



**UNIVERSITEIT VAN PRETORIA  
UNIVERSITY OF PRETORIA  
YUNIBESITHI YA PRETORIA**

**A Comparative Evaluation of the Surface Roughness, Surface  
Hardness and Microleakage of a Pure Ormocer with an  
Ormocer-Based Composite and a Nanocomposite Restorative  
Material.**

**Dr. Karien Jansen van Rensburg**

**Dissertation submitted in fulfilment of the Degree of MSc (Dent) at the  
Department of Odontology, School of Dentistry, Faculty of Health Sciences  
University of Pretoria, Pretoria, South Africa**

**SUPERVISOR: Dr D. Kritzinger MSc (Odont)**  
**CO-SUPERVISOR: Dr S. Arnold MSc (Odont)**

**AUGUST 2021**



# Table of Contents

<b>Table of Contents</b> .....	ii
<b>Declaration and Conflict of Interest</b> .....	v
<b>Acknowledgements</b> .....	vi
<b>Abbreviations</b> .....	viii
<b>Summary</b> .....	ix
<b>Key words</b> .....	xi
<b>List of Tables</b> .....	xii
<b>List of Figures</b> .....	xiii
<b>List of Appendices</b> .....	xix
Appendix A: Ethical Clearance .....	xix
Appendix B: Patient Consent form .....	xix
<b>Chapter 1: Introduction and Literature Review</b> .....	1
1.1 The Historical Evolution of Composite Resin Materials .....	2
1.2 Composition of Composite Resins .....	3
1.2.1 Inorganic Matrix .....	4
1.2.2 Organic Matrix .....	7
1.2.3 Organosilane Coupling Agent .....	8
1.2.4 Photoinitiator System .....	9
1.3 Nanocomposite Resins .....	10
1.3.1 Properties of Nanocomposites .....	12
1.4 Ormocers .....	13
1.4.1 Ormocer-Based Composites .....	19
1.4.2 Pure Ormocers .....	21
1.4.2.1 Cytotoxicity of Pure Ormocers vs. Dimethacrylate-Based Composites .....	22



1.5	The Importance of Surface Roughness Evaluation .....	24
1.6	The Importance of Surface Hardness Evaluation.....	25
1.7	The Importance of Microleakage Evaluation. ....	25
<b>Chapter 2 : Aim and Objectives .....</b>		<b>27</b>
2.1	Aim.....	27
2.2	Objective .....	27
2.3	Null Hypothesis .....	27
<b>Chapter 3 : Materials and Methods .....</b>		<b>28</b>
3.1	Study Design.....	28
3.2	Study Settings.....	28
3.3	Research Object Selection.....	28
3.4	Measurement.....	33
3.4.1	Surface Roughness .....	33
3.4.2	Surface Hardness.....	42
3.4.3	Microleakage .....	47
3.4.4	Stereomicroscope Images .....	60
3.5	Ethical Considerations .....	63
3.6	Statistical Considerations .....	64
3.6.1	Sample Size .....	64
3.6.2	Data Capturing .....	64
3.6.3	Statistical Analysis.....	65
<b>Chapter 4 : Results.....</b>		<b>66</b>
4.1	Surface Roughness.....	66
4.1.1	Scanning Electron Microscope (SEM) Images .....	70
4.2	Surface Hardness .....	71
4.3	Microleakage.....	73
4.3.1	Occlusal Microleakage.....	73



4.3.2	Gingival Microleakage. ....	74
4.3.3	Occlusal Microleakage vs. Gingival Microleakage.....	77
<b>Chapter 5 : Discussion</b> .....		<b>82</b>
5.1	Surface Roughness.....	82
5.2	Surface Hardness .....	87
5.3	Microleakage.....	89
5.4	Limitations of this study.....	92
<b>Chapter 6 : Conclusions</b> .....		<b>94</b>
<b>References:</b> .....		<b>96</b>
<b>Appendix A: Ethical Clearance</b> .....		<b>112</b>
<b>Appendix B: Patient consent form</b> .....		<b>114</b>



# Declaration and Conflict of Interest

I, Karien Jansen van Rensburg, declare that this dissertation, entitled “**A Comparative Evaluation of the Surface Roughness, Surface Hardness and Microleakage of a Pure Ormocer with an Ormocer-Based Composite and a Nanocomposite Restorative Material.**”, which I herewith submit to the University of Pretoria is my own original work and has never been submitted for any degree or examination at any other institution of higher learning.

All resources used or quoted in this dissertation have been specified and acknowledged in the complete references found at the end of this manuscript.

Furthermore, I declare that I have no competing interests, either financial or non-financial that represent a conflict of interest associated with the research carried out or any other aspects related to the content of this manuscript.

---

Karien Jansen van Rensburg

August 2021



# Acknowledgements

I would like to extend my sincerest appreciation and gratitude to the following individuals:

- Dr Dorette Kritzinger – Supervisor, Department of Odontology, University of Pretoria for her guidance, assistance and support.
- Dr Samantha Arnold – Co-Supervisor, Department of Odontology, University of Pretoria for her mentorship, support and guidance.
- Dr Silvia Jarchow – Scientific Service Manager at VOCO GmbH, Germany for the donation of all VOCO material and products.
- Ms. Deidre Ann Chanell – Representative of VOCO GmbH for whom it was never too much effort to assist on short notice.
- Ms. Karen Venter for ordering all necessary products and materials to complete my studies.
- Dr Paul Brandt for his assistance in the writing of my protocol.
- Professor Zunaid I. Vally – Head of Department of Odontology, University of Pretoria for financially contributing to this study.
- Mr Subusiso Mahlalela - Laboratory Manager of the Department of Material Science and Metallurgical Engineering, University of Pretoria for training, assisting and guiding me in the use of their micro-hardness tester and stereomicroscope.



- Mr Carl Coetzee – Scanning Electron Microscope and Microscopy specialist of the Department of Material Science and Metallurgical Engineering, University of Pretoria for his assistance and training me in the use of their Scanning Electron Microscope.
- Professor Piet Becker – Statistician, Department of Health Sciences, Research Office, University of Pretoria for his contribution.
- Ms Marizanne Booyens – Studio Manager, Department for Education Innovation, University of Pretoria for designing all the illustrations used in this dissertation.
- All my colleagues, past and present, for your support and encouragement.
- My husband Ray Jansen van Rensburg for his endless support, encouragement and love. What an exceptional honour and privilege to experience life with you.
- My beautiful children, Lené and Anru Jansen van Rensburg. You are precious gifts and I am so grateful for and proud of you.
- My mother, Rinie Vermeulen. Thank you so much for language editing but more so for your love and support throughout the years.
- My family for their continuous support and encouragement.
- My Heavenly Father who has showed me on multiple occasions that anything is possible through Him who gives me strength.

**“The things that are impossible with people are possible with God.”**

**- Luke 18:27**



## Abbreviations

%	-	percentage
µm	-	micrometre/s
Bis-EMA	-	Bisphenol-A diglycidyl methacrylate ethoxylate
Bis-GMA	-	Bisphenol-A glycidyl dimethacrylate
°C	-	degree Celsius
Class V	-	Greene Vardiman Black classification of cavities
cm	-	centimetre/s
CQ	-	Camphorquinone stabilizer
DMA	-	Dimethacrylate
g	-	gram/s
HEMA	-	2-hydroxy-ethyl-methacrylate
HV	-	Vickers Pyramid Number unit of hardness
LED	-	Light Emitting Diode
mm	-	millimetre/s
MPa $\sqrt{m}$	-	megapascals times the square root of the distance measured in metres
MPTS	-	3-methacryloxypropyltrimethoxysilane
mW/cm <sup>2</sup>	-	milliwatt per square centimetre/s
nm	-	nanometer/s
pH	-	power of hydrogen
PPRF	-	Pre-polymerized resin fillers
rpm	-	Revolutions per minute
sec	-	second/s
SEM	-	Scanning Electron Microscopy
Sof-Lex	-	Sof-Lex Diamond Polishing System
TEGDMA	-	Triethylene glycol dimethacrylate
UDMA	-	Urethane dimethacrylate
v/v	-	volume/volume percentage
VHN	-	Vickers Hardness Number
w/w	-	weight per weight





## Summary

**Introduction:** Resin composite is a popular, universally used, tooth coloured direct restorative material. Although much progress has been made to the filler technology in resin composites over the years, no fundamental changes have been made to the composition of the monomer matrix since Bowen introduced dimethacrylates in the early 1960s. As an alternative group of polymers, ormocers were developed as a new material class. Ormocer is an acronym for Organically Modified Ceramic. The first generation of ormocers were expected to combine both the advantages of inorganic polymers and organic polymers. However, due to the ongoing challenges to improve handling properties and to incorporate filler particles, conventional dental monomers, such as Bis-GMA and UDMA, had to be added to the ormocer matrix, diminishing the initial promising advantages of this material. It therefore becomes necessary to refer to this added dimethacrylate, first generation ormocer materials as ormocer-based composites. Pure ormocers are organically modified, non-metallic, inorganic compounds that are dimethacrylate-diluent-free. This unique material group differ from conventional composites in that the matrix has an organic but also an inorganic component. Ormocers are expected to combine both the advantages of inorganic polymers such as mechanical strength and thermal stability, as well as the advantages of organic polymers such as impact resistance and flexibility. Disadvantages such as polymerization shrinkage, high wear and leaching of monomers may be reduced by the large size of the ormocers' monomer molecules. **Aim:** The aim of this in vitro study was to determine whether a new generation of pure ormocers offer any clear differences when compared to a first generation ormocer-based composite and conventional nanocomposite in terms of surface roughness, surface hardness and microleakage. **Materials and Methods:** A pure ormocer (Admira Fusion) a first generation ormocer-based composite (Admira) and a nanocomposite (Filtek Z350 XT) were evaluated. Twelve disk samples (10mm x 2mm) of each material were prepared for both surface roughness and surface hardness. For surface roughness, all samples were finished and polished strictly according to the manufacturers' instructions and measured with a profilometer. For surface hardness, samples were stored in an incubator, polished and a Vickers diamond indenter (500g load and dwell time of 40sec) was used to record values. For microleakage, 36 standardised, Class V



cavities were prepared and randomly divided into three groups. Restored teeth were thermally fatigued, immersed in 2% methylene blue solution for 48 hours, sectioned and scored for occlusal and gingival microleakage.

**Results:** Statistical significance was set at  $p < 0.05$ . With surface roughness, there was no statistical significant difference between the experimental conditions after curing the materials through a Mylar strip and before polishing. The one-way analysis of variance (ANOVA) identified no significant difference in terms of surface roughness between the three material groups ( $p > 0.05$ ) when polished with water-cooling. There was however a statistical significant difference when the ormocer-based composite ( $p = 0.003$ ) and the nanocomposite ( $p < 0.001$ ) was compared with the pure ormocer when polished dry. A significant statistically higher surface hardness was identified for the nanocomposite compared to both the pure ormocer ( $p < 0.001$ ) and ormocer-based composite ( $p < 0.001$ ). Fisher's exact test identified no significant difference in terms of occlusal microleakage ( $p = 0.534$ ). Gingival microleakage revealed a marginal significant difference with the nanocomposite leaking marginally less compared to the pure ormocer ( $p = 0.093$ ). **Conclusion:** Based on the comparative evaluation and statistical analysis of the surface roughness and microleakage, there is no difference in using a pure ormocer compared to an ormocer-based composite or nanocomposite. The surface hardness of the nanocomposite was statistically significantly higher than for the pure ormocer and ormocer-based composite. The choice of material would be subject to the clinical condition and the practitioner's preference; however, the nanocomposite should be used in areas, which require increased surface hardness.



## Key words

Ormocers

Ormocer-Based Composites

Nanocomposites

Surface Roughness

Surface Hardness

Microleakage



# List of Tables

Table 3-1: Materials used in this study. ....	29
Table 3-2: Curing times for different materials as instructed by manufacturers.....	31
Table 3-3: Polishing systems, manufacturers' details and batch numbers. ....	33
Table 3-4: Polishing systems used according to the manufacturers' instruction.....	39
Table 3-5: Total etch, material placement, finishing and polishing procedures for each material according to the manufacturers' instructions .....	50
Table 4-1: Pairwise comparisons between experimental conditions, indicating no statistical differences. ....	67
Table 4-2: Pairwise comparisons between experimental conditions. Statistical differences shown by the yellow highlighted cells. ....	68
Table 4-3: Pairwise comparisons between materials. Statistical significant differences are indicated by the yellow highlighted cells.....	71
Table 4-4: Occlusal microleakage scores.....	73
Table 4-5: Gingival microleakage scores. Marginal statistical significant difference indicated by yellow highlighted cell. ....	75
Table 4-6: Pairwise comparison between the pure ormocer and the ormocer-based composite.....	76
Table 4-7: Pairwise comparison between the ormocer-based composite and the nanocomposite.....	77
Table 4-8: Pairwise comparison between the pure ormocer and the nanocomposite. Statistical significant difference indicated by yellow highlighted cell.....	78
Table 4-9: Occlusal vs Gingival microleakage of the pure ormocer. ....	79
Table 4-10: Occlusal vs Gingival microleakage of the ormocer-based composite. ..	80
Table 4-11: Occlusal vs Gingival microleakage of the nanocomposite. Statistical significant difference indicated by yellow highlighted cell.....	81



# List of Figures

Figure 1-1: The linear development of dental composite formulations based on filler particle adaptations. .... 6

Figure 1-2: Ormocer resin matrix with organic polymerizable side chains added to an inorganic polysiloxane backbone. Multiple methacrylate groups with double bonds are available for bonding..... 14

Figure 1-3: A silicon atom that is tetrahedrally surrounded by oxygen atoms and a methacrylate saline compound with double bonds present as a special coating (indicated by yellow sphere) on the surface of each glass particle..... 15

Figure 1-4: Methacrylate saline compound with double bonds present on the surface of the nanoparticles..... 16

Figure 1-5: Methacrylate saline compound with double bonds within the ormocer matrix forming part of a network of linking units and double bonds..... 17

Figure 1-6: The blue light of light curing initiates a chain reaction and the double bonds of the elements react with one another to form a stable three-dimensional network..... 18

Figure 1-7: Shorter Bis-GMA molecule with only two methacrylate groups, with their double bonds, available for bonding..... 19

Figure 3-1: The dental materials used in the current study: A) Admira with Admira Bond, B) Admira Fusion with Futurabond U, C) Filtek Z350 XT with Single Bond Universal Adhesive. .... 32

Figure 3-2: The polishing systems used in the current study: A) Dimanto, B) Sof-lex Diamond polishing system, Polishing Spiral (pink) and Pre-polishing Spiral (beige). .... 33

Figure 3-3: A) ISOMET low speed saw used to cut aluminium pipe for cylindrical moulds, B) Cylindrical mould being cut by low speed saw, C) Aluminium cylindrical mould (10mm diameter x 2mm height). .... 34

Figure 3-4: D-Light Pro dual wavelength LED curing light..... 35

Figure 3-5: Bluephase radiometer measuring light intensity before curing samples. 35



Figure 3-6: A) Mylar strips were placed on both sides of the uncured material, B) Sample pressed between two glass slabs, 1mm thick, C) Light finger pressure used to extrude excess material, D) Polymerization of samples according to the manufacturers' instruction..... 36

Figure 3-7: A) Samples removed from mould with finger pressure, B) Completed Admira Fusion samples C) Completed Filtek Z350 XT samples, D) Completed Admira samples. .... 37

Figure 3-8: A) Red and yellow striped, flame shaped finishing diamond burs, B) NSK NLX nano electric micromotor. .... 38

Figure 3-9: Arrow marked on transparent plastic so that all samples could be polished in the same direction. .... 38

Figure 3-10: A) Wheel template with markings of 0°, 120° and 240°, B) Measurement taken on 0° with the SurfTest SJ 210 profilometer C) The profilometer being calibrated using the precision specimen..... 40

Figure 3-11: A) Reading in progress B) Reading completed on the sample in the specific direction..... 41

Figure 3-12: A) Two random samples from each group. B) Carbon spattered samples. C) Scanning electron microscope. .... 42

Figure 3-13: Twelve completed samples of A) Admira Fusion, B) Admira and C) Filtek Z350 XT. .... 43

Figure 3-14: Samples stored in glass containers filled with distilled water. A) Admira Fusion, B) Admira, C) Filtek Z350 XT. .... 44

Figure 3-15: Incubator..... 44

Figure 3-16: Five indentations in a straight line, no closer than 0.5mm to the adjacent indentation..... 45

Figure 3-17: A) Vickers Diamond Indenter, Struers, Duramin-40 AC 3. B) 500g load applied with a dwell time of 40sec. C) Projected image after indentation was made..... 46

Figure 3-18: A) Diamond Dome shaped Fissure bur measured to 2mm with a rubber stopper. B) Rubber stopper secured using silicone. C) Silicone glue gun used to secure the rubber stopper. .... 47

Figure 3-19: A) Silicone mould used. B) A permanent marker was used to outline the cavity form. C) The outlined box shaped cavity..... 48



Figure 3-20: A) Prepared cavity with the cemento-enamel junction located in the middle of the cavity. B) Hu-Friedy Williams periodontal probe used to confirm measurements..... 49

Figure 3-21: A) Each group was marked with a label and placed within an enclosed sift. B) 5°C Cold bath, C) 55°C Heat bath. .... 53

Figure 3-22: Proto-tech thermal cycler and PolyScience cooling and heat baths..... 54

Figure 3-23: A) Silicone moulds used to embed the apices in acrylic resin, B) Apical foramens of the teeth sealed with acrylic resin, to prevent dye penetration. .... 54

Figure 3-24: Tooth surfaces coated with nail varnish, except for a 2mm band around the margins of each restoration..... 55

Figure 3-25: Samples immersed in 2% methylene blue dye solution for 48 hours. ... 55

Figure 3-26: Sample embedded in clear self-cure resin. .... 56

Figure 3-27: A) Slow-speed diamond saw cutting the sample vertically in a buccolingual direction through the centre of the restoration. B) Example of a vertically cut sample..... 57

Figure 3-28: Olympus SZX7 Stereomicroscope used to visually examine dye penetration of each sample..... 57

Figure 3-29: Graphical illustration of the criteria used to score the occlusal and gingival microleakage..... 59

Figure 3-30: Sample with an occlusal microleakage score of 1 and a gingival microleakage score of 4. .... 60

Figure 3-31: Sample with an occlusal microleakage score of 3 and a gingival microleakage score of 1. .... 60

Figure 3-32: Sample with an occlusal microleakage score of 4 and a gingival microleakage score of 2. .... 61

Figure 3-33: Sample with an occlusal microleakage score of 2 and a gingival microleakage score of 0. .... 61

Figure 3-34: Sample with an occlusal microleakage score of 4 and a gingival microleakage score of 3. .... 62

Figure 4-1: Mean roughness values of materials before polishing and after curing through a Mylar strip. Values calculated from three readings of each of the 12 samples per material. .... 67



Figure 4-2: The bar graph indicates the combined mean surface roughness of all three readings for each of the 12 samples per material after finishing and polishing procedures. Statistical differences are illustrated graphically. Experimental conditions under the same black line are not statistically different from one another, while those that do not share a common line differ statistically significantly from one another. .... 69

Figure 4-3: Pure ormocer A) 500x magnification and B) 1000x magnification after polishing. Visible scratch lines and pits can be observed..... 70

Figure 4-4: Ormocer-based composite A) 500x magnification and B) 1000x magnification after polishing. Visible scratch lines and irregularities can be observed. .... 70

Figure 4-5: Nanocomposite A) 500x magnification and B) 1000x magnification after polishing. Visible scratch lines, voids and pits can be observed. .... 71

Figure 4-6: The bar graph indicates the combined mean surface hardness of all five readings for each of the 12 samples per material. Statistical differences are illustrated graphically where materials under the same black line are not statistically different from one another, while those that do not share a common line differ statistically significantly from one another. .... 72

Figure 4-7: Bar graph indicates the percentage of occlusal microleakage according to the score criteria used. .... 74

Figure 4-8: Bar graph indicates the percentage of gingival microleakage according to the score criteria used. .... 75

Figure 4-9: Bar graph indicates the percentage of gingival microleakage of the pure ormocer vs the ormocer-based composite according to the score criteria used. .... 76

Figure 4-10: Bar graph indicating the percentage of gingival microleakage of the ormocer-based composite vs the nanocomposite according to the score criteria used..... 77

Figure 4-11: Bar graph indicates the percentage of gingival microleakage of the pure ormocer vs the nanocomposite according to the score criteria used... 78

Figure 4-12: Bar graph indicates the percentage of occlusal microleakage with gingival microleakage of the pure ormocer according to the score criteria used. .... 79





Figure 4-13: Bar graph indicates the percentage of occlusal microleakage with gingival microleakage of the ormocer-based composite according to the score criteria used..... 80

Figure 4-14: Bar graph indicates the percentage of occlusal microleakage with gingival microleakage of the nanocomposite according to the score criteria used. .... 81



# List of Appendices

Appendix A: Ethical clearance

Appendix B: Patient consent form



# Chapter 1: Introduction and Literature Review

Much progress has been made on the composition of filler technology in composite resins over the years.<sup>1</sup> However, no fundamental changes have been made to the composition of the monomer matrix since the introduction of dimethacrylates by Bowen in early 1960.<sup>2</sup> As an alternative group of polymers, ormocers were developed as a new material class.<sup>3</sup> Ormocer is an acronym for Organically Modified Ceramic.<sup>3</sup> The first generation of ormocers were expected to combine both the advantages of inorganic polymers and organic polymers. However, due to the ongoing challenges to improve handling properties and to incorporate filler particles, conventional dental dimethacrylate monomers, such as Bis-GMA and UDMA, had to be added to the ormocer matrix, diminishing the initial promising advantages of this material.<sup>3</sup> It therefore becomes necessary to refer to this added dimethacrylate, first generation ormocer materials as ormocer-based composites.<sup>3</sup>

Controlling the degree of cure, polymerization shrinkage and adhesion to adhesive systems and tooth structure become critical in order to improve biocompatibility and biofunctional properties of resin-based dental composites.<sup>4,5,6</sup> Materials are exposed to stresses during polymerization shrinkage of the matrix as well as aging in the oral environment.<sup>6</sup> Saliva's aqueous medium, masticatory forces, variations in pH and temperature fluctuations exert detrimental effects on the resin matrix and fillers.<sup>6,7</sup> Persistent complications were experienced with initial tooth-coloured restorations such as gap formation with the possibility of secondary caries, caused by polymerization shrinkage.<sup>8</sup> Additional complications included: fractures due to the loss of occlusal relationships, increased degradation, and wear.<sup>8</sup> To overcome these obstacles, new matrices were developed and the filler content manipulated in terms of size, shape, type and amount of filler used in the composite resin matrix.<sup>6</sup>

As an alternative group of polymers, pure ormocers were introduced as a new restorative material.<sup>9,10</sup> This unique material group is an organically modified, non-metallic, inorganic compound material.<sup>11</sup> The ormocer, Admira Fusion (VOCO GmbH, Cuxhaven, Germany), was introduced to the market in 2015, as the world's first pure



ceramic-based restorative material.<sup>12</sup> Admira Fusion features pure ormocer matrix chemistry without the addition of conventional dimethacrylates.<sup>3,12</sup>

## 1.1 The Historical Evolution of Composite Resin Materials

Composite resin is a popular, universally used, tooth coloured, direct restorative material.<sup>13</sup> Due to the material's superior aesthetics and advantages of adhesive technology when used in conjunction with a bonding system, it is favoured above dental amalgams.<sup>13</sup>

In dentistry, composite resins are used for multiple applications since they tend to resemble dental hard tissues in both function and appearance.<sup>14</sup> These applications include but are not limited to restorative materials, pit and fissure sealants, cavity liners, crowns, core build-ups, overlays, inlays, cements for single or multiple tooth indirect prostheses, provisional restorations, endodontic sealers, root canal posts and orthodontic devices.<sup>15</sup>

The formulation of dental composites is tailored to meet particular requirements and distinguish the different dental composites from one another.<sup>15,16</sup> The structure and composition of a composite will determine its clinical behaviour regarding mechanical, physical and aesthetic properties.<sup>17,18</sup>

Composite resins were introduced in the 1940s in an attempt to overcome the shortcomings of acrylic resins used in the field of basic conservative dentistry.<sup>18,19</sup> In 1955, Buonocore<sup>20</sup> made use of orthophosphoric acid in an attempt to improve the adhesion of acrylic resins to the enamel tooth surface. Acrylic resin monomers could only form linear chain polymers.<sup>18,19</sup>

Bisphenol-A glycidyl dimethacrylate (Bis-GMA) monomers, developed by Bowen in 1962, were then developed to attempt improvement of the physical properties of acrylic resins.<sup>2,21</sup> These early composites required mixing of a base paste with a



catalyst paste and were chemically cured.<sup>18</sup> Problems were however experienced with the mixing process, colour stability and proportions of these materials.<sup>18,19</sup>

Composites requiring electromagnetic radiation for polymerization were developed in the 1970s. These composites replaced composite materials which required mixing, together with their associated disadvantages.<sup>18,19</sup> The development of a photo-curable composite resin system, Nuva (Dentsply Sirona/Caulk, Konstanz, Germany) in the late 1970s was considered a major breakthrough in composite technology.<sup>19,22</sup>

The ideal dental restorative material should be biocompatible, resistant to masticatory forces and should aesthetically resemble that of natural enamel and dentine.<sup>19,23</sup> Furthermore, to ensure adequate longevity of a dental restoration, its mechanical and physical properties should mimic that of a natural tooth.<sup>19,23</sup>

Because of many modifications over the years, modern composite materials are reliable restorative materials for nearly all dental applications when used correctly.<sup>13</sup> Scientists, manufacturers, researchers and clinicians will continue their pursuit for an ideal restorative material that more closely resembles healthy tooth structure.<sup>19,23</sup>

## **1.2 Composition of Composite Resins**

The various types of composite materials are identified by their consistency.<sup>15</sup> They vary from packable composites, designed to avoid collapsing and to form tight contacts with adjacent teeth, to flowable composites with a viscosity so low they can be dispensed from fine bore syringes.<sup>15,24,25</sup> Packable composites were designed in an attempt to limit wear of a restoration, polymerization shrinkage and fracture resistance within the body and margins of the restoration.<sup>25</sup> Flowable composites are commonly used in areas where additional removal of tooth structure can be avoided such as small pits and grooves.<sup>25</sup> Flowable composites can also contain fluoride, making them ideal as a preventable sealant, especially for children with a high caries risk.<sup>25</sup>



There are three main components in the composition of composites.<sup>15,17,18</sup> The first component is the organic matrix, which has a dimethacrylate polymeric matrix.<sup>15,17,18</sup> The second component is a dispersed phase consisting of reinforced filler particles, usually fabricated of radiopaque glass, making up the inorganic matrix.<sup>15,17,18</sup> The third component is an interfacial phase of organo-silane coupling agents, fusing the filler particles to the organic matrix.<sup>15,17,18</sup>

Furthermore, composites also contain chemicals that control the polymerization process.<sup>15,19,26,27</sup> These chemicals are photoinitiators and co-initiators for visible light activation, and polymerization inhibitors that allow for the extension of working time and storage stability.<sup>15,19,26,27</sup> Surfactants are also added to enhance fluidity without reducing filler particles resulting in a decrease in mechanical properties and an increase in shrinkage.<sup>15,19,26,27</sup> Composites contains various pigments to allow for the various shades that can be utilized for aesthetic restorations.<sup>15,19,26,27</sup>

Each component of the composite material influences the properties of the composite in a different manner.<sup>25</sup> Typically, the filler content will determine the material's properties such as hardness, wear resistance, gloss, polishability, radiopacity and the release of fluoride.<sup>25</sup> The organic matrix determines the curing rate, polymerization shrinkage, water uptake, storage stability, light sensitivity and colour stability of the material.<sup>25</sup> The chemical composition of both the fillers and organic matrix will determine the material's translucency, thermal expansion coefficient, flexural strength, flexural modulus of elasticity, water solubility, consistency, and biocompatibility.<sup>25</sup>

### **1.2.1 Inorganic Matrix**

The inorganic matrix or dispersed phase is the mineral component of a composite resin and consists of filler particles.<sup>19,28</sup> The filler type and filler morphology have been areas of significant advancement, much more than that of the organic matrix.<sup>15,29</sup> Because the physical properties of a composite is so dependent on the influence of the filler particles, they are often used in the classification of dental composites based



on the particle size and type of filler used.<sup>25</sup> Quartz, silica and / or ceramic are usually used to fabricate filler particles.<sup>13</sup>

The higher the filler content of a composite, the greater the elastic modulus, wear resistance, tensile strength, surface hardness and flexural strength of the material.<sup>13</sup> Polymerization shrinkage, water absorption and linear coefficient are also reduced with increased filler content of a composite resin material.<sup>13,19,30</sup> The strength of a material is subjective to the chemistry of the resin phase at a given filler size, content and geometry.<sup>29,31,32,33</sup>

Conventional composites had macro-filler particles that far surpassed 1 $\mu$ m in size, often exceeding 50 $\mu$ m, the diameter of a human hair.<sup>15</sup> Macrofiller particles made polishing, and the retention of surface smoothness, very difficult even though the materials were very strong.<sup>15</sup> To aid in the reinforcement of filler particles into the matrix, the size of the particles were purposely reduced.<sup>15</sup> Wear resistance and polishability of materials improved significantly with the addition of smaller filler particles.<sup>15,29</sup>

“Microfill” composites were manufactured in an attempt to address long-term aesthetic issues and consisted of amorphous spherical silica reinforced particles approximately 40nm in size.<sup>15</sup> Lack of the concept of “nano” at the time prevented appropriate naming since these microfill composites would have been more accurately called “nanofills”.<sup>15</sup> These materials contained low filler levels but levels could be increased with the incorporation of highly filled, pre-polymerized resin fillers (PPRF) into the matrix to which further “microfill” particles could be added.<sup>15</sup> Although these “microfill” composites were more polishable, they were also weaker due to their low filler content.<sup>15</sup>

In order to achieve the manufacturing of a composite that provided both strength and enhanced polishability, further adjustment of the particle size was done to produce small particle hybrid composites.<sup>15</sup> Nearly all composites currently in use are hybrid composites.<sup>23</sup> This means that the composite contains at least two different fillers in



terms of shape, size or chemical composition.<sup>25</sup> Hybrid composites can further be divided into “midfills”, with a particle size slightly greater than 1µm but also containing some 40nm sized silica “microfillers”.<sup>15</sup>

“Minifill” or “microhybrids” resulted from further grinding and milling techniques and provided filler particles averaging 0.4-1.0µm in size.<sup>15</sup> Because of the strength and polishability provided by these materials, they can be considered universal composites suitable for both anterior and posterior restorations.<sup>15,24</sup>

“Nanofill” composites contain filler particles of nanoscale and most microhybrids have been adjusted by the manufacturers to include more nanoparticles and pre-polymerized resin fillers, resembling those found in microfill composites.<sup>15</sup> This group of composites are referred to as “nanohybrids”.<sup>15</sup> Distinguishing this group of composites from microhybrids are difficult.<sup>15</sup> The linear development of dental composite formulations based on their filler particle adaptations are depicted in Figure 1-1.

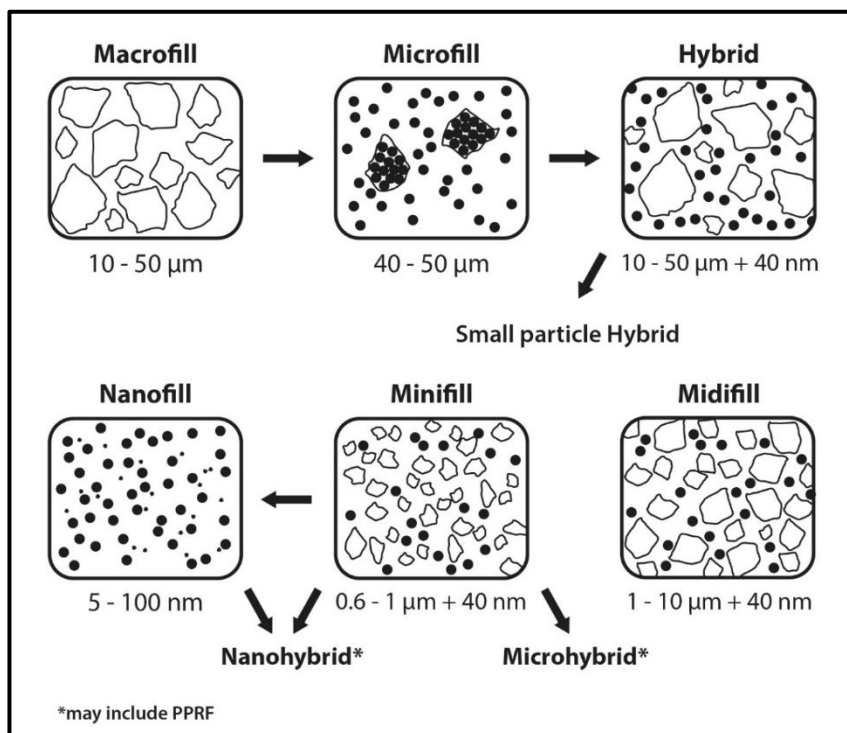


Figure 1-1: The linear development of dental composite formulations based on filler particle adaptations.<sup>15</sup>





The classification of composite resins based on filler size does not necessarily reflect the filler composition, the use of PPRF or filler morphology of the material.<sup>34</sup> Therefore, not all nanohybrids will display the same properties and some commercially available nanohybrids will have filler particles of a larger size ( $>1\mu\text{m}$ ).<sup>34,35,36</sup> Physical and mechanical properties differ greatly among materials or test-centres, a fact documented by numerous data reporting on nanohybrid comparisons.<sup>34</sup> Hardness, flexural strength or fracture toughness, for example, vary between 19-80HV O.5/20, 50-150MPa and  $1-2.5\text{MPa} \sqrt{m}$  respectively.<sup>34,35,37,38,39</sup> These properties are interconnected and depend upon filler geometry, composition, size distribution, surface coating, mass and filler volume content.<sup>34</sup>

### 1.2.2 Organic Matrix

Currently the focus for improvement has shifted from the inorganic filler matrix to the polymeric organic matrix.<sup>15</sup> This is done in an attempt to reduce polymerization shrinkage and its related stresses on tooth structure.<sup>15</sup>

The monomer content of an organic matrix should meet certain requirements:<sup>25</sup>

- The dental monomers must be colourless, in liquid form and show a high conversion rate during polymerization (homopolymerization or copolymerization with other monomers).
- Monomers must remain stable over a period of time.<sup>23</sup> Premature polymerization during storage in the refrigerator or at room temperature should be avoided.
- After light polymerization, polymers should show a high light and discolouration stability.



- The dental monomers must be resistant to the functional challenges of the oral environment and be biocompatible without any cancerogenic or mutagenic potential.

The ideal monomer for a restorative composite should have low polymerization shrinkage and low water sorption with exceptional mechanical properties after polymerization.<sup>25</sup>

In current commercial composites, the most predominant base monomer used is Bisphenol-A glycidyl dimethacrylate (Bis-GMA).<sup>15,16,25</sup> Bis-GMA has a very high viscosity and is often mixed with other dimethacrylates such as Urethane dimethacrylate (UDMA), Triethylene glycol dimethacrylate (TEGDMA) and other monomers to reduce the viscosity of the material.<sup>15,16,25</sup> The higher the proportion of TEGDMA and the lower the proportion of Bis-GMA, the more polymerization shrinkage will occur.<sup>13,40</sup> Replacing Bis-GMA with TEGDMA will reduce the flexural strength but increase the tensile strength of the material.<sup>13,40</sup>

Light polymerization converts monomers into polymer chains via cross-linking of the individual monomers.<sup>13</sup> Monomers that are not converted to polymers will be released from the restorative material during degradation.<sup>13</sup> The longer and more complete the light polymerization, the less the release of residual monomers.<sup>13</sup>

### **1.2.3 Organosilane Coupling Agent**

Without a coupling agent, there is no chemical bond between the filler particles of a conventional composite and its organic matrix.<sup>19</sup> The surface of the filler particles are usually modified with a coupling agent to ensure a strong and lasting bond between the matrix and filler particles.<sup>25</sup> The coupling agents have a methacrylate group on one end and a silane group on the other end which can bond the resin matrix to the filler particles, thus reducing the loss of filler particles over time.<sup>19,41</sup>



Material properties are dependent on a stable bond between the filler particles and the organic matrix.<sup>19</sup> Abrasion and fracture resistance of a restorative material are affected by the quality of the bond.<sup>42</sup> Vinyl, methyl-silane and epoxy are the most commonly used coupling agents.<sup>19</sup>

### 1.2.4 Photoinitiator System

Polymerization of most composites are solely light activated which depend completely on blue light to activate the photo-initiators.<sup>15,43</sup> Other composites have a chemically cured component giving it a dual-cure property.<sup>15,43</sup>

Photoinitiators must meet certain basic requirements:<sup>25</sup>

- show strong visible light absorption. Visible light absorption should relate with the emission spectrum of popular used light sources such as quartz-tungsten-halogen lights and light emitting diodes (LED). Light absorption should therefore fall within the blue region of the visible light spectrum (400-500nm).
- must have a high photoreactivity.
- should be soluble and compatible with commercially used dental resins.
- thermal storage stability should be sufficient.
- the photoinitiator and corresponding photolytic reaction products should be toxicologically harmless.
- must not form coloured by-products and should show good bleaching behaviour.



Camphoroquinone (CQ), with tertiary amines as co-initiators, meets most of these requirements and is therefore the most commonly used photoinitiator system.<sup>15,25,43</sup> Other photoinitiators used in some commercial formulations include PPD (1-phenyl-1,2-propanedione), Irgacure 819 (bisacylphosphine oxide) and Lucirin TPO (monoacylphosphine oxide).<sup>44</sup> Based on promising experimental results additional photoinitiators such as OPPI (p-octyloxy-phenyl-phenyl iodonium hexafluoroantimonate), have been proposed.<sup>44,45,46</sup>

### 1.3 Nanocomposite Resins

The adhesion of a composite resin restorative material to enamel and dentine becomes a vital decisive factor in the longevity and reliability of a restoration.<sup>19</sup> The quality of the bond between tooth structure and restorative material will ultimately influence the mechanical strength, marginal adaptation and marginal seal of an adhesive restoration.<sup>19</sup>

Structurally the particle size of conventional composites (40nm to 0.7nm) differ extensively from that of hydroxyapatite crystals, enamel rods and dentinal tubules (1nm to 10nm).<sup>19</sup> This could compromise the adhesion of restorative material to tooth structure.<sup>19</sup> The nanosized filler particles of nanocomposites have the potential to provide a more natural and stable interface between the hard tissues of the tooth and the adhesive restoration.<sup>19</sup>

Nanocomposites are available as nanofill and nanohybrid types.<sup>47</sup> Nanofill types contain nanomers that are nano-sized filler particles.<sup>18,47,48,49</sup> Groups of these particles form nanoclusters.<sup>18,47,48,49</sup> Nanohybrids contain milled glass fillers and nanoparticles.<sup>18,47,48,49</sup>

Nanofillers greatly differ from traditional fillers.<sup>48</sup> Various techniques are used to manufacture nanofillers such as flame pyrolysis, flame spray pyrolysis and sol-gel



processes.<sup>18,48</sup> Synthetic chemical processes are used to produce building blocks on a molecular scale in order to produce filler particles below 100nm in size.<sup>48</sup>

Nano-sized filler particles can further be categorized into two groups.<sup>14</sup> The first group, nanomeric particles, contains discrete nanoparticles sized between 5-100nm.<sup>14</sup> These silica nanoparticles are monodispersed and non-aggregated.<sup>48</sup> Thickening of the composite paste consistency as a result of an increased filler surface area and due to smaller filler particle sizes, allows for only a limited content of nanoparticles resulting in low loading levels within the composite matrix.<sup>14,25</sup>

The second group of nano-sized fillers, nanoclusters, consists of clusters of primary nanoparticles of which the size may exceed 100nm by far.<sup>18,48</sup> With appropriate surface treatment, these nanoparticle clusters are manageable in high content within the composite matrix.<sup>18,48</sup>

Nanocluster fillers can be divided into two types.<sup>48</sup> With the first type the primary particle size ranges from 2-20nm, while the spheroidal cluster of particles has a broad size averaging 0.6 $\mu$ m.<sup>48</sup> It consists of zirconia-silica particles synthesized from a colloidal solution of silica and a zirconyl salt.<sup>18,48</sup> The second type of nanocluster filler has a general secondary particle size distribution with an average of 0.6 $\mu$ m, and is synthesized from 75nm primary particles of silica.<sup>48</sup> These silica particles are treated with 3-methacryloxypropyltrimethoxysilane (MPTS).<sup>48</sup> MPTS acts as a coupling agent containing a silica ester functional group on the one end that enables bonding with the inorganic surface.<sup>48</sup> On its other end it contains a methacrylate group to make the filler resin compatible before light polymerization in order to prevent any aggregation or agglomeration of these filler particles.<sup>48</sup>

Nanofiller particles are usually invisible due to their extremely small size.<sup>18</sup> These particles are unable to scatter or absorb visible light because their dimensions fall below the wavelength of visible light (0.4 – 0.8 $\mu$ m), therefore providing the advantage of improved optical properties.<sup>18</sup>



### 1.3.1 Properties of Nanocomposites

#### Polymerization Shrinkage

Nanocomposites have a low shrinkage value mainly due to the strong interfacial interactions between the nanoparticles and the resin monomers as well as the low shrinkage epoxy resin.<sup>18,50,51,52</sup> The degree of shrinkage between different commercial nanocomposites also depends on the chemistry and total monomer content of the organic matrix.<sup>18,50,51,52</sup>

Nanocomposites can accommodate more filler particles due to their small size and therefore less resin monomer matrix is present.<sup>18</sup> Since the degree of polymerization shrinkage is linked to the amount of resin monomer matrix, an increase in filler levels with limited resin monomer matrix will ultimately result in reduced polymerization shrinkage and improved physical properties.<sup>18</sup>

#### Water Resorption

The chemical structure of a polymer matrix determines the dimensional changes of a polymer composite in a solvent.<sup>18</sup> These dimensional changes are complex and difficult to predict, but generally, nanofill composites show more water resorption than nanohybrid composites.<sup>18,53</sup>

#### Flexural Strength

Filler content and filler chemistry of a composite determine the flexural strength properties.<sup>52</sup> Compared to hybrid or microhybrid composites, the flexural strength of nanocomposites were found to be statistically equivalent and even significantly higher than that of microfill composites.<sup>54</sup> Nanofill composites have a higher filler load than nanohybrids, and therefore show a greater flexural strength.<sup>54</sup>



## **Wear and Gloss Retention**

Due to the uniqueness of nanofiller particles, nanocomposites can provide a superior polish and gloss retention comparable to that of microfill composites, and mechanical strength and wear resistance comparable to that of hybrid composites.<sup>18</sup>

With hybrid and microhybrid composites, Scanning Electron Microscope (SEM) images reveal pits where particles have been plucked from the surface, as well as large particles protruding from the surface.<sup>55,56,57,58</sup> The surface is therefore not as smooth or glossy as that of nanocomposites and microfills.<sup>55,56,57,58</sup>

In nanocomposites wear occurs less from larger secondary particles being plucked out of the resin and more from breaking off of nano-sized primary particles from nanoclusters.<sup>55,56,57,58</sup> This results in smaller defects and better gloss retention.<sup>55,56,57,58</sup> Nanocomposites also offer wear resistance and physical properties equal to that of several commercial hybrid composites.<sup>18</sup>

With the combination of good long term aesthetics and optimal physical and mechanical properties, it can be concluded that nanocomposites are indicated for use of all posterior and anterior restorative applications.<sup>18</sup>

## **1.4 Ormocers**

A restorative material with a new type of resin matrix called ORMOCER, was developed by the Fraunhofer Institute of Silicate Research (ISC) and introduced to the market in 1998.<sup>59</sup>

Ormocers were originally designed for use in science and technology.<sup>10,13</sup> They were manufactured for special surfaces such as non-stick surfaces, non-reflective coatings, protective coatings, and anti-static coatings.<sup>10,13,60</sup> To synthesize ormocers, monomers such as silicone alkoxides, various other metal alkoxides, organically modified silicon alkoxides and in some cases organic monomers are used.<sup>61</sup>



Inorganic-organic co-polymers with inorganic silanated filler particles make up the composition of this unique material.<sup>62</sup> Ormocers differ uniquely from conventional composites in that the matrix has an organic, but also an inorganic component.<sup>10</sup> Synthesis of the ormocer matrix is based on a saline precursor.<sup>62</sup> Multifunctional urethane and thioether(meth)acrylate alkoxy silanes are used to synthesize this material via a solution and gelation (sol-gel) process.<sup>62</sup> Organically modified ceramic particles are created by hydrolyses and inorganic polycondensation in this sol-gel process.<sup>63,64</sup> Unlike conventional composites that present with a carbon backbone, ormocer resin matrix consists of an inorganic silicon dioxide backbone on which polymerizable carbon-carbon double-bond-containing side-chains are grafted, producing three-dimensional compound polymers (Figure 1-2).<sup>65,66</sup> Ormocers are therefore correctly described as three dimensionally cross-linked co-polymers within the matrix presenting as a polymer even before light curing.<sup>65,67,68</sup>

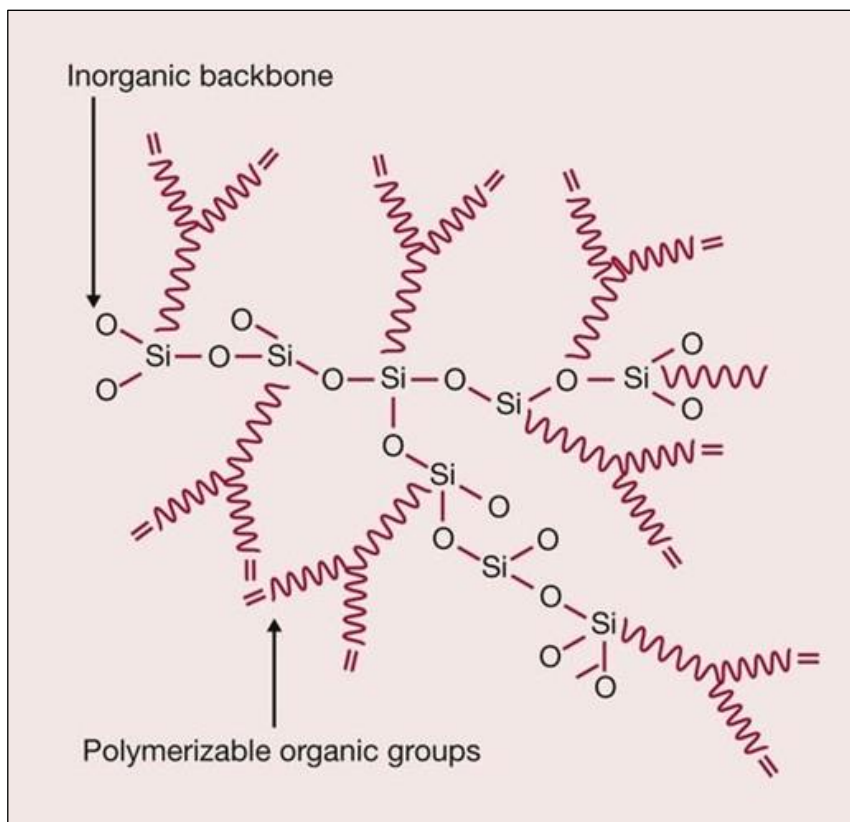


Figure 1-2: Ormocer resin matrix with organic polymerizable side chains added to an inorganic polysiloxane backbone. Multiple methacrylate groups with double bonds are available for bonding.<sup>69</sup>





Pure ormocers such as Admira Fusion are formed with the combination of nanohybrid technology and ormocer technology.<sup>63,64</sup> They contain three main elements, which are all based on silicate oxide.<sup>63,64</sup>

The three elements of a pure ormocer are:

1. Inorganic mixture of different sized glass particles:

A silicone oxide network forms the base of each glass particle.<sup>63</sup> Each silicon atom is tetrahedrally surrounded by oxygen atoms which then further connect to more silicon atoms (Figure 1-3).<sup>63</sup> Imbedded within this silicone oxide network are metal atoms that provide increased radiopacity to improve the radiological view of this material.<sup>63</sup>

Through a salinization process that takes place in an upstream reaction, the surface of each glass particle is modified by a special coating, indicated by the yellow sphere in Figure 1-3.<sup>63,64</sup> The coating or coupling agent contains methacrylate-saline compounds with double bonds that enable connection with further double bonds of the other elements within the material matrix.<sup>63</sup>

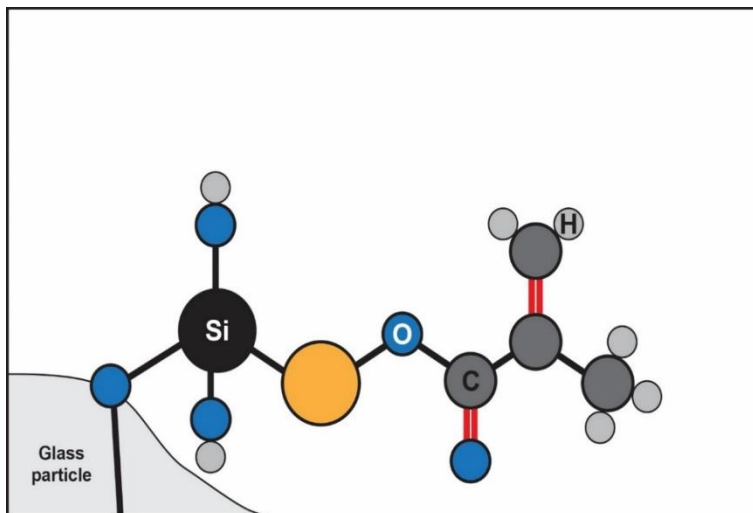


Figure 1-3: A silicon atom that is tetrahedrally surrounded by oxygen atoms and a methacrylate saline compound with double bonds present as a special coating (indicated by yellow sphere) on the surface of each glass particle.



## 2. Nanoparticles:

These particles, although smaller than glass particles, are similar in structure.<sup>63</sup> A silicone oxide network also forms the base of these particles with the silicon atom tetrahedrally surrounded by oxygen atoms (Figure 1-4).<sup>63</sup> The surfaces of the silicone nanoparticles are also silanated.<sup>63,64</sup> During polymerization, the different elements of the material connect via the double bonds of the methacrylate compounds present on the surface of each element.<sup>63</sup> Both the nanoparticles and the glass particles are imbedded in the ormocer matrix.<sup>63</sup>

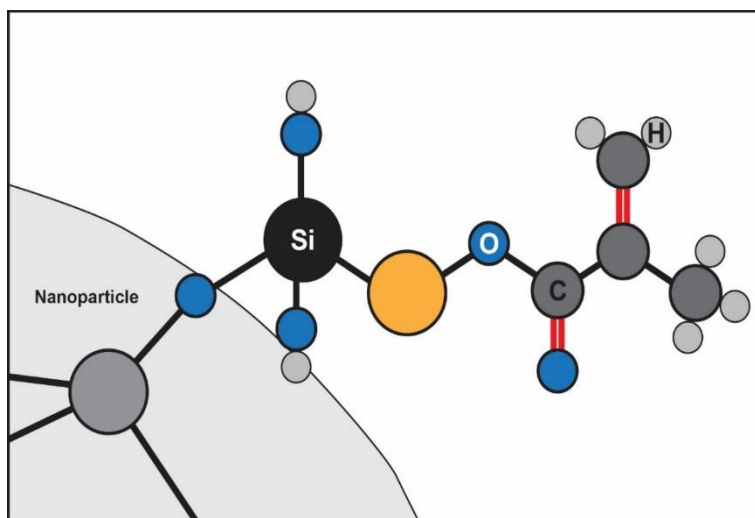


Figure 1-4: Methacrylate silane compound with double bonds present on the surface of the nanoparticles.

## 3. Ormocer Resin Matrix:

The unique ormocer resin matrix is also based on a silicon oxide network (Figure 1-2 & Figure 1-5).<sup>63</sup> It contains a silicate backbone which is highly cross-linked and contains additional methacrylate groups (Figure 1-2).<sup>63</sup> The multifunctional ormocer resin enables a quantitative fixation inside the polymer network of this material.<sup>63,64</sup> After polymerization, a stable three-dimensional network is created by the strong connection of the glass particles, nanoparticles



and ormocer resin, in which all the solid particles are immobilized (Figure 1-6).<sup>63</sup>

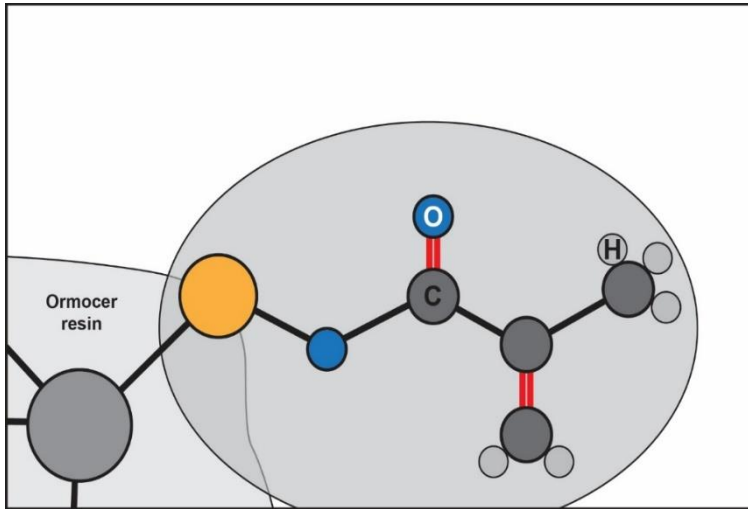


Figure 1-5: Methacrylate saline compound with double bonds within the ormocer matrix forming part of a network of linking units and double bonds.

During polymerization, the organic lateral side chains are able to react with conventional photoinitiators.<sup>3,62,66</sup> A chain reaction is initiated by the blue light of the curing light which enables the double bonds of each element to react with one another to form a chain or a network respectively.<sup>63</sup> A three-dimensional network of the organic portion of the methacrylate groups form after polymerization (Figure 1-6).<sup>13</sup>

Ormocer resin is prominent because of its highly cross-linked structure on the one hand and its tremendous amounts of linking units in the form of the double bonds on the other hand (Figure 1-2).<sup>62,63</sup> It has a much higher bond compatibility than conventional composites because of the high degree of cross linkages between the chemical elements (Figure 1-6).<sup>63</sup>

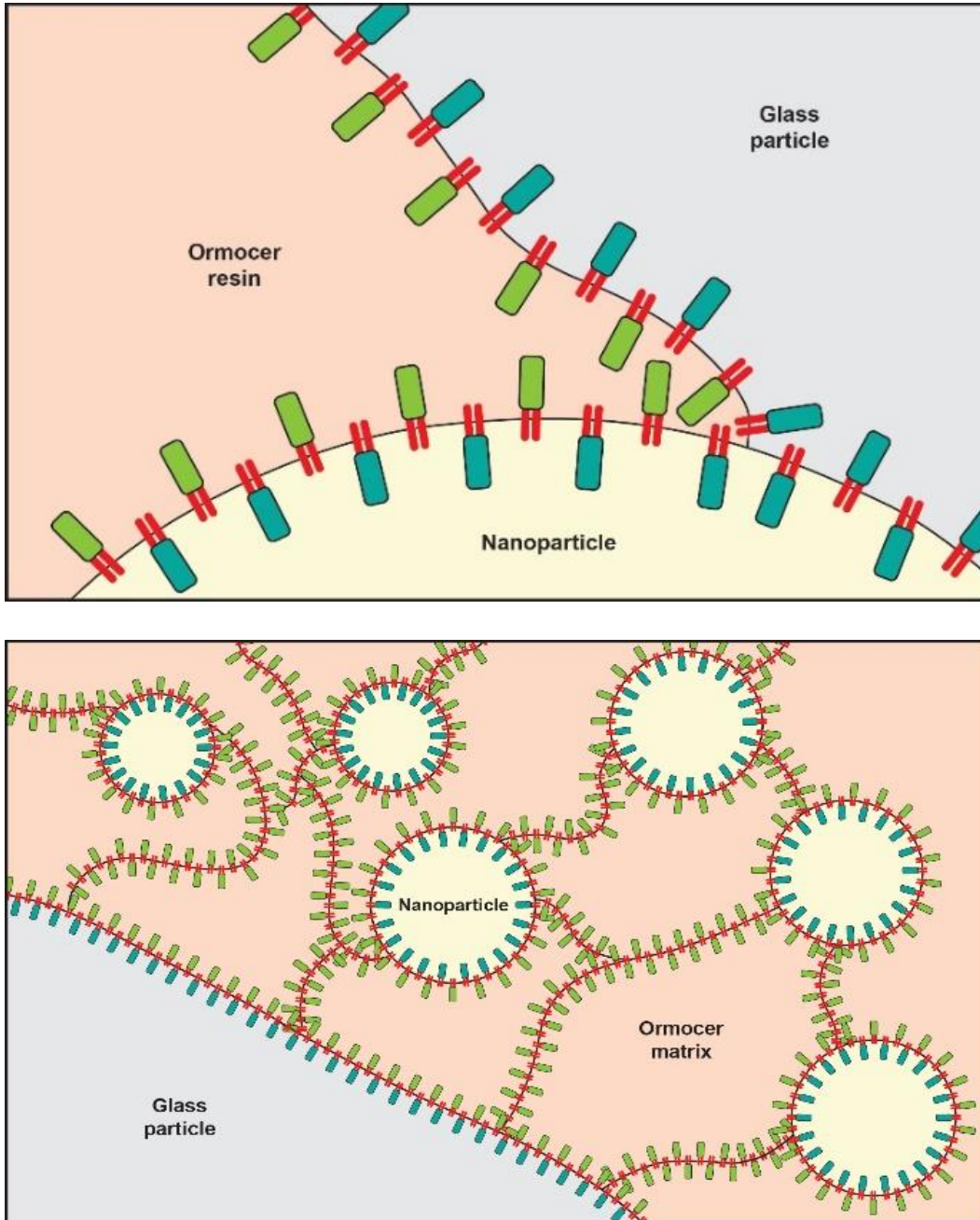


Figure 1-6: The blue light of light curing initiates a chain reaction and the double bonds of the elements react with one another to form a stable three-dimensional network.

When compared to the organic dimethacrylate monomer matrix of conventional composites, ormocers show considerably less polymerization shrinkage.<sup>62</sup> The lower volumetric shrinkage of ormocers can be explained by the longer inorganic



polysiloxane molecules (Figure 1-2), which are much longer than Bis-GMA of conventional composites (Figure 1-7).

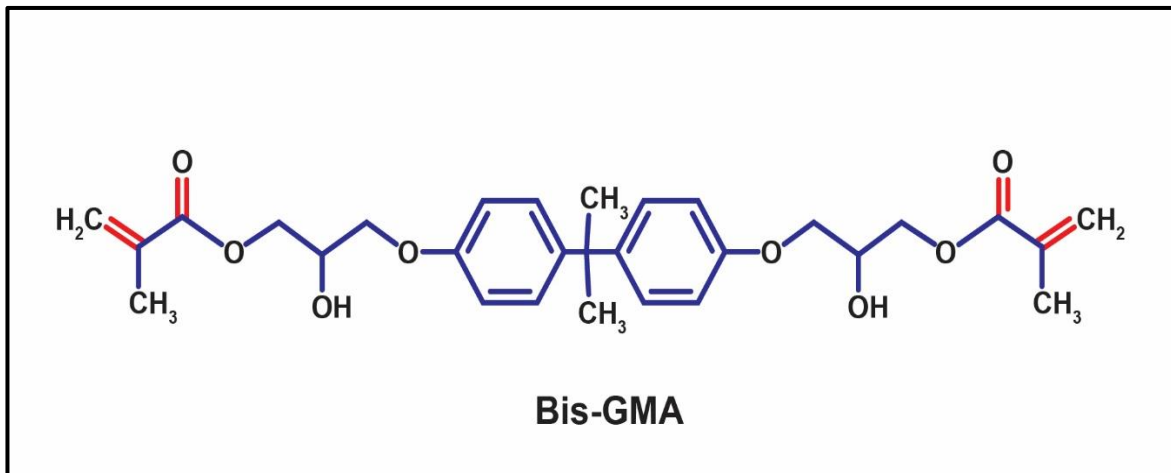


Figure 1-7: Shorter Bis-GMA molecule with only two methacrylate groups, with their double bonds, available for bonding.<sup>70</sup>

The multiple polymerization prospects in this material allow ormocers to cure without leaving much residual monomers.<sup>62</sup> Monomers are securely imbedded in the matrix and due to the material's ability to double the capacity of conversion of monomers to polymers, the amount of free monomers is ultimately reduced, and the physical properties are improved.<sup>10,13,62</sup> Larger monomer molecules may also reduce wear.<sup>66</sup>

### 1.4.1 Ormocer-Based Composites

The first generation of ormocers was expected to combine both the advantages of inorganic polymers (e.g. thermal stability, mechanical strength and chemical resistance) and organic polymers (e.g. flexibility and impact resistance).<sup>67</sup> However, due to the ongoing challenges to improve handling properties and to incorporate filler particles, conventional dental dimethacrylate monomers, such as Bis-GMA and UDMA, had to be added to the ormocer matrix, diminishing the initial promising advantages of this material.<sup>3,6,68</sup> It therefore becomes necessary to refer to this added dimethacrylate, first generation ormocer materials as ormocer-based composites.<sup>6</sup>



During the process of polymerization of conventional composites, mobile monomers start to link together forming an increasingly dense polymer network.<sup>60</sup> At the beginning of the process (pre-gel state), volumetric shrinkage is compensated for by the flowable status of the material.<sup>60</sup> As the network becomes more dense, internal stresses created can no longer be compensated for by the flowable status of the material (post-gel state).<sup>60</sup> These internal stresses within the material during polymerization can lead to detachment of the restorative material from the cavity walls and lead to possible marginal deficiencies.<sup>60</sup>

Since ormocer-based composites contain considerably less monomers than conventional composites, reduced shrinkage and shrinkage stress can be expected as well as improved biocompatibility.<sup>60</sup> A clinical trial conducted over a one-year, and another over a two-year period assessing the quality of ormocer-based restorations, found the clinical application to be acceptable, but concerns were raised regarding the marginal adaptation of the restorations.<sup>1</sup> Due to poor adaptation and adhesion, the indication for Class V restorations were also questioned.<sup>1,8</sup>

A one-year study by Oberländer *et al.*<sup>71</sup>, found that an ormocer-based composite (Definite, Degussa, Hanau, Germany) failed to meet the requirements for longevity of a Class II restoration when compared to conventional composite resins.<sup>71</sup> This is in contrast with the study by Bottenberg *et al.*<sup>66,72</sup> that found no difference between the longevity of the ormocer-based composite and Bis-GMA-based composite restorations.<sup>66,72</sup> The five-year control of the study did however show a stronger tendency of one of the two ormocer-based composite materials to discolour compared to other composite resin materials.<sup>72</sup>

Tagtekin *et al.*<sup>73</sup> investigated the wear resistance of ormocers-based composites and it was shown to be slightly more than that of conventional hybrid composites.<sup>73</sup> However, this finding was contradicted in a study done by Say *et al.*<sup>74</sup> that found the wear resistance of ormocer-based composites to be much lower than and the microhardness comparable to that of hybrid composites.<sup>74</sup> Some ormocer-based



composites contain nanoparticles such as zirconia-oxide nanoparticles.<sup>75</sup> Theoretically, this should increase the surface hardness and therefore the polishability of these restoration.<sup>75</sup>

The coefficient of thermal expansion for ormocer-based composites has been shown to be similar to that of natural tooth structure.<sup>76</sup> This property limits the possibility of interfacial gap formation due to internal tension created by the expansion and shrinkage of the material because of temperature changes in the oral cavity.<sup>76</sup>

A systemic review and meta-analysis investigation of clinical trials concluded that ormocer-based composites show evidence of inferior long-term clinical behaviour when compared to conventional composites and do not live up to their initial promise.<sup>6</sup>

### **1.4.2 Pure Ormocers**

Ormocers are a patented group of advanced restorative materials characterized by their innovative ormocer matrix technology and nanohybrid technology.<sup>14,63</sup> Pure ormocers differ from the first generation of ormocer-based composites in that the ormocer matrix chemistry does not contain additional conventional dimethacrylates.<sup>3</sup>

Ormocers also differ from conventional polymers of composites as ormocers are a three-dimensional polymeric composite.<sup>14</sup> They consists of a large polymer back bone, functionalized with organic units that are polymerizable (Figure 1-2).<sup>14</sup> The resin matrix is known for its large molecules, able to form significantly more double bond linkages than those of conventional monomers.<sup>60</sup> This leads to an extremely strong and reliable polymer network, when undergoing polymerization, and prevents leaching of matrix components such as uncured monomers.<sup>60</sup>

These large ormocer molecules also ensure limited volumetric shrinkage during polymerization, especially when compared to dimethacrylate-based composites.<sup>60</sup> According to the review article “Recent advances and modifications of dental restorative materials – a review” by Sri Vasavi Kadiyala<sup>14</sup>, ormocers show limited



volumetric shrinkage of only 1.97% .<sup>14</sup> This is the lowest value documented for a resin based filling material up to date.<sup>14</sup>

The complete absence of conventional monomers is only one feature of this innovative restorative material.<sup>60</sup> Another is the use of nanohybrid filler technology that bounds the ormocer resin.<sup>60</sup> Silicone oxide structures form the basis for the resin matrix and the nano- and glass ceramic filler particles. <sup>60,63</sup> This system provides the foundation for pure silicate technology.<sup>60</sup> The use of nanotechnology for the ormocer resin matrix allows for this restorative material to reach 84% fillers by weight.<sup>60</sup>

To summarize the differences between pure ormocer and ormocer-based restorative material:<sup>60</sup>

- Pure ormocers do not have conventional monomers in the resin matrix.<sup>60</sup>
- Pure ormocers make use of pure silicate technology.<sup>60</sup>

#### **1.4.2.1 Cytotoxicity of a Pure Ormocer vs. Dimethacrylate-Based Composites:**

Extensive research has shown adverse biocompatibility associated with conventional composites mainly due to the release of unbound free/residual monomers.<sup>77,78</sup> It has been shown that between 15-50% of the methacrylic groups remain as free monomers in the organic matrix both during and after polymerization.<sup>77,78</sup> Free monomers can have an impact on the structural stability of composite, decreasing the physical and mechanical properties of the material.<sup>78</sup>

Moderate to severe cytotoxic effects have been detected throughout the extensive group of monomers, co-monomers, initiators and co-initiators.<sup>79</sup> Furthermore mechanical and chemical degradation of the composite material over time leads to the leaching of these substances that further contributes to composite toxicity.<sup>80</sup>





Allergological and toxicological potential of ormocers are lower than that of conventional composites since ormocer acrylates and methacrylates are silane-bound and co-valently linked to the inorganic components.<sup>64</sup> Several studies have shown reduced amounts of free/residual monomers and therefore less cytotoxicity associated with ormocers when compared to conventional dimethacrylate-based composites.<sup>3,81,82</sup> Research conducted by Schubert *et al.*<sup>77</sup>, concluded that the pure ormocer Admira Fusion was significantly less cytotoxic to mouse L929 cells and human gingival fibroblasts than resin-based composites Filtek Supreme XTE (3M ESPE, St Paul, USA) and GrandioSO (VOCO). Cytotoxicity of three different materials and their flowable compositions were examined by Al-Hiyasat *et al.*<sup>82</sup>, (ormocer-based composite: Admira (VOCO), nanocomposite: Z350 (3M ESPE), and hybrid composite: Tetric Ceram (Ivoclar Vivadent, Schaan, Liechtenstein). The highest toxicity values for standard composites were shown to be with the ormocer-based composite. However, the flowable ormocer-based composite showed the least toxicity compared to the standard flowable composites.<sup>82</sup> These findings were contradicted by another study done by Polydorou *et al.*<sup>83</sup>, that showed the ormocer-based composite, Ceram X (Dentsply Sirona, Pennsylvania, USA) to release fewer free/residual monomers (such as UDMA, TEGDMA or Bis-GMA) when compared to a self-curing composite such as Clearfil-Core (Kuraray Noritake, Osaka, Japan), or a nanohybrid composite such as Filtek Supreme XT (3M ESPE).<sup>83</sup> In vitro studies comparing polymerized disks of Admira (ormocer-based composite) with Tetric Ceram (hybrid composite) or Z250 (3M ESPE) (nanocomposite), revealed higher 3T3 fibroblast cytotoxicity for the ormocer-based composite, which could be the result of higher release of Bis-GMA.<sup>76,82,83</sup>

Pure ormocers such as Admira Fusion might be the crucial technological advancement necessary to overcome the recorded cytotoxic adverse effects of resin based dental restorative materials.<sup>77</sup> This new restorative material is handled in the same method as conventional composites and is compatible with all conventional bonding system, composites and light-curing units.<sup>60</sup>

Due to the unique cross-linking and chemical nature of this material, it should be a highly biocompatible filling material.<sup>14</sup> Advantages expected from pure ormocers when compared to conventional composites include minimal shrinkage, aesthetics



resembling that of natural tooth structure, resistance to masticatory forces and outstanding biocompatibility.<sup>14</sup>

## 1.5 The Importance of Surface Roughness Evaluation

Finishing and polishing techniques used can significantly affect the quality and aesthetics of a restoration.<sup>84</sup> Finishing of a restoration entails gross contouring to obtain the correct tooth morphology, aesthetics and occlusion.<sup>85</sup> Polishing reduces the roughness and surface imperfections of restorations and is therefore critical to the wear reduction and marginal integrity of a restoration.<sup>85</sup>

Surface roughness seems to greatly affect early adhesion of bacterial cells on the restoration surface.<sup>86,87</sup> Together with surface texture, this will ultimately affect periodontal health.<sup>86,87</sup> In order to prevent bacterial adhesion and plaque accumulation a surface roughness threshold of below 0.2 $\mu$ m is necessary.<sup>87</sup> Profilometry makes use of a profilometer that can measure the surface profile of a material in order to give a quantitative measure of its roughness.<sup>88</sup> It is the most common method to evaluate the surface roughness of composite materials.<sup>88,89</sup>

Various techniques for finishing and polishing are available and have been investigated.<sup>90</sup> It has been suggested in multiple studies that certain polishing techniques are better suited to certain specific materials.<sup>91</sup>

The physio-chemical properties of the material are closely related to its surface roughness.<sup>92,93</sup> Filler particles are harder than the resin matrix and often the filler particles will be exposed on the surface of the restoration after finishing and polishing procedures. This leads to the formation of surface irregularities.<sup>92,93,94</sup> Studies have however shown that the particle structure and size rather than its hardness plays a role in the final surface roughness of the restoration.<sup>92,93</sup>



Smoothly polished surfaces reduce plaque accumulation, gingival irritation and secondary caries.<sup>95</sup> Surface discolouration can be minimized and aesthetics improved with accurate finishing and polishing techniques.<sup>85,95</sup>

## 1.6 The Importance of Surface Hardness Evaluation

Physical properties of a material can greatly affect the clinical longevity of a restoration.<sup>96</sup> One such physical property is surface hardness, which in turn correlates to compressive strength, abrasion resistance and degree of conversion.<sup>97</sup>

Low surface hardness levels relate to poor wear resistance and low abrasion resistance.<sup>98,99</sup> Low surface hardness levels can also result in a decrease in fatigue resistance and ultimate failure of a restoration.<sup>100</sup> Under occlusal forces composite restorations undergo a degree of deformation, the amount of which will be determined by their surface hardness.<sup>100</sup> Adequate surface hardness of a restoration is critical to withstand high stress bearing forces in the oral environment.<sup>101</sup> A high resistance to these forces will improve the clinical performance of the restoration.<sup>101</sup>

Vickers hardness tests are usually performed to determine the surface hardness of a material.<sup>102</sup> This test is based on the ability of a material to resist surface penetration of a diamond indenter under a specific load.<sup>102</sup>

## 1.7 The Importance of Microleakage Evaluation

Microleakage is a microscopic opening between the cavity walls and restoration that cannot be detected clinically and acts as a passage for bacteria, molecules, ions and fluids to enter through the tooth-restoration interface.<sup>103</sup> To ensure longevity and a good clinical performance of the restorative material, impenetrable adherence to the cavity walls is of utmost importance.<sup>103</sup>



Microleakage can result in hypersensitivity, secondary caries, pulpal irritation, increased wear of the restorative material and marginal staining.<sup>103,104</sup> Microleakage evaluation can be done through a variety of techniques, described in literature.<sup>105</sup> The dye penetration technique is often used and trusted.<sup>106</sup>



## Chapter 2 : Aim and Objectives

### 2.1 Aim

The aim of this study was to determine whether a new generation of pure ormocers exhibits any clear differences when compared to a first generation ormocer-based composite and conventional nanocomposite.

### 2.2 Objective

The objectives of this study was to determine and compare a pure ormocer (polished both dry and wet), with a first generation ormocer-based composite and a nanocomposite in terms of:

- surface roughness measured with a profilometer and scanning electron microscope (SEM) analysis.
- surface hardness tested with a Vickers Diamond Indenter and
- microleakage evaluated by dye penetration under a Stereomicroscope.

### 2.3 Null Hypothesis

The null hypothesis was that there would be no difference in terms of surface hardness, surface roughness and microleakage between the pure ormocer, nanocomposite and ormocer-based composite.



# Chapter 3 : Materials and Methods

## 3.1 Study Design

In-vitro, quantitative comparative study.

## 3.2 Study Settings

- The Oral and Dental Hospital, School of Dentistry at the University of Pretoria;
- The Department of Material Sciences and Metallurgical Engineering, University of Pretoria.

## 3.3 Research Object Selection

Non-carious premolars, with no restorations or developmental defects, were randomly chosen from a pool of extracted adult human teeth.

A pure ormocer (Admira Fusion), a first generation ormocer-based composite (Admira), and a nanocomposite resin (Filtek Z350 XT, 3M ESPE) were chosen for this study. These products were chosen because they are readily available in South Africa. Each of the restorative materials evaluated in this study was used in combination with its corresponding adhesive system as recommended by the respective manufacturers.

The adhesive systems are (Figure 3-1: A-C and Table 3-1):

- Futurabond U (VOCO) for Admira Fusion.
- Adper Single Bond Universal Adhesive (3M ESPE) for Filtek Z350 XT.
- Admira Bond (VOCO) for Admira.



Table 3-1: Materials used in this study.

Trade name	Material	Composition	Filler content, percentage	Manufacturer	Batch Number
<b>Admira Fusion</b>	Nanohybrid Pure Ormocer	Matrix: Resin Ormocer Filler: Silicon oxide nano filler, glass ceramics filler (1µm)	84 (w/w) 69 (v/v)	VOCO GmbH, Cuxhaven, Germany.	1915328 1945202
<b>Futurabond U</b>	Bonding System	34% phosphoric acid Adhesive: Liquid 1: Acidic adhesive monomer HEMA BIS-GMA, HEDMA, UDMA Catalyst Liquid 2: Ethanol initiator, catalyst.		VOCO GmbH, Cuxhaven, Germany.	1917239



Trade name	Material	Composition	Filler content, percentage	Manufacturer	Batch Number
<b>Admira</b>	Microhybrid Ormocer-Based Composite	Matrix: Bis-GMA, UDMA, TEGDMA Filler: Glass ceramic silicon oxide (0.7µm)	79 (w/w) 56 (v/v)	VOCO GmbH, Cuxhaven, Germany.	1908546
<b>Admira Bond</b>	Bonding System	36% phosphoric acid Adhesive: Acetone, ormocer matrix, DMA polyfunctional methacrylate, CQ stabilizer		VOCO GmbH, Cuxhaven, Germany.	1917136
<b>Filtek Z350 XT</b> <u>Other trade names for Filtek Z350 XT:</u> Filtek Supreme XTE, Filtek Supreme Plus, Filtek Supreme Ultra, Filtek Supreme, Filtek supreme XT	Nanofilled Composite	Matrix: Bis-GMA, TEGDMA, UDMA, Bis-EMA Filler: Silica nanofillers (5-75nm) zirconia/silica nanoclusters (0.6 – 1.4µm)	78.5 (w/w) 59 (v/v)	3M, ESPE, St Paul, USA	NA62301





Trade name	Material	Composition	Filler content, percentage	Manufacturer	Batch Number
<b>ESPE Adper Single Bond Universal Adhesive</b>	Bonding System	36% phosphoric acid with colloidal silica Adhesive: Bis-GMA, HEMA, DMA, polyalkenoic acid copolymer, initiator, water, ethanol		3M, ESPE, St Paul, USA	5695133

All materials were polymerized with a dental curing light in accordance with the respective manufacturer's instructions (Table 3-2).

Table 3-2: Curing times for different materials as instructed by manufacturers.

Material	Duration of polymerization (output 1000–2000 mW/cm <sup>2</sup> )
Admira Fusion	20sec per 2mm increment
Admira	40sec per 2mm increment
Filtek Z350 XT	10sec per 2mm increment

All three of these materials with their respective bonding systems are indicated for direct anterior and posterior restorations, core build-ups, splinting and indirect inlays.

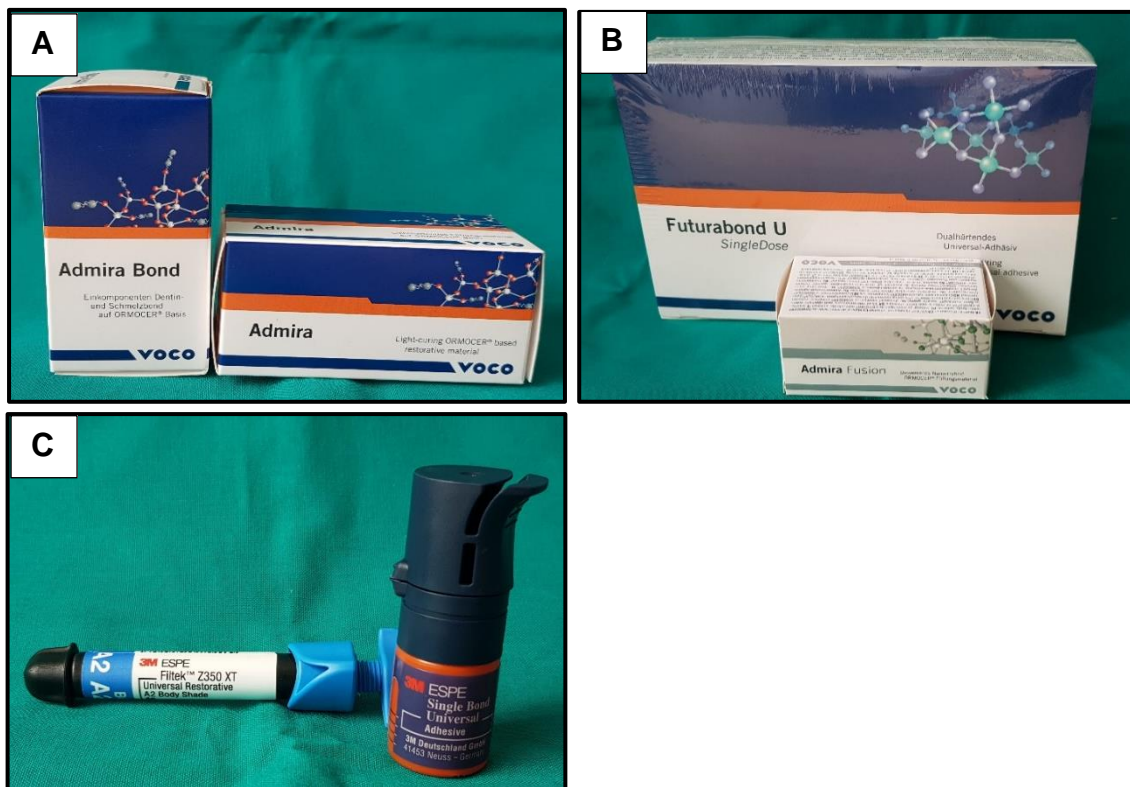


Figure 3-1: The dental materials used in the current study: A) Admira with Admira Bond, B) Admira Fusion with Futurabond U, C) Filtek Z350 XT with Single Bond Universal Adhesive.

Polishing systems were chosen for each material based on the recommendation from the manufacturers.

Polishing systems are (Figure 3-2):

- Dimanto (VOCO) for both Admira and Admira Fusion.
- Sof-Lex Diamond Polishing System (3M ESPE) for Filtek Z350 XT.

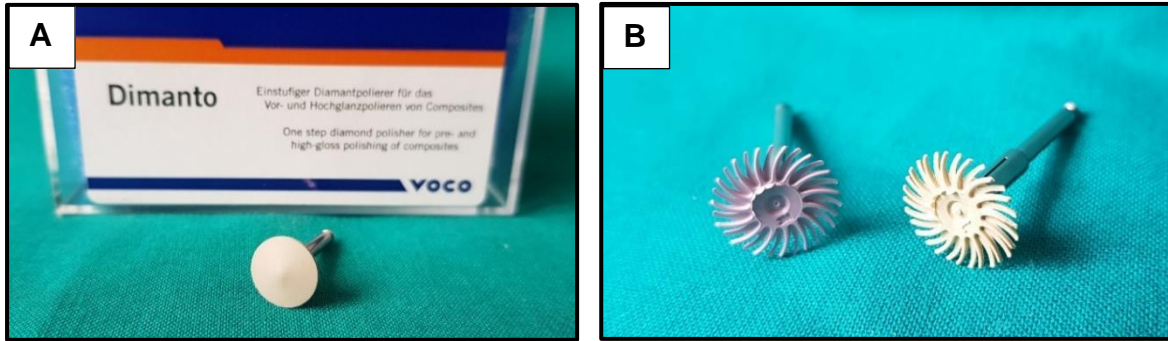


Figure 3-2: The polishing systems used in the current study: A) Dimanto, B) Sof-lex Diamond polishing system, Polishing Spiral (pink) and Pre-polishing Spiral (beige).

Table 3-3: Polishing systems, manufacturers' details and batch numbers.

Polishing System	Manufacturer	Batch Number
Dimanto	VOCO GmbH, Cuxhaven, Germany.	1921077
Sof-Lex Diamond Polishing System	3M, ESPE, St Paul, USA	NA48359

### 3.4 Measurement

#### 3.4.1 Surface Roughness

Twelve samples of each material, A2 shade, were prepared using cylindrical aluminium moulds, 10mm diameter x 2mm height.<sup>107</sup> The shade A2 was chosen because it is readily available and research has shown that this shade of composite does not significantly influence curing at a depth of 2mm.<sup>108</sup> The height of 2mm for the moulds are necessary since most composites are placed and cured in 2mm increments.<sup>108,109</sup> The cylindrical aluminium moulds were cut from aluminium pipe using an ISOMET low speed saw (Buehler, Lake Bluff, USA), (Figure 3.3: A-C).

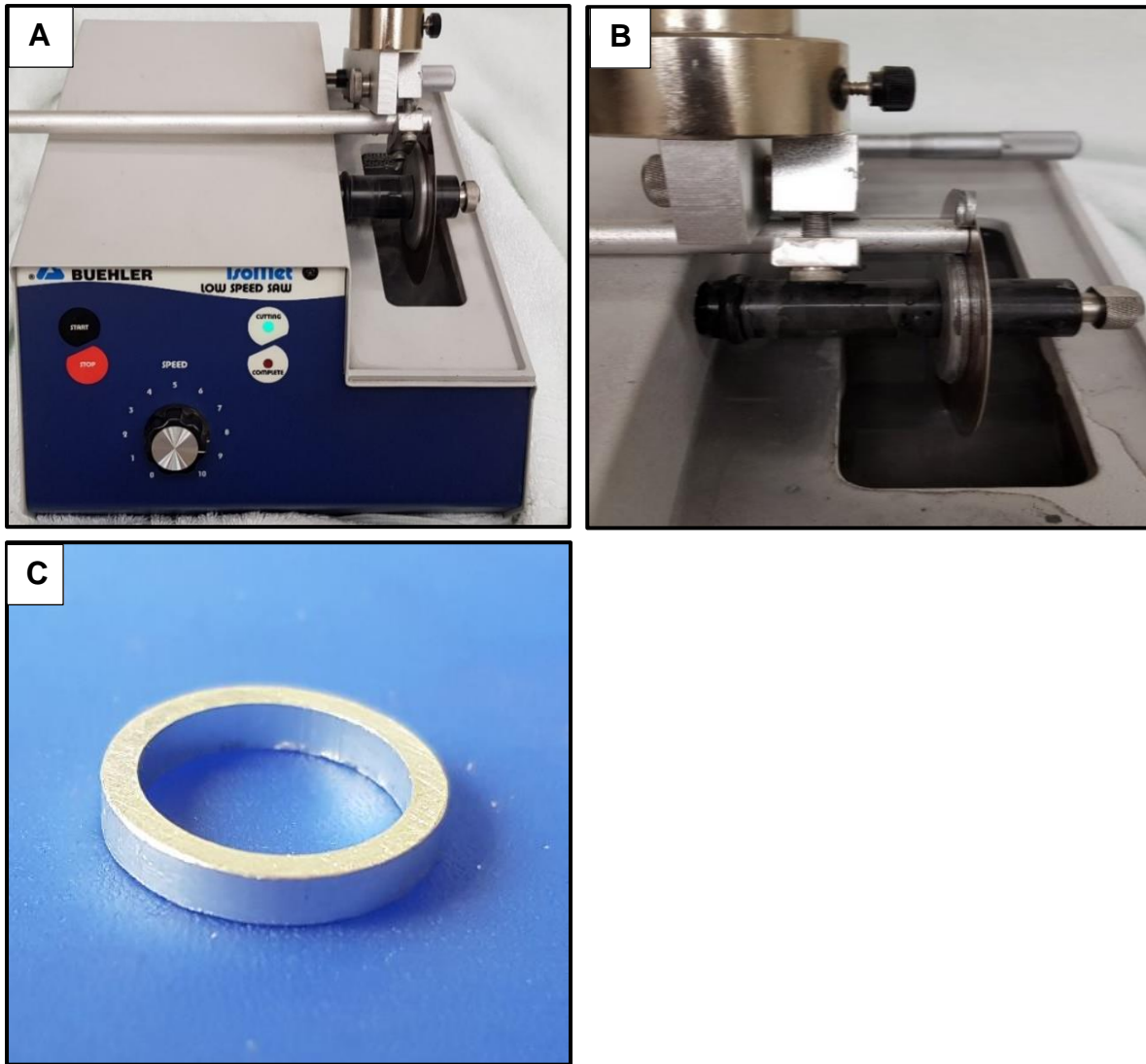


Figure 3-3: A) ISOMET low speed saw used to cut aluminium pipe for cylindrical moulds, B) Cylindrical mould being cut by low speed saw, C) Aluminium cylindrical mould (10mm diameter x 2mm height).

The same investigator performed all sample preparations, finishing and polishing procedures, strictly in accordance with the manufacturers' instructions, in order to reduce variability.<sup>110</sup> All materials were polymerized, using a D-Light Pro dual wavelength LED curing light (Blue light: 460-465nm, Violet light: 400-405nm) (Figure 3-4) with irradiance of 1400mW/cm<sup>2</sup> on high power mode and 700mW/cm<sup>2</sup> in low power mode (GC Europe, Leuven, Belgium). Polymerization was done on high power mode through the top and bottom glass slide, for the duration instructed by the individual manufacturers for each material (Table 3-1).<sup>111</sup>



Figure 3-4: D-Light Pro dual wavelength LED curing light.

A Bluephase radiometer (Ivoclar Vivadent) was used to test the intensity of the curing light before curing each sample (Figure 3-5).

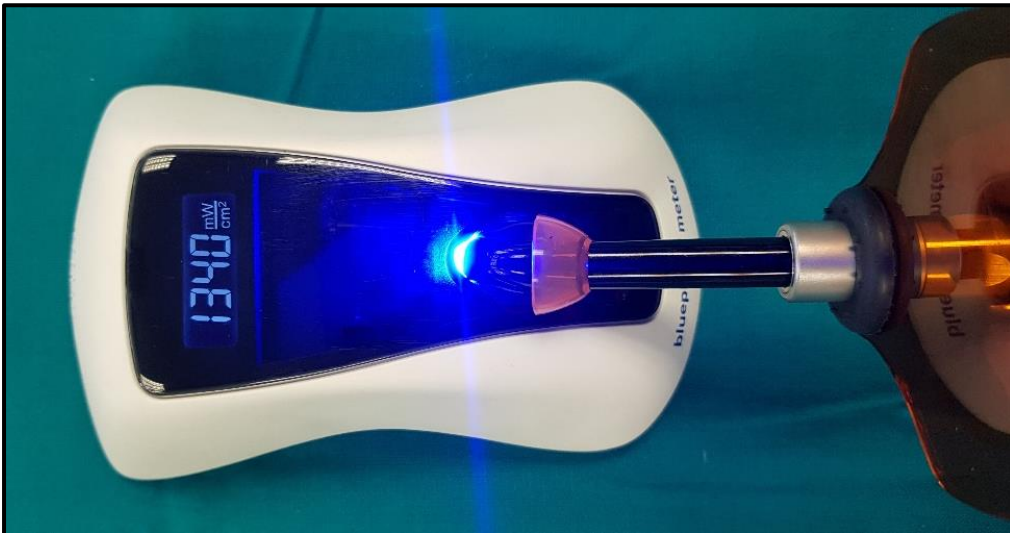


Figure 3-5: Bluephase radiometer measuring light intensity before curing samples.



Cylindrical moulds were slightly overfilled.<sup>112</sup> Mylar strips were placed on either side of the uncured material and pressed between two glass slides, 1mm thick, with light finger pressure to extrude excess material (Figure 3-6: A-D).<sup>107,112</sup>

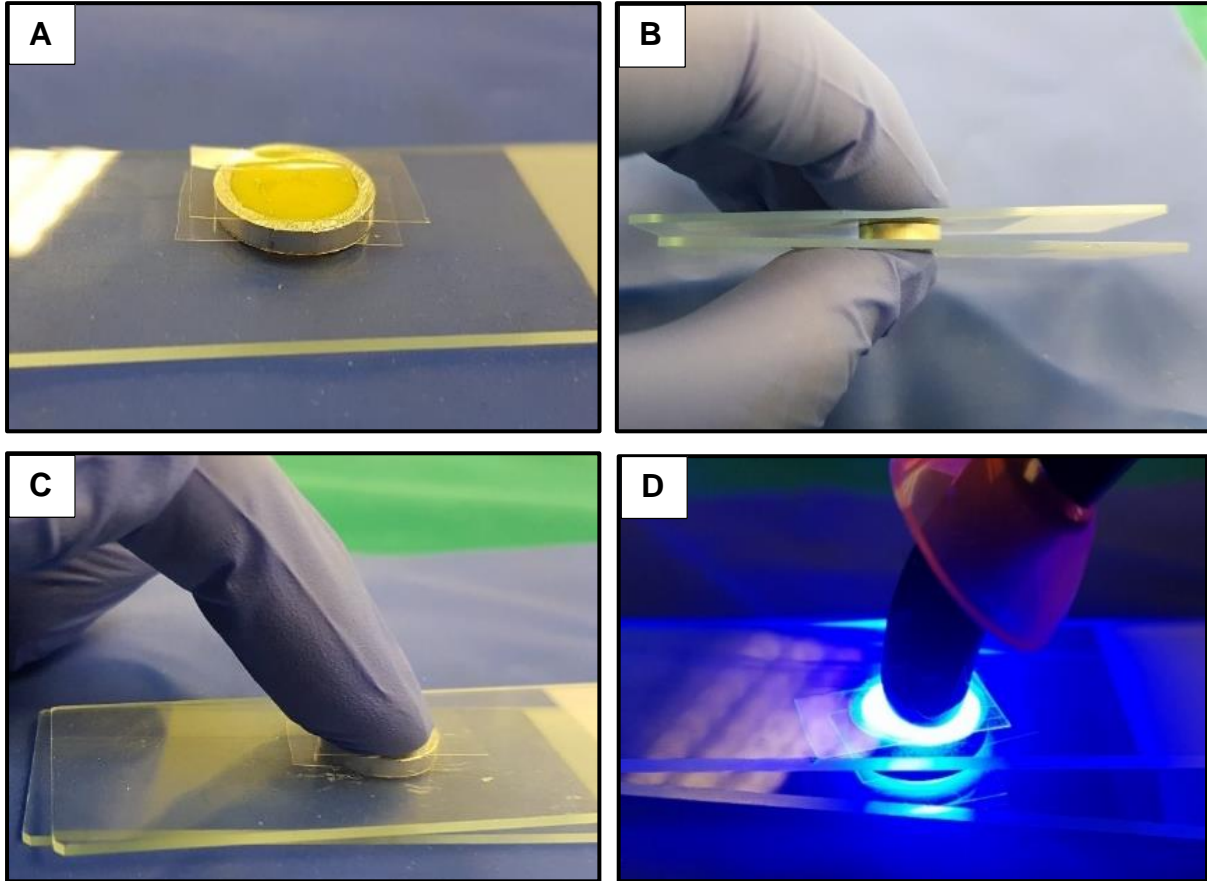


Figure 3-6: A) Mylar strips were placed on both sides of the uncured material, B) Sample pressed between two glass slabs, 1mm thick, C) Light finger pressure used to extrude excess material, D) Polymerization of samples according to the manufacturers' instruction.



After polymerization, the material samples were removed from the moulds using finger pressure, and glued to a transparent plastic backing (Figure 3-7: A -D).

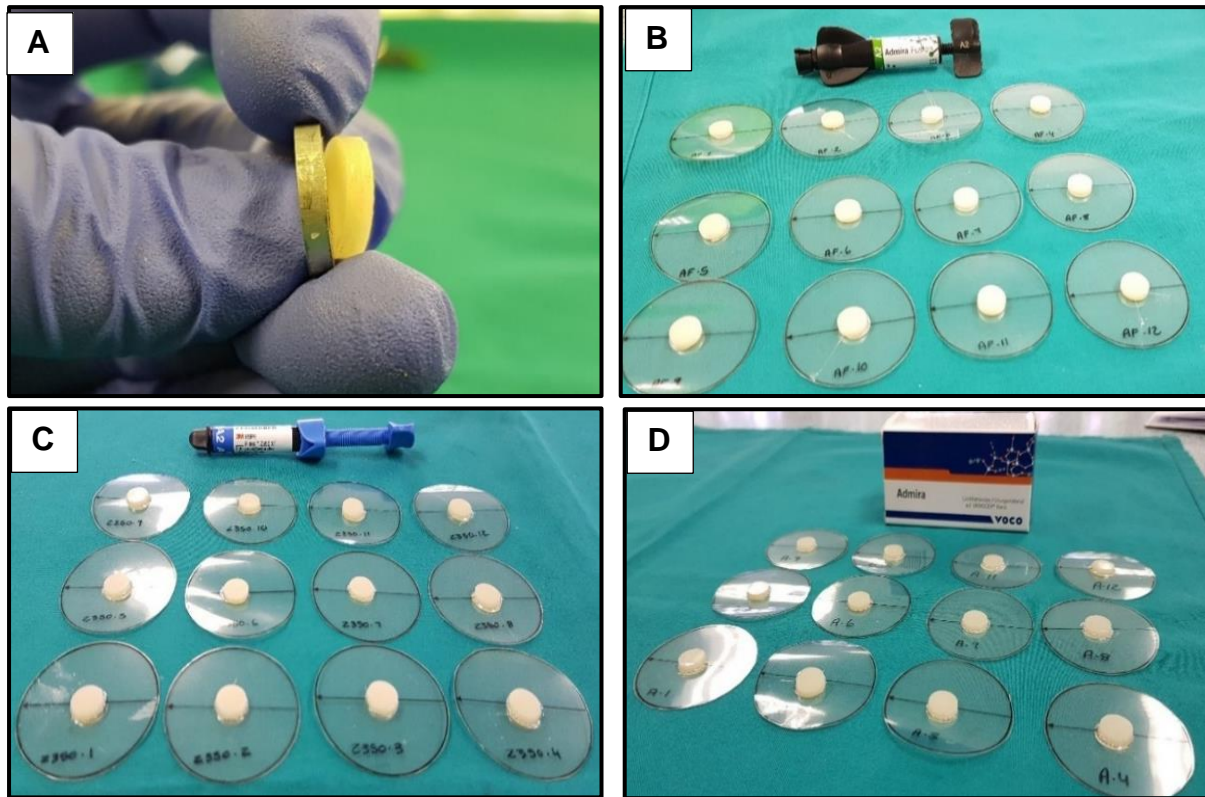


Figure 3-7: A) Samples removed from mould with finger pressure, B) Completed Admira Fusion samples C) Completed Filtek Z350 XT samples, D) Completed Admira samples.

Samples were then finished with a red stripe, flame shaped finishing diamond bur ISO 806 314 249 514 012 (Dentsply Sirona/Mailefer, Ballaigues, Switzerland) followed by a yellow stripe, flame shaped finishing diamond bur, ISO 806 314 249 504 012 (Dentsply Sirona/Mailefer) (Figure 3-8: A), under copious amounts of water spray for ten seconds each.<sup>107</sup> The rotation speed of the bur, 200000rpm, was regulated by an NSK NLX nano electric micromotor (NSK, 1800 Global Parkway, USA) (Figure 3-8: B).

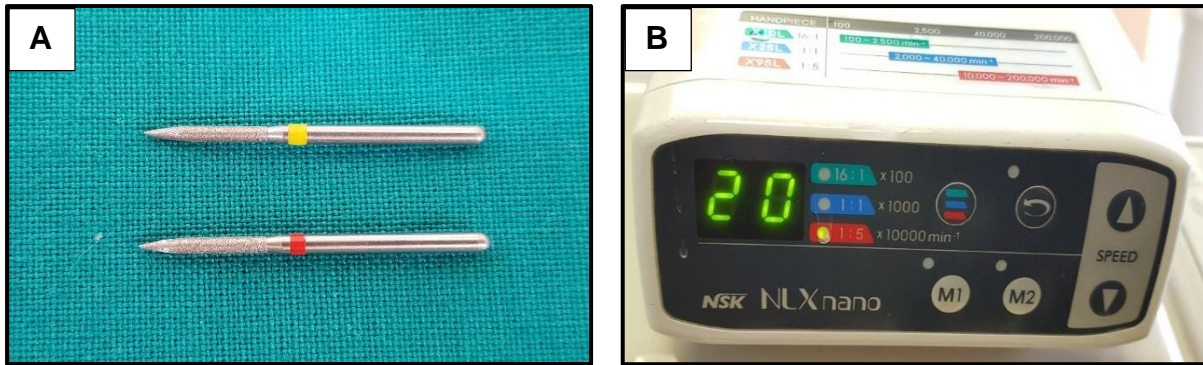


Figure 3-8: A) Red and yellow striped, flame shaped finishing diamond burs, B) NSK NLX nano electric micromotor.

Literature recommends the use of diamond burs rather than carbide burs during finishing procedures.<sup>113,114</sup> The damage caused by diamond-finishing burs are more easily corrected with a good polishing system than with carbide finishing burs.<sup>113,114</sup>

Samples were finished and polished, strictly according to the manufacturers' instructions, in the direction of an arrow that was marked on a transparent plastic backing as done in a study by Senawongse and Pongprueska<sup>115</sup> who also polished all samples in one direction (Figure 3-9).<sup>107,115</sup> A new polishing bur was used for each sample and each sample was polished for 20sec with the indicated polishing burs (Table3-3 & Figure 3-2).

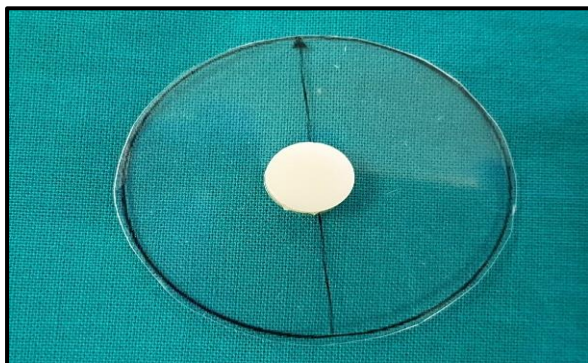


Figure 3-9: Arrow marked on transparent plastic so that all samples could be polished in the same direction.





Admira Fusion was polished with and without water since the Dimanto polishing system can be used with or without water-cooling.<sup>114</sup> Instructions for use of Admira Fusion do not indicate whether polishing should be done under water-cooling or not.<sup>116,117</sup> A separate set of 12 samples were consequently made and polished dry instead of wet in order to see if any significant differences were apparent between dry and wet finishing of the material.

Table 3-4: Polishing systems used according to the manufacturers' instruction.

<b>Material</b>	<b>Polishing system used</b>	<b>Manufacturer</b>	<b>Speed of handpiece</b>	<b>Time period polished</b>
Admira Fusion	Dimanto	VOCO GmbH, Cuxhaven, Germany.	5000rpm	20sec
Admira	Dimanto	VOCO GmbH, Cuxhaven, Germany.	5000rpm	20sec
Filtek Z350 XT	Sof-Lex Diamond Polishing System (Beige pre-polishing bur and pink polishing bur)	3M, ESPE, St Paul, USA	20000rpm	20sec



After polishing, the samples were mounted on a wheel template with three markings: 0°, 120° and 240° (Figure 3-10: A). Three measurements in different directions were recorded for each sample of each group using a SurfTest SJ 210 profilometer (Mitutoyo, Tokyo, Japan) (Figure 3-10: B and Figure 3-11). This was done in accordance with previous studies to ensure a representative surface roughness value for the entire sample and not only the roughness of a certain area on the sample.<sup>107,118,119,120,121</sup> After the three readings per sample, the profilometer was calibrated using the precision specimen (Figure 3-10: C).

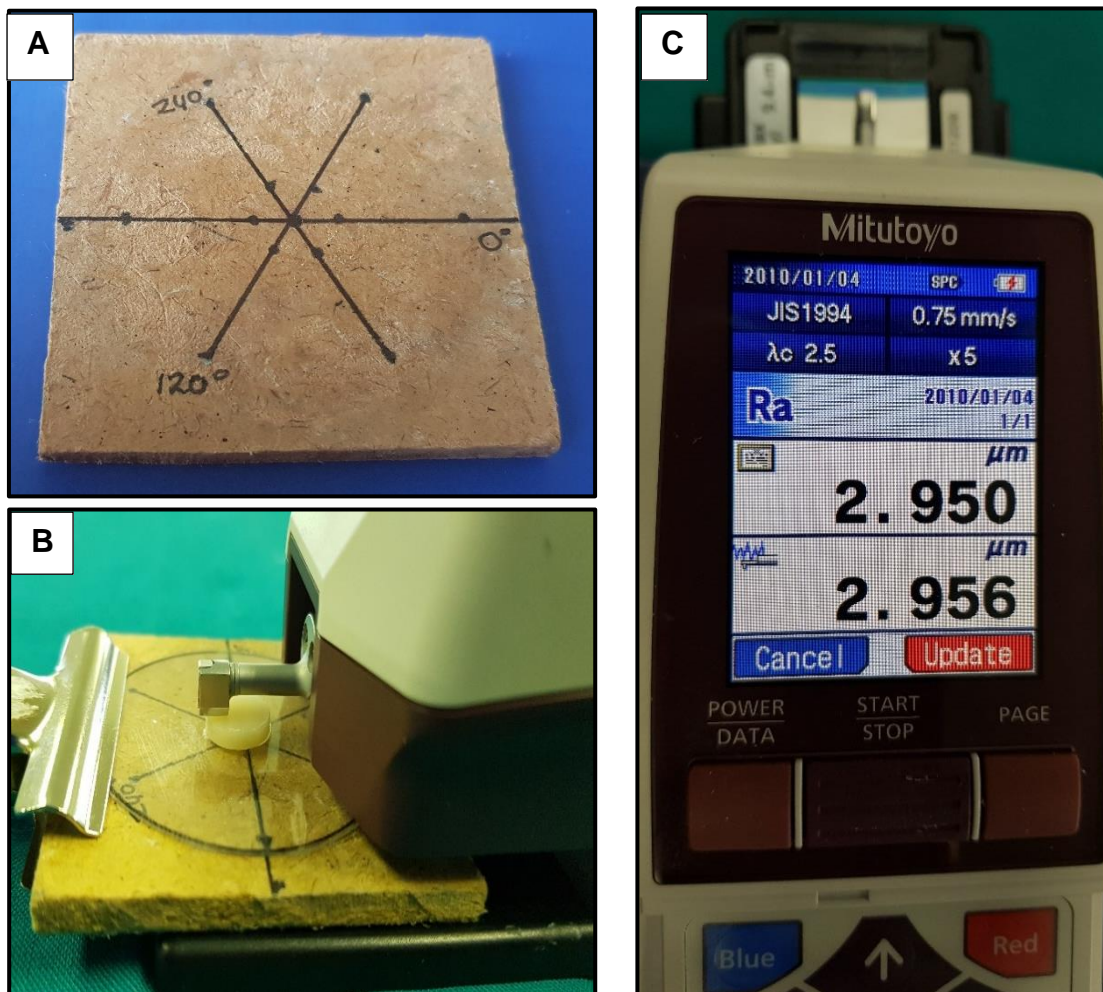


Figure 3-10: A) Wheel template with markings of 0°, 120° and 240°, B) Measurement taken on 0° with the SurfTest SJ 210 profilometer C) The profilometer being calibrated using the precision specimen.

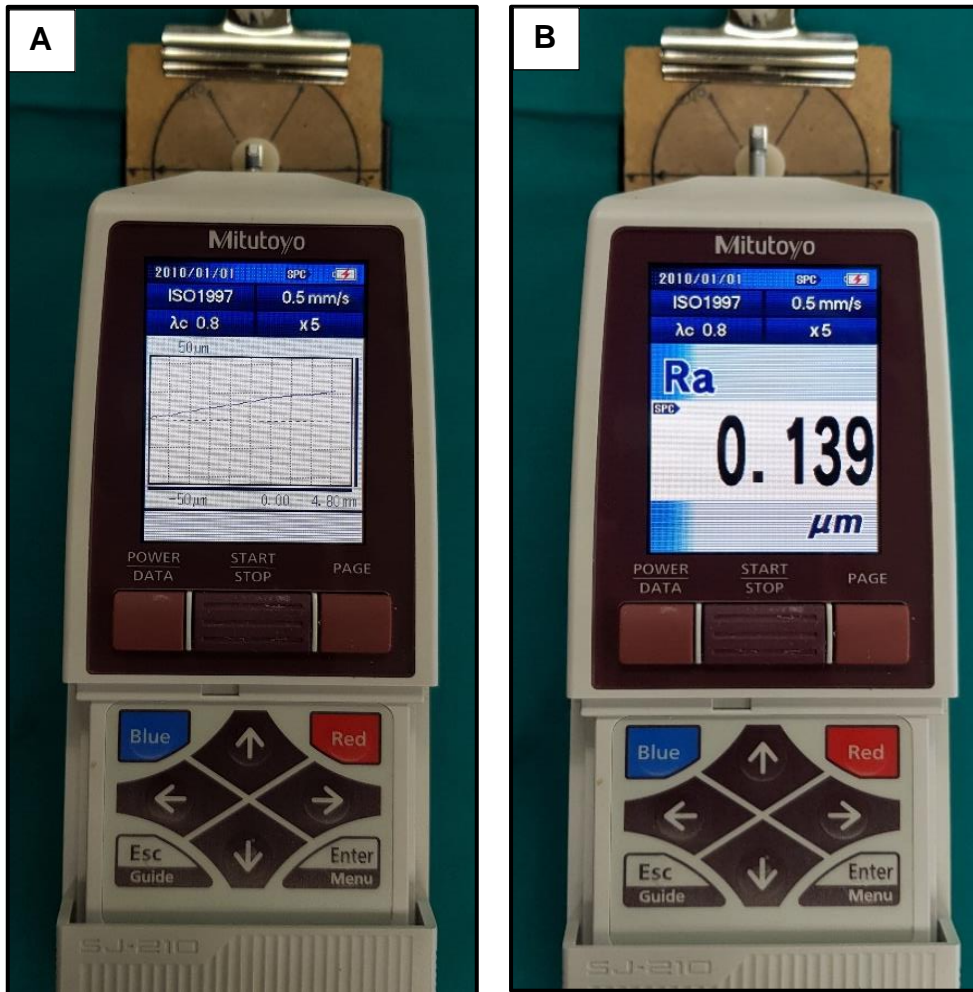


Figure 3-11: A) Reading in progress B) Reading completed on the sample in the specific direction.

After profilometry measurements, as a comparative measure of interest, random samples from each group were evaluated under the scanning electron microscope (SEM) (JEOL JSM-5800 LV, Tokyo, Japan) to visually examine and compare the surface topography of the materials surfaces after polishing and to compare the SEM images with the profilometry results (Figure 3-12: A and C).



The samples were carbon spattered, investigated and photographed under 500x and 1000x magnification (Figure 3-12: B).<sup>107</sup>

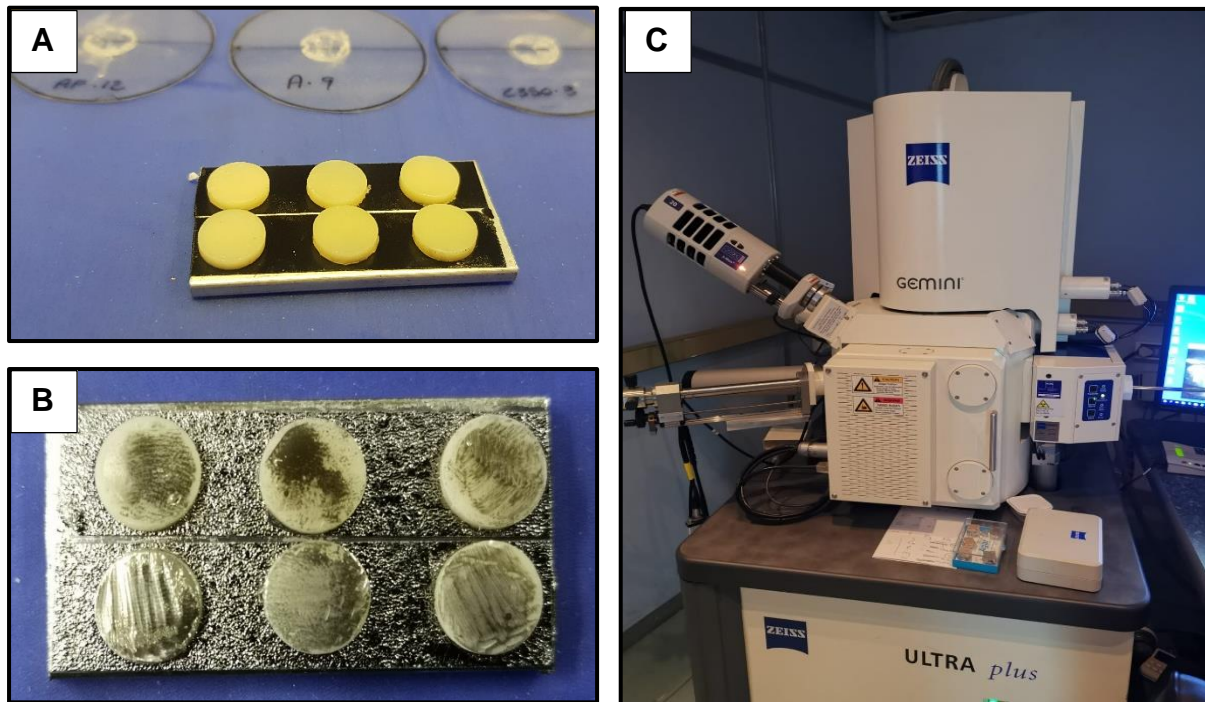


Figure 3-12: A) Two random samples from each group. B) Carbon spattered samples. C) Scanning electron microscope.

### 3.4.2 Surface Hardness

Twelve specimens of each material were prepared using cylindrical aluminium moulds, 10mm diameter x 2mm height (Figure 3-13). This was done in the same method described for the testing of surface roughness. For each brand, the A2 shade was selected. All materials were polymerized according to the manufacturers' instructions (Table 3-2).<sup>36,122</sup>

Cylindrical moulds were slightly overfilled.<sup>107,112</sup> Mylar strips were placed on either side of the uncured material and pressed between two 1mm thick glass slides with light finger pressure to extrude excess material (Figure 3-6).<sup>107,112</sup>



A Bluephase radiometer was used to test the intensity of the curing light after curing each sample (Figure 3-5).

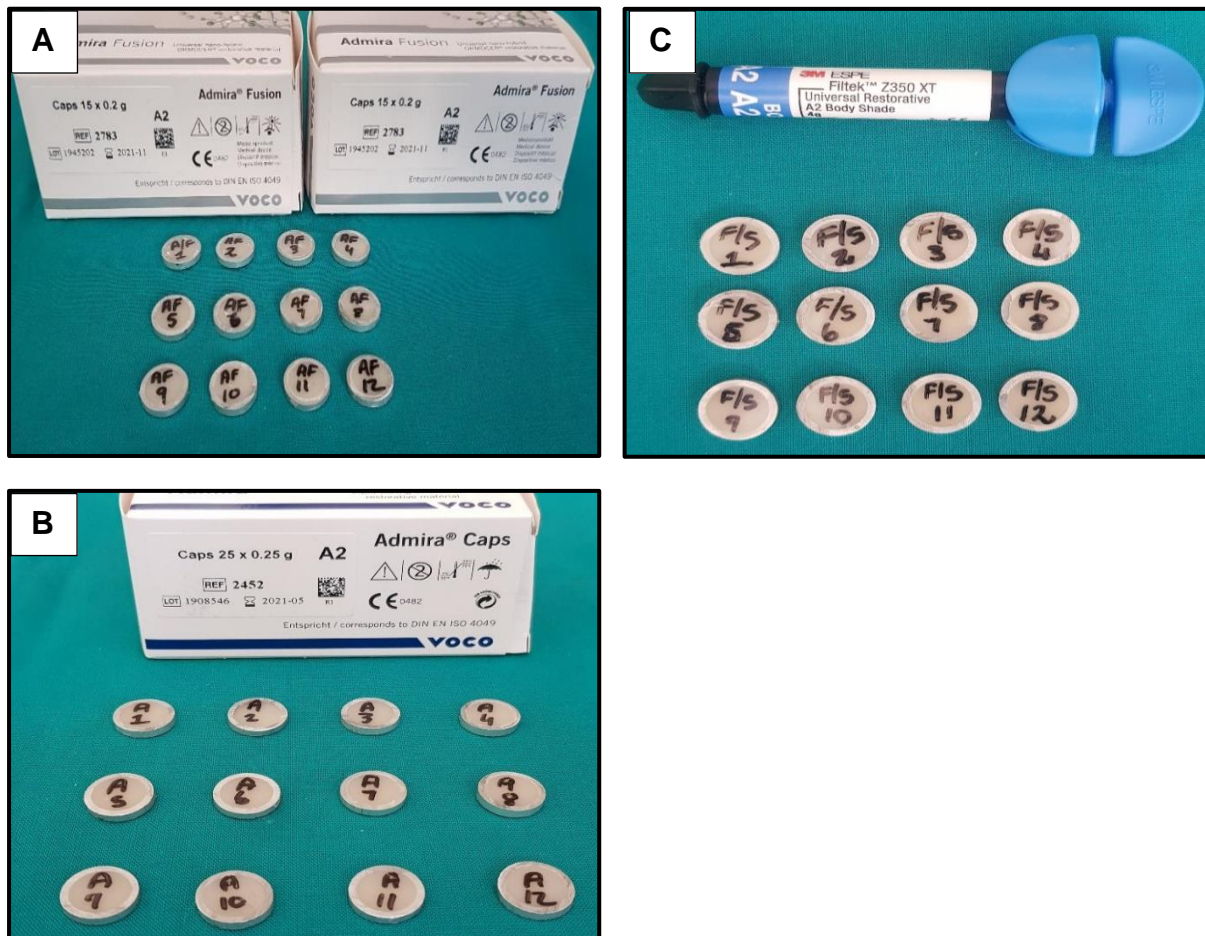


Figure 3-13: Twelve completed samples of A) Admira Fusion, B) Admira and C) Filtek Z350 XT.

After polymerization, the samples were placed in glass containers filled with distilled water (Figure 3-14) and stored in an incubator (Binder ED23, Tuttlingen, Germany) (Figure 3-15) at 37°C $\pm$  1°C, for 24 hours. This was done to allow water-absorption in order to simulate the oral environment and to allow for dark polymerization.<sup>98,123,124</sup>

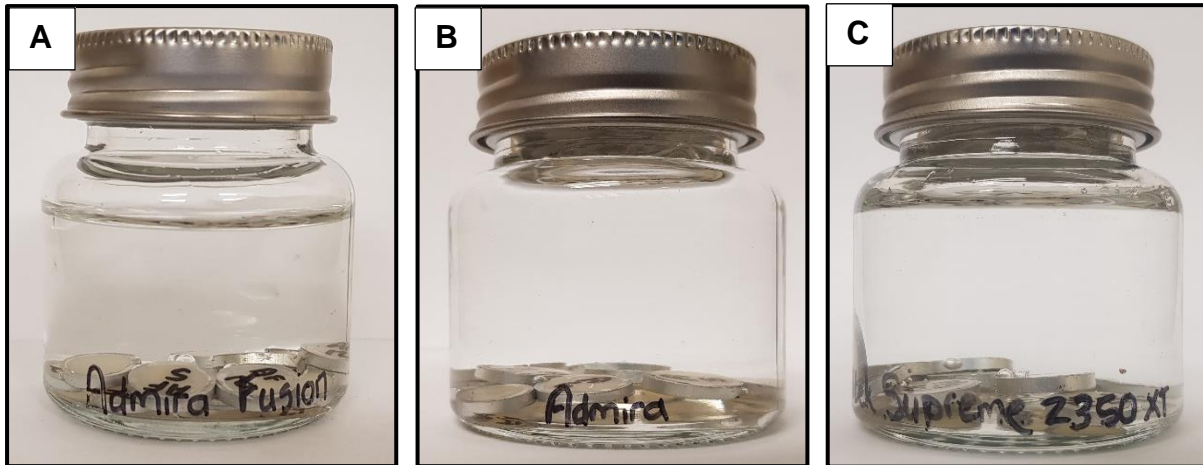


Figure 3-14: Samples stored in glass containers filled with distilled water. A) Admira Fusion, B) Admira, C) Filtek Z350 XT.



Figure 3-15: Incubator.

Prior to testing of surface hardness, the outer surface of each sample was polished with silicon carbide paper in the series of 400-800-1200 grit under profuse water-cooling to prevent heat build-up.<sup>42,98</sup> This was done to remove any uncured resin.<sup>122</sup>



Five hardness values were recorded for each sample surface and averaged as a single value.<sup>123,125</sup> The five indentations were equally placed in a straight line and neither closer than 0.5mm to the adjacent indentation (Figure 3-16).<sup>123</sup>



Figure 3-16: Five indentations in a straight line, no closer than 0.5mm to the adjacent indentation.

Microhardness was tested with a microhardness tester using a Vickers Diamond Indenter (Struers, Duramin-40 AC 3, Pederstrupvej, Denmark). A 500g load was applied with a dwell time of 40sec (Figure 3-17).<sup>98,126</sup>

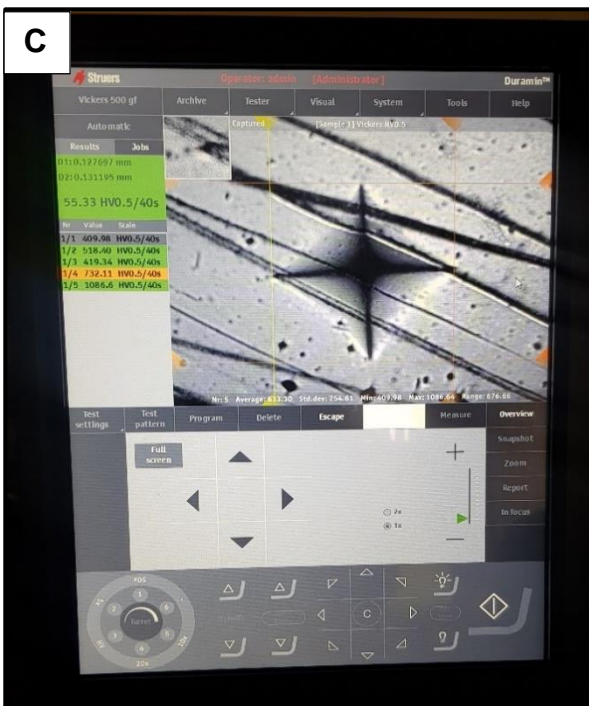
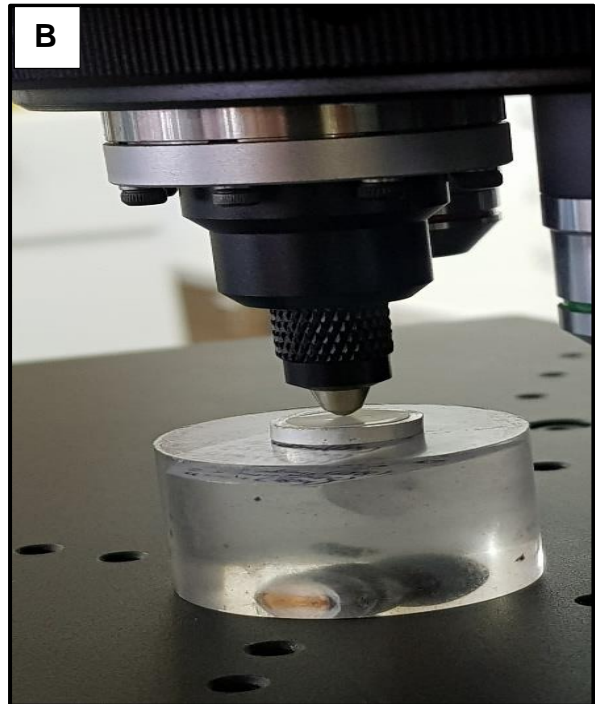
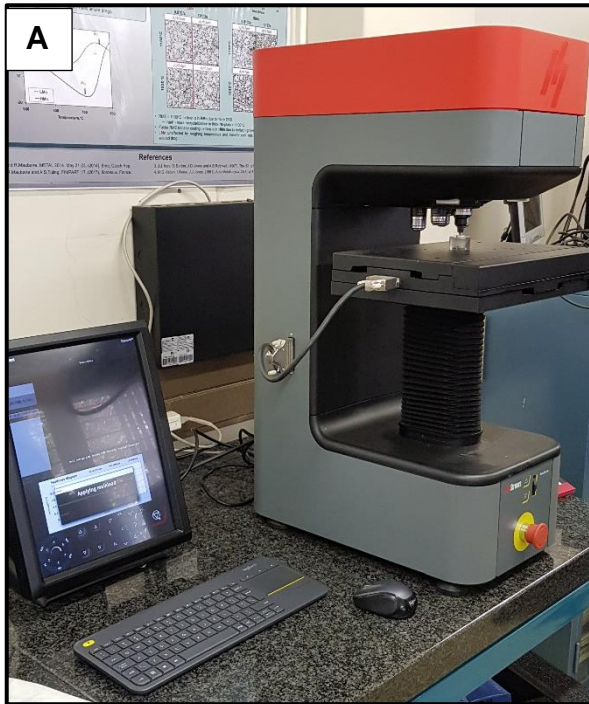


Figure 3-17: A) Vickers Diamond Indenter, Struers, Duramin-40 AC 3. B) 500g load applied with a dwell time of 40sec. C) Projected image after indentation was made.





### 3.4.3 Microleakage

A total of 18 non-carious, crack and restoration free human premolars, extracted for reasons unrelated to this study, was collected. After debridement with a universal scaler (NSK Varios 370, NSK, Tokyo, Japan), the teeth were stored in distilled water at room temperature for no longer than one month.<sup>122,127,128</sup>

Using a high speed handpiece (NSK DynaLED M600LG QD, NSK) mounted with a water-cooled, diamond dome end fissured bur (ISO 838.012 E11.001FG; Edenta AG, Hauptstrasse, Switzerland), 36 box-shaped, standardized, non-bevelled Class V cavities were prepared on the buccal and lingual surface of each tooth.<sup>122,128</sup> Parameters of each cavity preparation were approximately 3mm x 3mm x 2mm.<sup>122</sup> To ensure an even 2mm depth for each cavity, the burs were measured and a rubber stopper was placed and secured with silicon, using a silicon glue gun (Figure 3-18: A-C) .

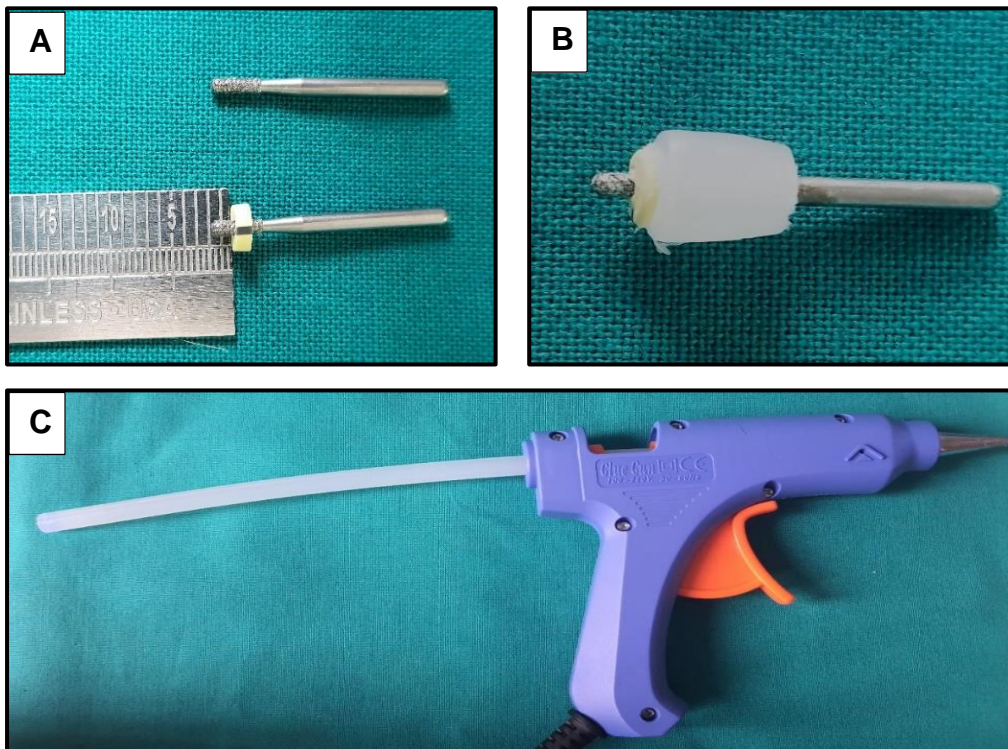


Figure 3-18: A) Diamond Dome shaped Fissure bur measured to 2mm with a rubber stopper. B) Rubber stopper secured using silicone. C) Silicone glue gun used to secure the rubber stopper.



The cavities were prepared in such a way that the cemento-enamel junction was located in the middle of each preparation (Figure 3-20: A).<sup>129 122,130</sup> The bur was replaced after every fifth preparation.<sup>122,130</sup> The cavities were outlined with a permanent marker and a silicone mould on both the buccal and lingual surfaces of each tooth before preparation began (Figure 3-19: A-C).<sup>131</sup>

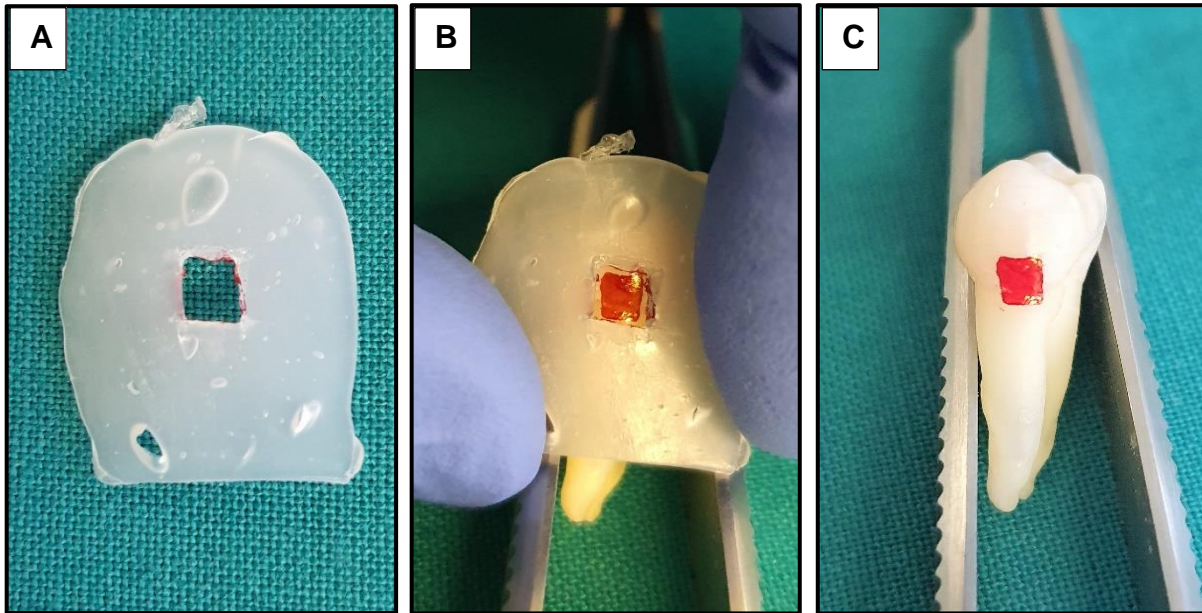


Figure 3-19: A) Silicone mould used. B) A permanent marker was used to outline the cavity form. C) The outlined box shaped cavity.

The dimensions of the preparations were confirmed using a Hu-Friedy Williams periodontal probe (Hu-Friedy Mfg. Co.,LLC, United States) (Figure 3-20: B).<sup>131</sup>

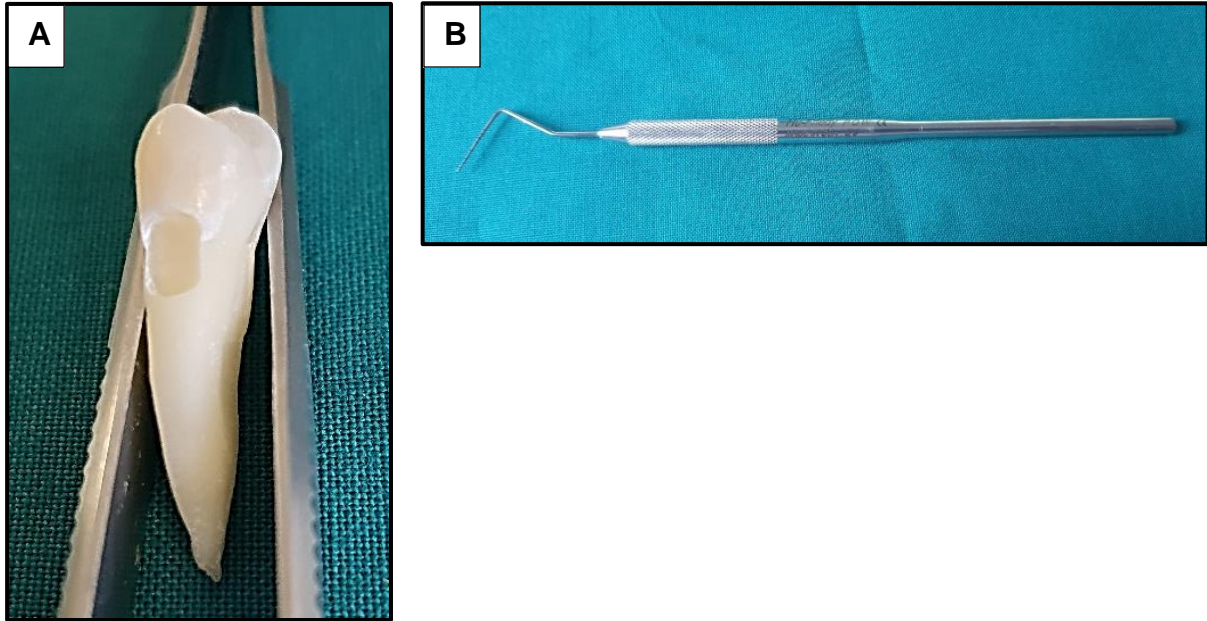


Figure 3-20: A) Prepared cavity with the cemento-enamel junction located in the middle of the cavity. B) Hu-Friedy Williams periodontal probe used to confirm measurements.

Following the preparation of all teeth, they were stored in distilled water at room temperature ( $23\pm 1^\circ\text{C}$ ).<sup>132</sup> The teeth were then randomly divided into three groups of six teeth containing a buccal and lingual cavity preparation.

In each group, the cavities were packed with a restorative material and its corresponding bonding system according to the recommendations and instructions of the respective manufacturers (Figure 3.1: A-C).

- Group 1: A pure ormocer (Admira Fusion) with its corresponding bonding system (Futurabond U).
- Group 2: An ormocer-based composite (Admira) with its corresponding bonding system (Admira Bond).
- Group 3: A nanocomposite (Filtek Z350 XT) with its corresponding bonding system (Adper Single Bond Universal Adhesive).



The same operator prepared all of the cavity preparations, as well as the total etch techniques, bonding and material placement procedures (Table 3-5). For each material, A2 shade was selected. All the restorative materials were placed in a single increment and light cured according to the manufacturers' instructions (Table 3-2 and Table 3-5).<sup>122</sup> All materials were polymerized, using a D-Light Pro dual wavelength LED curing light (Blue light: 460-465nm, Violet light: 400-405nm) with irradiance of 1400mW/cm<sup>2</sup> on high power mode and 700mW/cm<sup>2</sup> on low power mode) (Figure 3-4). A Bluephase radiometer was used to test the intensity of the curing light before curing each sample (Figure 3-5).

Table 3-5: Total etch, material placement, finishing and polishing procedures for each material according to the manufacturers' instructions:

<b>Material:</b>	<b>Admira<sup>116,133</sup></b>	<b>Admira Fusion<sup>116,117</sup></b>	<b>Filtek Z350 XT<sup>134,135</sup></b>
<b>Etching time:</b>	Etch was applied to the enamel for 20sec and the dentine for 15sec. <sup>133</sup> Etchant was rinsed off for 20sec and the cavity air-dried. <sup>133</sup>	Etch was applied to the enamel for 20sec and the dentine for 15sec. <sup>117</sup> Etchant was then rinsed off for 20sec and lightly air-dried to a silky matt appearance. <sup>117</sup>	Etch was applied to the enamel and dentine and left for 15sec. <sup>134</sup> Etchant was rinsed off for 20sec and the cavity air-dried. <sup>134</sup>



<b>Material:</b>	<b>Admira<sup>114,131</sup></b>	<b>Admira Fusion<sup>114,115</sup></b>	<b>Filtek Z350 XT<sup>132,133</sup></b>
<b>Bonding system and application:</b>	Admira Bond was applied and left on the cavity walls for 30sec. <sup>133</sup>	The single use Futurabond U package was activated for each cavity. The liquid was pressed out and mixed with an applicator before applying the bonding system to the cavity walls. The bonding system was rubbed against the cavity walls for 20sec. <sup>117</sup>	Single Bond Universal Adhesive was applied to the cavity walls and rubbed for 20sec <sup>134</sup> .
<b>Curing time for bonding system:</b>	The bonding system was lightly air-dried for five sec and light cured for 20sec. <sup>133</sup>	The bonding system was lightly air-dried for five sec and light cured for 10sec. <sup>117</sup>	The bonding system was lightly air-dried for five sec and light cured for 10sec. <sup>134</sup>



<b>Material:</b>	<b>Admira<sup>114,131</sup></b>	<b>Admira Fusion<sup>114,115</sup></b>	<b>Filtek Z350 XT<sup>132,133</sup></b>
<b>Curing time for restorative material:</b>	Material was placed in a single increment and light cured for 40sec. <sup>133</sup>	Material was placed in a single increment and light cured for 20sec. <sup>117</sup>	Material was placed in a single increment and light cured for 10sec (with output 1000–2000 mW/cm <sup>2</sup> ). <sup>134</sup>
<b>Finishing and Polishing:</b>	A yellow stripe flame shaped diamond bur was used to work off the restoration for 10sec. Polishing was done with a Dimanto polishing disc for 10sec. <sup>116</sup>	A yellow stripe flame shaped diamond bur was used to work off the restoration for 10sec. Polishing was done with a Dimanto polishing disc for 10sec. <sup>116</sup>	A yellow stripe flame shaped diamond bur was used to work off the restoration for 10sec. Polishing was done with a beige Pre-Polishing Spiral Sof-lex disc followed by a pink Diamond Polishing Spiral Sof-lex disc for 10sec each. <sup>135</sup>

After placement of the restorative materials, the restorations were worked off with fine-grit finishing diamond burs (yellow stripe flame shaped finishing diamond bur (ISO 806



314 249 504 012), and polished according to the manufacturers' instructions and recommendations (Table 3-5, Figure 3-2 and Figure 3-8: A).<sup>122,136</sup>

All samples were then stored in distilled water within an Binder incubator (Figure 3-15) at 37°C± 1°C, for seven days to allow for water-absorption and to simulate the oral environment.<sup>98,122,123,136</sup> After storage each group was marked with a label (Figure 3-21: A) and subjected to thermocycling. Thermocycling involved 3000 cycles varying between 5°C (Figure 3-21: B) and 55°C (Figure 3-21: C), with a dwell time of 20sec.<sup>122</sup> Thermocycling was done to simulate clinical stress.<sup>129</sup>

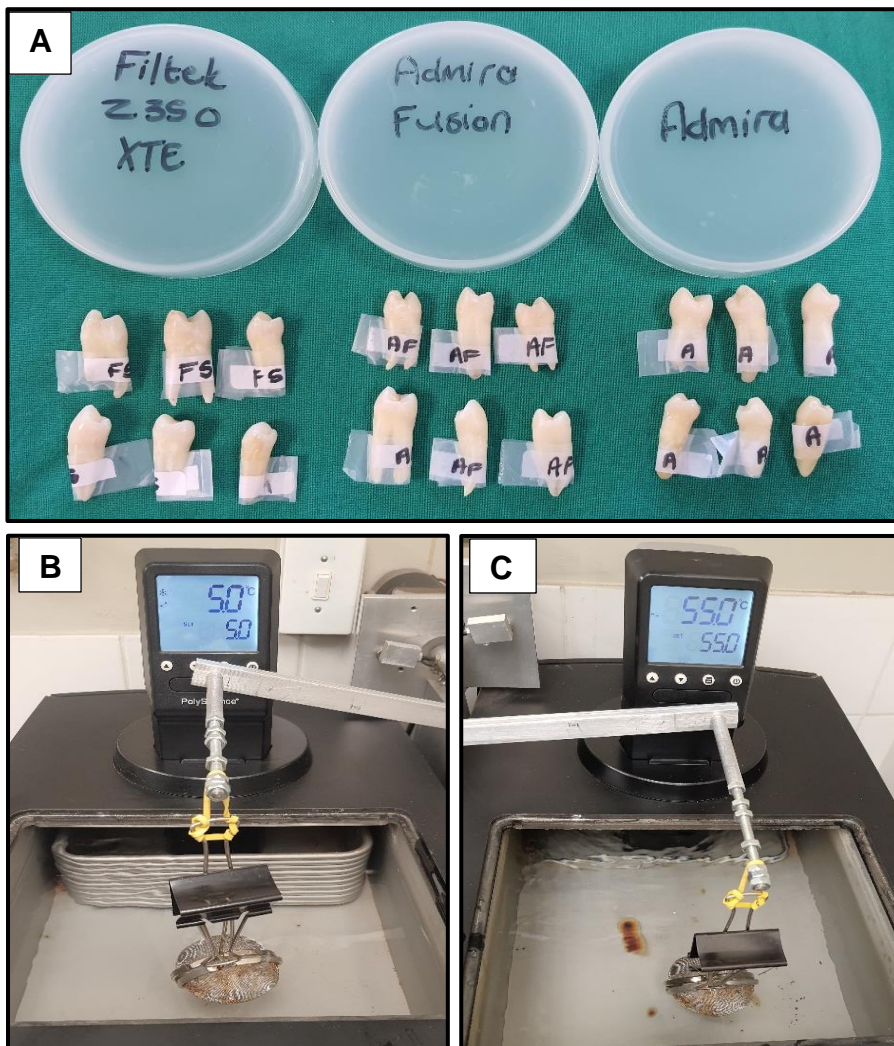


Figure 3-21: A) Each group was marked with a label and placed within an enclosed sift. B) 5°C Cold bath, C) 55°C Heat bath.



For thermocycling, a cooling and heat bath (PolyScience, Illinois, USA), as well as a thermal cycler (Proto-tech, Portland, USA), was used (Figure 3-22).



Figure 3-22: Proto-tech thermal cycler and PolyScience cooling and heat baths.

Following thermocycling, silicon moulds were used to seal the root apices with clear self-cure acrylic resin (Excel Rapid Repair Cold Cure Acrylic, Wright Health Group Ltd, Dundee DD2 3QD, United Kingdom), to prevent dye penetration through the apical foramen (Figure 3-23: A-B).<sup>104</sup>



Figure 3-23: A) Silicone moulds used to embed the apices in acrylic resin, B) Apical foramina of the teeth sealed with acrylic resin, to prevent dye penetration.





Tooth surfaces were coated with two coats of nail varnish up to 2mm from the margins of each restoration (Figure 3-24).<sup>122,137</sup>

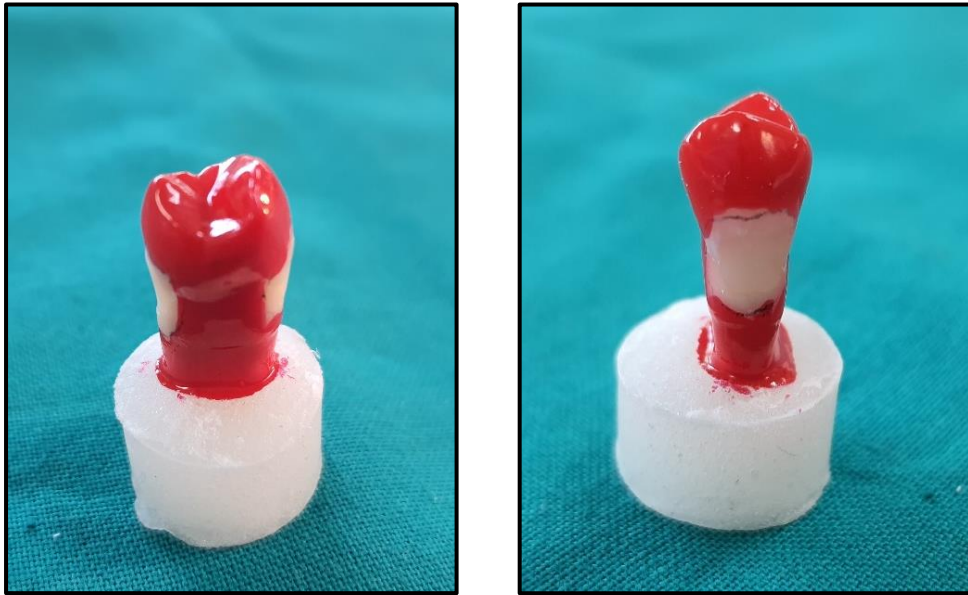


Figure 3-24: Tooth surfaces coated with nail varnish, except for a 2mm band around the margins of each restoration.

Samples were then immersed in 2% methylene blue dye solution for 48 hours at room temperature, after which they were rinsed and dried (Figure 3-25).<sup>62</sup>



Figure 3-25: Samples immersed in 2% methylene blue dye solution for 48 hours.



The nail varnish was removed with hand instruments and the samples were then embedded in clear self-cure acrylic resin (Excel Rapid Repair Cold Cure Acrylic, Wright Health Group Ltd), using a silicone mould (Figure 3-26).<sup>136</sup>



Figure 3-26: Sample embedded in clear self-cure resin.

Using an ISOMET slow speed diamond saw (Figure 3-3: A) with water-cooling, each sample was cut vertically in a bucco-lingual direction through the centre of the restoration (Figure 3-27).<sup>122,137</sup>

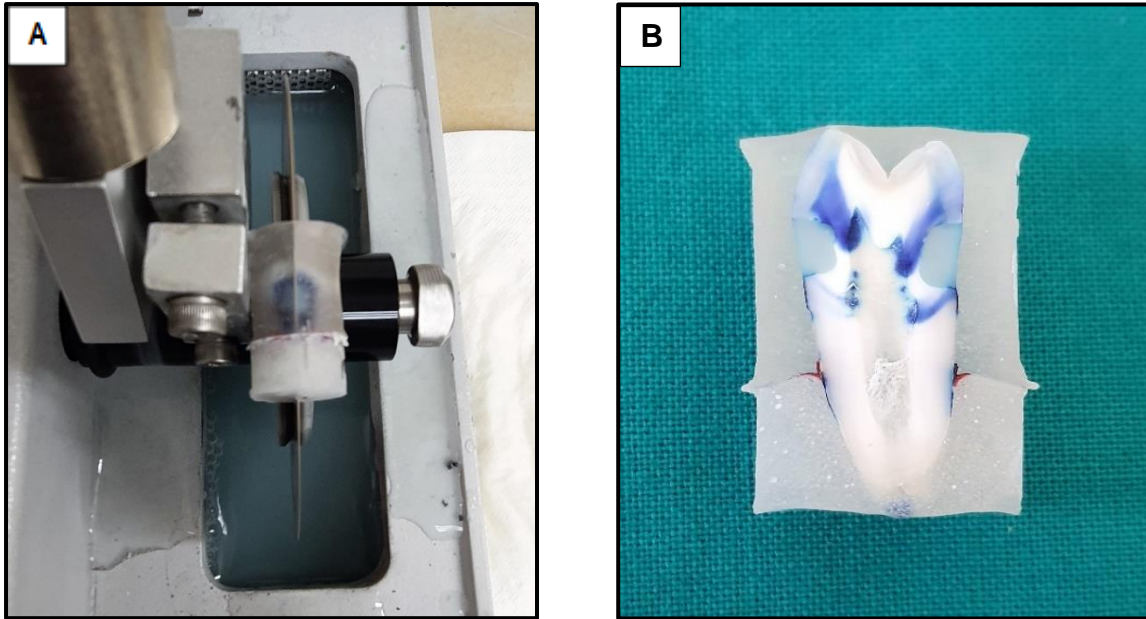


Figure 3-27: A) Slow-speed diamond saw cutting the sample vertically in a buccolingual direction through the centre of the restoration. B) Example of a vertically cut sample.

Under an Olympus SZX7 Stereomicroscope (Olympus Corporation, Shinjuku, Tokyo, Japan) at 25x magnification, sections of each group were visually examined for dye penetration (Figure 3-28).<sup>136,138</sup>



Figure 3-28: Olympus SZX7 Stereomicroscope used to visually examine dye penetration of each sample.



Occlusal and gingival microleakage was scored according to the following criteria (Figure 3-29):

Occlusal margin: <sup>139</sup>

- 0 - No dye penetration
- 1 - Dye penetration not beyond the dentine-enamel junction
- 2 - Dye penetration further than the dentine-enamel junction but not beyond the junction of the occlusal and axial wall.
- 3 - Dye penetration along the axial wall
- 4 - Dye penetration beyond the cavity depth in pulpal direction.

Gingival margin: <sup>136</sup>

- 0 - No dye penetration
- 1 - Dye penetration that extended less than or up to  $\frac{1}{2}$  of gingival wall
- 2 - Dye penetration further than  $\frac{1}{2}$  or up to  $\frac{3}{4}$  of the gingival wall
- 3 - Dye penetration greater than  $\frac{3}{4}$  of the gingival wall or up to and along the axial wall.
- 4 - Dye penetration beyond the gingival and axial wall in pulpal direction.

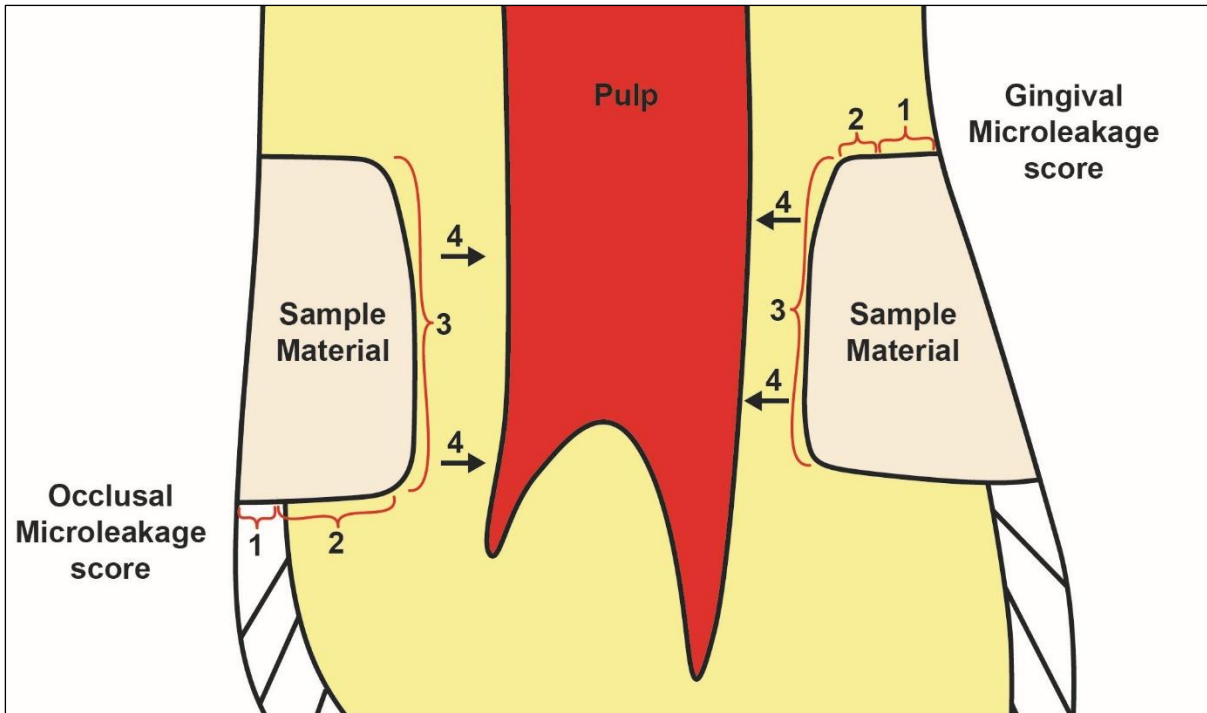


Figure 3-29: Graphical illustration of the criteria used to score the occlusal and gingival microleakage.



### 3.4.4 Stereomicroscope images

Figures 3-30 to 3-34 are representative images of microleakage scoring under the stereomicroscope (Magnification x25).

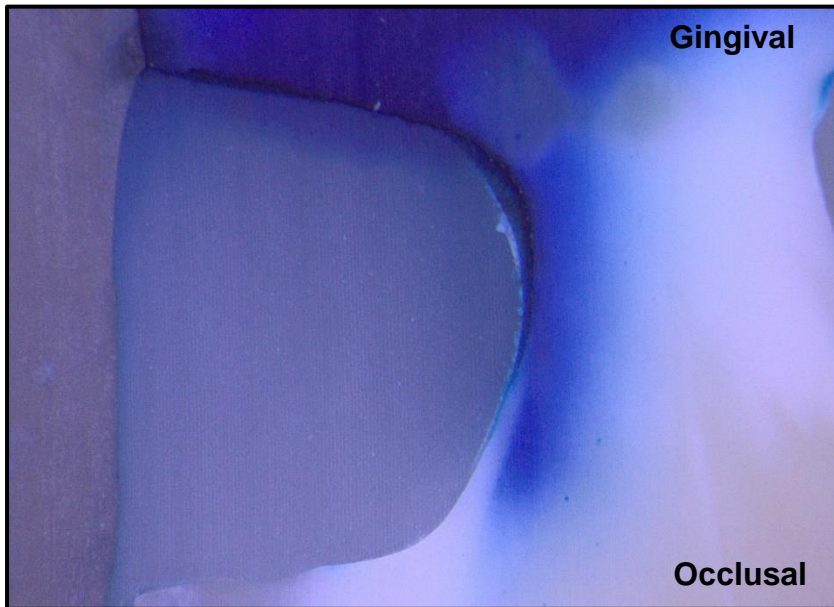


Figure 3-30: Sample with an occlusal microleakage score of 1 and a gingival microleakage score of 4.

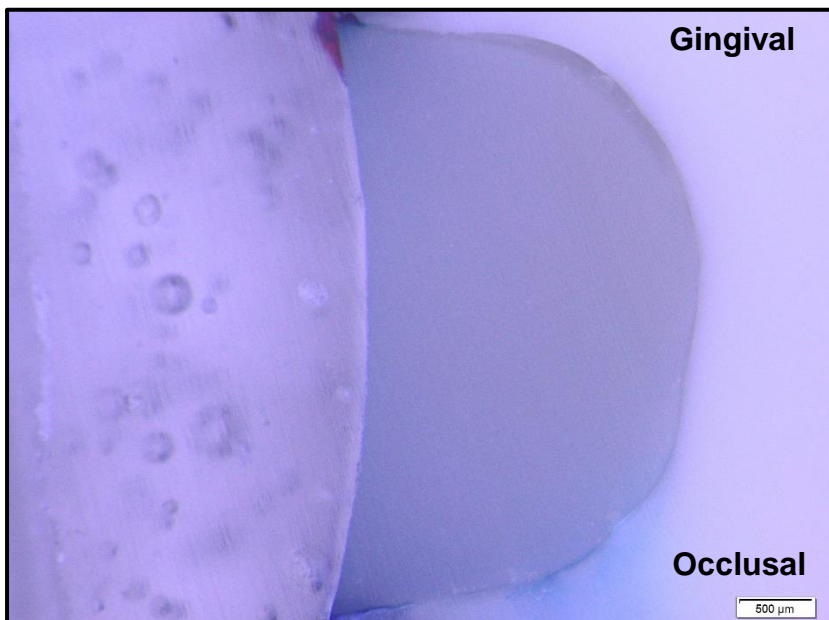


Figure 3-31: Sample with an occlusal microleakage score of 3 and a gingival microleakage score of 1.

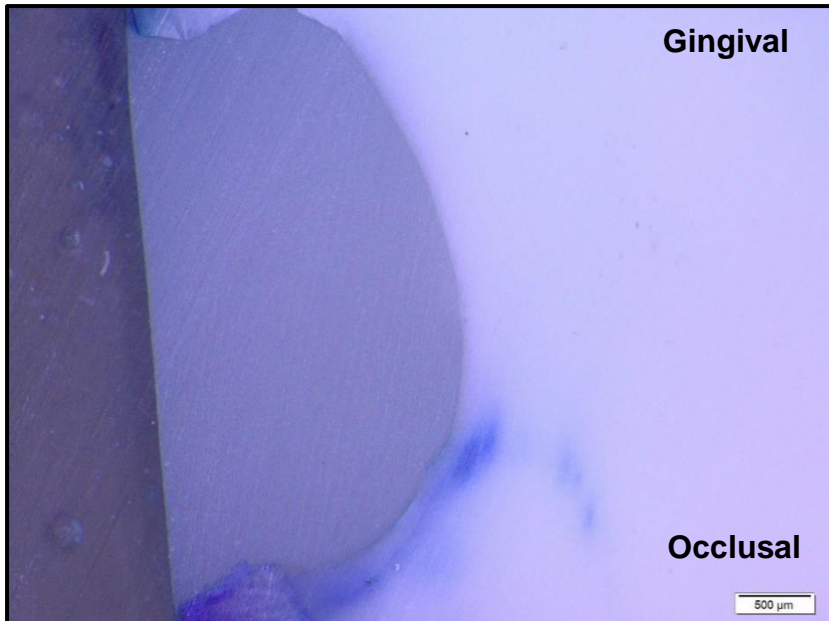


Figure 3-32: Sample with an occlusal microleakage score of 4 and a gingival microleakage score of 2.

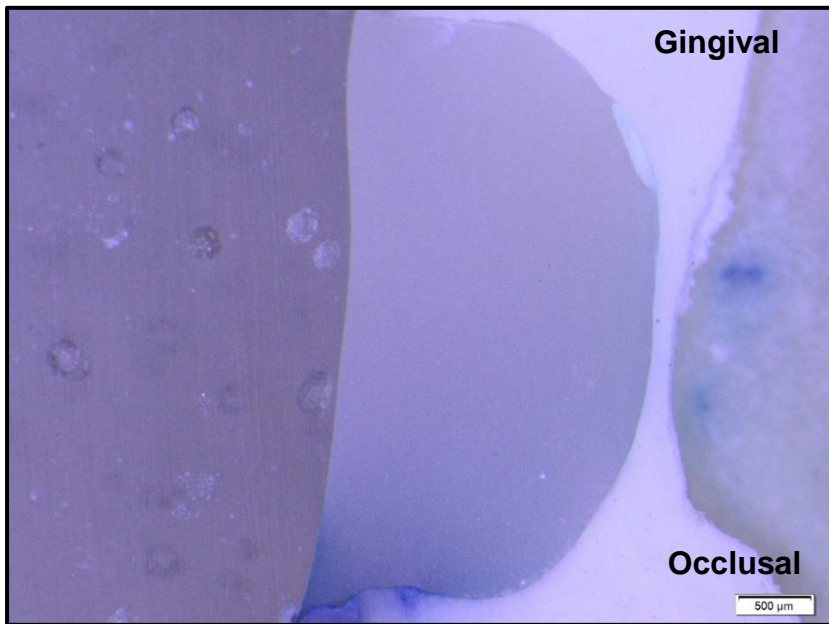


Figure 3-33: Sample with an occlusal microleakage score of 2 and a gingival microleakage score of 0.

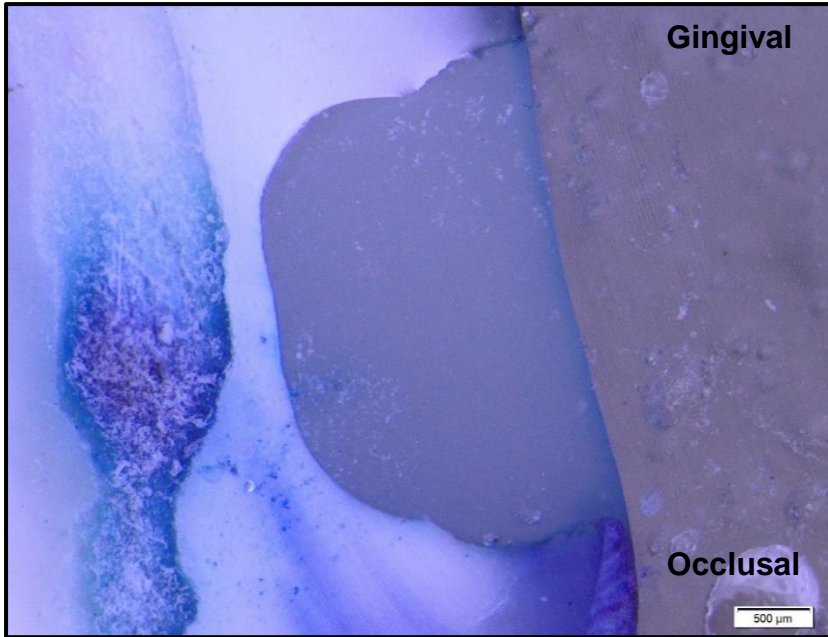


Figure 3-34: Sample with an occlusal microleakage score of 4 and a gingival microleakage score of 3.





### 3.5 Ethical Considerations

Approval was obtained from the University of Pretoria's Faculty of Health Sciences, Research Ethics Committee (Reference number: 207/2019) (Appendix A). The Helsinki Declaration was also signed.

The teeth collected for the purposes of this study were from a collection of adult teeth, extracted as part of a comprehensive treatment plan for each individual patient and therefore unrelated to the aims of this study. All patients are required to sign a patient information leaflet and consent to any treatment plan before treatment commences. The consent form gives the patient the option to allow extracted teeth to be used for research purposes (Appendix B).

Teeth were collected from the Oral and Dental Hospital, Outpatient Dental Extraction Clinic, University of Pretoria Oral Health Centre (UPOHC) (Appendix B).

Teeth are retained and distributed amongst researchers for research projects. It is not possible to link a tooth to a specific patient since teeth are kept in a pool of extracted teeth. The identities of the patients were therefore unknown. No genetic testing was performed on the teeth and individual informed consent could be waived for the use of extracted human teeth for the purpose of this study.

Safety and ethical guidelines for the handling of human teeth were adhered to at all times. After the completion of all research on extracted teeth, the teeth will be discarded subject to the provisions of the Waste Act 59 of 2008 and the Health Professions Council of South Africa's Guidelines for good practice in the health care professions Booklet 16.

Since extracted teeth can be considered potentially infectious, they will be disposed of in medical waste containers after the current dissertation has been examined in fulfilment of the Degree of MSc at the Department of Odontology, School of Dentistry, Faculty of Health Sciences university of Pretoria, Pretoria, South Africa.



There was no conflict of interest present between myself as the main researcher, and the Dental Company VOCO, which provided sponsorship of all VOCO materials. 3M products were not sponsored.

## **3.6 Statistical Considerations**

### **3.6.1 Sample Size**

Data was observed on a continuous scale and groups were compared using analysis of variance (ANOVA) and when adjusting for baseline an analysis of covariance (ANCOVA) was used.

Variation was expected to be small and hence for each of the three experiments a sample size of at least 12 samples per group, i.e. at least 36 per experiment, were adequate as the residual degrees of freedom were at least 33.

The latter is in line with the norm for acceptable sample size when residual degrees of freedom are at least 30. The conservative approach was followed here, compared to the norm of 14 residual degrees of freedom, which is often accepted when small variation is expected, i.e. six teeth per group.

### **3.6.2 Data Capturing**

Values for each test performed were recorded on a MS Excel document designed specifically for the purpose of this study.

All data was collected and combined by the researcher. The supervisor and co-supervisor confirmed the resulting datasets. Thereafter, these datasets were submitted to a statistician for analysis.



### 3.6.3 Statistical Analysis

Data summary by restorative material was reported, but was not restricted to mean, standard deviation and 95% confidence intervals for all three outcomes.

Data analysis employed a one-way ANOVA (surface roughness and surface hardness), with factor group at three levels. Pairwise comparisons among materials were tested with the Bonferroni adjustment.

For microleakage, the opportunity was there to assess two cavities per tooth. In this case, data analysis made use of mixed-effects regression with fixed effect group and the tooth was specified as random effect. Material groups were compared with respect to their distribution over score using Fisher's exact test.

Following any one of the data analysis approaches, pairwise comparisons between groups were done. In the Stata Release 15 Statistical Software the margins command facilitated the latter. Testing was done at the 0.05 level of significance.



## Chapter 4 : Results

Surface Roughness, Surface Hardness and Microleakage were tested at  $p < 0.05$  level of significance.

### 4.1 Surface Roughness

The four different experimental conditions were compared in one-way analysis of variance (ANOVA). Pairwise comparisons among materials were tested with the Bonferroni adjustment.

The values recorded after polymerization with the Mylar strips and before polishing were statistically compared for all four experimental conditions (Table 4.1).

Four experimental conditions:

1. Ormocer-based composite (Admira) polished according to the manufacturer's instructions.
2. Pure ormocer (Admira Fusion) to be polished without water, according to the manufacturer's instructions.
3. Pure ormocer (Admira Fusion) to be polished with water, according to the manufacturer's instructions.
4. Nanocomposite (Filtek Z350 XT) polished according to the manufacturer's instructions.

Mylar strip finish for all experimental conditions gave the smoothest finish. No statistical significant differences were found between the four experimental conditions, before polishing (Table 4-1 and Figure 4-1).



Table 4-1: Pairwise comparisons between experimental conditions, indicating no statistical differences.

Pairwise comparisons before polishing		
Comparison experimental groups	Mean surface Roughness ( $\mu\text{m}$ )	Bonferroni Adjusted p-value
Pure ormocer polished wet vs Pure ormocer polished dry	0.102 vs 0.187	1.000
Pure ormocer polished dry vs Ormocer-based composite	0.214 vs 0.187	1.000
Pure ormocer polished wet vs Ormocer-based composite	0.214 vs 0.102	1.000
Nanocomposite vs Pure ormocer polished dry	0.319 vs 0.187	0.821
Nanocomposite vs Pure ormocer polished wet	0.319 vs 0.102	0.102
Nanocomposite vs Ormocer-based composite	0.319 vs 0.214	1.000

\*Statistical significance is set at  $p < 0.05$

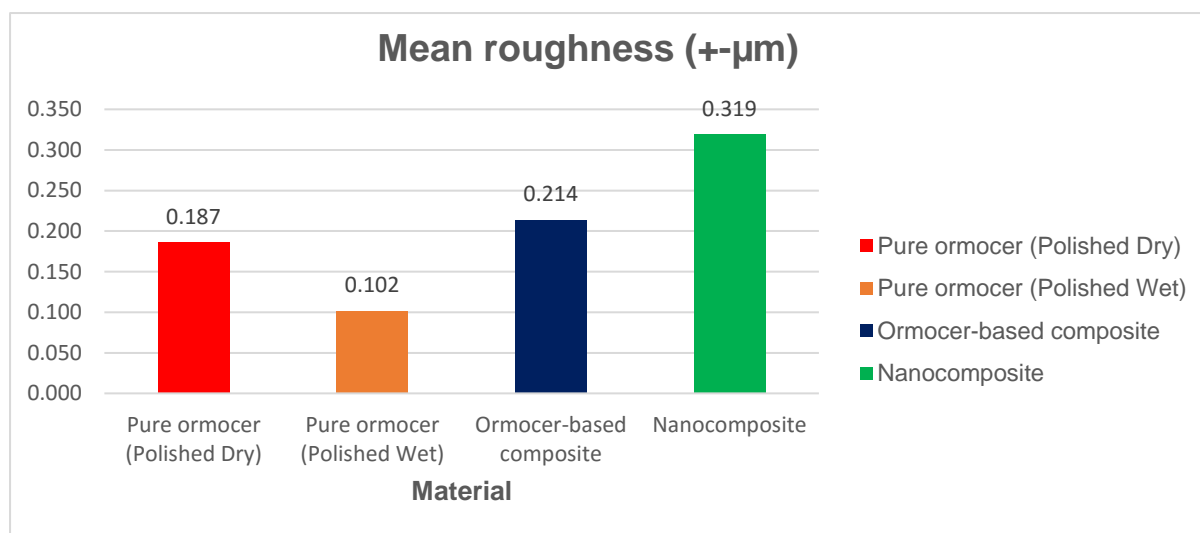


Figure 4-1: Mean roughness values of materials before polishing and after curing through a Mylar strip. Values calculated from three readings of each of the 12 samples per material.



After polishing strictly according to the manufacturers' instructions, statistically significant differences were found between the four experimental conditions.

Pairwise comparisons were done to identify between which experimental conditions the differences were found (Table 4-2).

Table 4-2: Pairwise comparisons between experimental conditions. Statistical differences shown by the yellow highlighted cells.

<b>Pairwise comparisons after polishing</b>		
<b>Comparison experimental groups</b>	<b>Mean surface Roughness (µm)</b>	<b>Bonferroni Adjusted p-value</b>
Pure ormocer polished wet vs Pure ormocer polished dry	1.028 vs 1.188	0.373
Ormocer-based composite vs Pure ormocer polished dry	0.871 vs 1.188	0.003 *
Ormocer-based composite vs Pure Ormocer polished wet	0.871 vs 1.028	0.397
Nanocomposite vs Pure ormocer polished dry	0.826 vs 1.188	<0.001 *
Nanocomposite vs Pure ormocer polished wet	0.826 vs 1.028	0.115
Nanocomposite vs Ormocer-based composite	0.826 vs 0.871	1.000

\*Statistical significant differences (p<0.05)

Statistical significant differences were found between the ormocer-based composite and the pure ormocer when polished without water (p=0.003), as well as between the nanocomposite and the pure ormocer, when polished without water (p<0.001) (Figure 4-2). No statistically significant differences were found between the ormocer-based composite, the pure ormocer when polished with water and the nanocomposite (Figure 4-2). For the pure ormocer there was no significant difference in terms of surface roughness regardless of whether polishing was done with or without water-cooling using Dimanto polishing discs (p=0.373).

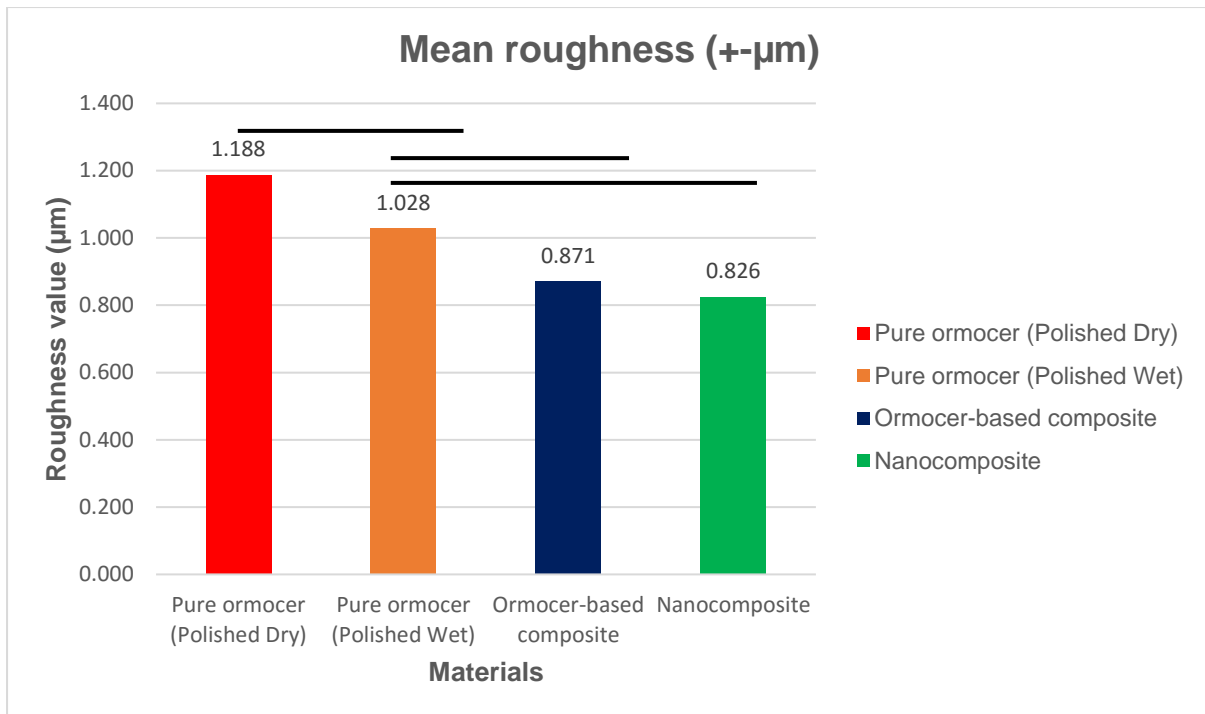


Figure 4-2: The bar graph indicates the combined mean surface roughness of all three readings for each of the 12 samples per material after finishing and polishing procedures. Statistical differences are illustrated graphically. Experimental conditions under the same black line are not statistically different from one another, while those that do not share a common line differ statistically significantly from one another.



### 4.1.1 Scanning Electron Microscope (SEM) Images

Random samples from each group of materials were evaluated under the SEM after polishing, to visually examine and compare the surface topography of the materials with that of the profilometry results.

Some of the SEM findings (500x and 1000x magnification) are shown in Figures 4-3 – 4-5.

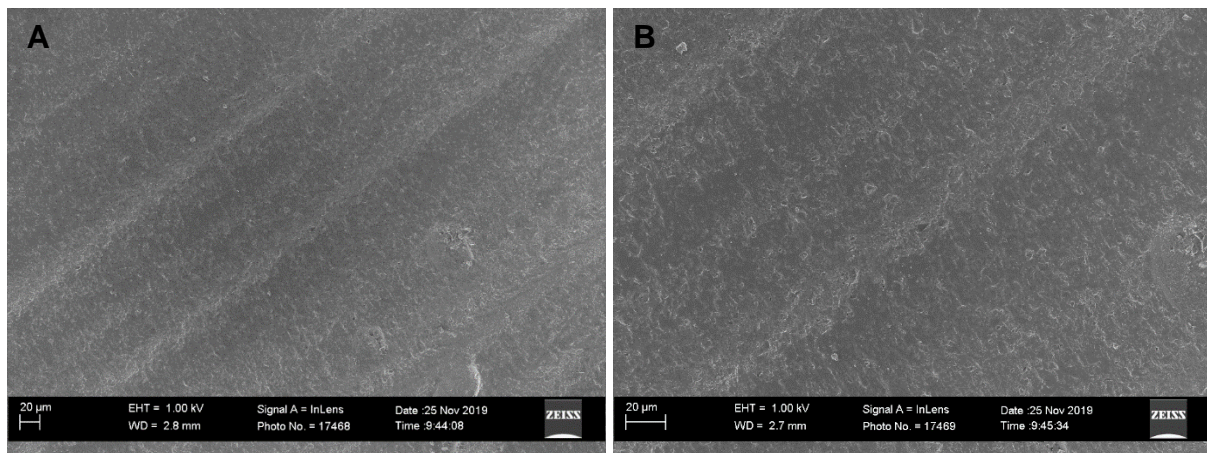


Figure 4-3: Pure ormocer A) 500x magnification and B) 1000x magnification after polishing. Visible scratch lines and pits can be observed.

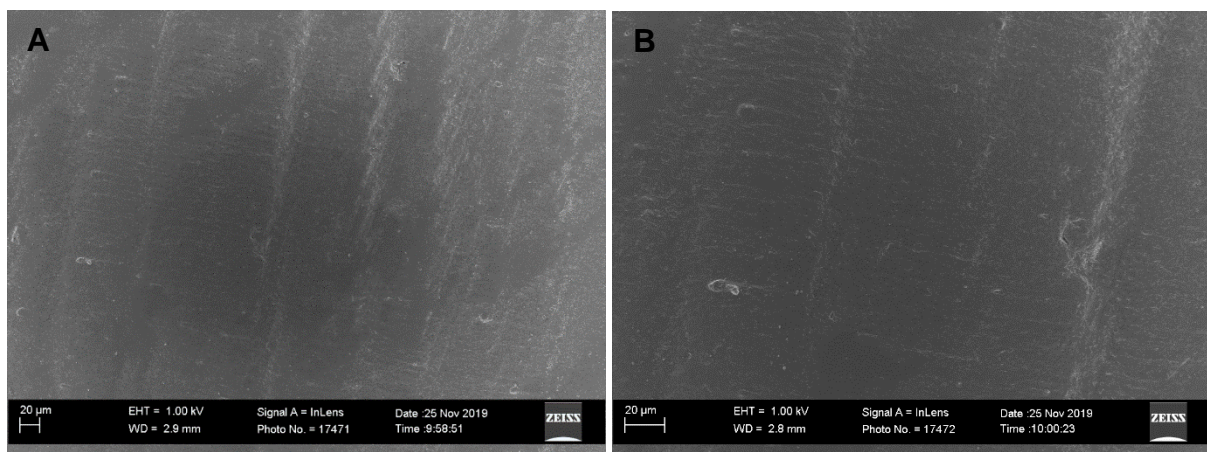


Figure 4-4: Ormocer-based composite A) 500x magnification and B) 1000x magnification after polishing. Visible scratch lines and irregularities can be observed.



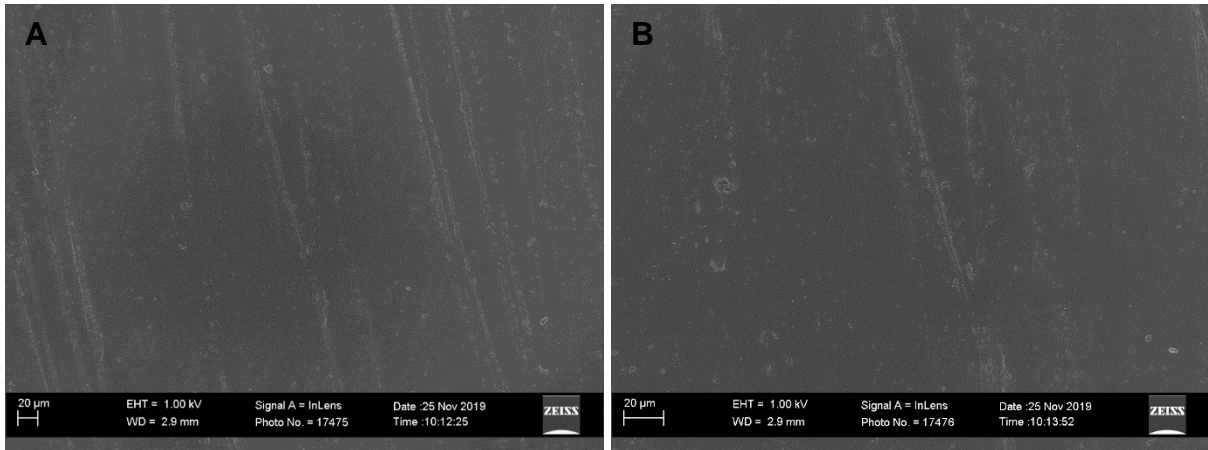


Figure 4-5: Nanocomposite A) 500x magnification and B) 1000x magnification after polishing. Visible scratch lines, voids and pits can be observed.

## 4.2 Surface Hardness

One-way analysis of variance determined that there is a statistically significant difference among the three materials with respect to surface hardness. Pairwise comparisons among materials were tested with the Bonferroni adjustment to determine the statistical significant differences (Table 4-3).

Table 4-3: Pairwise comparisons between materials. Statistical significant differences are indicated by the yellow highlighted cells.

Pairwise comparisons		
Comparison Surface Hardness Groups	Mean Surface Hardness (VHN)	Bonferroni Adjusted P-value
Ormocer-based composite vs Pure ormocer	70.059 vs 73.762	0.617
Nanocomposite vs Pure ormocer	100.946 vs 73.762	<0.001 *
Nanocomposite vs Ormocer-based composite	100.946 vs 70.059	<0.001 *

\*Statistical significant differences ( $p < 0.05$ )



Pairwise statistical comparisons revealed that the pure ormocer and the ormocer-based composite do not differ significantly ( $p=0.617$ ). The surface hardness of the nanocomposite was statistically significantly higher than both the pure ormocer ( $p<0.001$ ) and the ormocer-based composite, ( $p<0.001$ ) (Figure 4-6).

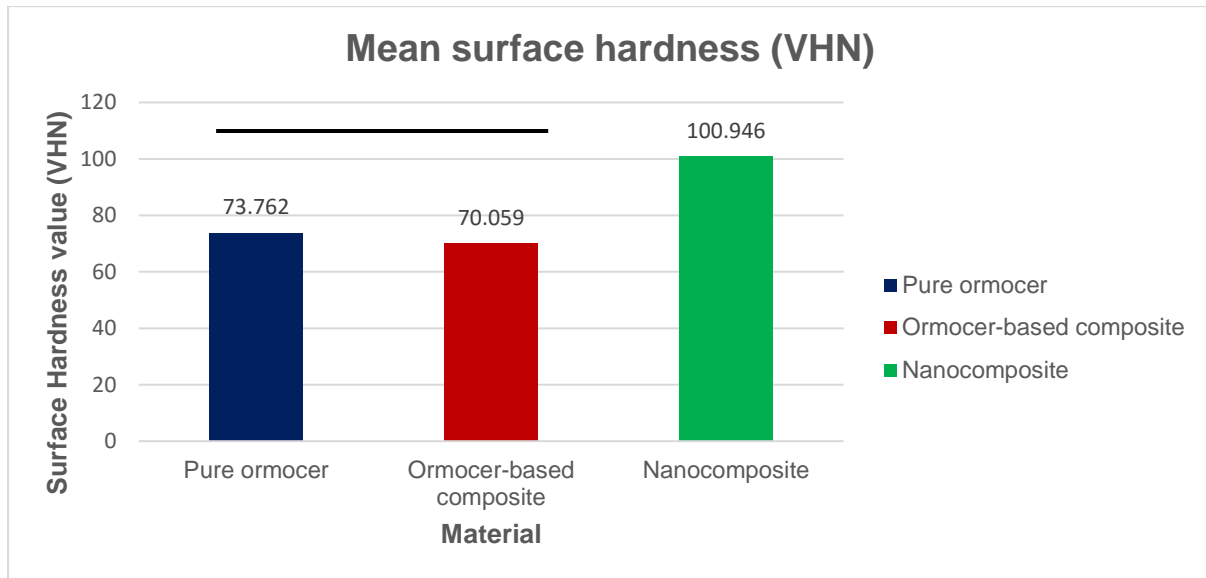


Figure 4-6: The bar graph indicates the combined mean surface hardness of all five readings for each of the 12 samples per material. Statistical differences are illustrated graphically where materials under the same black line are not statistically different from one another, while those that do not share a common line differ statistically significantly from one another.



## 4.3 Microleakage

Occlusal and gingival microleakage data for the three material groups were compared using the Fisher's exact test. Pairwise comparisons among materials were tested with the Bonferroni adjustment.

### 4.3.1 Occlusal Microleakage

Occlusal microleakage showed no statistical significant differences between the materials ( $p=0.534$ ). Exploratory observation suggested less leakage with the ormocer-based composite and the nanocomposite, since +/- 50% of leakage scores occurred between 1-3. With the pure ormocer, 50% of leakage scores occurred at 4 (Table 4-4 and Figure 4-7). With a larger sample size, differences may emerge more prominently.

Table 4-4: Occlusal microleakage scores.

Occlusal Microleakage (%)						
Score	0	1	2	3	4	TOTAL
<b>Pure Ormocer</b>	8.31 (*1)	8.33 (*1)	16.67 (*2)	16.67 (*2)	50.00 (*6)	100 (*12)
<b>Ormocer-Based Composite</b>	16.67 (*2)	16.67 (*2)	8.33 (*1)	41.67 (*5)	16.67 (*2)	100 (*12)
<b>Nanocomposite</b>	0	8.33 (*1)	16.67 (*2)	50.00 (*6)	25.00 (*3)	100 (*12)
<b><math>p^{**} = 0.534</math></b>						
* Number of the 12 samples tested with the same score						
** Fisher's Exact Test						

\* Statistical significance is set at  $p < 0.05$

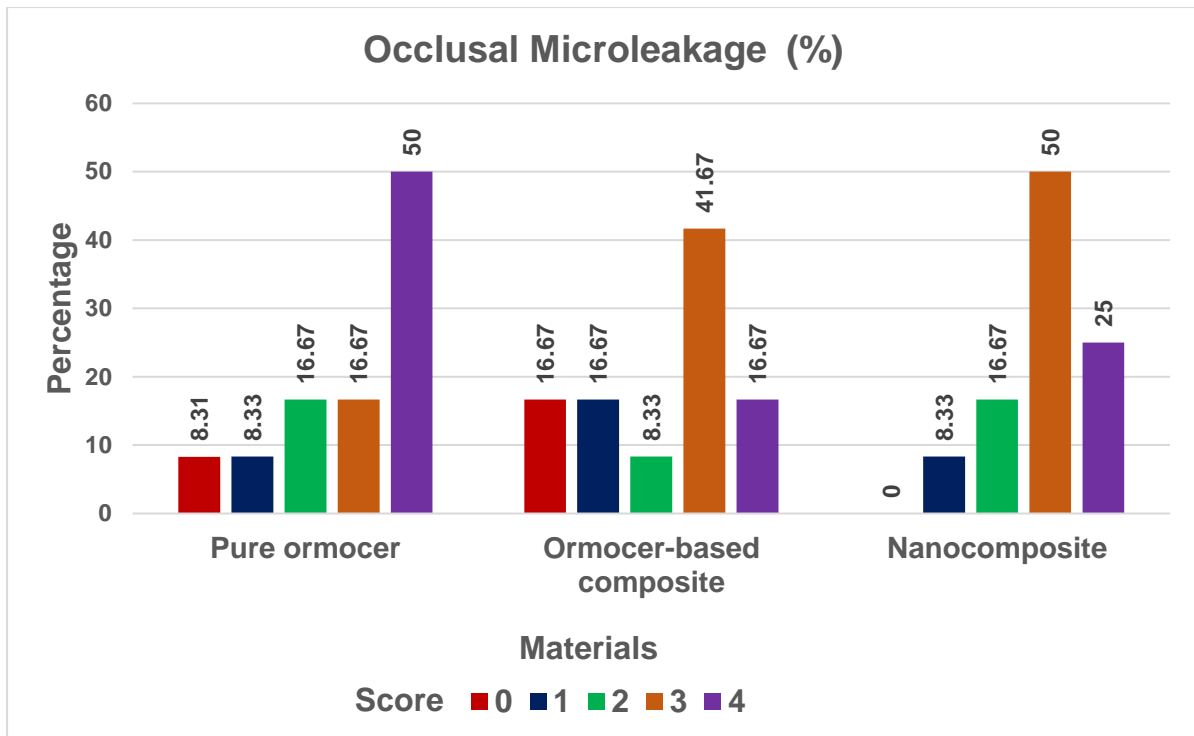


Figure 4-7: Bar graph indicates the percentage of occlusal microleakage according to the score criteria used.

### 4.3.2 Gingival Microleakage

Gingival microleakage analysis was tested against the following criteria of significance:

- $p \leq 0.05$ : Statistically significant
- $0.05 < p \leq 0.1$ : Marginally significant
- $p > 0.1$ : Not significant

Fisher's exact test revealed marginally significant differences between the materials with respect to gingival microleakage ( $p=0.093$ ) (Table 4-5).



Table 4-5: Gingival microleakage scores. Marginal statistical significant difference indicated by yellow highlighted cell.

Gingival Microleakage (%)						
Score	0	1	2	3	4	TOTAL
PureOrmocer	0	0	0	33.33 (*4)	66.67 (*8)	100 (*12)
Ormocer-Based Composite	0	16.67 (*2)	8.33 (*1)	25.00 (*3)	50.00 (*6)	100 (*12)
Nanocomposite	16.67 (*2)	16.67 (*2)	0	0	66.67 (*8)	100 (*12)

**p\*\* = 0.093**

\* Number of the 12 samples tested with the same score  
 \*\* Fisher's Exact Test

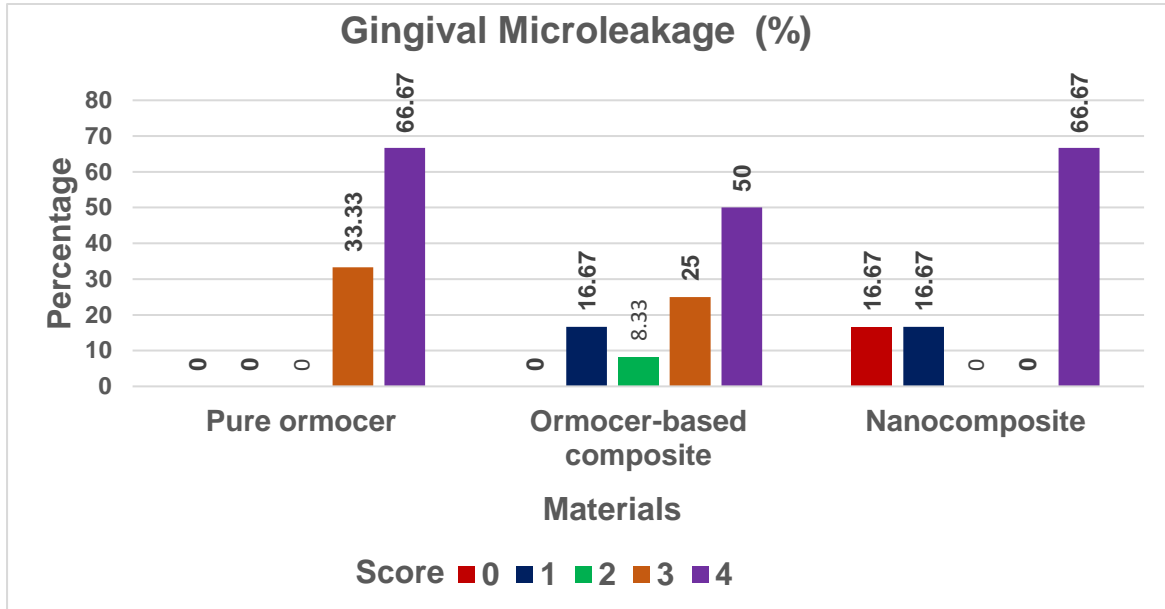


Figure 4-8: Bar graph indicates the percentage of gingival microleakage according to the score criteria used.



Pairwise comparisons among the materials were tested with the Bonferroni adjustment to determine the reason for the marginal significant difference in leakage between the material groups. No significant differences were found between the pure ormocer vs the ormocer-based composite ( $p=0.485$ ) and the ormocer-based composite vs the nanocomposite ( $p=0.199$ ) (Tables 4-6 – 4-8 and Figures 4-9 – 4-11). The marginally significant difference can be explained by comparing the pure ormocer with the nanocomposite ( $p=0.036$ ) (Table 4-8 and Figure 4-11). The nanocomposite showed marginally less gingival microleakage than the pure ormocer.

Table 4-6: Pairwise comparison between the pure ormocer and the ormocer-based composite.

Pure Ormocer vs Ormocer-Based Composite (%)						
Score	0	1	2	3	4	TOTAL
Pure Ormocer Gingival	0	0	0	33.33	66.67	100
Ormocer-Based Composite Gingival	0	16.67	8.33	25	50	100
$p^{**} = 0.485$						
** Fisher's Exact Test						

\*Statistical significance is set at  $0.05 < p \leq 0.1$

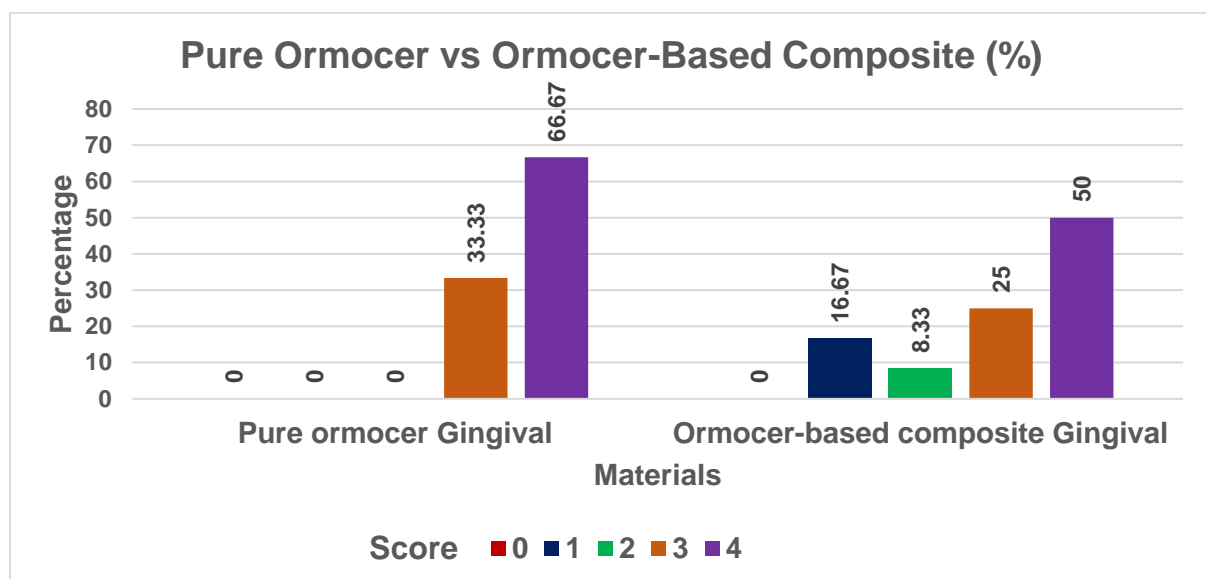


Figure 4-9: Bar graph indicates the percentage of gingival microleakage of the pure ormocer vs the ormocer-based composite according to the score criteria used.



Table 4-7: Pairwise comparison between the ormocer-based composite and the nanocomposite.

Ormocer-Based Composite vs Nanocomposite (%)						
Score	0	1	2	3	4	TOTAL
<b>Ormocer-based composite Gingival</b>	0	16.67	8.33	25	50	100
<b>Nanocomposite Gingival</b>	16.67	16.67	0	0	66.67	100

**p\*\* = 0.199**

\*\* Fisher's Exact Test

\*Statistical significance is set at  $0.05 < p \leq 0.1$

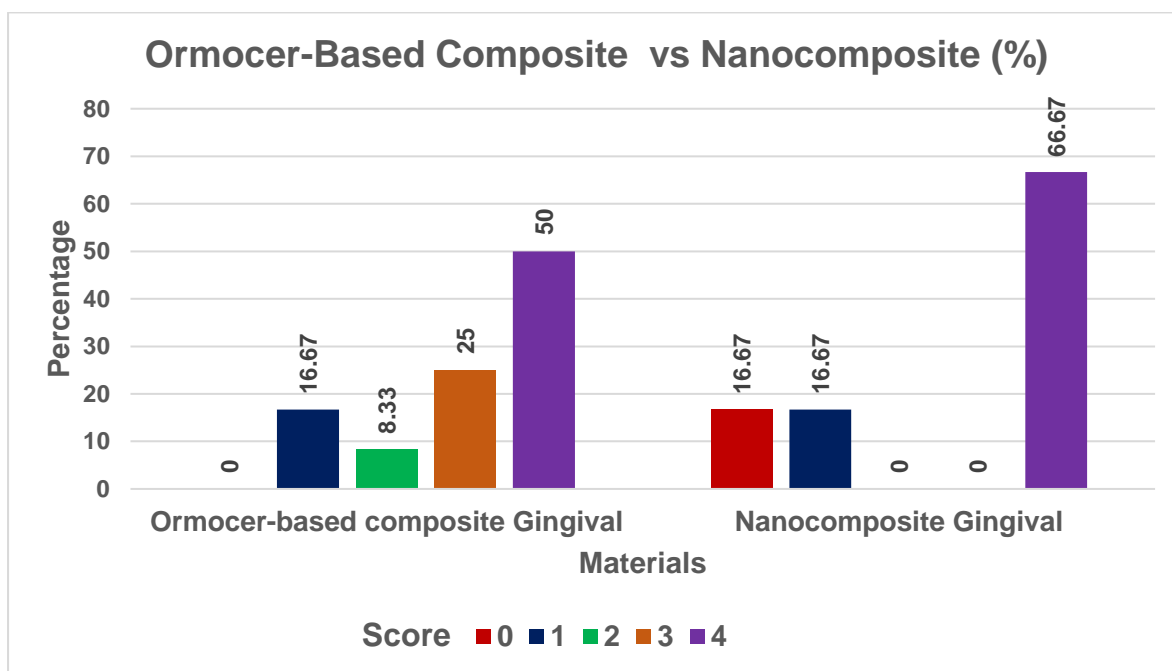


Figure 4-10: Bar graph indicating the percentage of gingival microleakage of the ormocer-based composite vs the nanocomposite according to the score criteria used.



Table 4-8: Pairwise comparison between the pure ormocer and the nanocomposite. Statistical significant difference indicated by yellow highlighted cell.

Pure Ormocer vs Nanocomposite (%)						
Score	0	1	2	3	4	TOTAL
Pure Ormocer Gingival	0	0	0	33.33	66.67	100
Nanocomposite Gingival	16.67	16.67	0	0	66.67	100
<b>p** = 0.036</b>						
** Fisher's Exact Test						

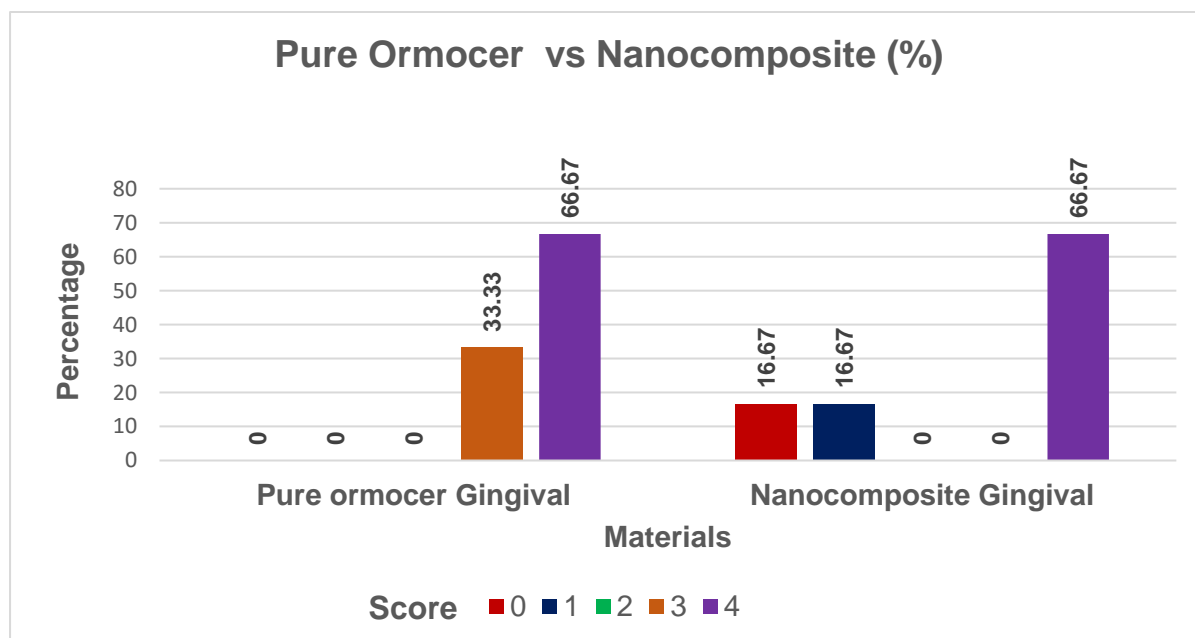


Figure 4-11: Bar graph indicates the percentage of gingival microleakage of the pure ormocer vs the nanocomposite according to the score criteria used.

### 4.3.3 Occlusal Microleakage vs. Gingival Microleakage

Occlusal and gingival microleakage scores within each material group were compared with one another to determine any statistically significant differences.





No statistical significant difference was found between the pure ormocer ( $p=0.340$ ) and the ormocer-based composite ( $p=0.441$ ) when the occlusal microleakage was compared to the gingival microleakage of each material group (Tables 4-9 - 4-10 and Figures 4-12 – 4-13). The occlusal microleakage of the nanocomposite showed a statistically significant difference when compared to the gingival microleakage of the nanocomposite ( $p=0.004$ ). The occlusal microleakage of the nanocomposite was significantly less than the gingival microleakage for the same material (Table 4-11 and Figure 4-14).

Table 4-9: Occlusal vs Gingival microleakage of the pure ormocer.

Pure Ormocer Microleakage (%)						
Score	0	1	2	3	4	TOTAL
Occlusal	8.33	8.33	16.67	16.67	50	100
Gingival	0	0	0	33.33	66.67	100
$p^{**} = 0.340$						
** Fisher's Exact Test						

\*Statistical significance set at  $p < 0.05$

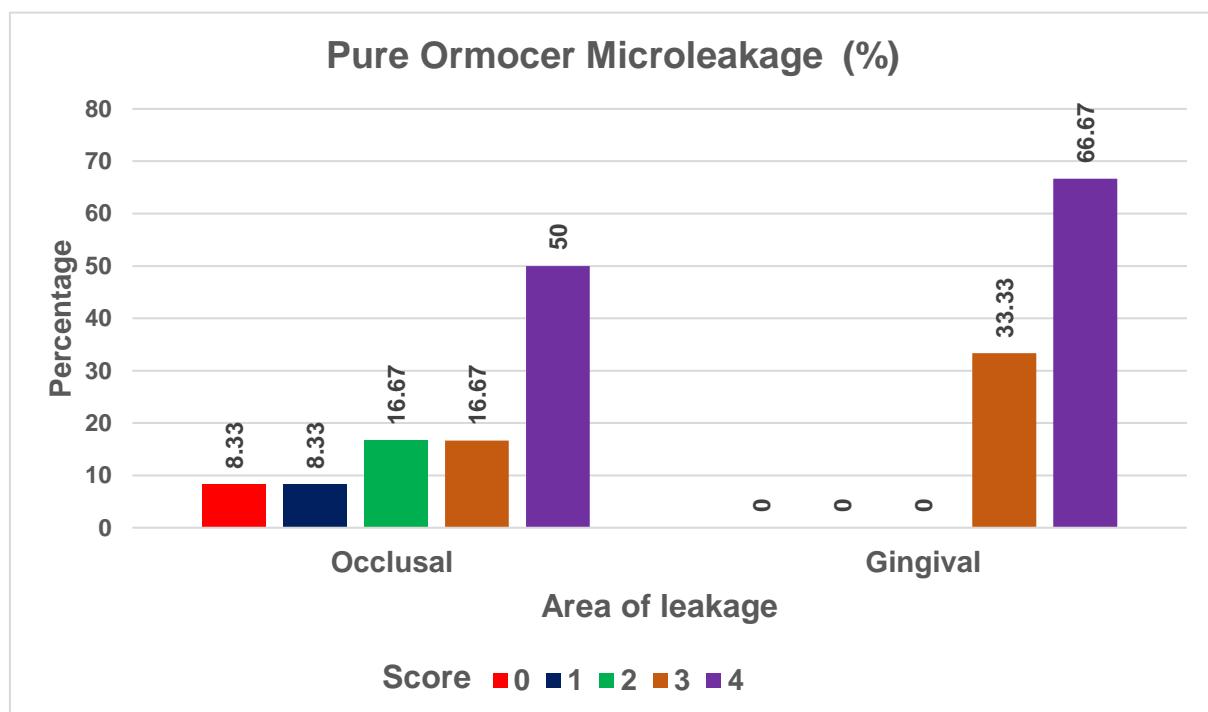


Figure 4-12: Bar graph indicates the percentage of occlusal microleakage with gingival microleakage of the pure ormocer according to the score criteria used.



Table 4-10: Occlusal vs Gingival microleakage of the ormocer-based composite.

Ormocer-Based Composite Microleakage (%)						
Score	0	1	2	3	4	TOTAL
Occlusal	16.67	16.67	8.33	41.67	16.67	100
Gingival	0	16.67	8.33	25	50	100
<b>p** = 0.441</b>						
** Fisher's Exact Test						

\*Statistical significant difference set at  $p < 0.05$

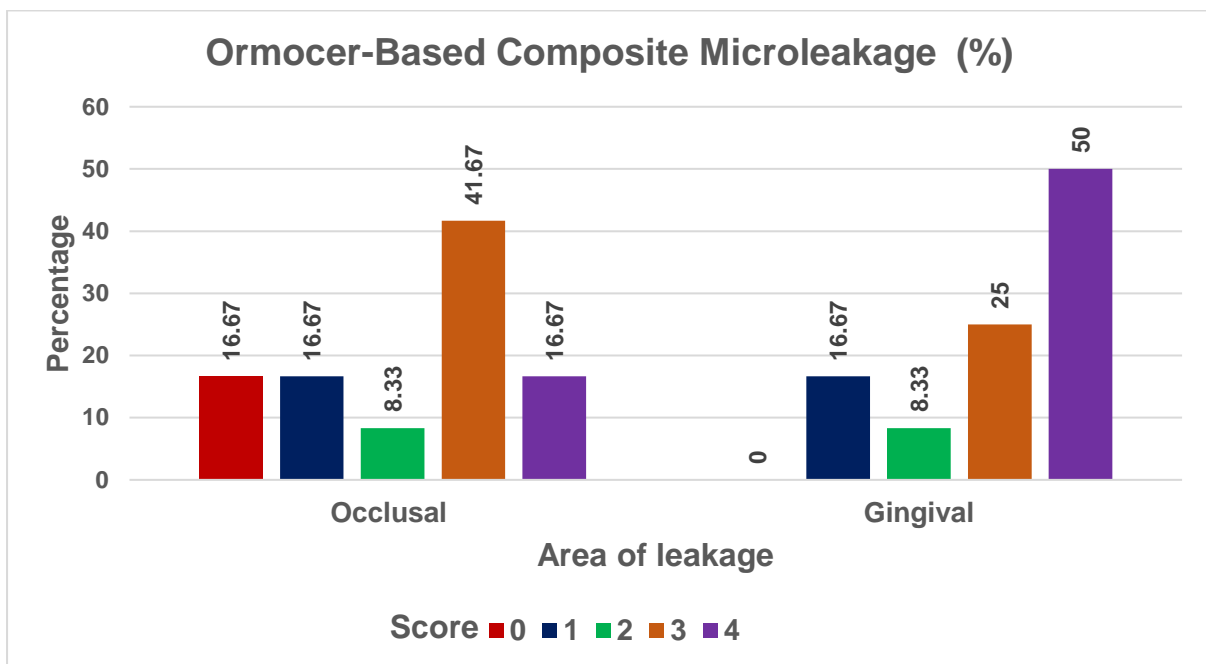


Figure 4-13: Bar graph indicates the percentage of occlusal microleakage with gingival microleakage of the ormocer-based composite according to the score criteria used.



Table 4-11: Occlusal vs Gingival microleakage of the nanocomposite. Statistical significant difference indicated by yellow highlighted cell.

Nanocomposite Microleakage (%)						
Score	0	1	2	3	4	TOTAL
Occlusal	0	8.33	16.67	50	25	100
Gingival	16.67	16.67	0	0	66.67	100
<b>p** = 0.004</b>						
** Fisher's Exact Test						

\*Statistical significant difference set at  $p < 0.05$

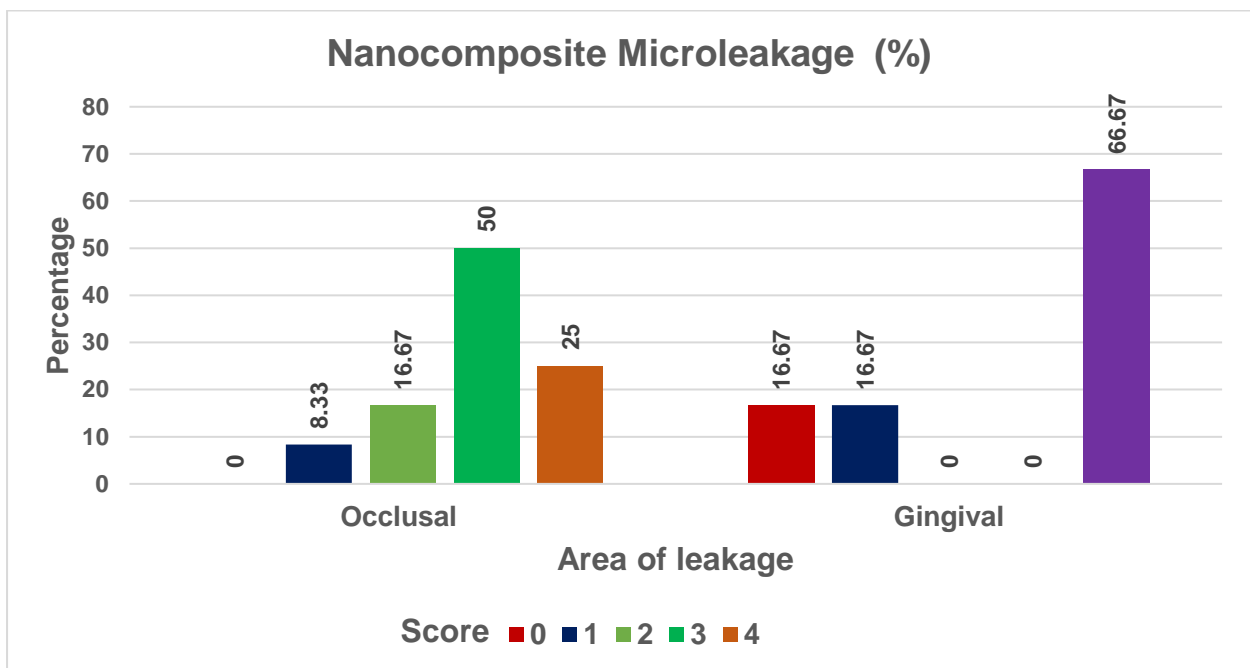


Figure 4-14: Bar graph indicates the percentage of occlusal microleakage with gingival microleakage of the nanocomposite according to the score criteria used.



## Chapter 5 : Discussion

Interest in composite resins have increased due to their improved aesthetics in dental restorations.<sup>66,140</sup> Polymerization shrinkage and inadequate wear resistance continue to be some of the major disadvantages of composite resins.<sup>66,140</sup> Therefore the development of new restorative systems, such as pure ormocers, becomes critical in the search for restorations with greater longevity.<sup>127</sup> The restorative materials' filler type and content greatly influence the surface hardness and correlate to the polishability of that material.<sup>141</sup> Obtaining adequate surface hardness ensures that restorative materials will be able to withstand forces in dental stress bearing areas.<sup>101</sup> Surface roughness is important for clinical aesthetics, resistance to dental plaque accumulation and ultimately the longevity of the restoration.<sup>142</sup> Without an inadequate marginal seal, microleakage will occur at the tooth-restoration interface, resulting in ultimate failure of the placed restoration.<sup>104</sup> Surface roughness, surface hardness and microleakage can therefore be regarded as material properties that contribute to the longevity of composite resin restorations and justify the selection of these test parameters for the current study.<sup>101,104,142</sup>

### 5.1 Surface Roughness

While the initial high shine of a restoration may be important to the patient, the surface quality of the restoration after months and years of service becomes the main concern for the dentist.<sup>143</sup> Profilometry was found to be an acceptable method to study the surface roughness of composite materials.<sup>114</sup>

Both intrinsic and extrinsic factors will affect the surface roughness of composite resins.<sup>144</sup> Intrinsic factors include durability of the filler and resin matrix bond, filler type, size, shape and distribution, as well as the type of material, its resin matrix composition and degree of polymerization.<sup>144</sup> The various methods of finishing and polishing relate to the extrinsic factors and entail the characteristics of the polishing tool such as its flexibility, geometrical shape, abrasive particles and its method of application.<sup>145</sup>



A study done by Marghalani *et al.*<sup>101</sup> on post-irradiation Vickers microhardness, observed that composite samples cured only from the top showed higher hardness values on the top surface than the bottom surface.<sup>101</sup> The close contact of the light guide to the top surface leads to a higher degree of polymerization.<sup>124</sup> Scattering and absorption of light through the composite material lead to a decrease in light intensity and the amount of polymerization at the bottom surface.<sup>124</sup> With the current study, all samples were therefore polymerized through the top and bottom of the glass slides.

It is well known that curing composites through a Mylar polyester strip provides the smoothest obtainable surface finish.<sup>146</sup> This statement was confirmed by previous studies done by Pirani *et al.*,<sup>147</sup> Reis *et al.*,<sup>148</sup> and Özgünaltay *et al.*<sup>149</sup> With the current study no statistically significant differences were found between the four experimental conditions after curing through a Mylar strip and before polishing occurred. The lowest surface roughness values were recorded after curing the materials through a Mylar strip, which is in accordance with the results of previous studies.<sup>120,150,151,152</sup> During the process of finishing and polishing, resin matrix is removed between the filler particles and as a result filler particles are more prominent on the composite surface, resulting in increased surface roughness.<sup>153</sup>

Although curing through a Mylar strip provides the smoothest surface finish, the top part of the composite has a polymer-rich layer.<sup>154</sup> This layer needs to be removed to ensure a surface that is more wear resistant, harder and therefore more aesthetically stable.<sup>154</sup> Finishing and contouring of the restoration after placement become necessary to correct the morphology and shape of a tooth before polishing.<sup>155</sup> Jung<sup>156</sup> reported that although the use of diamond burs provided a rougher surface finish than that of a carbide bur, it was more successful in gross removal and contouring of composites after restoration placement.<sup>156</sup> This statement was confirmed by Ferracane *et al.*<sup>157</sup> To mimic the most likely clinical conditions, all samples were first worked off with a red stripe, followed by a yellow stripe diamond-finishing bur.



Previous studies suggest that each material behaves independently to the various polishing techniques.<sup>144,158</sup> Different smoothness results are obtained when the same polishing technique is applied to different materials.<sup>144,158</sup> Since certain polishing techniques are better suited to specific materials, polishing of the different materials in the current study was done strictly according to the manufacturers' recommendations and instructions.<sup>91,121,144,159</sup>

According to the manufacturer, Admira Fusion should preferably be polished with Dimanto polishing discs, which can be used with or without water-cooling.<sup>116</sup> Instructions for use of Admira Fusion do not specifically mention that polishing should occur with cooling provided and therefore polishing was done with and without water-cooling to evaluate any significant difference between the two methods.<sup>117</sup> Admira and Filtek Z350 XT instructions for use indicate that polishing should be done under cooling and therefore water-cooling was used.<sup>133,134,135</sup>

After polishing each of the materials, with the manufacturer's recommended polishing systems, the results of this study show no statistically significant difference between the surface roughness of the ormocer-based composite, the pure ormocer (when polished with water-cooling) and the nanocomposite. The lack of statistical significant differences between these materials suggest that all three materials exhibit approximately the same surface roughness and therefore there is no real difference in terms of surface roughness to using any of these material groups. A study done by Baseren,<sup>152</sup> supports this finding when both the ormocer-based composite (Admira) and the nanocomposite (Filtek Supreme, 3M ESPE) were polished with multiple different polishing systems, but there was no significant difference in surface roughness among the tested materials ( $p > 0.05$ ).<sup>152</sup> In Baserens' study there was however statistical significant differences between the different polishing systems applied to the materials.<sup>152</sup> The current study's findings were also confirmed by a study done by Hahnel *et al.*<sup>126</sup>, that showed no statistical significant difference in the surface roughness of a pure ormocer when compared to a nanocomposite.<sup>126</sup> Cunha *et al.*<sup>160</sup> compared the surface roughness of two ormocer-based composites with that of a



microhybrid conventional composite after toothbrushing and found no statistical significant differences between these material groups.<sup>160</sup>

There was also no statistically significant difference when comparing the surface roughness of the pure ormocer when polished with and without water-cooling. These findings suggests that the pure ormocer, Admira Fusion, can be polished with Dimanto polishing discs with or without water-cooling, as per the manufacturer's instructions related to the polishing disc.

Statistically significant differences were however found, after polishing, in the surface roughness of both the ormocer-based composite and the nanocomposite when compared to pure ormocer polished without water. The pure ormocer when polished without water, showed a higher surface roughness than both the ormocer-based composite and the nanocomposite. These results are in accordance with a study done by Nasoohi,<sup>161</sup> where the surface roughness of all sample composites (microhybrid and nanohybrid composite resins) were higher following dry finishing and polishing as opposed to samples with wet finishing and polishing.<sup>161</sup> The high heat generated during dry polishing could influence the bond between the filler particles and the resin matrix, resulting in separated filler particles and increased surface roughness.<sup>162</sup>

A literature review done by Bollen *et al.*,<sup>163</sup> stated that surface roughness above 0.2 $\mu$ m could lead to increased bacterial adhesion on the restorative materials and the formation of secondary caries<sup>163</sup>. Within this study, only the pure ormocer (Admira Fusion) showed surface roughness values below 0.2 $\mu$ m before polishing. A study done by Yap *et al.*,<sup>164</sup> contradicts this finding where both the ormocer-based composite (Admira) and the nanocomposite (Filtek Supreme Translucent, 3M ESPE) presented with surface roughness values below the benchmark.<sup>164</sup> In the same study, surface roughness values of the ormocer-based composite were found to be similar to that of nanocomposites after polishing.<sup>164</sup> After polishing, all materials used in the current study showed surface roughness values above the benchmark of 0.2 $\mu$ m. This is in contrast with a study done by Colombo *et al.*,<sup>110</sup> where the pure ormocer (Admira Fusion) showed surface roughness values lower than 0.2 $\mu$ m in most of the groups



with different finishing and polishing techniques.<sup>110</sup> In the same study the nanocomposite (Filtek Supreme XTE) showed surface roughness values above  $0.2\mu\text{m}$  in most of the groups.<sup>110</sup> Yap *et al.*<sup>164</sup> found both the ormocer-based composite (Admira) and the nanocomposite (Filtek Supreme Translucent) to be below  $0.2\mu\text{m}$  after finishing and polishing.<sup>164</sup> These were the only two materials in Yap's study where the smooth surface finish obtained with the use of matrix strips was not violated by the finishing and polishing procedures.<sup>164</sup>

A possible reason for the high surface roughness values of the current study could be the use of rubber polishers as a polishing method for all the materials.<sup>110</sup> Rubber polishers tend to be rigid and wear with time.<sup>110</sup> This could also explain why the surface roughness values for the nanocomposite were lower ( $0.826\mu\text{m}$ ) than that of the pure ormocer ( $1.028\mu\text{m}$ ), since the Dimanto polishing disc used to polish the pure ormocer is much more rigid than that of the Sof-Lex spirals. Colombo's<sup>110</sup> study suggests that the use of only rubber polishers do not provide sufficient surface smoothness.<sup>110</sup>

The SEM images for all materials showed relatively smooth surfaces with visible scratch lines and irregularities after polishing. The presence of voids and pits are visible and may be attributed to the loss of filler particles that are plucked from the surface during polishing.<sup>165</sup> These images correspond with the profilometer readings obtained in the current study.

In terms of surface roughness, the null hypothesis was proven correct. There was no statistical difference in terms of surface roughness between the pure ormocer (when polished with water-cooling), the ormocer-based composite or the nanocomposite.





## 5.2 Surface Hardness

Hardness is a surface characteristic that can be defined as the ability of a material to resist permanent indentation or penetration.<sup>166</sup> The type and amount of filler in composite materials greatly influence its surface hardness.<sup>141</sup> Mechanical properties, such as polishability and abrasion resistance, are greatly dependant on the material hardness.<sup>141</sup> It has also been shown that surface hardness can act as an indicator of the degree of polymerization of a material.<sup>167</sup> The higher the conversion rate of carbon double bonds, the better the physical properties and surface hardness of a material.<sup>42</sup>

To ensure a high degree of polymerization within the current study, all samples were stored in distilled water at 37°C for 24 hours. This allowed for water absorption and “dark polymerization” in order to simulate the oral environment. Polymerization is not completed after initial exposure to the curing light.<sup>168</sup> Only about 70% of the composite resin is polymerized during the first 10 minutes after which the polymerization reaction will continue for a period of 24 hours.<sup>169,170,171</sup> Storage for 24 hours in the current study therefore allowed for the continued setting reaction during “dark polymerization”.<sup>168</sup> Furthermore, storage at 37°C may also allow an increase in surface hardness.<sup>101</sup> Marghalani *et al.*<sup>101</sup> found in their study that the surface hardness of a material increases when aged at body temperature of 37°C.<sup>101</sup> Increased temperatures will also lead to an increase in the mobility and polymerization of remaining free monomers, a fact confirmed by several studies.<sup>172,173</sup> After polymerization and storage the current study made use of silicon carbide paper to remove the soft resin-rich layer of uncured monomers.<sup>101</sup> Removal of this layer allows for testing of a stable harder surface and simulate clinical conditions since most restorations are polished after placement.<sup>101</sup>

Results of the current study showed no statistical significant difference between the surface hardness of the pure ormocer (Admira Fusion) and the ormocer-based composite (Admira). The lack of statistical significant difference between these two materials suggest that in terms of surface hardness there is no real advantage to using either of these materials. In a study done by Leprince *et al.*,<sup>37</sup> all samples were dry and stored in the dark for 24 hours.<sup>37</sup> Results of their study were in contrast to the



current study as they found the pure ormocer to have increased surface microhardness when compared to the ormocer-based composites.<sup>37</sup> These findings can partly be explained by the higher filler content of a pure ormocer.<sup>37</sup> Cavalcante *et al.*<sup>174</sup> also contradicted the results of the current study. Their study compared the surface hardness of a pure ormocer to that of an ormocer-based composite, nanohybrid composite and nanocomposite after 24-hour water storage.<sup>174</sup> The study concluded that the pure ormocer preserved surface integrity and was the only material that did not show a reduction in surface hardness values.<sup>174</sup> Water diffuse internally through defects, pores and the resin matrix, dissolving filler particles.<sup>175</sup> The absence of methacrylate monomers in pure ormocers has been shown to reduce water uptake and solubility.<sup>174</sup> Pure ormocers present as polymers and tend to absorb water at a different degree.<sup>176</sup> The unique matrix formulation of pure ormocers are therefore important and can explain the improved stability of this material compared to ormocer-based composites and conventional composite material.<sup>174</sup>

The current study did reveal a statistical significant differences in surface hardness when the nanocomposite (Filtek Z350 XT) was compared with both the pure ormocer (Admira Fusion) and the ormocer-based composite (Admira). The nanocomposite presented with a larger Vickers hardness value. The larger the Vickers hardness measurement number, the harder the surface.<sup>166</sup> The findings within the current study correlate with the findings of Poggio *et al.*,<sup>123</sup> where a nanocomposite (Filtek Supreme XTE) showed the highest values of microhardness followed by a pure ormocer (Admira Fusion) both before and after immersion in an acidic drink for a week<sup>123</sup>. Baeshen *et al.*<sup>177</sup> also found higher hardness values for the nanocomposite (Filtek Supreme XT) than for the pure ormocer (Admira Fusion) before surface finishing and polishing.<sup>177</sup> A possible reason for this could be the materials' filler composition.<sup>177</sup> Admira has barium glass fillers that are lower in hardness than the zirconia fillers used in Filtek Supreme nanocomposite restorative materials.<sup>177</sup> The type of filler, filler load, and the interactions between the filler and matrix influence the surface hardness to a greater extent than the organic matrix structure.<sup>42</sup> The findings of the current study however contradict those of a study done by Hahnel *et al.*,<sup>126</sup> where the pure ormocer had a significantly higher Vickers hardness number value than the nanocomposite Filtek



Supreme XT. In a study conducted by Tagtekin *et al.*,<sup>73</sup> the ormocer-based composite (Admira) also showed a higher surface hardness value compared to the conventional hybrid composite (Amelogen, Ultradent, Utah, USA). Marghalani *et al.*<sup>101</sup> found higher Vickers hardness values when the ormocer-based composite (Definite) were compared to nanohybrid composites.<sup>101</sup>

In terms of surface hardness the null hypothesis was rejected. The nanocomposite showed statistical significant higher surface hardness than the pure ormocer and the ormocer-based composite. There were no statistical significant differences in terms of surface hardness between the pure ormocer and ormocer-based composite.

### 5.3 Microleakage

Marginal adaptation of a material to the cavity walls will determine the material's durability and longevity in the oral cavity.<sup>104</sup> The main cause of microleakage is the shrinkage that occur in resin based materials during polymerization.<sup>104</sup> The amount of polymerization shrinkage within a resin containing dental material is dependant on the filler load, the surface treatment of the fillers and the molecular weight of the monomer.<sup>104</sup> The more filler particles present in the material, the lower the amount of weak polymer matrix, the higher the strength and modulus of elasticity and the lower the polymerization shrinkage.<sup>104</sup>

Newer generation dental resin materials such as ormocers and nanocomposites show less polymerization shrinkage.<sup>104</sup> Due to the nano-sized particles of nanocomposites, less polymerization shrinkage and lower microleakage were observed, making this class of materials superior to conventional composite resins.<sup>75</sup> Ormocers also showed reduced polymerization shrinkage due to the highly cross-linked, three-dimensional polymer network that forms after polymerization.<sup>13,62</sup>

The differences in the coefficient of thermal expansion between tooth structure and restorative material lead to interfacial gap formation and microleakage.<sup>178,179</sup> Restorative material tends to expand and contract more with temperature changes



than enamel and dentine.<sup>178,179</sup> Thermocycling, varying between 5°C and 55°C, was therefore used in the current study to mimic these thermal changes and stresses in the oral environment.<sup>129</sup> Several studies have shown that there were no significant differences in microleakage when samples were subjected to 250, 1000 or 5000 thermocycles.<sup>180</sup> The current study subjected all samples to 3000 cycles, with a dwell time of 20 seconds in each temperature bath.<sup>122</sup> No standardisation has been established for the technical procedures of in vitro microleakage evaluations.<sup>181</sup> Of all the various microleakage test techniques available, the most common method used is that of dye penetration.<sup>104,181</sup> The present study ensured that each material was used with its proprietary adhesive system as recommended by the individual manufacturers.

In the current study, no statistical significant differences were found in the occlusal microleakage of any of the three material groups. This would suggest that in terms of microleakage on enamel surfaces there is no real difference to using any of these materials. These results were confirmed by the study done by Garapati *et al.*<sup>139</sup> where no statistical significant difference in terms of occlusal microleakage was found between the ormocer-based composite (Admira) and the nanocomposite (Filtek Supreme). A study done by Sudhapalli *et al.*,<sup>104</sup> compared microleakage between an ormocer-based composite (Admira), nanocomposite (Tetric N-Ceram, Ivoclar Vivadent) and a conventional microfilled composite (Tetric Ceram) with all margins ending on enamel. Their findings contradict that of the current study, as the ormocer-based composite showed the least occlusal microleakage, followed by the nanocomposite.<sup>104</sup> Kalra *et al.*<sup>62</sup> also found no statistical significant difference in the microleakage of an ormocer-based composite (Admira) compared to that of a hybrid composite (Spectrum TPH, Dentsply Sirona, Weybridge, England).<sup>62</sup> Politi *et al.*<sup>132</sup> and Mchugh *et al.*<sup>138</sup> found significantly lower microleakage scores for the pure ormocer (Admira Fusion) when compared to the nanohybrid composite (Tetric EvoCeram, Ivoclar Vivadent).<sup>132,138</sup>

In the current study, comparisons in gingival microleakage revealed a marginally significant difference between the nanocomposite (Filtek Z350 XT) and the pure ormocer (Admira Fusion), with the nanocomposite showing marginally less leakage.



No statistical significant differences were found in the gingival microleakage when comparing the pure ormocer (Admira Fusion) to the ormocer-based composite (Admira), nor in the nanocomposite (Filtek Z350 XT) to the ormocer-based composite (Admira). These results were contradicted by Hooshmand *et al.*,<sup>122</sup> where the ormocer-based composite demonstrated significantly higher gingival microleakage than the nanohybrid.<sup>122</sup> A study done by Civelek *et al.*,<sup>182</sup> showed less microleakage at the cemento-enamel junction for the ormocer-based composite (Admira) when compared to a hybrid composite (Filtek Z-250, 3M ESPE).<sup>182</sup>

When the current study compared occlusal microleakage with gingival microleakage within each individual material, no statistical significant difference was found within the pure ormocer (Admira Fusion) and the ormocer-based composite (Admira) scores. This would suggest that in terms of microleakage there is no difference in using either of these materials on enamel or dentine/cementum surfaces. These results are in contrast with a study done by Gerdolle *et al.*,<sup>183</sup> where occlusal microleakage for Admira was significantly lower than gingival microleakage. However, thermocycling was not done before testing of microleakage commenced.<sup>183</sup> A study done by Yazici *et al.*,<sup>184</sup> support the current study with regards to the ormocer-based composite (Admira), where no statistical significant differences were observed with either occlusal or gingival microleakage.<sup>184</sup> The same results were supported on primary teeth in a study done by AL-Harbi *et al.*<sup>185</sup>

The current study did however show statistical significant differences between the occlusal microleakage and the gingival microleakage of the nanocomposite. The nanocomposite leaked significantly less occlusally than gingivally. Based on the result of the current study the nanocomposite would still however be a better choice for the practitioner than the pure ormocer, since the nanocomposite shows a marginally statistical significant improvement in terms of gingival microleakage.

Rosin *et al.*<sup>1</sup> concluded in their two year clinical evaluation that the ormocer-based composite (Definite) provides an overall acceptable performance with regard to marginal quality and retention of class V restorations.<sup>1</sup>



In terms of occlusal microleakage the null hypothesis was proven correct. There was no statistical difference in terms of occlusal microleakage between the pure ormocer the ormocer-based composite or the nanocomposite.

In terms of gingival microleakage the null hypothesis was rejected. A statistical marginal significant difference was revealed between the nanocomposite and the pure ormocer, with the nanocomposite leaking marginally less than the pure ormocer. There was no statistical significant difference in terms of gingival microleakage between the pure ormocer and the ormocer-based composite.

## **5.4 Limitations of this study**

Material properties are not the only factors that need to be taken into account in the success or failure of a restoration.<sup>2</sup> Other factors such as the adhesive force between the composite and the dentine, diameter and direction of the dentine tubules, as well as the quality and origin of the tooth's hard tissues, should also be taken into account.<sup>186</sup>

Different results might have been obtained for the microleakage test if bonding adhesives from different manufacturers were used. The current study made use of the bonding systems as recommended by the individual manufacturers for each material group.<sup>187</sup>

With the current study's occlusal microleakage results, explanatory observations could suggest less microleakage for Admira and Filtek Z350 XT than for Admira Fusion. A larger study might be necessary to observe whether stronger significant differences between materials might emerge.

In vitro studies are essential for an early assessment of the dental material. As in the case of any in vitro study, caution must be exercised when extrapolating the results to



the clinical situation. Even though samples were stored in glass containers filled with distilled water and stored in an incubator at  $37^{\circ}\text{C} \pm 1^{\circ}\text{C}$ , for 24 hours, not all the intraoral variables can be simulated entirely. Some of the variables include oral hygiene, masticatory forces, types of food, oral temperature, and humidity variations and presence of salivary enzymes and bacterial by-products. Long-term clinical studies are necessary to assess the clinical performance of this new pure ormocer material to corroborate the materials in vitro established results.



## Chapter 6 : Conclusions

Within the limitations of this study, the following can be concluded:

### Surface Roughness

- The smoothest surface finish was obtained when curing all materials through a Mylar strip before polishing.
- There is no statistically significant difference in terms of surface roughness between the ormocer-based composite, pure ormocer (polished with water-cooling) or the nanocomposite.
- Both the ormocer-based composite and nanocomposite showed significantly smoother surfaces when polished with water-cooling than the pure ormocer when polished without water-cooling.

### Surface Hardness

- No statistically significant differences were found between the pure ormocer and the ormocer-based composite.
- The nanocomposite revealed a statistically significant higher surface hardness than both the ormocer-based composite and the pure ormocer.





## Microleakage

- None of the restorative systems used in the current study could eliminate either occlusal or gingival microleakage.
- There is no statistical significant difference in terms of occlusal microleakage between the pure ormocer, the ormocer-based composite nor the nanocomposite.
- There is no statistical significant difference in terms of gingival microleakage between the ormocer-based composite and the pure ormocer nor between the nanocomposite and the ormocer-based composite.
- The nanocomposite showed marginal statistical significantly less gingival microleakage than the pure ormocer.

Based on the comparative evaluation and statistical analysis of the surface roughness, and microleakage, there is no difference in using a pure ormocer compared to an ormocer-based composite or nanocomposite. The surface hardness of the nanocomposite was statistically significantly higher than for the pure ormocer and ormocer-based composite. The choice of material would be subject to the clinical condition and the practitioner's preference; however, the nanocomposite should be used in areas, which require increased surface hardness.



## References

1. Rosin M, Schwahn C, Kordass B, Konschake C, Greese U, Teichmann D, Hartmann A, Meyer G. A multipractice clinical evaluation of an ormocer restorative-2-year results. *Quintessence Int.* 2007; 38(6):e306-15.
2. Bowen R. Dental filling material comprising vinyl silane treated fused silica and a binder consisting of the reaction product of bis-phenol and glycydyl acrylate. United States Patent No. 3066112. 1962.
3. Moszner N, Gianasmidis A, Klapdohr S, Fischer UK, Rheinberger V. Sol-gel materials 2. Light-curing dental composites based on ormocers of cross-linking alkoxy silane methacrylates and further nano-components. *Dent Mater.* 2008; 24(6):851-6.
4. Alshali RZ, Silikas N, Satterthwaite JD. Degree of conversion of bulk-fill compared to conventional resin-composites at two time intervals. *Dent Mater.* 2013; 29(9):e213-e7.
5. Alrahlah A, Silikas N, Watts D. Post-cure depth of cure of bulk fill dental resin-composites. *Dent Mater.* 2014; 30(2):149-54.
6. Monsarrat P, Garnier S, Vergnes JN, Nasr K, Grosogeat B, Joniot S. Survival of directly placed ormocer-based restorative materials: A systematic review and meta-analysis of clinical trials. *Dent Mater.* 2017; 33(5):e212-e20.
7. Ferracane J, Berge H, Condon J. In vitro aging of dental composites in water—effect of degree of conversion, filler volume, and filler/matrix coupling. *J Biomed Mater Res A.* 1998; 42(3):465-72.
8. Rosin M, Steffen H, Konschake C, Greese U, Teichmann D, Hartmann A, Meyer G. One-year evaluation of an ormocer restorative-a multipractice clinical trial. *Clin Oral Investig.* 2003; 7(1):20-6.
9. Lopes L, Cefaly D, Franco EB, Mondelli RFL, Lauris JRP, Navarro MFdL. Clinical evaluation of two "packable" posterior composite resins: Two-year results. *Clin Oral Investig.* 2003; 7(3):123-8.
10. Kournetas N, Chakmakchi M, Kakaboura A, Rahiotis C, Geis-Gerstorfer J. Marginal and internal adaptation of class ii ormocer and hybrid resin composite restorations before and after load cycling. *Clin Oral Investig.* 2004; 8(3):123-9.



11. Greiwe K, Schottner G. Ormocere: Eine neue werkstoffklasse. FhG-Berichte. 1990; 2:64.
12. VOCO [Internet]. Admira fusion scientific compendium. Germany.2016 [updated 2016; cited 2021 January 29]. Available from: [https://www.voco.dental/us/portaldata/1/resources/products/scientific-reports/us/Admira\\_Fusion\\_Scientific\\_Compendium.pdf](https://www.voco.dental/us/portaldata/1/resources/products/scientific-reports/us/Admira_Fusion_Scientific_Compendium.pdf).
13. Zimmerli B, Strub M, Jeger F, Stadler O, Lussi A. Composite materials: Composition, properties and clinical applications. A literature review. Schweiz Monatsschr Zahnmed. 2010; 120(11):972-86.
14. Sri Vasavi Kadiyala DJDR. Recent advances and modifications of dental restorative materials - a review. Int J Adv Multidiscip Res. 2016; 03(07):1609-16.
15. Ferracane JL. Resin composite—state of the art. Dent Mater. 2011; 27(1):29-38.
16. Peutzfeldt A. Resin composites in dentistry: The monomer systems. Eur J Oral Sci. 1997; 105(2):97-116.
17. Krämer N, Garcia-Godoy F, Frankenberger R. Evaluation of resin composite materials. Part ii: In vivo investigations. Am J Dent. 2005; 18(2):75-81.
18. George R. Nanocomposites—a review. J Dent Oral Biosc. 2011; 2:38-40.
19. Terry DA. Direct applications of a nanocomposite resin system: Part 1--the evolution of contemporary composite materials. Pract Proced Aesthet Dent. 2004; 16(6):417-22.
20. Buonocore MG. A simple method of increasing the adhesion of acrylic filling materials to enamel surfaces. J Dent Res. 1955; 34(6):849-53.
21. Bowen R. Properties of a silica-reinforced polymer for dental restorations. J Am Dent Assoc. 1963; 66(1):57-64.
22. Rueggeberg FA. From vulcanite to vinyl, a history of resins in restorative dentistry. J Prosthet Dent. 2002; 87(4):364-79.
23. Amaechi B, Amerongen J, Loveren C. Fundamentals of operative dentistry: A contemporary approach. Fourth ed: Hanover park, Illinois: Quintessence Publishing Co Inc; 2013.



24. Bayne SC, Thompson JY, Swift EJ, Jr., Stamatiades P, Wilkerson M. A characterization of first-generation flowable composites. *J Am Dent Assoc.* 1998; 129(5):567-77.
25. Moszner N, Hirt T. New polymer-chemical developments in clinical dental polymer materials: Enamel–dentin adhesives and restorative composites. *J Polym Sci A Polym Chem.* 2012; 50(21):4369-402.
26. Klapdohr S, Moszner N. New inorganic components for dental filling composites. *Monatsh Chem.* 2005; 136(1):21-45.
27. Ruyter I. Composites-characterization of composite filling materials: Reactor response. *J Adv Dent Res.* 1988; 2(1):122-33.
28. Iga M, Takeshige F, Ui T, Torii M, Tsuchitani Y. The relationship between polymerization shrinkage measured by a modified dilatometer and the inorganic filler content of light-cured composites. *Dent Mater J.* 1991; 10(1):38-45, 98.
29. Randolph LD, Palin WM, Leloup G, Leprince JG. Filler characteristics of modern dental resin composites and their influence on physico-mechanical properties. *Dent Mater.* 2016; 32(12):1586-99.
30. Jun S-K, Kim D-A, Goo H-J, Lee H-H. Investigation of the correlation between the different mechanical properties of resin composites. *Dent Mater J.* 2013; 32(1):48-57.
31. Pfeifer CS, Silva LR, Kawano Y, Braga RR. Bis-gma co-polymerizations: Influence on conversion, flexural properties, fracture toughness and susceptibility to ethanol degradation of experimental composites. *Dent Mater.* 2009; 25(9):1136-41.
32. Rüttermann S, Dluzhevskaya I, Großsteinbeck C, Raab WH-M, Janda R. Impact of replacing bis-gma and tegdma by other commercially available monomers on the properties of resin-based composites. *Dent Mater.* 2010; 26(4):353-9.
33. Asmussen E, Peutzfeldt A. Influence of uedma, bisgma and tegdma on selected mechanical properties of experimental resin composites. *Dent Mater.* 1998; 14(1):51-6.



34. Kim K-H, Ong JL, Okuno O. The effect of filler loading and morphology on the mechanical properties of contemporary composites. *J Prosthet Dent.* 2002; 87(6):642-9.
35. Scougall-Vilchis RJ, Hotta Y, Hotta M, Idono T, Yamamoto K. Examination of composite resins with electron microscopy, microhardness tester and energy dispersive x-ray microanalyzer. *Dent Mater J.* 2009; 28(1):102-12.
36. Randolph LD, Palin WM, Leloup G, Leprince JG. Filler characteristics of modern dental resin composites and their influence on physico-mechanical properties. *Dent Mater.* 2016; 32(12):1586-99.
37. Leprince J, Palin WM, Mullier T, Devaux J, Vreven J, Leloup G. Investigating filler morphology and mechanical properties of new low-shrinkage resin composite types. *J Oral Rehabil.* 2010; 37(5):364-76.
38. Ilie N, Rencz A, Hickel R. Investigations towards nano-hybrid resin-based composites. *Clin Oral Investig.* 2013; 17(1):185-93.
39. Belli R, Petschelt A, Lohbauer U. Are linear elastic material properties relevant predictors of the cyclic fatigue resistance of dental resin composites? *Dent Mater.* 2014; 30(4):381-91.
40. Lussi A. Composite materials: Composition, properties and clinical applications. *Schweiz Monatsschr Zahnmed.* 2010; 120(11):972-9.
41. Ikejima I, Nomoto R, McCabe JF. Shear punch strength and flexural strength of model composites with varying filler volume fraction, particle size and silanation. *Dent Mater.* 2003; 19(3):206-11.
42. Manhart J, Kunzelmann KH, Chen HY, Hickel R. Mechanical properties of new composite restorative materials. *J Biomed Mater Res A.* 2000; 53(4):353-61.
43. Stansbury JW. Curing dental resins and composites by photopolymerization. *J Esthet Restor Dent.* 2000; 12(6):300-8.
44. Park Y-J, Chae K-H, Rawls HR. Development of a new photoinitiation system for dental light-cure composite resins. *Dent Mater.* 1999; 15(2):120-7.
45. Neumann MG, Miranda Jr WG, Schmitt CC, Rueggeberg FA, Correa IC. Molar extinction coefficients and the photon absorption efficiency of dental photoinitiators and light curing units. *J Dent.* 2005; 33(6):525-32.



46. Shin D-H, Rawls HR. Degree of conversion and color stability of the light curing resin with new photoinitiator systems. *Dent Mater.* 2009; 25(8):1030-8.
47. Moszner N, Klapdohr S. Nanotechnology for dental composites. *Int J Nanotechnol.* 2004; 1(1-2):130-56.
48. Mitra SB, Wu D, Holmes BN. An application of nanotechnology in advanced dental materials. *J Am Dent Assoc.* 2003; 134(10):1382-90.
49. Dresch W, Volpato S, Gomes JC, Ribeiro NR, Reis A, Loguercio AD. Clinical evaluation of a nanofilled composite in posterior teeth: 12-month results. *Oper Dent.* 2006; 31(4):409-17.
50. Fortin D, Vargas MA. The spectrum of composites: New techniques and materials. *J Am Dent Assoc.* 2000; 131 Suppl:26S-30S.
51. Chen MH, Chen CR, Hsu SH, Sun SP, Su WF. Low shrinkage light curable nanocomposite for dental restorative material. *Dent Mater.* 2006; 22(2):138-45.
52. Boaro LC, Goncalves F, Guimaraes TC, Ferracane JL, Versluis A, Braga RR. Polymerization stress, shrinkage and elastic modulus of current low-shrinkage restorative composites. *Dent Mater.* 2010; 26(12):1144-50.
53. Ortengren U, Wellendorf H, Karlsson S, Ruyter IE. Water sorption and solubility of dental composites and identification of monomers released in an aqueous environment. *J Oral Rehabil.* 2001; 28(12):1106-15.
54. Lohbauer U, Frankenberger R, Kramer N, Petschelt A. Strength and fatigue performance versus filler fraction of different types of direct dental restoratives. *J Biomed Mater Res B Appl Biomater.* 2006; 76(1):114-20.
55. Kramer N, Reinelt C, Richter G, Petschelt A, Frankenberger R. Nanohybrid vs. Fine hybrid composite in class ii cavities: Clinical results and margin analysis after four years. *Dent Mater.* 2009; 25(6):750-9.
56. Palaniappan S, Bharadwaj D, Mattar DL, Peumans M, Van Meerbeek B, Lambrechts P. Three-year randomized clinical trial to evaluate the clinical performance and wear of a nanocomposite versus a hybrid composite. *Dent Mater.* 2009; 25(11):1302-14.
57. Karabela MM, Sideridou ID. Effect of the structure of silane coupling agent on sorption characteristics of solvents by dental resin-nanocomposites. *Dent Mater.* 2008; 24(12):1631-9.



58. Mahmoud SH, El-Embaby AE, AbdAllah AM, Hamama HH. Two-year clinical evaluation of ormocer, nanohybrid and nanofill composite restorative systems in posterior teeth. *J Adhes Dent.* 2008; 10(4):315-22.
59. Moszner N, Salz U. New developments of polymeric dental composites. *Prog Polym Sci.* 2001; 26(4):535-76.
60. Wolter H. Werkstoffe mit biss. Teil I: Ormocer. *DZW Die Zahnarzt Woche.* 2015.
61. Haas K-H, Wolter H. Synthesis, properties and applications of inorganic–organic copolymers (ormocer® s). *Curr Opin Solid State Mater Sci.* 1999; 4(6):571-80.
62. Kalra S, Singh A, Gupta M, Chadha V. Ormocer: An aesthetic direct restorative material; an in vitro study comparing the marginal sealing ability of organically modified ceramics and a hybrid composite using an ormocer-based bonding agent and a conventional fifth-generation bonding agent. *Contemp Clin Dent.* 2012; 3(1):48-53.
63. VOCO [Internet]. Universal nano-hybrid ormocer restorative material. Germany.2021 [updated 2021; cited 2021 January 29]. Available from: <https://www.voco.dental/en/products/direct-restoration/ormocer/admira-fusion.aspx>.
64. Sivakumar A, Valiathan A. Dental ceramics and ormocer technology–navigating the future. *Trends Biomater Artif Organs.* 2006; 20(1):40-3.
65. Hickel R, Dasch W, Janda R, Tyas M, Anusavice K. New direct restorative materials. *Int Dent J.* 1998; 48(1):3-16.
66. Bottenberg P, Alaerts M, Keulemans F. A prospective randomised clinical trial of one bis-gma-based and two ormocer-based composite restorative systems in class ii cavities: Three-year results. *J Dent.* 2007; 35(2):163-71.
67. Shafqat SS, Hamdan S, Rigit ARH, Tien NKH, Saleh SF, Khan AA. Synthesis and characterization of heterocyclic-ormocers composites through sol-gel process: A review. *5th International Conference on Science & Technology: Applications in Industry & Education (ICSTIE 2014).* p. 1-8.
68. Ilie N, Hickel R. Resin composite restorative materials. *Aust Dent J.* 2011; 56 Suppl 1:59-66.



69. Richard Van Noort. Resin composites and polyacid-modified resin composites. Introduction to dental materials. 4th Edition ed: St Louis, Elsevier Health Sciences; 2013.
70. Pratap B, Gupta RK, Bhardwaj B, Nag M. Resin based restorative dental materials: Characteristics and future perspectives. Jpn Dent Sci Rev. 2019; 55(1):126-38.
71. Oberländer H, Hiller K-A, Thonemann B, Schmalz G. Clinical evaluation of packable composite resins in class-ii restorations. Clin Oral Investig. 2001; 5(2):102-7.
72. Bottenberg P, Jacquet W, Alaerts M, Keulemans F. A prospective randomized clinical trial of one bis-gma-based and two ormocer-based composite restorative systems in class ii cavities: Five-year results. J Dent. 2009; 37(3):198-203.
73. Tagtekin DA, Yanikoglu FC, Bozkurt FO, Kologlu B, Sur H. Selected characteristics of an ormocer and a conventional hybrid resin composite. Dent Mater. 2004; 20(5):487-97.
74. Say EC, Civelek A, Nobecourt A, Ersoy M, Guleryuz C. Wear and microhardness of different resin composite materials. Oper Dent. 2003; 28(5):628-34.
75. Saunders SA. Current practicality of nanotechnology in dentistry. Part 1: Focus on nanocomposite restoratives and biomimetics. Clin Cosmet Investig Dent. 2009; 1:47-61.
76. Ilie N, Hickel R. Investigations on mechanical behaviour of dental composites. Clin Oral Investig. 2009; 13(4):427-38.
77. Schubert A, Ziegler C, Bernhard A, Burgers R, Miosge N. Cytotoxic effects to mouse and human gingival fibroblasts of a nanohybrid ormocer versus dimethacrylate-based composites. Clin Oral Investig. 2018; (1):133-9.
78. Ferracane JL. Elution of leachable components from composites. J Oral Rehabil. 1994; 21(4):441-52.
79. Geurtsen W, Lehmann F, Spahl W, Leyhausen G. Cytotoxicity of 35 dental resin composite monomers/additives in permanent 3t3 and three human primary fibroblast cultures. J Biomed Mater Res. 1998; 41(3):474-80.





79. Jaffer F, Finer Y, Santerre J. Interactions between resin monomers and commercial composite resins with human saliva derived esterases. *Biomaterials*. 2002; 23(7):1707-19.
81. Susila AV, Balasubramanian V. Correlation of elution and sensitivity of cell lines to dental composites. *Dent Mater*. 2016; 32(3):e63-72.
82. Al-Hiyasat A, Darmani H, Milhem M. Cytotoxicity evaluation of dental resin composites and their flowable derivatives. *Clin Oral Investig*. 2005; 9(1):21-5.
83. Polydorou O, Konig A, Hellwig E, Kummerer K. Long-term release of monomers from modern dental-composite materials. *Eur J Oral Sci*. 2009; 117(1):68-75.
84. Aytac F, Karaarslan ES, Agaccioglu M, Tastan E, Buldur M, Kuyucu E. Effects of novel finishing and polishing systems on surface roughness and morphology of nanocomposites. *J Esthet Restor Dent* . 2016; 28(4):247-61.
85. 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.
86. Paravina RD, Roeder L, Lu H, Vogel K, Powers JM. Effect of finishing and polishing procedures on surface roughness, gloss and color of resin-based composites. *Am J Dent*. 2004; 17(4):262-6.
87. Jefferies SR. Abrasive finishing and polishing in restorative dentistry: A state-of-the-art review. *Dent Clin N Am*. 2007; 51(2):379-97.
88. Takahashi R, Jin J, Nikaido T, Tagami J, Hickel R, Kunzelmann K-H. Surface characterization of current composites after toothbrush abrasion. *Dent Mater J*. 2013; 32(1):75-82.
89. Pedrini D, Candido M, Rodrigues Jr A. Analysis of surface roughness of glass-ionomer cements and compomer. *J Oral Rehabil*. 2003; 30(7):714-9.
90. Koc-Vural U, Baltacioglu I, Altinci P. Color stability of bulk-fill and incremental-fill resin-based composites polished with aluminum-oxide impregnated disks. *Restor Dent Endod*. 2017; 42(2):118-24.
91. Yap A, Ng J, Yap S, Teo C. Surface finish of resin-modified and highly viscous glass ionomer cements produced by new one-step systems. *Oper Dent*. 2004; 29(1):87-91.



92. Toledano M. Evaluation of two polishing methods for resin composites. *Am J Dent.* 1994; 7:328-30.
93. Yap A, Lye K, Sau C. Surface characteristics of tooth-colored restoratives polished utilizing different polishing systems. *Oper Dent.* 1997; 22(6):260-5.
94. Nagem Filho H, D'azevedo MTF, Nagem HD, Marsola FP. Surface roughness of composite resins after finishing and polishing. *Braz Dent J.* 2003; 14(1):37-41.
95. Kumari RV, Nagaraj H, Siddaraju K, Poluri RK. Evaluation of the effect of surface polishing, oral beverages and food colorants on color stability and surface roughness of nanocomposite resins. *Int J Oral Health Dent.* 2015; 7(7):63.
96. Asmussen E, Peutzfeldt A. Influence of specimen diameter on the relationship between subsurface depth and hardness of a light-cured resin composite. *Eur J Oral Sci.* 2003; 111(6):543-6.
97. Watts D, McNaughton V, Grant A. The development of surface hardness in visible light-cured posterior composites. *J Dent.* 1986; 14(4):169-74.
98. Say E, Civelek A, Nobecourt A, Ersoy M, Guleryuz C. Wear and microhardness of different resin composite materials. *Oper Dent.* 2003; 28(5):628-34.
99. Kawai K, Iwami Y, Ebisu S. Effect of resin monomer composition on toothbrush wear resistance. *J Oral Rehabil.* 1998; 25(4):264-8.
100. Chinelatti MA, Chimello DT, Ramos RP, Palma-Dibb RG. Evaluation of the surface hardness of composite resins before and after polishing at different times. *J Appl Oral Sci.* 2006; 14(3):188-92.
101. Marghalani HY. Post-irradiation vickers microhardness development of novel resin composites. *Mater Res.* 2010; 13(1):81-7.
102. Rode KM, de Freitas PM, Lloret PR, Powell LG, Turbino ML. Micro-hardness evaluation of a micro-hybrid composite resin light cured with halogen light, light-emitting diode and argon ion laser. *Lasers Med Sci.* 2009; 24(1):87-92.
103. Kidd EA. Microleakage: A review. *J Dent.* 1976; 4(5):199-206.
104. Sudhapalli SK, Sudhapalli S, Razdan RA, Singh V, Bhasin A. A comparative evaluation of microleakage among newer composite materials: An in vitro study. *Contemp Clin Dent.* 2018; 9(4):587.



105. Owens BM, Halter TK, Brown DM. Microleakage of tooth-colored restorations with a beveled gingival margin. *Quintessence Int.* 1998; 29(6)
106. Fattah T, Kazemi H, Fekrazad R, Assadian H, Kalhori KA. Er, cr: Ysgg laser influence on microleakage of class v composite resin restorations. *Lasers Med Sci.* 2013; 28(5):1257-62.
107. Kritzinger D, Brandt P, De Wet F. The effect of different polishing systems on the surface roughness of a nanocomposite and a microhybrid composite. *SADJ.* 2017; 72(6):249-57.
108. Rueggeberg F, Caughman WF, Curtis J, Davis H. Factors affecting cure at depths within light-activated resin composites. *Am J Dent.* 1993; 6(2):91-5.
109. Caughman WF, Rueggeberg F, Curtis J, W J. Clinical guidelines for photocuring: Restorative resins. *J Am Dent Assoc.* 1995; 126(9):1280-6.
110. Colombo M, Vialba L, Beltrami R, Federico R, Chiesa M, Poggio C. Effect of different finishing/polishing procedures on surface roughness of ormocer-based and different resin composites. *Dent Res J.* 2018; 15(6):404.
111. Taher NM. The effect of bleaching agents on the surface hardness of tooth colored restorative materials. *J Contemp Dent Pract.* 2005; 6(2):18-26.
112. Beltrami R, Ceci M, De Pani G, Vialba L, Federico R, Poggio C, Colombo M. Effect of different surface finishing/polishing procedures on color stability of esthetic restorative materials: A spectrophotometric evaluation. *Eur J Dent.* 2018; 12(1):49-56.
113. Goldstein G, Waknine S. Surface roughness evaluation of composite resin polishing techniques. *Quintessence Int.* 1989; 20(3):199.
114. Joniot S, Gregoire G, Auther A, Roques Y. Three-dimensional optical profilometry analysis of surface states obtained after finishing sequences for three composite resins. *Oper Dent.* 2000; 25(4):311-5.
115. Senawongse P, Pongprueksa P. Surface roughness of nanofill and nanohybrid resin composites after polishing and brushing. *J Esthet Restor Dent.* 2007; 19(5):265-73; discussion 74-5.



116. VOCO [Internet]. Dimanto instructions for use. Germany. 2017 [updated 2021; cited 2021 January 7]. Available from: [https://www.voco.dental/en/Portaldata/1/Resources/products/instructions-for-use/e1/dimanto\\_ifu-e1.pdf](https://www.voco.dental/en/Portaldata/1/Resources/products/instructions-for-use/e1/dimanto_ifu-e1.pdf).
117. VOCO [Internet]. Admira fusion instructions for use. Germany. 2015 [updated 2015; cited 2021 January 7]. Available from: [https://www.voco.dental/en/Portaldata/1/Resources/products/instructions-for-use/e1/admira-fusion\\_ifu\\_e1.pdf](https://www.voco.dental/en/Portaldata/1/Resources/products/instructions-for-use/e1/admira-fusion_ifu_e1.pdf).
118. Turkun LS, Turkun M. The effect of one-step polishing system on the surface roughness of three esthetic resin composite materials. *Oper Dent*. 2004; 29(2):203-11.
119. Da Costa JB, Goncalves F, Ferracane JL. Comparison of two-step versus four-step composite finishing/polishing disc systems: Evaluation of a new two-step composite polishing disc system. *Oper Dent*. 2011; 36(2):205-12.
120. Korkmaz Y, Ozel E, Attar N, Aksoy G. The influence of one-step polishing systems on the surface roughness and microhardness of nanocomposites. *Oper Dent*. 2008; 33(1):44-50.
121. Scheibe KG, Almeida KG, Medeiros IS, Costa JF, Alves CM. Effect of different polishing systems on the surface roughness of microhybrid composites. *J Appl Oral Sci*. 2009; 17(1):21-6.
122. Hooshmand T, Tabari N, Keshvad A. Marginal leakage and microhardness evaluation of low-shrinkage resin-based restorative materials. *Gen Dent*. 2013; 61(1):46-50; quiz 1.
123. Poggio C, Viola M, Mirando M, Chiesa M, Beltrami R, Colombo M. Microhardness of different esthetic restorative materials: Evaluation and comparison after exposure to acidic drink. *Dent Res J (Isfahan)*. 2018; 15(3):166-72.
124. Ciccone-Nogueira JC, Borsatto MC, Souza-Zaron WCd, Ramos RP, Palma-Dibb RG. Microhardness of composite resins at different depths varying the post-irradiation time. *J Appl Oral Sci*. 2007; 15(4):305-9.



125. Schneider LF, Cavalcante LM, Silikas N, Watts DC. Degradation resistance of silorane, experimental ormocer and dimethacrylate resin-based dental composites. *J Oral Sci.* 2011; 53(4):413-9.
126. Hahnel S, Henrich A, Burgers R, Handel G, Rosentritt M. Investigation of mechanical properties of modern dental composites after artificial aging for one year. *Oper Dent.* 2010; 35(4):412-9.
127. Mahmoud SH, Al-Wakeel Eel S. Marginal adaptation of ormocer-, silorane-, and methacrylate-based composite restorative systems bonded to dentin cavities after water storage. *Quintessence Int.* 2011; 42(10):e131-9.
128. Haller B, Hofmann N, Klaiber B, Bloching U. Effect of storage media on microleakage of five dentin bonding agents. *Dent Mater.* 1993; 9(3):191-7.
129. Synarellis A, Kouros P, Koulaouzidou E, Strakas D, Koliniotou-Koumpia E. In vitro microleakage of class v composite restorations prepared by er, cr: Ysgg laser and carbide bur. *Balk J Dent Med.* 2017; 21(1):24-31.
130. El-Housseiny A, Farsi N. Sealing ability of a single bond adhesive in primary teeth. An in vivo study. *Int J Paediatr Dent.* 2002; 12(4):265-70.
131. Jacker-Guhr S, Ibarra G, Oppermann L, Lühns A-K, Rahman A, Geurtsen W. Evaluation of microleakage in class v composite restorations using dye penetration and micro-ct. *Clin Oral Investig.* 2016; 20(7):1709-18.
132. Politi I, McHugh L, Al-Fodeh R, Fleming G. Modification of the restoration protocol for resin-based composite (rbc) restoratives (conventional and bulk fill) on cuspal movement and microleakage score in molar teeth. *Dent Mater.* 2018; 34(9):1271-7.
133. VOCO [Internet]. Admira instructions for use. Germany.2012 [updated 2012; cited 2021 January 7]. Available from: [https://www.voco.dental/en/Portaldata/1/Resources/products/instructions-for-use/e1/admira\\_ifu\\_e1.pdf](https://www.voco.dental/en/Portaldata/1/Resources/products/instructions-for-use/e1/admira_ifu_e1.pdf).
134. 3M ESPE [Internet]. Filtek™ z350 xt universal restorative system. USA.2010 [updated 2010; cited 2021 January 7]. Available from: <https://multimedia.3m.com/mws/media/631547O/filtek-z350-xt-technical-product-profile.pdf>.



135. 3M ESPE [Internet]. Sof-lex™ finishing and polishing system. USA.2013 [cited 2021 January 7]. Available from: <https://multimedia.3m.com/mws/media/850789O/sof-lex-finishing-and-polishing-system-brochure.pdf>.
136. Erdilek D, Dorter C, Koray F, Kunzelmann KH, Efes BG, Gomec Y. Effect of thermo-mechanical load cycling on microleakage in class ii ormocer restorations. *Eur J Dent*. 2009; 3(3):200-5.
137. Kubo J, Yokota H, Sata Y, Hayashi Y. The effect of flexural load cycling on the microleakage of cervical resin composites. *Oper Dent*. 2001; 26(5):451-9.
138. McHugh LE, Politi I, Al-Fodeh RS, Fleming GJ. Implications of resin-based composite (rbc) restoration on cuspal deflection and microleakage score in molar teeth: Placement protocol and restorative material. *Dent Mater*. 2017; 33(9):e329-e35.
139. Garapati S, Das M, Mujeeb A, Dey S, Kiswe SP. Cuspal movement and microleakage in premolar teeth restored with posterior restorative materials. *Int J Oral Health Dent*. 2014; 6(5):47.
140. Roulet J. The problems associated with substituting composite resins for amalgam: A status report on posterior composites. *J Dent*. 1988; 16(3):101-13.
141. Schmage P, Nergiz I, Sito F, Platzer U, Rosentritt M. Wear and hardness of different core build-up materials. *J Biomed Mater Res Part B Appl Biomater*. 2009; 91(1):71-9.
142. Mair L, Stolarski T, Vowles R, Lloyd C. Wear: Mechanisms, manifestations and measurement. Report of a workshop. *J Dent*. 1996; 24(1-2):141-8.
143. David C. Sarrett. Ada professional product review. *J Am Dent Assoc*. 2014; 9(3)
144. Marghalani HY. Effect of finishing/polishing systems on the surface roughness of novel posterior composites. *J Esthet Restor Dent*. 2010; 22(2):127-38.
145. Buchgraber B, Kqiku L, Allmer N, Jakopic G, Stadler P. Surface roughness of one nanofill and one silorane composite after polishing. *Coll Antropol*. 2011; 35(3):879-83.
146. Roeder LB, Powers JM. Surface roughness of resin composite prepared by single-use and multi-use diamonds. *Am J Dent*. 2004; 17(2):109-12.



147. Pirani C, Gullifa A, Marchionni S, Piana G. New methods to finish composite restorations: Sem evaluation. *Ital J Oper Dent.* 2004; 2:234-6.
148. Reis AF, Giannini M, Lovadino JR, Ambrosano GM. Effects of various finishing systems on the surface roughness and staining susceptibility of packable composite resins. *Dent Mater.* 2003; 19(1):12-8.
149. Özgünaltay G, Yazici A, Görücü J. Effect of finishing and polishing procedures on the surface roughness of new tooth-coloured restoratives. *J Oral Rehabil.* 2003; 30(2):218-24.
150. Erdemir U, Sancakli HS, Yildiz E. The effect of one-step and multi-step polishing systems on the surface roughness and microhardness of novel resin composites. *Eur J Dent.* 2012; 6(2):198-205.
151. Attar N. The effect of finishing and polishing procedures on the surface roughness of composite resin materials. *J Contemp Dent Pract.* 2007; 8(1):27-35.
152. Baseren M. Surface roughness of nanofill and nanohybrid composite resin and ormocer-based tooth-colored restorative materials after several finishing and polishing procedures. *J Biomater Appl.* 2004; 19(2):121-34.
153. Goncalves L, Filho JD, Guimarães JG, Poskus LT, Silva EM. Solubility, salivary sorption and degree of conversion of dimethacrylate-based polymeric matrixes. *J Biomed Mater Res Part B App. Biomater.* 2008; 85(2):320-5.
154. Stoddard JW, Johnson GH. An evaluation of polishing agents for composite resins. *J Prosthet Dent.* 1991; 65(4):491-5.
155. Anusavice KF, Phillips RW. *Phillips' science of dental materials.*: St. Louis, Mo: Saunders; 2003.
156. Jung M. Surface roughness and cutting efficiency of composite finishing instruments. *Oper Dent.* 1997; 22(3):98-104.
157. Ferracane J, Condon J, Mitchem J. Evaluation of subsurface defects created during the finishing of composites. *J Dent Res.* 1992; 71(9):1628-32.
158. Antonson SA, Yazici AR, Kilinc E, Antonson DE, Hardigan PC. Comparison of different finishing/polishing systems on surface roughness and gloss of resin composites. *J Dent.* 2011; 39:e9-e17.



159. Endo T, Finger WJ, Kanehira M, Utterodt A, Komatsu M. Surface texture and roughness of polished nanofill and nanohybrid resin composites. *Dent Mater J*. 2010; 29(2):213-23.
160. Cunha LG, Alonso RC, Santos PH, Sinhoreti MA. Comparative study of the surface roughness of ormocer-based and conventional composites. *J Appl Oral Sci*. 2003; 11(4):348-53.
161. Nasoohi N, Hoorizad M, Tabatabaei SF. Effects of wet and dry finishing and polishing on surface roughness and microhardness of composite resins. *J Dent (Tehran, Iran)*. 2017; 14(2):69.
162. Lopes GC, Franke M, Maia HP. Effect of finishing time and techniques on marginal sealing ability of two composite restorative materials. *J Prosthet Dent*. 2002; 88(1):32-6.
163. Bollenl CM, Lambrechts P, Quirynen M. Comparison of surface roughness of oral hard materials to the threshold surface roughness for bacterial plaque retention: A review of the literature. *Dent Mater*. 1997; 13(4):258-69.
164. Yap AU, Yap SH, Teo CK, Ng JJ. Comparison of surface finish of new aesthetic restorative materials. *Oper Dent*. 2004; 29(1):100-4.
165. Kaplan BA, Goldstein GR, Vijayaraghavan TV, Nelson IK. The effect of three polishing systems on the surface roughness of four hybrid composites: A profilometric and scanning electron microscopy study. *J Prosthet Dent*. 1996; 76(1):34-8.
166. Yap A, Cheang P, Chay P. Mechanical properties of two restorative reinforced glass–ionomer cements. *J Oral Rehabil*. 2002; 29(7):682-8.
167. Asmussen E. Factors affecting the quantity of remaining double bonds in restorative resin polymers. *Eur J Oral Sci*. 1982; 90(6):490-6.
168. Pilo R, Cardash H. Post-irradiation polymerization of different anterior and posterior visible light-activated resin composites. *Dent Mater*. 1992; 8(5):299-304.
169. Ferracane J, Greener E. The effect of resin formulation on the degree of conversion and mechanical properties of dental restorative resins. *J Biomed Mater Res*. 1986; 20(1):121-31.





170. Eliades G, Vougiouklakis G, Caputo A. Degree of double bond conversion in light-cured composites. *Dent Mater.* 1987; 3(1):19-25.
171. Chung KH, Greener E. Correlation between degree of conversion, filler concentration and mechanical properties of posterior composite resins. *J Oral Rehabil.* 1990; 17(5):487-94.
172. Quance S, Shortall A, Harrington E, Lumley P. Effect of exposure intensity and post-cure temperature storage on hardness of contemporary photo-activated composites. *J Dent.* 2001; 29(8):553-60.
173. Hansen EK. After-polymerization of visible light activated resins: Surface hardness vs. Light source. *Eur J Oral Sci.* 1983; 91(5):406-10.
174. Cavalcante LM, Schneider LF, Silikas N, Watts DC. Surface integrity of solvent-challenged ormocer-matrix composite. *Dent Mater.* 2011; 27(2):173-9.
175. Kalachandra S, Wilson T. Water sorption and mechanical properties of light-cured proprietary composite tooth restorative materials. *Biomaterials.* 1992; 13(2):105-9.
176. Mortier E, Gerdolle DA, Dahoun A, Panighi MM. Influence of initial water content on the subsequent water sorption and solubility behavior in restorative polymers. *Am J Dent.* 2005; 18(3):177-81.
177. Baeshen H, Alturki B, Albishi W, Alsadi F, El-Tubaigy K. Mechanical and physical properties of two different resin-based materials: A comparative study. *J Contemp Dent.* 2017; 18(10):905-10.
178. Nelsen RJ, Paffenbarger GC, Wolcott RB. Fluid exchange at the margins of dental restorations. *J Am Dent Assoc.* 1952; 44(3):288-95.
179. Gonzalez MAG, Kasim NHA, Aziz RA. Microleakage testing. *Ann Dent UM.* 1997; 4(1):31-7.
180. Rossomando KJ, Wendt Jr SL. Thermocycling and dwell times in microleakage evaluation for bonded restorations. *Dent Mater.* 1995; 11(1):47-51.
181. Raskin A, D'Hoore W, Gonthier S, Degrange M, Déjou J. Reliability of in vitro microleakage tests: A literature review. *J Adhes Dent.* 2001; 3(4)
182. Civelek A, Ersoy M, L Hotelier E, Soyman M, Say E. Polymerization shrinkage and microleakage in class ii cavities of various resin composites. *Oper Dent.* 2003; 28(5):635-41.



183. Gerdolle DA, Mortier E, Droz D. Microleakage and polymerization shrinkage of various polymer restorative materials. *J Dent Child (Chic)*. 2008; 75(2):125-33.
184. Yazici AR, Celik C, Ozgunaltay G. Microleakage of different resin composite types. *Quintessence Int*. 2004; 35(10):790-4.
185. Al-Harbi SD, Farsi N. Microleakage of ormocer-based restorative material in primary teeth: An in vivo study. *J Clin Pediatr Dent*. 2007; 32(1):13-7.
186. Leloup G, D'Hoore W, Bouter D, Degrange M, Vreven J. Meta-analytic review of factors involved in dentin adherence. *J Dent Res*. 1998; 77:944.
187. Krejci I, Häusler T, Sägeser D, Lutz F. New adhesives in class v restorations under combined load and simulated dentinal fluid. *Dent Mater*. 1994; 10(5):331-5.



# Appendix A: Ethical Clearance



Faculty of Health Sciences

**Institution:** The Research Ethics Committee, Faculty Health Sciences, University of Pretoria complies with ICH-GCP guidelines and has US Federal wide Assurance.

- FWA 00002567, Approved dd 22 May 2002 and Expires 03/20/2022.
- IORG #: IORG0001762 OMB No. 0990-0279 Approved for use through February 28, 2022 and Expires: 03/04/2023.

Faculty of Health Sciences Research Ethics Committee

13 October 2021

## Approval Certificate Amendment

Dear Dr K. Jansen van Rensburg

**Ethics Reference No.:** 207/2019

**Title:** A Comparative evaluation of the Surface Roughness, Surface Hardness and Microleakage of a PureOrmocer with an Ormocer-Based Composite and a Nanocomposite Restorative Material.

The **Amendment** as supported by documents received between 2021-09-27 and 2021-10-13 for your research, was approved by the Faculty of Health Sciences Research Ethics Committee on 2021-10-13 as resolved by its quorate meeting.

Please note the following about your ethics approval:

- Please remember to use your protocol number (207/2019) on any documents or correspondence with the Research Ethics Committee regarding your research.
- Please note that the Research Ethics Committee may ask further questions, seek additional information, require further modification, monitor the conduct of your research, or suspend or withdraw ethics approval.

**Ethics approval is subject to the following:**

- The ethics approval is conditional on the research being conducted as stipulated by the details of all documents submitted to the Committee. In the event that a further need arises to change who the investigators are, the methods or any other aspect, such changes must be submitted as an Amendment for approval by the Committee.

We wish you the best with your research.

Yours sincerely

On behalf of the FHS REC, Professor Werdie (CW) Van Staden  
MBChB, MMed(Psych), MD, FCPsych(SA), FTCL, UPLM  
*Chairperson: Faculty of Health Sciences Research Ethics Committee*

The Faculty of Health Sciences Research Ethics Committee complies with the SA National Act 61 of 2003 as it pertains to health research and the United States Code of Federal Regulations Title 46 and 40. This committee abides by the ethical norms and principles for research, established by the Declaration of Helsinki, the South African Medical Research Council Guidelines as well as the Guidelines for Ethical Research: Principles Structures and Processes, Second Edition 2016 (Department of Health).

Research Ethics Committee  
Room 4-60, Level 4, Tswelopele Building  
University of Pretoria, Private Bag X323  
Arcadia 0007, South Africa  
Tel +27 (0)12 366 3664  
Email [despeka.beke@up.ac.za](mailto:despeka.beke@up.ac.za)  
[www.up.ac.za](http://www.up.ac.za)

Fakulteit Gesondheidswetenskappe  
Lefapha la Disaense tsa Mapheho



# Appendix B: Patient consent form

UNIVERSITY OF PRETORIA ORAL HEALTH CENTRE  
(ORAL AND DENTAL HOSPITAL)

UNIVERSITEIT VAN PRETORIA MONDGESONDHEIDSENTRUM  
(HOSPITAAL VIR TAND- EN MONDHEELKUNDE)

Dear Patient,

Geagte Pasiënt,

The personnel and students of the University of Pretoria Oral Health Centre (Oral and Dental Hospital) (which is a Teaching Hospital) appreciate your confidence in us for dental treatment. Although we strive to complete treatment as speedily as possible, our primary task is the training of students. For this reason, the treatment of patients will necessarily be more time consuming compared to the private sector.

Die personeel en studente van die Universiteit van Pretoria Mondgesondheidsentrum (Hospitaal vir Tand- en Mondheelkunde) (wat 'n Opleidingshospitaal is) waardeer die vertroue wat u in ons stel deur hier vir u tandheelkundige behandeling aan te meld. Alhoewel ons daarna streef om behandeling so spoedig moontlik af te handel, is ons primêre taak om studente op te lei. Daarom verloop pasiënte se tandheelkundige behandeling noodwendig stadiger as byvoorbeeld in die privaatsektor.

The student, who is responsible for your treatment, is dependent on your promptness, co-operation and availability. While we strive to train students to treat you in the best possible manner, we kindly request your indulgence with the progress of your treatment plan. We would appreciate your informing us of any unfavourable circumstances. In this way we shall be able to improve our service to you.

Die student wat verantwoordelik is vir u behandeling, is afhanklik van u stiptelikheid, beskikbaarheid en samewerking. Terwyl ons poog om studente op te lei om u gedurende die verloop van u behandelingsplan reg te behandel, vra ons u begrip. Ons sal dit egter waardeer indien u ons in kennis sal stel indien ons nie aan u verwagtinge voldoen nie. So kan ons die diens aan u verbeter.

Refusal by a patient to be treated by a particular student/dentist to whom he/she is allocated, is not acceptable. In such circumstances, further routine treatment for a patient will be re-considered. We appreciate your co-operation in this regard. If you have any enquiries, please discuss it with a lecturer/ dentist on duty.

Weiering deur 'n pasiënt om deur 'n student/tandarts aan hom/haar toegeken gesien te word is nie aanvaarbaar nie. In so 'n geval sal verdere roetine behandeling aan die pasiënt heroorweeg word. Indien u enige navrae het, bespreek dit asseblief met 'n dosent/tandarts aan diens.

The Oral and Dental Hospital is a teaching hospital and for this purpose, information and material obtained from you during treatment are used for **teaching** purposes. This information and material can include clinical information and photos, dental radiographs and extracted teeth.

Die Hospitaal vir Tand- en Mondheelkunde is 'n opleidingshospitaal en vir hierdie doel sal inligting en materiaal verkry van u gedurende behandeling gebruik word vir **onderrigdoeleides**. Hierdie inligting en materiaal kan insluit kliniese inligting en fotos, tandheelkundige x-strale en geekstraeerde tande.

Please provide us with permission should you agree to the use of your information and material. The use of these will be handled **anonymously** and you will therefore **not be identifiable** in any way.

Verskaf asseblief toestemming indien u bereid is om u inligting en materiaal beskikbaar te stel vir gebruik. Die gebruik hiervan sal **anoniem** hanteer word en u sal dus op **geen manier identifiseerbaar** wees nie.

I will allow my information and material to be used for teaching purposes. Yes

Ek gee toestemming dat my inligting en materiaal vir onderrigdoeleides gebruik word. Ja

I do not want my information and materials to be used for teaching purposes. No

Ek wil nie hê dat my inligting en materiaal vir onderrig-doeleides gebruik word nie. Nee

I understand that my refusal to grant permission for the use my information and materials **will not** in any way affect the treatment I receive at the Oral and Dental Hospital. Should you choose this option **please inform** your treating student/Dentist.

Ek verstaan dat my weiering om toestemming te verleen vir die gebruik van my inligting en materiaal, **geen invloed** sal hê op die behandeling wat ek by die Hospitaal vir Tand- en Mondheelkunde ontvang nie. Indien u hierdie opsie kies, **stel** asseblief u behandelende student/tandarts in kennis.

Patient: \_\_\_\_\_

Pasiënt: \_\_\_\_\_

Parent/ Guardian: \_\_\_\_\_

Ouer/Voog: \_\_\_\_\_

Signature: \_\_\_\_\_

Handtekening: \_\_\_\_\_

Date: \_\_\_\_\_

Datum: \_\_\_\_\_

File nr: \_\_\_\_\_

Lêer nr: \_\_\_\_\_

(Informed Consent for Hospital 2019 new suggested form)