer setting reaction competition. *J Dent Res*. 2010;89(1):82-86.
33. Kan K, Messer L, Messer H. Variability in cytotoxicity and fluoride release of resin-modified glass-ionomer cements. *J Dent Res*. 1997;76(8):1502-1507.
34. Deepa G, Shobha T. A clinical evaluation of two glass ionomer cements in primary molars using atraumatic restorative treatment technique in India: 1 year follow up. *Int J Paediatr Dent*. 2010;20(6):410-418.
35. Crowley C, Doyle J, Towler M, Hill R, Hampshire S. The influence of capsule geometry and cement formulation on the apparent viscosity of dental cements. *J Dent*. 2006;34(8):566-573.
36. Forsten L. Short- and long-term fluoride release from glass ionomers and other fluoride-containing filling materials in vitro. *Scand J Dent Res*. 1990;98(2):179-185.
37. Croll TP, Berg JH, Donly KJ. Dental repair material: a resin-modified glass-ionomer bioactive ionic resin-based composite. *Compend Contin Educ Dent*. 2015;36(1):60-65.
38. May E, Donly KJ. Fluoride release and re-release from a bioactive restorative material. *Am J Dent*. 2017;30(6):305-308.
39. Jackson R, Morgan M. The new posterior resins and a simplified placement technique. *J Am Dent Assoc*. 2000;131(3):375-383.
40. Gladys S, Van Meerbeek B, Braem M, Lambrechts P, Vanherle G. Comparative physico-mechanical characterization of new hybrid restorative materials with conventional glass-ionomer and resin composite restorative materials. *J Dent Res*. 1997;76(4):883-894.
41. Christensen G. Compomers vs. resin-reinforced glass ionomers. *J Am Dent Assoc*. 1997;128(4):479-480.
42. Cildir S, Sandalli N. Fluoride release/uptake of glass-ionomer cements and polyacid-modified composite resins. *Dent Mater J*. 2005;24(1):92-97.
43. Nicholson J. Polyacid-modified composite resins ("compomers") and their use in clinical dentistry. *Dent Mater*. 2007;23(5):615-622.

44. Shaw A, Carrick T, McCabe J. Fluoride release from glass-ionomer and compomer restorative materials: 6-month data. *J Dent*. 1998;26(4):355-359.
45. Mount G. Clinical performance of glass-ionomers. *Biomaterials*. 1998;19(6):573-579.
46. Ikemura K, Tay F, Endo T, Pashley D. A review of chemical-approach and ultramorphological studies on the development of fluoride-releasing dental adhesives comprising new pre-reacted glass ionomer (PRG) fillers. *Dent Mater J*. 2008;27(3):315-339.
47. Gordan V, Blaser P, Watson R, et al. A clinical evaluation of a giomer restorative system containing surface prereacted glass ionomer filler: results from a 13-year recall examination. *J Am Dent Assoc*. 2014;145(10):1036-1043.
48. Manuja N, Pandit I, Srivastava N, Gugnani N, Nagpal R. Comparative evaluation of shear bond strength of various esthetic restorative materials to dentin: an in vitro study. *J Indian Soc Pedod Prev Dent*. 2011;29(1):7-13.
49. Subramaniam P, Girish Babu K, Jayasurya S. Evaluation of Solubility and Microleakage of Glass Carbomer Sealant. *J Clin Pediatr Dent*. 2015;39(5):429-434.
50. Çehreli S, Yalçinkaya Z, Çehreli Z, Tirali R. Microleakage of newly developed glass carbomer cement in primary teeth. *Eur J Dent*. 2013;7(1):15-21.
51. Brito CR, Velasco LG, Bonini GAVC, Imparato JCP, Raggio DP. Glass ionomer cement hardness after different materials for surface protection. *J Biomed Mater Res - Part A*. 2010;93(1):243-246.
52. Hotta M, Hirukawa H, Yamamoto K. Effect of coating materials on restorative glass-ionomer cement surface. *Oper Dent*. 1992;17(2):57-61.
53. Hankins AD, Hatch RH, Benson JH, Blen BJ, Tantbirojn D, Versluis A. The effect of a nanofilled resin-based coating on water absorption by teeth restored with glass ionomer. *J Am Dent Assoc*. 2014;145(4):363-370.
54. Pandey P, Ewing G. Rheological characterization of petrolatum using a controlled stress rheometer. *Drug Dev Ind Pharm*. 2008;34(2):157-163.
55. van Heugten A, Versluijs-Helder M, Vromans H. Elucidation of the variability in consistency of pharmacopoeia quality petrolatum. *Drug Dev Ind Pharm*. 2017;43(4):595-599.
56. Cefaly DF, Seabra BG, Tapety CM, Taga EM, Valera F, Navarro MF. Effectiveness of surface protection of resin modified glass ionomer cements evaluated

- spectrophotometrically. *Oper Dent*. 2001;26(4):401-405.
57. Bagheri R, Taha NA, Azar MR, Burrow MF. Effect of G-Coat Plus on the mechanical properties of glass-ionomer cements. *Aust Dent J*. 2013;58(4):448-453.
 58. Gale M, Darvell B. Thermal cycling procedures for laboratory testing of dental restorations. *J Dent*. 1999;27(2):89-99.
 59. Giordano R. Materials for chairside CAD/CAM-produced restorations. *J Am Dent Assoc*. 2006;137 Suppl(9 SUPPL.):14S-21S.
 60. Pacifici E, Bossù M, Giovannetti A, La Torre G, Guerra F, Polimeni A. Surface roughness of glass ionomer cements indicated for uncooperative patients according to surface protection treatment. *Ann Stomatol (Roma)*. 4(3-4):250-258.
 61. Hashimoto M, Ohno H, Kaga M, Endo K, Sano H, Oguchi H. *In-vivo* degradation of resin-dentin bonds in humans over 1 to 3 years. *J Dent Res*. 2000;79(6):1385-1391.
 62. De Munck J, Van Meerbeek B, Yoshida Y, et al. Four-year water degradation of total-etch adhesives bonded to dentin. *J Dent Res*. 2003;82(2):136-140.
 63. Cenci M, Venturini D, Pereira-Cenci T, Piva E, Demarco F. The effect of polishing techniques and time on the surface characteristics and sealing ability of resin composite restorations after one-year storage. *Oper Dent*. 2008;33(2):169-176.
 64. Santerre J, Shajii L, Leung B. Relation of dental composite formulations to their degradation and the release of hydrolyzed polymeric-resin-derived products. *Crit Rev Oral Biol Med*. 2001;12(2):136-151.
 65. Kitasako Y, Burrow M, Nikaido T, Tagami J. The influence of storage solution on dentin bond durability of resin cement. *Dent Mater*. 2000;16(1):1-6.
 66. Bates J, Stafford G, Harrison A. Masticatory function—a review of the literature: (II) Speed of movement of the mandible, rate of chewing and forces developed in chewing. *J Oral Rehabil*. 1975;2(4):349-361.
 67. Toledano M, Osorio R, Albaladejo A, Aguilera FS, Osorio E. Differential effect of in vitro degradation on resin-dentin bonds produced by self-etch versus total-etch adhesives. *J Biomed Mater Res - Part A*. 2006;77(1):128-135.
 68. Li H, Burrow M, Tyas M. The effect of load cycling on the nanoleakage of dentin bonding systems. *Dent Mater*. 2002;18(2):111-119.
 69. Whitehead S, Shearer A, Watts D, Wilson N. Comparison of methods for measuring surface roughness of ceramic. *J Oral Rehabil*. 1995;22(6):421-427.

70. Zhang X, Anderson P, Dowker S, Elliott J. Optical profilometric study of changes in surface roughness of enamel during in vitro demineralization. *Caries Res.* 2000;34(2):164-174.
71. Cilli R, de Mattos MCR, Honorio HM, Rios D, de Araujo PA, Prakki A. The role of surface sealants in the roughness of composites after a simulated toothbrushing test. *J Dent.* 2009;37(12):970-977.
72. Erkli H, Ersöz E. Farklı fluor jellerin rezin materyallerin yüzey pürüzlülüğü üzerine etkisinin karşılaştırılması. *Gazi Üniversitesi Diş Hekim Fakültesi Derg.* 2012;29(2):79-85.
73. Gurdogan EB, Ozdemir-Ozenen D, Sandalli N. Evaluation of Surface Roughness Characteristics Using Atomic Force Microscopy and Inspection of Microhardness Following Resin Infiltration with Icon®. *J Esthet Restor Dent.* 2017;29(3):201-208.
74. Caughman W, Rueggeberg F. Shedding new light on composite polymerization. *Oper Dent.* 2002;27(6):636-638.
75. Callister, William D., and David G. Rethwisch. Fundamentals of materials science and engineering. Vol. 471660817. London: Wiley, 2000
76. Poskus L, Placido E, Cardoso P. Influence of placement techniques on Vickers and Knoop hardness of class II composite resin restorations. *Dent Mater.* 2004;20(8):726-732.
77. Attin T, Kocabiyik M, Buchalla W, Hannig C, Becker K. Susceptibility of enamel surfaces to demineralization after application of fluoridated carbamide peroxide gels. *Caries Res.* 2003;37(2):93-99.
78. Kanık Ö. Yüzey örtücü ile kaplanmış farklı restoratif cam iyonomer simanların özelliklerinin karşılaştırmalı olarak in-vivo ve in-vitro incelenmesi. Afyon Kocatepe Üniversitesi 2011.
79. Kazak M, Koymen S, Yurdan R, Tekdemir K, Donmez N. Effect of thermal aging procedure on the microhardness and surface roughness of fluoride ion containing materials. *Ann Med Res.* 2020;27(3):888.
80. Yap AU, Ng SC, Siow KS. Soft-start polymerization: influence on effectiveness of cure and post-gel shrinkage. *Oper Dent.* 2001;26(3):260-266.
81. Wattanapayungkul P, Yap AUJ, Chooi KW, Lee MFLA, Selamat RS, Zhou RD. The effect of home bleaching agents on the surface roughness of tooth-colored restoratives with time. *Oper Dent.* 2004;29(4):398-403.

82. Faridi MA, Khabeer A, Haroon S. Flexural Strength of Glass Carbomer Cement and Conventional Glass Ionomer Cement Stored in Different Storage Media over Time. *Med Princ Pract*. 2018;27(4):372-377.
83. Menne-Happ U, Ilie N. Effect of gloss and heat on the mechanical behaviour of a glass carbomer cement. *J Dent*. 2013;41(3):223-230.
84. Frencken JE. The ART approach using glass-ionomers in relation to global oral health care. *Dent Mater*. 2010;26(1):1-6.
85. Algera TJ, Kleverlaan CJ, Pahl-Andersen B, Feilzer AJ. The influence of environmental conditions on the material properties of setting glass-ionomer cements. *Dent Mater*. 2006;22(9):852-856.
86. Zhao J, Xie D. Effect of Nanoparticles on Wear Resistance and Surface Hardness of a Dental Glass-ionomer Cement. *Journal of Composite Materials*. 2009;43(23):2739-2752.
87. Yesilyurt C, Er K, Tasdemir T, Buruk K, Celik D. Antibacterial activity and physical properties of glass-ionomer cements containing antibiotics. *Oper Dent*. 2009;34(1):18-23.
88. Berg JH. Glass ionomer cements. *Pediatr Dent*. 2002;24(5):430-438.
89. Van Meerbeek B, Peumans M, Poitevin A, et al. Relationship between bond-strength tests and clinical outcomes. *Dent Mater*. 2010;26(2).
90. Tekbaş Atay M. , Oğuz Ahmet B. S. , Sayın Özel G. Ağız Ortamının Simulasyonu Açısından Termal ve Loading Siklusun Önemi. *Ata Diş Hek Fak Derg*. 2016; 26(4): 0-0.
91. Ereifej NS, Oweis YG, Eliades G. The effect of polishing technique on 3-D surface roughness and gloss of dental restorative resin composites. *Oper Dent*. 2013;38(1): E1-E12
92. Park SH, Krejci I, Lutz F. Microhardness of resin composites polymerized by plasma arc or conventional visible light curing. *Oper Dent*. 2002;27(1):30-37.
93. Nicholson JW, Czarnecka B. Kinetic studies of water uptake and loss in glass-ionomer cements. *J Mater Sci Mater Med*. 2008;19(4):1723-1727.
94. Gemalmaz D, Yoruc B, Ozcan M, Alkumru HN. Effect of early water contact on solubility of glass ionomer luting cements. *J Prosthet Dent*. 1998;80(4):474-478.
95. Miyazaki M, Keith Moore B, Onose H. Effect of surface coatings on flexural properties of glass ionomers. *Eur J Oral Sci*. 1996;104(5-6):600-604.
96. Hattab FN, Amin WM. Fluoride release from glass ionomer restorative materials

- and the effects of surface coating. *Biomaterials*. 2001;22(12):1449-1458.
97. Kamatham R, Reddy S. Surface coatings on glass ionomer restorations in Pediatric dentistry-Worthy or not. *J Indian Soc Pedod Prev Dent*. 2013;31(4):229-233.
 98. Leirskar J, Nordbø H, Mount GJ, Ngo H. The influence of resin coating on the shear punch strength of a high strength auto-cure glass ionomer. *Dent Mater*. 2003;19(2):87-91.
 99. Klinke T, Daboul A, Turek A, Frankenberger R, Hickel R, Biffar R. Clinical performance during 48 months of two current glass ionomer restorative systems with coatings: A randomized clinical trial in the field. *Trials*. 2016;17(1):1-14.
 100. Lu H, Roeder LB, Lei L, Powers JM. Effect of surface roughness on stain resistance of dental resin composites. *J Esthet Restor Dent*. 2005;17(2):102-108.
 101. Da Silva RC, Zuanon ACC. Surface roughness of glass ionomer cements indicated for atraumatic restorative treatment (ART). *Braz Dent J*. 2006;17(2):106-109.
 102. Jung M, Bruegger H, Klimek J. Surface Geometry of Three Packable and One Hybrid Composite after Polishing. *Oper Dent*. 2003;28(6):816-824.
 103. Heintze SD, Forjanic M, Rousson V. Surface roughness and gloss of dental materials as a function of force and polishing time in vitro. *Dent Mater*. 2006;22(2):146-165.
 104. Rios D, Honório HM, de Araújo PA, Machado MA de AM. Wear and superficial roughness of glass ionomer cements used as sealants, after simulated toothbrushing. *Pesqui Odontol Bras*. 2002;16(4):343-348.
 105. Ahmad Shiekh R, Ab Rahman I, Malik Masudi S, Luddin N. Modification of glass ionomer cement by incorporating hydroxyapatite-silica nano-powder composite: Sol-gel synthesis and characterization. *Ceram Int*. 2014;40(2):3165-3170.
 106. Garcia-Contreras R, Scougall-Vilchis RJ, Contreras-Bulnes R, Sakagami H, Morales-Luckie RA, Nakajima H. Mechanical, antibacterial and bond strength properties of nano-titanium-enriched glass ionomer cement. *J Appl Oral Sci*. 2015;23(3):321-328.
 107. Abu-Bakr N, Han L, Okamoto A, Iwaku M. Evaluation of the surface roughness of compomer by laser scanning microscopy. *Dent Mater J*. 2001;20(2):172-180.
 108. Marigo L, Rizzi M, La Torre G, Rumi G. 3-D surface profile analysis: different finishing methods for resin composites. *Oper Dent*. 2001;26(6):562-568.
 109. Bala O, Arisu HD, Yikilgan I, Arslan S, Gullu A. Evaluation of surface roughness and hardness of different glass ionomer cements. *Eur J Dent*. 2012;6(1):79-86.

110. Cibim DD, Saito MT, Giovani PA, et al. Novel Nanotechnology of TiO₂ Improves Physical-Chemical and Biological Properties of Glass Ionomer Cement. *Int J Biomater*. 2017;2017:7123919.
111. Rai R, Gupta R. In vitro evaluation of the effect of two finishing and polishing systems on four esthetic restorative materials. *J Conserv Dent*. 2013;16(6):564-567.
112. Yıldırım M, Patır A, Seymen F, Gençay K. Estetik restoratif materyallerinin cila işlemlerinden sonra yüzey yapısının SEM ile incelenmesi. *Atatürk Üniv Diş Hek Fak Derg*. 2012;22(3):277-286.
113. De Paula AB, De Fúcio SBP, Alonso RCB, Ambrosano GMB, Puppini-Rontani RM. Influence of chemical degradation on the surface properties of nano restorative materials. *Oper Dent*. 2014;39(3).
114. Baldağ İA. Çinko içerikli bir cam iyonmer simanın fiziksel özelliklerinin *in vitro* koşullarda değerlendirilmesi. Gazi Üniversitesi Sağlık Bilimleri Enstitüsü. 2014
115. Al-Angari SS, Hara AT, Chu TM, Platt J, Eckert G, Cook NB. Physicomechanical properties of a zinc-reinforced glass ionomer restorative material. *J Oral Sci*. 2014;56(1):11-16.
116. Korkut E, Botsalı MS, Şener Y. Evaluation of Mechanical and Fluoride Release Properties of a Bioactive Glass Added Glass Ionomer Based Fissure Sealant. *Atatürk Üniversitesi Diş Hekim Fakültesi Derg*. 2018;28(4):511-517.
117. Wang L, D'Alpino PHP, Lopes LG, Pereira JC. Mechanical properties of dental restorative materials: relative contribution of laboratory tests. *J Appl Oral Sci*. 2003;11(3):162-167.
118. Silva RC, Zuanon ACC, Esberard RR, Candido MSM, Machado JS. In vitro microhardness of glass ionomer cements. In: Journal of Materials Science: Materials in Medicine. Vol 18. *J Mater Sci Mater Med*; 2007:139-142.
119. Shintome LK, Nagayassu MP, Di Nicoló R, Myaki SI. Microhardness of glass ionomer cements indicated for the ART technique according to surface protection treatment and storage time. *Braz Oral Res*. 2009;23(4):439-445.
120. Ellakuria J, Triana R, Mínguez N, et al. Effect of one-year water storage on the surface microhardness of resin-modified versus conventional glass-ionomer cements. *Dent Mater*. 2003;19(4):286-290.
121. Xie D, Brantley W, Culbertson B, Wang G. Mechanical properties and microstructures of glass-ionomer cements. *Dent Mater*. 2000;16(2):129-138.
122. Silva KG, Pedrini D, Delbem ACB, Cannon M. Microhardness and fluoride release

- of restorative materials in different storage media. *Braz Dent J.* 2007;18(4):309-313.
123. McKinney J, Wu W. Chemical Softening and Wear of Dental Composites. *J Dent Res.* 1985;64(11):1326-1331.
124. Baloch F, Mirza A, Baloch D. An in-vitro study to compare the microhardness of glass ionomer cement set conventionally versus set under ultrasonic waves. *Int J Health Sci (Qassim).* 2010;4(2):149.
125. Zoergiebel J, Ilie N. An in vitro study on the maturation of conventional glass ionomer cements and their interface to dentin. *Acta Biomater.* 2013;9(12):9529-9537.
126. Shimada Y, Yamamoto K, Fukushima S, et al.. Evaluation of wear resistance of coating materials on GI restorative. *Dent Mater J.* 2015;31:24–25.
127. Ryu W, Park H, Lee J, Seo H. Effect of Nano-filled Protective Coating on Microhardness and Wear Resistance of Glass-ionomer Cements. *J Korean Acad Pediatric Dent.* 2019;46(2):226-232.

8. CURRICULUM VITAE

Personal Information

Name	Yağmur	Surname	YILDIRIM
-------------	--------	----------------	----------

Education

Degree	Department	The Name of Institution Graduated From	Graduation Year
University	Dentistry	Yeditepe University Faculty of Dentistry	2017
High School		Ümraniye Anadolu Lisesi	2010

Languages

Languages	Grades
------------------	---------------

English	70 (YDS)
---------	----------

Computer Skills

Program	Level
Microsoft Office	Good