VILNIUS UNIVERSITY
FACULTY OF MEDICINE
INSTITUTE OF DENTISTRY

Jakob Huels

Master thesis

Resin Composites in Modern Dentistry. The Composite Resin Processing Steps Impact on Success of the Restoration

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Scientific Supervisor: Doc. Dr. Rūta Bendinskaitė

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1. ABSTRACT

OBJECTIVE: The aim of this review is to investigate recent developments in dental resin composites. Furthermore, the processing steps such as cavity design, adhesion and polymerization are examined and how they affect the quality of a restoration.

METHOD: Narrative literature review. The literature search is limited to the period 2017-2023. Articles examining composites for CAD/CAM applications were excluded, as were studies investigating composite for purposes other than direct restorations.

CONCLUSIONS:

Developments in the field of resin composites focus on the incorporation of nanoparticles into the matrix as well as antibiotic agents to tackle secondary caries. A minimally invasive cavity design is supported. The beveling of margins and the surface preparation by the operator are considered more important factors compared to the choice of material. With both etching modes, clinically acceptable results are achieved, and failures are more related to the resin composite material used. Incremental layering with up to 2mm increments is the standard technique. The polymerization shrinkage is material dependent. Increased irradiation distance negatively affects polymerization.

KEY WORDS: Resin composite, Cavity design, Adhesive systems, Polymerization shrinkage, Polishing

2.1 INTRODUCTION.

Dental resin composites (DRCs) offer the ability of minimally invasive procedures in dentistry to preserve sound tooth structures while providing aesthetic acceptable results. A restoration is a clinical procedure that consists of the excavation of decayed or in other words damaged tooth structure and replacing it with a durable material that is biocompatible [1]. Nowadays, resin composites are one of the materials widely used in many dental offices. Next to great mechanical and physical properties, these materials also offer a great esthetic compatibility compared to materials used in the past [2]. These composite restorations seem to offer a good long-term longevity and come along with relatively low annual failure rates of 3-11% [3]. The choice of composite resin material does not influence the longevity of the restoration if the operator uses the correct technical method. During processing, there are many different steps that must be observed and can affect the quality of the result if they are not carefully carried out. In general, secondary caries and fractures are the main reasons for the failure of a restoration. However, another factor could also be aesthetics, with particular attention to the anterior, visible area, where high aesthetics are required [4].

2.2 MAIN ARGUMENT

The objective of this thesis is to briefly review about the latest developments in the field of resin composites. Furthermore, this work focuses on the processing of the materials and how each step impacts on the success of the restoration. For this purpose, the different processing steps and their effects on the result are to be examined, such as the cavity design, adhesive systems, modes of application, light curing, and finishing and polishing procedures and their action on the surface. To assess the physicomechanical properties and clinical performance of these materials, in the following, articles will be presented and compared to other studies.

2.3 HYPOTHESIS

The quality and longevity of a composite resin filling depends on the quality of processing and the precise observance of the processing steps by the operator. Neglecting important workflow steps can lead to compressed results and restricted function of a filling. The operator skill and experience are perhaps a more contributing factor towards the quality and outcome of the filling compared to the choice of material.

2.4 METHOD OF RESEARCH

The literature reviewed during this thesis is limited to the time of publication from 2017-2023. Research websites and databases used are PubMed, Vilniaus university library, Google Scholar and Elsevier/ScienceDirect. In vitro and in vivo performed studies were both included. Studies that investigated resin composites for CAD/CAM procedures, composite inlays, and composite used for orthodontic purposes were excluded.

3. REVIEW

3.1.1 RECENT DEVELOPMENTS OF RESIN COMPOSITES.

New treatment methods and increasing demands in clinics are accelerating the development of new or improved restorative materials. In the field of conservative dentistry, minimally invasive procedures demand to preserve as much sound tooth structure as possible. Right now, three main aspects of recent developments can be divided into advancing antimicrobial properties, the regeneration of hard and soft tissues, and lastly the biochemical properties [5]. One of the main reasons for composite restorations to fail is secondary caries. This disease is oral biofilm-dependent and acts via the mechanism, that bacteria produce acids which further destroy the tooth structure, which leads ultimately to a leakage of the restoration at the tooth-restoration margin. The moist and warm oral cavity is suitable environment for oral microbiota and promotes the growth with sufficient nutrients and water. Because of that, since the 1950´s researchers started to incorporate antibiotic agents into restorative materials. This strategy produced three different approaches; The release of antimicrobial agents into the oral cavity, the anchorage via polymerization of the agent to the resin matrix and antifouling agents that prevent oral microbes from adhesion [6]. Soluble antibacterial agents are incorporated into the resin matrix and these so-called leachable agents are most commonly Triclosan (TCN), chlorhexidine (CHX), Benzalkonium chloride (BC) and Chitosan. However, the downside of approach is, that the effect is short lasting, and the concentration of leachate is decreasing drastically after a few days [7]. The contact-dependent strategy uses antimicrobial molecules anchored by covalent bonds to the polymer. Their mode of action is physically piercing and destroying the bacteria´s cell wall. Materials commonly found are Chitosan as well as quaternary ammonium compounds (QACs) [6]. Multifunctional strategies combine the two above mentioned approaches and have been developed for years. The aim is to combine antimicrobial agents together with releasing and leachable agents. Zhang et al. made a study to develop a protein-repellent and antibacterial composite and investigated the effects of combining 2-methacryloyoxyethyl phosphorylcholine (MPC) with quaternary ammonium dimethylaminohexadecyl methacrylate (DMAHDM) on composite properties. The idea of the study was to produce a resin composite with protein-repellant capabilities and antimicrobial properties without compromising mechanical properties. During the study composite with 3% MPC and 1.5% DMADHM showed a protein adsorption around 1/10 compared to commercial composites and much greater reduction in biofilm growth on the surface. This approach was promising when tackling secondary caries and the materials seem to have a wide applicability not only limited to resin composites [8].

3.1.2 NANOPARTICLES IN RESIN COMPOSITES.

Dental resin composites were introduced in the last century and play an important role in modern dentistry. Since its introduction, the DRCs have undergone many improvements to enable their usage instead of using dental amalgams. The main advantages are conservative tooth preparation, aesthetics, and bonding capabilities to tooth structures while being moderate in costs compared to ceramics. Nanotechnology is used in many fields of dentistry and the reinforcement of DRCs with metal oxide nanoparticles is important to improve the mechanical properties such as wear resistance, flexible strength, tensile strength, and fracture resistance [9]. Nanoparticles used in dental related restorative materials can be made of silica, different polymers, hydroxyapatite, and metal/metal-oxide. Nanoparticles in dentistry mostly include noble metals such as gold, silver, platinum and metal-oxide nanoparticles like iron oxide or zinc oxide [10]. Zinc oxide nanoparticles (ZnO NPs) are one of the NPs used in DRCs and could improve mechanical as well as antibacterial properties. Zinc is a trace element and found in the human boy in muscles, bone, skin, and hard tissues of the tooth. ZnO NP is generally graded as a safe substance and its antimicrobial properties are the main reasons for its use. According to a study by Wang et al. incorporated ZnO NPs in resin composites inhibit the growth of Streptococci mutans without compromising mechanical properties. This effect can be seen as beneficial in the prevention of secondary caries. Compared to DRCs without ZnO NPs, DRCs containing an amount of 2% ZnO have higher compressive strength and show a reduction of 78% in bacterial number in this study. However, the excessive use of ZnO NPs leads to a decrease of most mechanical properties [11,12]. Next to the organic resin matrix, DRCs have a high loading of inorganic fillers. These fillers contribute mainly to the mechanical properties. Studies show that the best performance of a DRC is achieved when the number of inorganic particles is close to the maximum filler loading (MFL) [13].

3.2. CAVITY DESIGN.

In the field of conservative dentistry, the first step of most restorations is to eliminate carious tissue and bacteria from the affected tooth. For resin composite restorations, the minimum cavity design is supported. DRCs do not need a minimum thickness or the removal of sound tooth structures for retention when comparing to amalgam restorations. To overcome the disadvantages of polymerization shrinkage, it is generally accepted to keep the restoration as small as possible. Furthermore, there are modified cavity designs with the placement of bevels and rounded internal angles. Beveling provides exposed enamel rods which are suitable for bonding. This occurs because the surface area of cut enamel increases and these enamel margins produce oblique sections of enamel prisms allowing for a stronger bond between the enamel and DRC [14,15]. However, there is still controversy about the margin design and whether to bevel or not. A study by Apel et. al published in 2021 investigated occlusal stresses in beveled versus non-beveled restorations in class I using composite restorative material. The study compared two different forms of bevel, a defined short bevel and a long bevel or infinite bevel to the unbeveled restoration, all performed on a plastic model tooth. In two different steps, 600N and later 923N vertical load was applied to the restorations and histograms were used to simulate the redistribution of the stresses applied between the restoration and the tooth structure. Results showed that when no bevel is present, the most stresses occur at the interface between tooth and composite. The short and long bevel showed during the simulation that the tensile stresses at the interfaces gradually disappeared as the bevel becomes longer. However, the study or simulation is very limited, since only vertical forces are applied which would most likely not resemble the forces occurring during chewing and due to the anatomy of cusps would unlikely occur in a vertical manner [16]. To further understand the effect of the cavity design, a study performed by Firouzmandi et. al investigated fracture strength and marginal adaptation of conservative and extended MOD cavities restored with Cention N, bonded Cention N and resin composite. To do so, 120 maxillary premolars were divided into six groups. The fracture strength in MPa was observed with a universal testing machine and marginal adaptation was tested by taking impressions and puring them with epoxy resin. The resin replicas were then examined with scanning electron microscope (x400). The results show that the preparation size is linked to the fracture resistance, because the groups with conservatively extended restorations have significantly greater fracture resistance compared to extended restorations. Only in the groups (1) and (4) was no significant difference between fracture resistance visible. The marginal adaptability also revealed significant differences. Among the conservative MOD restorations was no difference visible, compared to the extended restorations which showed differences between the groups. Composite showed the least marginal adaptation, and between Cention and bonded Cention was no significant difference. This leads to the assumption, that with greater extend of the cavity the material choice plays a greater role compared to conservative cavities, where all used materials performed similar [17]. Another study that focuses on the cavity design was performed by Anand et. al. The aim was to verify, that the strength of a restoration is not dependent on the cavity design, in contrast to the material properties. For this purpose, two cavity designs were compared, a conventional box and a minimally invasive concave or U-shaped cavity with a 4-degree taper. The used composite materials are microhybrid Restofill and Esthet-X. Twenty cavities were prepared in stainless steel moulds for each design, 10 per material and filled in 2mm increments, condensed to remove voids, and cured with QTH curing light for 40 seconds. With a universal testing machine, the samples were compressed with a speed of 1mm/min and the maximum load at fracture was observed. The results are showing that the compressive strength was greater in both materials used for the U-shaped design compared to the box shape. In the box design group was a difference between the two materials visible (33MPa Restofill, 21.25 Esthet-X). However, in the U-shaped concave design was almost identical compressive strength visible (49MPa Restofill, 49.49MPa Esthet-X). This in vitro study is limited to only two materials and there is just testing of compressive stress without taking flexural and tensile strength into account. Still, it is highlighted and concluded that a conservative concave design with a U-shape and small taper provides higher resistance irrespective of the materials used [18]. Resin-composite restorations are not only limited to caries treatments, but another study is also reviewed which was performed in-vivo to evaluate the clinical performance of non-carious cervical lesions (NCCLs). The study by Lührs et. al published in 2020 assigned 85 NCCLs with cervical margins in dentine and coronal margins in enamel according to four different treatment protocols. The groups are: dentin surface cleaning (clean), dentin surface roughening with a round bur and flowable composite (prep-flow), dentin surface roughening with cervical groove preparation (groove), dentin surface roughening with cervical groove preparation and flowable composite (groove-flow). After 7.7 years 64 of those restorations were available for follow up (75.3%) and total retention rate was at 82.8% irrespective of the test group. When comparing the loss rates after follow-up, the rate for the “clean” group showed significantly different results with 27,8% compared to 7,1% for “prep-flow”, 15,4% for “groove” and 5,3% for “groove-flow”. Therefore, the cavity design and the roughening of dentin leads to a higher longevity of restorations placed in NCCLs and this could be considered for clinical protocols to achieve higher survival rates [19]. Next to these studies, which focused on the survival rate or outcome of different cavity designs and preparation of dentine or enamel, there are several classifications for cavity designs reaching back to 1998 were the first classification was published by Mount and Hume. Already back then, the principle of minimal extension and the encouragement to preserve maximum natural tooth structure was understood [20]. These proposals lead to the SiSta classification of cavity design in 2006. Nowadays there is in principle consensus that the properties of the material are not determining the design of composite restorations. As a result of removing diseased tissue only, there is no standard cavity design for DRCs restorations [21].

3.3.1 ADHESIVE SYSTEMS.

Adhesive systems revolutionized dentistry in a manner by allowing procedures that have been considered as impossible in the past. Adhesive systems allow to bond materials to tooth structures by bonding to enamel and dentin on the one side and allowing to bind with a composite restoration on the other side of the interface [22]. Adhesive systems are all resin-based materials and because of the exposure to oxygen, that inhibits the polymerization of the adhesive on the exposed surface, unreacted methacrylate groups form, which further allow to bond the restorative materials such as DRCs. There are different systems or strategies available to perform the adhesion to enamel and dentin [22]. To guarantee a strong bond between the adhesive layer and the DRCs, dental adhesives are mainly composed of monomers, like those used in dental composite materials. Bis- GMA (Bisphenol-glycidyl methacrylate) is probably the most common used monomer found in dental adhesive systems and it is showing excellent bonding properties when used on enamel. The downside of this hydrophobic monomer is that it is not able to penetrate or infiltrate dentin very well because of the hydrophilic nature of the moister dentine. To enhance wetting properties, more hydrophilic monomers are used as primers in dental adhesives such has HEMA (hydroxyethyl methacrylate), which is completely miscible in water. A mixture of both materials is often found in dental adhesives to provide adequate characteristics of hydrophilicity. Solvents are also commonly found in adhesives systems besides monomers. The organic solvents increase the wettability and infiltration of the adhesive resins into dentine. Often used solvents are ethanol, acetone, water, and in some systems that combine primer and bonding resins in one mixture, percentages up to 50% of solvents can be found [22].

3.3.2 ETCH-AND-RINSE APPROACH.

Dental adhesive systems can be divided into two different systems. The first approach contains the removal of the smear layer established with etch-and-rinse technique. By acid etching with 30-40% phosphoric acid, the smear layer is completely removed, and the dentin is demineralized which results in exposed dentin collagen. Clinically it is accepted, that by applying phosphoric acid, smear layer is removed however the concentration of the phosphoric acid plays a role. Lower concentration such as 20% shows a less effective etching effect and comes with an incomplete removal of the smear layer, however a high concentration, like 65% found in Super-Bond C&B Red Activator (Sun Medical Co., Ltd., Moriyama Japan) shows inferior bond strength and lower demineralization effect. The optimal concentration routinely used in clinics is 30-40% [23]. After complete removal of the smear layer in the etch-and-rinse strategy, a hybrid layer is formed when adhesive monomers infiltrate micro-porosities of dentine. Yamauchi et. al performed a study with the null hypothesis, that the etching mode would not make a difference to the bond fatigue resistance of universal adhesives. Four universal adhesives were tested in etch-and-rinse and self-etch mode during the study. (1) Adhese Universal, Ivoclar Vivadent, (2) All-Bond Universal, Bisco Schaumburg, (3) G-Premio Bond, GC Tokyo, (4) Scotchbond Universal Adhesive, 3M Oral Care. Pre-etching agent was 35% phosphoric acid and Z100 Restorative (3M Oral Care) resin composite for specimens. Results of this study show that there is no difference between the two etching modes regarding initial bond strength and further that the initial bond strength was material-dependent regardless of etching mode [24].

3.3.3 SELF-ETCH APPROACH.

When a self-etching adhesive is used, the bonding outcome is mainly influenced by the etching ability of the adhesive and the smear layer characteristics. Self-etching adhesives can be classified according to their pH. Strong self-etching adhesives (pH $\leq$ 1), intermediately strong self-etching adhesives (pH 1-2), mild self-etching adhesives (pH ~2), and the ultra-mild self-etching adhesives (pH > 2.5). Better etching ability is shown by the adhesive systems with lower pH, however the use of strong self-etching should be avoided [23]. A separate etching step is not required, because acidic monomers within the self-etching adhesive simultaneously condition and prime the tooth tissues. The bonding mechanism consists of two aspects, micro-physical retention, and chemical bonding, whereby micro-physical retention is achieved by an exchange of minerals that are removed and replaced by resin monomers before polymerization process. During clinical practice, self-etch systems do not require separate acid etching step and therefore the moist control after rinsing is not needed, making the process simplified for the practitioner. The self-etch technique is considered to reduce postoperative sensitivity and is less sensitive technical wise [25]. A study performed by Soares et. al, published in 2022, evaluated the clinical efficacy after six and twelve months of three adhesive systems (two-step etch-and-rinse, two-step self-etch, one-step self-etch) used in primary molars resin composite restorations. The results of this study show that there were no significant changes in the aesthetic, biological and functional parameters over the observed period. Statistically significant difference was only found for the marginal adaptation, but when comparing the three groups there is no differences between them. Therefore, it was concluded, that the examined self-etch adhesives have a clinical success comparable to the etch-and-rinse adhesive in primary molars with class II cavities [26]. Another clinical study performed by Cruz et. al published in 2021 compared the clinical performance of Adhese Universal (ADH) when two different application modes are used. 26 patients and a total of 117 non-carious cervical lesions were divided into two groups, the first consists of 59 fillings using the etch-and-rinse approach compared to 58 fillings applied with self-etch mode. For all the restorations Tetric EvoCeram (Ivoclar Vivadent) resin composite is used and the 24-month clinical performance was evaluated to compare differences in marginal coloring, marginal adaptation, hypersensitivity as well as fractures and retention according to World Dental Federation (FDI) criteria. The results of this study show, that there are significant differences between the baseline and the end of the period for marginal coloring, marginal adaptation, and hypersensitivity in self-etch mode. At the end of the 2-year period, 10 fillings of the etch-and-rinse mode were lost compared to two fillings in the self-etch mode group and therefore it is concluded, that this certain resin composite shows better results when it is applied in self-etch mode [27]. To further investigate the clinical performance of self-etch and etch-and-rinse adhesives, a systematic review with meta-analysis, published in 2022 by Vieira et. al can be used, which relates to the question of whether restorations in posterior teeth performed with self-etch or etch-and-rinse differ in the failure rate. All the used studies were randomized clinical trials and after exclusion criteria, 699 composite restorations were analyzed during 2 to 8 years. The authors state that these clinical trials use the same evaluation criteria for failed dental restorations according to United Stated Public Health Services (USPHS) and conclude that currently available evidence indicates a better performance of etch-and-rinse adhesives compared to self-etch adhesives in posterior composite restorations in terms of failure rate [28].

3.4 MODE OF APPLICATION.

Among the most important causes of failure of direct composite restorations is the polymerization shrinkage of methacrylate-based composites. One main concern remains the bulk volumetric shrinkage, which is caused by a molecular densification, more precise, when van der Waals separations become replaced by covalent C-C bonds which are more compact. Because of this volumetric change, stresses at the interface between composite and tooth tissues occur, which could lead ultimately to micro-crack formation and fracture at either the composite or the tooth substrate, resulting in gap formation, microleakage and sensitivity [29]. The polymerization shrinkage and shrinkage stress can be affected by the cavity configuration, quality of adhesion, placement technique and light curing protocols. The placement techniques are generally recognized as a considerable factor regarding shrinkage stress. To reduce shrinkage stress, specific restorative techniques could be used and in current literature the administration of composite layers instead of a bulk technique is recommended. Factors leading to a reduction of shrinkage stress are the use of a small volume of material, lower cavity configuration factor (C-factor, ratio of bonded to unbonded surface area), and small or minimal contact to opposing cavity walls during polymerization process [30]. One incremental technique is the horizontal placement technique. As the name indicates, horizontal composite layers a used with a thickness less than 2mm. It is reported in literature, that this technique increases the C-factor and therefore shrinkage stresses between opposing cavity walls are increased. Compared to horizontal increments, the resin composite can be placed in an oblique technique, accomplished by placing the composite in wedge shaped increments which are photocured twice. First it is photocured through the cavity walls and secondly from occlusal side, to direct the polymerization towards the adhesive surface and to reduce any distortion of the cavity walls [30]. Another technique is the vertical layering technique. During this technique small increments of composite is placed vertically, filling the tooth from one wall towards the other in steps. The curing is performed from the obverse side of the wall from which the composite is applied and reduces the space originating due to polymerization shrinkage at the gingival wall. Another technique is the split-increment horizontal layering technique. The first horizontal increment in this technique is split up into four parts. Each of these portions is positioned with one side up against the cavity wall and the other against a portion of the cavity floor. The created diagonal cut is then filled completely and cured. The other diagonal is cured in two steps, one half at each time. Next to this technique, it is also possible to build each cusp individually by using the successive cusp buildup technique. Each cusp is built up individually, up to the occlusal level, with small increments and minimum manipulation to prevent the formation of any voids within the increments. This technique is more time consuming than others, however it provides strength and aesthetically pleasing results. Another esthetically promising technique is the so-called stratified layering technique. Here, composite with a higher chroma than the anticipated final chroma of the restoration is placed at the center of the preparation on dentin. A lower chroma composite is placed at the cusp walls, to achieve acceptable aesthetic results. In another variation, a clinician could perform the separate dentine and enamel buildup, using an index. This variation can be used in such cases, where the occlusal surface of the tooth that is going to be restored is still intact. Preoperative an impression of the occlusal surface is taken and once the dentin buildup is performed by layering and curing, the index is used to precisely form the final increments of enamel. One advantage of this technique is the reduction of time needed for finishing procedures, since the preoperative anatomy is resembled [29,30]. Incremental layering techniques are accepted as standard techniques for the placement of composite resins. With increments that are usually no more than 2mm thick, these modes of application ensure proper curing, while reducing polymerization shrinkage, due to reduced volume of composite placed and keeping the C-factor low. Drawbacks are the contamination or incorporation of voids into the increments or between the layers. Compared to a bulk filling technique, the incremental layering is also more time consuming, and these drawbacks forced some manufactures to develop and introduce composite resins especially designed for bulk filling techniques. These materials allow the clinicians to place increments with a thickness up to 4mm [31]. Bulk fill composites were introduced to save time and lower the costs of restorations, while their main advantage is the application in increments with a thickness of up to 4mm and not requiring a longer curing time or higher light intensity for curing. In some products, manufacturers claim, that the bulk-fill composites have lower polymerization shrinkage compared to flowable and conventional composites [32].

3.5 POLYMERIZATION SHRINKAGE.

Resin composites are materials with good mechanical and physical properties, however, during curing, they undergo a volumetric shrinkage of 2-5% and this process is named total chemical or intrinsic shrinkage. The polymerization consists of a pre- and post-gel phase. During the pre-gel state of the material, stresses can be neglected because of the material flow from the free surfaces towards the bonded surface of the restoration. When a semi-rigid polymer network has formed, after gelation, plastic deformation is prevented, and stresses start to develop. When the vitrified stated is reached, the elastic modulus raises, and the capacity of stress relaxation diminishes significantly. As a result of these material properties, stresses are transferred to the bonding interfaces as well as the remaining tooth substrates, which ultimately can lead to adhesive failures, microcracks in enamel and cuspal deflection [33]. These failures further promote degradation and marginal staining of the restoration, and may contribute to postoperative sensitivity, secondary caries as well as pulpal inflammation. The main approaches to reduce the stress caused by polymerization shrinkage are development and improvement of the material properties and filling techniques [34]. A study from Sampaio et. al quantified the volumetric polymerization shrinkage (VPS) of different bulk-fill and conventional resin composites. Thirty extracted sound human third molars were used as specimens and prepared with flattened cusps and a box shaped class I cavity with the size 4mm x 4mm and 2.5mm depth. The five tested materials are the following: (1) Filtek Z100, (2) Tetric Evoceram Bulk Fill, (3) Tetric EvoFlow Bulk fill, (4) Filtek Bulk fill, (5) Filtek Bulk fill Flowable. Adper Single Bond Plus adhesive and Bluephase 20i curing light was used for all groups. The micro-computed tomography images were transferred into a rendering software to calculate the VPS. The results of this study show, that a significant statistical difference was found between the groups. The VPS ranged from 2.31% to 3.96%. The tested bulk-fill materials did not show statistically significant differences, both high viscosity and flowable. Filtek Z100, a conventional resin composite, demonstrated statistically higher VPS than both high viscosity bulk fill materials. Based on the results it was concluded that high viscosity bulk-fill resin composites showed decreased VPS compared to a high viscosity conventional resin composite [35]. Another study that evaluated the volumetric shrinkage of bulk-fill versus conventional resin composite was performed by Jassé et. al and published in 2020. 24 class II MOD cavities were prepared on extracted human molars and filled in three different groups as follows: (1) Bulk-fill with SureFil SDR flow, first increment 4mm, second 2m; (2) bulk-fill with SureFil SDR flow as base, 4mm first increment, covered with 2mm conventional nanohybrid composite Esthet-X HD; (3) Esthet-X HD in incremental layers. To evaluate VPS, AcuVol device was used after light curing. Results of this study show, that the claimed-low-shrinkage bulk-fill composite presented a higher percentage (4,94%) of volumetric polymerization shrinkage compared to the conventional Esthet-X composite (2,71%). However, this trial is limited to two materials and 30 teeth only, and only long-term clinical trials are valuable to confirm clinical success of the materials [36]. Yu et. al published a study in 2021 with the null hypotheses, that there are no significant differences in polymerization shrinkage and shrinkage stress between contemporary bulk-fill and non-bulk-fill resin-based composites. Six materials were tested, three bulk-fill (Sonicfill, Tetric N-Ceram Bulk Fill, Filtek Bulk Fill Posterior Restorative) and three conventional non-bulk-fill composites (Harmonize, Tetric N-Ceram, Filtek Z350 XT). Polymerization shrinkage was examined with Acuvol volumetric shrinkage analyzer. The volume was recorded before the curing, and 5 minutes post curing, while curing was performed for 20 seconds with Bluephase light by Ivoclar. The results of the polymerization shrinkage test show, that the mean values ranged from 1.72% to 2.13%. Arising results of the three bulk-fill composites are comparable to the conventional composites used in this study. The polymerization shrinkage of Sonicfill and Harmonize was significantly lower compared to the other groups tested. In the conclusion of the presented study, the null hypothesis, that there are no significant differences was rejected. Furthermore, the conclusion is drawn that the polymerization shrinkage is material dependent [37]. To examine the mechanical properties of bulk-fill composites, Boaro et.al performed a meta-analysis to compare bulk-fill and conventional composites according to the polymerization shrinkage, polymerization stress, cusp deflection, marginal quality, microhardness, flexural and fracture strength, and clinical performance. The results in terms of shrinkage are, that the viscosity of the material plays an important role, and the shrinkage is dependent on it. Bulk-fill composites show similar shrinkage compared to conventional resin composites within the regular viscosity range. Flowable bulk-fill composites showed lower polymerization shrinkage in this study compared to flowable conventional composites [38].

3.6 LIGHT CURING.

Most common light sources used in dental clinics are quartz tungsten halogen (QTH) and light-emitting diode (LED). The QTH has a broad emission spectrum and initiates the polymerization of most known resin-based composites. The downside of this devices is its heat production, and it becomes weaker over time. The LED devices consume less energy, have a higher lifetime and a narrow spectral output makes them more efficient to activate camphoroquinone [39]. Adequate performance of resin composites is only guaranteed when an optimal conversion of monomers into polymers is accomplished. Incomplete polymerization can lead to compromised mechanical properties, causing fractures or secondary caries. To ensure adequate polymerization, it is recommended to have the tip of the light curing unit (LCU) as near as possible to the resin composite. In some cases, however, it is unavoidable to have a greater distance between the LCU and the composite. The distance between the surface of the composite and the LCU can reach up to 8mm in deep caries restorations or even exceed this distance in core restorations of endodontically treated teeth. Increased irradiation distances may negatively affect the adhesion to dentin as well as the mechanical properties of RBCs. Oh et. al performed a study, to assess the impact of increasing irradiation distance on material properties such as flexural strength (FS), micro-shear bond strength (μSBS), and the degree of conversion (DC). Bar-shaped specimens of 8mm x 2mm x 2mm were made and filled with the resin composites, then cured at four different irradiation distances (0mm,2mm,4mm,8mm). The light curing was performed for 20s. In addition, it was examined, if increasing the time to 30s or 40s during light curing could make up decreased irradiance. Results for the FS test indicate that only the Z3P showed significantly lower FS at an 8mm irradiation distance compared to shorter distances. The mean FS of Z3P was significantly greater compared to the mean FSs of Z3F and SDR resin composites at 0-4mm distances. The micro-shear bond strength results revealed that all groups together had no statistically significant differences at irradiation distances of 0mm, 2mm, and 4mm. The highest irradiation distance of 8mm revealed, that μSBS is significantly lower than at shorter distances, only the Z3F composite revealed no μSBS differences for 4 and 8mm irradiation distances. The DC tended to decrease significantly with increased irradiation distances, for the Z3P composite the mean DC (measured at the surface) showed lower numbers at 4mm irradiation distance (45.57 %) and 8mm (44.22 %) compared to 50.52% at 0mm and 50.88 % at 2mm. Additionally the study revealed, that a twice as long curing time of 40s for Z3P at 8mm irradiation distance led to comparable FS, μSBS, and DC values to 20s curing time at 0mm irradiation distance. Furthermore, increasing the curing time to 60 seconds showed no significant differences compared to 40 seconds [40]. Especially for bulk-fill composites, the irradiation distance plays an important role, since they are cured in increments up to 4mm. Therefore, the bottom of the restoration becomes vulnerable to light scattering and light attenuation in air, because in those cases the material is further away from the light source, and this increased distance between light curing guide and material further leads to a decrease in power density. A study by Diab et. al investigated the effect of curing distance on the curing effectiveness of two bulk-fill composites, here Tetric N Ceram (TN) and Filtek Bulk Fill (FK). The prepared specimens, in a mold with 5mm diameter and 4mm depth, covered with a transparent matrix, were light cured with a polywave light-emitting diode (LED) at highest intensity mode. The radiant emittance was 1058 ± 8.40 mW/cm^2 and power output 643 ± 2.12 mW. The results show significant differences at top and bottom Knoop hardness number (KHN) between the different curing distances, and significant differences between the two materials. Light curing at 8mm resulted in a significantly lower hardness ratio for the TN, additionally the hardness ratio at 6mm was significantly lower than at 0 and 4mm. The FK differences in KHN and HR were only significant between light curing at 0 and 8mm. In this study, the effect of irradiation distance on the effectiveness of cure was material dependent. One explanation could be that the specimens receive less irradiance when the distance between material and LCU increases [41]. To further evaluate, if the light curing protocol has beneficial effects on the outcome or stability of the restoration, Unsal et. al performed a study to evaluate the effect of additional light curing on the color stability of resin composites. Four different resin composites, all manufactured by 3M ESPE, were used to prepare the specimens. For Filtek Ultimate, Filtek Z550 and Filtek Z250, 8 x 2mm discs were prepared and for the tested bulk-fill material Filtek Bulk Fill, an 8 x 4mm disc specimen was used. For each group a total of 80 discs was produced using a Plexiglas mold, light cured with either QTH for 40 seconds or with an LED for 20 seconds. In the next step, the prepared discs were further divided into two groups according to the surface treatment, nonpolished and polished, and one half of these specimens was light cured again using the same unit and curing time as in the first step.

In total, the study created thirty-two groups, each consisting of 10 specimens. The baseline color values were measured with a spectrophotometer (Vita Easyshade compact) and after 7 days of storage in a coffee solution, the color values were measured again. The results show that the additional light curing, and the type of composite used had both significant impact on discoloration. The type of light source also showed an effect, but only for the nonpolished and single time cured bulk-fill composite group as well as for the group that used Filtek Ultimate and was polished and additionally light cured. Filtek Ultimate showed highest values of discoloration in the group that was nonpolished, polymerized with LED without additional light curing compared to the polished group of Z550, polymerized with LED and additional light curing which showed the lowest values of discoloration. Between Filtek Z250 and Filtek Z550 groups was no significant differences, and the bulk-fill groups were the ones most affected by discoloration in this study. Additional light curing, regardless of the source of light, therefore contributed in a positive way to less discoloration in all groups and the physical-mechanical properties of the material might have been improved. Finishing and polishing of composite restorations also played a similar role, since untreated surfaces showed higher values of discoloration and therefore these steps should be performed to maintain proper aesthetics and contribute to lower the discoloration of composite restorations [39]. Most of the LED units have different curing modes with varying intensities, built in by the manufacturers, including a constant mode, low-grade, pulse mode and step cure/soft cure modes. The standard mode usually has the highest intensity and since there is a lack of literature, Haji et. al performed an experimental in vitro study to evaluate the depth of cure (DoC) in smart dentin replacement (SDR) bulk-fill composite restorations, polymerized by the different curing modes of LED curing units. The hypothesis of this study was that there is no difference expected in DoC between the curing modes. Cylindrical composite specimens (8 x 4mm) were fabricated using SureFil SDR Flow, and polymerized using and LED (Mini LED, Satelec, France) with an emitting spectrum range of 420-480nm. The specimens were divided into 3 groups, each consisting of 11 specimens and group 1 was polymerized in constant mode at maximum power for 10 seconds, group 2 with pulse mode polymerized in 10 successive bursts each lasting 1 second, with a separation of 250msec, group 3 in ramped mode, consisting of a gradual power rise lasting for 10 seconds followed by another 10 seconds at full power. The curing guide was kept away 3mm from the resin composite surface, and all groups were cured in a dark room. After polymerization the specimens were tested according to ISO 4049 scrapping method, each specimen three times and the mean was taken. The DoC was measured at the half of the cured sample length. Results of this study show, that according to Tukey´s honestly significant difference (HSD) there is a significant difference among constant, pulse and ramped mode. Ramped polymerization mode showed the maximum DoC for this certain bulk-fill and the minimum DoC was found for the pulse mode. The limitations of this study are that only one material with a quite small number of samples was used and only one type of LCU was used [42].

3.7 FINISHING PROCEDURES.

The esthetic appearance of a resin composite restoration is influenced by finishing and polishing procedures. Contouring, shaping, and smoothening of the restoration, to remove excess material and give an anatomical shape are related to the finishing procedures. After these steps, the polishing is performed to create a surface that has an enamel like texture and a gloss like that of enamel. Not only the esthetic appearance is affected by the polishing, but also other mechanical properties. Rough surfaces may lead to plaque accumulation, promote staining, abrasiveness, and can cause tactile perception by the patient. During finishing and polishing steps, heat is produced since these processes are frictional. An excessive amount of heat generated by the operator could affect the adhesive bond at the interface between tooth and restoration. The effect of different finishing and polishing procedures is investigated in several studies, however, there seems to be a lack of consensus about differences occurring between wet or dry finishing and polishing on the surface characteristics of resin composites. To evaluate, if irrigation during the finishing and polishing procedure affects the outcome of resin composite restorations, Silva et. al performed a study, published in 2021, that focused on the question whether it influences the material properties of resin composites. Six studies were included for this systematic review, the oldest published in 1991 and the most recent one was published in 2019. All these included studies evaluated the finishing and polishing under dry and wet conditions. In five of six studies, Sof-Lex discs (3M ESPE, USA) were used, and Super-Snap discs (Shofu Dental, USA) were used in one study. For finishing, diamond finishing burs (Diatech, Switzerland) and multilaminated carbide bur (48L-10, Angelus, Brazil) were used in these studies. Results for different types of materials (nanofilled, macrofilled, microfilled, hybrid, microhybrid, nanohybrid) were reported. The conclusions from the included studies show a variety in such way, that some authors stated that dry finishing showed superior or equal results compared to wet finishing, or that one should finish composite dry to obtain the smoothest surface. Others however stated that the finishing and polishing with abrasive discs, multilaminated discs, and spirals with irrigation was more effective. The author of this systematic review therefore concluded that different finishing and polishing methods influence the microhardness, color, roughness, and surface temperature of resin composites.

There was no evidence that favored either wet or dry finishing and polishing procedures found in this systematic review [43]. To further investigate whether there is a difference between dry and wet finishing, one could review a study from Nasoohi et. al, published in 2017. Microhardness and roughness of microhybrid and nanohybrid composites were investigated by dry and wet polishing methods. Thirty specimens were prepared of each composite. All tested composites were applied to a mold and placed between two transparent mylar strips, light cured for 20 seconds using a QTH LCU, according to manufacturer's instructions. The control group (C) was neither finished nor polished after removal of the mylar strips. In group (W), the specimens were finished and polished using aluminum oxide discs (coarse, medium, fine, super fine) (Soflex, 3M ESPE, USA), while water cooling was provided. The dry finishing and polishing group (D) used the same discs, but without any water application during the process. However, the specimens were rinsed off after each disc. A profilometer was used to measure the mean surface roughness and microhardness was measures by Vickers hardness tester (200g load within 15s). The surface roughness was significantly higher for group W compared to group C and the values for D were significantly higher compared to group W as well. Grandio samples had significantly higher roughness values in both W and D group, compared to the other composite resins. In the control group C, this difference was not significant. Aesthetic Enamel, All Purpose Body and Polofil Supra showed no significant difference in surface roughness values in group C, W, and D. The results of surface hardness test indicated that all composites among group C showed lower hardness values than in group W and D. In addition, surface hardness values for all composites who received finishing and polishing under wet conditions, were significantly higher than in group C. The values for the dry finished and polished group D were also significantly higher than for group W. One explanation for the underlying surface roughness values is, that the finishing and polishing action removes parts of the matrix between the filler particles of the composite. These filler particles consequently stick out of the surface and therefore increase the surface roughness. Increased values of surface hardness in the wet and dry polished groups are likely a result of the changes within the composite that occur due to the raised temperatures at the surface of the composite. This increase in temperature can lead to an increase in cross-linking between the polymer chains and a greater hardness of the material [44]. Another study performed by Marufu et. al evaluated the effect of different finishing protocols on color stability of DRCs after exposure to staining solutions. A nanofill, Filtek Z350 (3M ESPE, USA) and a mycrohybrid, Vit-l-escence (Ultradent, USA) resin composite were evaluated according to three different finishing and polishing protocols, first the Mylar strip (Maquira Industries, Brazil), Soflex polishing disc (3M ESPE

Dental products, Germany), and white polishing stone (Prima Dental, UK). For each of the composites, 75 specimens were prepared and further divided into the three groups according to the finishing procedure. Mylar finish (M) was achieved by curing with Mylar strip on both sides of the specimens. The Soflex discs (D) were put on a slow-speed hand piece and sequentially used for 30 seconds each (Coarse, medium, fine, superfine). White polishing stones (S) was used for 2 minutes, also on slow-speed and minimal pressure. For the staining, red wine (R), black tea (T), distilled water (C), Khat solution (made from Khat plant) (K1), and dilution of Khat solution 1:3 (K2) was used, and the specimens remained for two weeks at 37 °C inside the light-proof containers. For color measurements a digital spectrophotometer (Vita Easyshade, Vita Zahnfabrik) was used, and the mean value for the specimens was calculated. After the staining period, all test-specimens, except (D) finished Vit-l-escence in K1 and K2 solution, demonstrated clinically unacceptable color differences. In this study, the disc polishing was thought to produce a smoother surface compared with the white stone, since the disc polishing was a multistep technique with decreasing abrasiveness in each step. It was further concluded, that the Soflex disc finish had better color stability in contrast to White polishing stone and Mylar finish. This applied to both, nanofill and microhybrid composites. The effect of the staining solution was also found to be dependent from the polishing protocol, which should be chosen according to the type of filler system [45].

3.8 CLINICAL SUCCESS RATES

Being one of the most common used materials for direct restorations, it is important for today's oral healthcare to question the clinical performance of dental resin composites. It is further important to understand reasons for failure and during the last decades, it became clear that not only the materials and application techniques play a contributing role towards the longevity, but also several other factors such as patients individual caries risk, parafunctional habits, restoration size, and the location of the restoration. This led to several clinical investigations, that report the influence of risk factors which could compromise the clinical success of DRC restorations. Demarco et. al performed a study about the factors that influence the longevity of anterior and posterior direct composite restorations. The study selection included 33 studies, published between 2011 and 2021 that expressed the annual failure rates (AFR), success or survival rates of posterior and anterior direct composite restorations. Overall, AFR ranged from 0.08% to 6.3%, while for posterior restorations the AFR was 0.08% - 4.9% and 1.4% - 6.3% for anterior restorations. Cervical restorations investigated in this study showed AFRs of 2.8% - 4.6%. For posterior restorations, secondary caries was the most common reason that led to a failure of the restoration, additionally the need for endodontic treatment was reported as additional reason. For anterior restorations, fracture, color mismatch or marginal discoloration were the main reasons mentioned that led to failures of restorations. In 75% of the investigated studies, a higher number of surfaces restored compromised the longevity, whilst the resin composite did not influence the durability in 72.2% of the articles [46]. Lempel et. al performed a retrospective study, published in 2019, and figured out differences in long term performances of composite restorations in Class II cavities in vital and endodontically treated teeth (ETT). AFR of fillings in vital and ETT were comparable, however the hazard for failure was greater in ETT and statistically significant. In this 6–13-year observation period, vital teeth that were restored with resin composite showed survival rates of (98.97%) compared to ETT (76.8%). Secondary caries was the main reason for failure in vital teeth compared to vertical root fractures, cusp fractures, and loss of retention in ETT, and in can be added that occlusal stresses are having a negative effect on the longevity of restorations in these teeth [47]. In patients with severe tooth wear, that leads to loss of tooth structure and exposed dentin, functional and esthetical problems arise, so that a restorative treatment is indicated. A minimally invasive treatment including direct composite restorations can be indicated in some cases, and these restorations seem to show acceptable performances regarding the wear in those patients with high-risk profile such as bruxism or erosive processes. Increased vertical dimension of occlusion (VDO), bite force and mechanical or chemically related forces are of importance and should be regarded since the wear of a restoration is a multifactorial process [48]. Even if the factors compromising the longevity of a direct restoration are carefully observed, it can never be completely ruled out that a restoration fails or is considered failed when it is not meeting the standards anymore, that were designed by researchers and clinicians. If a restoration is replaced completely, the preparation size of the cavity usually increases and the risk of complications involving the pulp may cause further problems compromising the longevity. The concept of minimally invasive dentistry is to reduce adverse treatment effects to a minimum; therefore, repair is becoming more popular and could be considered as state-of-art even if it was traditionally considered as unfavorable and not done by many dentists [49]. The repair of a restoration includes the removal of damaged material of the restoration and any surrounding tissue that's defect, followed by a rebuild of the prepared site. Fernández et. al performed a clinical trial to assess the longevity of repairs in composite restorations that were initially planned to be restored with a complete replacement. The restorations were evaluated at baseline and again after 10 years and the results of this study show, that both groups behaved similarly. The parameters that were included in the evaluation are marginal adaptation, secondary caries, anatomy, and color. According to the results it was concluded, when clinically indicated, that a repair of composite restorations should be elected. The minimally invasive procedure of a repair can increase the longevity of restorations and the results achieved show that it's a safe treatment with effectiveness in long term. However, this trial consisted of a small sample group and its clinical importance can be questioned [50].

4. CONCLUSION

Current developments focus on the implementation of nanoparticles into the matrix to enhance chemical and mechanical properties, ensuring a better durability and stability within the oral cavity. A minimally invasive cavity design is supported. The beveling of margins and the surface preparation by the operator are considered more important factors compared to the choice of material. Adhesive systems can be divided into etch-and-rinse and self-etch approach. With both etching modes, clinically acceptable results are achieved, and failures are more related to the resin composite material used. The use of small volume increments and a low C-factor contribute to direct the polymerization towards the adhesive surface. Incremental layering is the standard technique. To reduce chair time, and to simplify workflow, the need for materials that are possible to place in bigger increments led to the invention of bulk-fill composites. The polymerization shrinkage is material dependent, but the reviewed studies indicate that the volumetric polymerization shrinkage of bulk-fill composites is to some extend comparable to that of conventional resin composites. The tip of the light curing unit should be in close distance to the composite. Increased irradiation distance negatively affects polymerization. Polishing increases the success of a filling since it reduces the surface roughness, inhibits plaque accumulation, abrasiveness, and staining. Surface microhardness is increased by polishing resin composites.

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