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Revisiting the Microleakage in Tooth-coloured Sandwich Restorations

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KEYWORDS

Sandwich technique, tooth-coloured restorative materials, polymerization shrinkage, microleakage

ABSTRACT

The placement of glass ionomer cement as lining material below composite fillings was introduced by McLean and Wilson in 1977. This technique incorporated different layers of restorative materials placed onto the tooth, similar to layers of a sandwich. It was proposed that this technique will provide a molecular seal to dentine in addition to mechanical and aesthetic properties of composite resin. Placement of a liner or an intermediate layer underneath the main bulk of restorative materials reduces polymerization shrinkage stress and resultant microleakage of the final restoration. To date, dentine adhesion and polymerization shrinkage are limitations of resin-based restorative materials. At present, a wide array of tooth-coloured restorative materials with different formulations is available. Despite advancements in restorative dentistry, no single technique or material is ideal in both clinical effectiveness and simplicity. Moreover, clinicians may find themselves in a dilemma when choosing restorative materials and techniques that can provide the best clinical results with minimal technique sensitivity or chairside time. The aim of this literature review is to present existing scientific evidence in microleakage and sandwich technique in restorations, and to discuss the multiple approaches in sandwich restorations in effort to reduce microleakage of dental restorations. Clinical recommendations will be given based on evidence from multiple studies.

INTRODUCTION

Microleakage has been a perennial problem in restorative dentistry and to date there is no non-leaking restorative material [1,2]. The amount of leakage that occurs depends on the restorative material used, cavity margin, technique used in restoration placement and dentist skill among others [3]. Amalgam is self-sealing and still remains a material of choice for posterior teeth due to its lower cost and technique sensitivity, superior mechanical strength, and durability [4]. One advantage of amalgam is decreased microleakage over time at all margins of the restorations [5]. Its use in non-carious cervical lesions is not indicated as a defined cavity preparation will require removal of intact tooth structure and the aesthetic position of the cavity. Tooth-coloured restorative materials such as composite resin(CR) and glass ionomer cement (GIC) have become popular among clinicians and patients due to their more conservative tooth preparations, better aesthetic appearance, and eliminate the concern regarding mercury toxicity from amalgam restorations [6]. While CR is now most widely used in Class II restorations, microleakage at dentine margins still proves to be problematic and affects the longevity of the restoration.

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McLean and Wilson first introduced in 1977 the use of GIC as lining material confined within the amelo-dentinal junction below CR restorations at the time when bonding to dentine was ineffective. The technique then, though the author did not specify, is essentially the closed-sandwich technique [7], as GIC with its poorer translucency and colour, was cutback and veneered with CR. Open-sandwich technique, in which a portion of cervical GIC is left exposed to the oral environment, was applied by Mount (1990) in anterior Class V cavities [8]. The author explained that closed-sandwich restorations negated the fluoride-releasing property of GIC [8]. Use of the sandwich technique for posterior CR restorations following the open-sandwich principle was reported later [9].

Conventional CR and GIC differ in terms of bonding mechanism to tooth structure and physical and mechanical properties. Like every other material, both have their shortcomings such as polymerization shrinkage for CR and poor mechanical strength for GIC [10]. The weak Van der Waals forces are converted to stronger covalent bonds during polymerization, closing the gap between monomer chains. Contraction stress is then generated towards tooth structure or bonding agents that oppose the direction of stress, thus resulting in marginal and adhesion failure [11]. In addition, microleakage can also be caused by differences in coefficient of thermal expansion [12] and elastic moduli [13] between CR and tooth structure.

Over the years, improvements in tooth-coloured restorative materials and placement techniques were introduced to minimize polymerization shrinkage and subsequent microleakage of the materials. Changes in the composition and properties of CR, dentine bonding systems (DBS) and GIC led to changes in material choices for use in specific cavities using the sandwich technique. Development of low shrinkage silorane-based CR and resin-reinforced GIC aimed to overcome their respective limitations. Bulk-fill CR was also introduced in recent years containing polymerization modulators which were claimed by manufacturers to reduce polymerization shrinkage [14,15]. While future developments of a CR that releases sufficient amounts of fluoride to prevent caries formation combined with a DBS capable of achieving chemical bonding to tooth structure may preclude the use of the sandwich technique, at present, the sandwich technique still maintains a certain degree of popularity.

There has been numerous literature investigating the efficacy of sandwich technique in producing restorations with minimal microleakage as compared to total bonding restorations. With the innovation of restorative materials with advanced formulations and different restorative techniques, clinicians find themselves in a dilemma on which restorative material and protocol to follow. This is due to multiple factors to be considered which include remaining tooth structure to support the restoration, access to subgingival regions of the cavity with risk of moisture contamination, technique sensitivity of the material, time and cost of procedure. Hence the aim of this paper is to review existing scientific evidence pertaining to reduction of microleakage by different approaches in sandwich restorations. Finally, clinical recommendations on restorative technique and choice of restorative material and bonding agents used are provided.

MICROLEAKAGE

Microleakage is defined as the passage of bacteria, fluids, molecules or ions between a cavity wall and the restorative material applied to it [16]. Restorations that involve margins in dentine have been shown to have more microleakage than restorations on enamel. This is true for both direct and indirect anterior and posterior restorations [17-19].

Microleakage of restorations had been tested both in vitro and in vivo [20]. Most of the laboratory studies involved measuring the depth of dye penetration when restoration margins were immersed in methylene blue dye, fuchsin dye or radioactive isotopes [21-23]. Scanning electron microscope was often used to examine the marginal gap or voids between the restoration and tooth surface [24]. On the other hand, in vivo studies of microleakage were conducted according to the Modified United States Public Health Service (USPHS) Ryge criteria [20].

Microleakage results in post-operative sensitivity, secondary caries, pulpitis, and discoloration, all of which Forss and Widström (2004) reported to be the major causes of failure in restorations [25]. The complications of microleakage are mainly contributed by the gap formation at the tooth-restoration interface. The presence of gap provides a space for plaque retention and subsequent pathway for bacterial penetration and colonization. In addition, the presence of gap at the bonding interface allows oral fluid penetration that contributes to hydrolytic degradation of the resin adhesive system, further deteriorating the bonding integrity of the overlying restoration [26]. The correlation of marginal gap and microleakage was found to be negative in Idriss et al's study (2007) while the influence of restorative materials and technique were found significant in affecting microleakage [27]. Opposite result was found by Olmez et al. (2004) as the study reported when investigating the correlation between internal voids and microleakage [28].

GIC was the first self-adhesive restorative material able to bond to dentine, it was proposed that its use as an intermediate layer will improve the bond of CR restorations to dentine. The sandwich technique retained its popularity with time because developments in dentine adhesive technology and CR placement techniques did not reduce microleakage at the cervical dentine margins to a substantial level [29]. Sandwich technique has a long track record of almost half a century, and is still applied clinically today, despite introduction of simplified dentine bonding systems.

TYPES OF SANDWICH RESTORATIONS

Sandwich technique is classified into open-sandwich and closed-sandwich (Figures 1 and 2). Open-sandwich technique involves placing a lining material such as GIC up to the cervical cavosurface margin while in closed-sandwich technique, the lining material is placed short of the cervical cavosurface margin. The main difference between these two techniques is that the open-sandwich technique exposes the GIC to the oral environment, whereas in closed-sandwich, GIC remains protected by the overlying resin restoration at the proximal margin [30]. Sandwich technique can be applied in Class II and Class V cavities. Black's classification defined Class II cavities as cavities located at the proximal surfaces of premolars and molars, while Class V cavities are located at the gingival third of the facial and lingual surfaces of any tooth. Class V cavities on anterior teeth also have greater aesthetic need compared to posterior teeth. According to Liebenberg (2006), when restoring a Class II cavity with gingival margin in dentine, open-sandwich technique with GIC should be used to improve the peripheral seal by means of chemical bond formed between GIC and dentine, rather than micromechanical retention from resin-dentine bond [31]. Later studies by Perdigão showed that chemical bond was also present in universal and self-etch adhesive through functional monomer methacryloyloxydecyl dihydrogen phosphate (MDP) [32]. On the other hand, cavities' enamel margins can be restored using CR because resin bonded to enamel was found to protect the confined resin-dentine bond from degradation [31].

Results of studies on open-sandwich technique for direct restorations are equivocal [13,33-36]. The open-sandwich restorations were shown to exhibit proximal marginal failure and poor marginal seal, as a result of the dissolution of GIC in contact with the oral environment [33]. The constant exposure of GICs in open-sandwich restorations caused water diffusion into the material, leading to the dissolution of components at the cement-water interface, followed by diffusion of dissolved components back into the aqueous medium [37]. In acidic conditions, diffusion of hydrogen ions into the exposed GIC in open-sandwich restorations can lead to the disintegration of the bond between metal cations and polycarboxylic acid [38]. Knibbs (1992) showed that at the 2-year evaluation of Class II sandwich restorations lined by GIC, four out of five marginal failures were related to the exposure of the cement [34]. This finding agreed with Stockton and Tsang's (2007) findings where Class II closed-sandwich restorations displayed less microleakage compared to open-sandwich restorations [13]. In the study, the authors placed the GIC over the entire gingival floor before removing the outer 0.5mm to expose the cavosurface margin prior to CR placement They reported reduction in microleakage, but proper placement of CR in closed sandwich technique was difficult due to limited access.

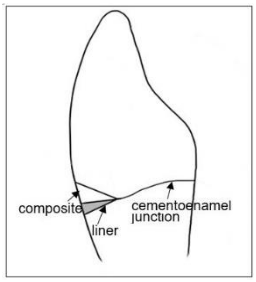

Figure 1 Open-sandwich technique [78]

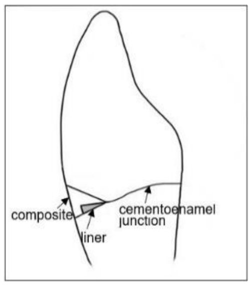

Figure 2 Closed-sandwich technique [78]

On the other hand, open-sandwich restorations demonstrated superior marginal sealing ability for Class II restorations in Fabianelli et al.'s (2010) study when compared to closed-sandwich [35]. Nonetheless, sandwich technique with GIC in direct Class II and Class V cavities were reported to show better clinical performance and retention rate than total bonding with CR in clinical studies [34,36]. These studies concluded that neither restorative technique was able to completely eliminate microleakage.

For indirect restorations using the same principle as open-sandwich technique, deep margin elevation or proximal box elevation procedure was suggested by Dietschi and Spreafico (1998) [39]. It involves placing direct composite over the dentinal floor of the cavity to coronally relocate the proximal margins of indirect adhesive restorations such as CAD/CAM-fabricated inlays or onlays. Roggendorf et al. (2012) and Frankenberger et al. (2013) both showed that the marginal quality of composite and ceramic inlay restorations was better with deep margin elevation when examined under scanning electron microscopy (SEM) [40,41]. Clinical evaluation by Bresser et al. (2019) showed good survival rates of indirect restoration with deep marginal elevation [42]. This technique facilitated better isolation and moisture control during impression-making and luting procedures, and enhances marginal adaptation of final restorations. However, indirect composite restorations showed more degradation than ceramic restorations over time [42].

CHOICE OF MATERIALS

Sandwich restorations comprise two layers of different restorative materials. The ideal properties of restorative material applied as a stress-breaking intermediate layer include low modulus of elasticity and viscosity. The flexibility of the lining acts as a buffer to contraction stress generated by the overlying bulk of resin-based material. Besides, the coefficient of thermal expansion of restorative material should be similar to that of tooth structure, as a large discrepancy between the restorative material and tooth structure may lead to thermal-induced stress at the cavity wall and subsequent marginal failure [43]. For the outer layer, which is the main bulk of restoration, the material used should have good mechanical properties which includes compressive strength and wear resistance especially in load-bearing Class II cavities. Aesthetic appearance and colour stability should also be considered when restoring the aesthetic zone. In the sandwich technique, it has been proposed that the dentine margin be lined with conventional GIC to improve the marginal seal before being restored with CR which has better mechanical strength and aesthetic properties [7].

(i) Glass Ionomer Cement

GIC was the earliest lining material of choice in anterior and posterior sandwich restorations, specifically Class II and Class V [7,8]. The advantages of GIC over CR include its adhesive properties, which is its ability to chemically bond with tooth structure by ionic interaction and cariostatic properties which was reported to release fluoride ion up to 10ppm initially and 1 to 3ppm long term [43]. GIC also has similar coefficient of thermal expansion (10.2-11.4ppm) to enamel (11.4ppm) and dentine (8.3ppm) [43]. The above properties are desirable in improving the marginal seal of restorations and prevention of secondary caries.

Similar to CR, surface conditioning before placement of GIC in sandwich technique removes the smear layer but not the smear plug and improves chemical adhesion [44]. Mazaheri et al.'s (2015) study showed that conditioning Class V dentine cavosurface margins with 20% polyacrylic acid produced less microleakage at the bonding interface, when compared to no conditioning and etching with 35% phosphoric acid [45]. Etching with phosphoric acid resulted in demineralization of larger amounts of calcium and phosphorus on dentine surfaces than necessary during chemical bond formation [46]. However, contradicting studies reported that the bonding interface between GIC and dentine with prior polyacrylic acid application undergo deterioration when aged in artificial saliva and thermocycling. Without dentine conditioning, remineralization was noticed at the interface produced by potential synergistic effect between GIC and saliva [47]. The author explained that the formation of apatite-like precipitation and remineralization that occurred at the bonding interface reduced porosity at the bonding interface [47].

Placement of GIC over dentine resulted in better marginal adaptation and reduction of microleakage [24]. These findings corresponded to the in vitro sandwich technique microleakage studies conducted by Fourie and Smit (2011) and Hagge et al. (2001) [48,49]. Clinical performance of sandwich technique in restoring non-carious cervical restoration had been shown to have higher retention rates as compared to CR restorations [36]. However, dissolution of GIC was reported with long-term evaluation, leading to marginal failure of restoration [50].

Conventional GIC was found to have inferior physical and aesthetic properties when compared to CR. Due to its poor wear and fatigue resistance, it is generally not used as bulk restorations in stress-bearing locations. Its limited usage in the anterior aesthetic region is attributed to the material's dullness and opacity [51] at initial placement, which only improves in translucency during the maturation process in the following 24 hours. It was also reported that earlier conventional GICs that had high fluoride content exhibit greater degree of opacity and hence less desirable appearance [52]. To overcome its poor wear and fatigue resistance, in addition to its inferior aesthetic properties, hydroxyehyl methacrylate (HEMA) and camphoroquinone were incorporated into GIC formulation, thus creating resin-modified GIC. Resin-modified GIC retained the fluoride-releasing properties and chemically bonds to tooth structure.

Microleakage studies by Wilder et al. (2000) and Rekha and Balagopal (2012) both showed that resin-modified GIC exhibited less microleakage than conventional GIC in sandwich restorations [53,54]. These results may be due to the combination of both chemical bonds from the polyacrylic acid component and hybrid layer from the resin component HEMA [55]. These findings disagreed with Shruthi et al.'s (2015) study where resin-modified GIC showed more microleakage than conventional GIC [56]. According to Toledano et al. (1999), conventional GIC undergoes more water sorption and hygroscopic expansion which compensates for the polymerization shrinkage of the material, resulting in smaller marginal gaps [55]. In addition, Gyanani et al. (2016) and Fourie and Smit (2011) studies found that using ultrasonic scaler tip for ultrasonic agitation during placement of resin-modified and conventional GIC in sandwich restorations resulted in less microleakage respectively [48,57]. The authors described the use of ultrasonic energy as a means to accelerate the curing process of material by causing the breakdown of glass particles, hence increasing the powder surface area and reactivity [48,57].

Resin-modified GIC shared a limitation with conventional GIC which is its susceptibility to dehydration. Dehydration of resin-modified GIC in open-sandwich technique led to microcrack formation, subsequently compromised mechanical strength [43]. In addition, the mechanical strength of resin-modified GIC was reported to surpass conventional GIC but not CR [58]. Opdam et al. (2007) reported that the lower survival rates of posterior CR sandwich restorations lined with resin-modified GIC (70.5%) compared to total-etch CR restorations without lining (88.1%) were due to the presence of weaker lining cement beneath the CR restoration [59]. Retention rates of Class V sandwich restorations with CR and GIC (100%) were superior when compared to CR with dentine bonding agent (87%) [60]. This is due to the ability of GIC and resin-modified GIC to form ionic bonds with the hydroxyapatite available in the dentine substrate leading to a better bonding, while the effectiveness of acid etching on sclerotic dentine may be inadequate, in turn causing lesser resin tag formation and inferior retention rate.

(ii) Flowable Composite

In CR restorations, shrinkage stress increases with configuration factor (C-factor), and the former contributes to adhesive failure and microleakage. C-factor is the ratio between the bonded to unbonded surfaces of CR restorations [61]. The highest C-factor was found in Class I cavities, with five bonded surfaces to one unbonded surface, while the least was found in Class IV cavities. Class II and Class V cavities have a C-factor of approximately two, with four bonded surfaces to two unbonded surfaces [3]. The use of flowable composite as the first layer in sandwich technique was indicated in Class I and Class II cavities [62]. The lower percentage of inorganic filler in flowable composite improves wettability and lowers viscosity, allowing it to fill up internal irregularities of the cavity, leading to better marginal adaptation.

Studies had shown the effectiveness of flowable composite in sandwich technique with its lower viscosity as a stress-breaker of contraction stress created by the polymerization of the overlying large CR in sandwich restorations [62,63]. Korkmaz et al. (2007) reported that placing 1mm of flowable composite beneath nanohybrid and ormocer composite in Class II CR restorations significantly reduced its microleakage [64]. Nevertheless, comparative evaluation on the marginal sealing ability of resin-modified GIC and flowable CR in sandwich restorations conducted in many studies agreed that resin-modified GIC performed better [49,65-68]. Ab Malik et al. (2013) explained that the chemical bond formed by resin-modified GIC to dentine had superior bond strength as compared to that of CR's micromechanical retention [68].

The limitation of flowable composite is a higher percentage of resin matrix when compared to that of conventional CR may lead to more contraction stress and microleakage. Similar to GIC, it has weaker mechanical properties compared to conventional CR and the presence of residual monomers during the first 24 hours post-maturation [69]. Residual monomers are the unpolymerized monomers of CR which were reported to have toxic properties that may cause allergic reactions and are detrimental to mechanical properties and clinical longevity of CR restorations [70].

(iii) Compomer

Compomer is a polyacid-modified CR which is similar to resin-modified GIC combining both mechanical and aesthetic properties of CR with cariostatic and chemical bonding of GIC. However, unlike GIC, compomer requires prior acid-etching and resin bonding agents [71]. According to the manufacturers, the current generations are indicated for Class II and V cavities.

Compomer in Class V sandwich restorations was found to exhibit the least microleakage when compared to flowable composite and resin-modified GIC [72]. A study by Dietrich et al. (2000) showed that the combination of compomer as an intermediate layer and CR in Class II sandwich restorations significantly reduced microleakage when compared to using either of the individual materials alone [73]. These findings were attributed to the similar coefficient of thermal expansion with tooth structure and reduced resin content in its composition [72]. In contrast, Moazzami et al. (2014) reported that compomer in sandwich restorations produced more microleakage than flowable composite but less microleakage than resin-modified GIC [16]. The limitation of compomer was their inferior fluoride-releasing and anticariogenic properties when compared to conventional GIC [74,75]. This was due to the lower porosity and higher resin content of compomer, which acts as a barrier for diffusion of fluoride and water [75].

(iv) Biodentine

Tricalcium silicate-based restorative material Biodentine (Septodont, Lancaster, Pennsylvania, USA) was introduced in 2010 and was indicated in the restoration of deep and large coronal carious lesions using sandwich technique and cervical lesions. According to the manufacturer, this bioactive dentine substitute had similar mechanical properties as dentine and was able to provide a tight seal to restorations without the need of prior conditioning. The micromechanical retention of this material involved an alkaline reaction, in contrast to the acid etching used in CR restorations. The alkaline environment causes dissolution of collagen structure in the dentinal tubules, and allows the entry of Biodentine to form micromechanical tags in the exposed dentinal tubules providing anchorage [76].

It was reported to have less microleakage when used in sandwich technique as compared to resin-modified GIC in Class II open sandwich restorations [77]. This finding was in agreement with studies by Darsan et al.'s (2018) and Raskin et al.'s (2012) [30, 78]. These findings were attributed to the formation of a hydroxyapatite layer in the presence of saliva at the bonding surface which protected it from degradation and maintained its marginal integrity [79]. These findings were contradictory to Camilleri et al.'s (2013) study which showed that use of Biodentine in open sandwich technique resulted in more microleakage than conventional and resin-modified GICs. The author demonstrated that etching Biodentine with 37% phosphoric acid before placement of overlying CR led to structural and chemical changes that diminished the adhesion between the two materials [80]. Biodentine had the disadvantages of higher cost and longer initial setting time of nine to twelve minutes when compared to CR and GIC [81].

COMPOSITE RESIN AND DENTINE BONDING

The usage of composite and dentine bonding system (DBS) is not considered as a sandwich technique per say as clinicians often apply GIC or resin-modified GIC as the intermediate layer beneath CR. However, the combination of CR and flowable composite in sandwich restorations warrants elaboration on the material properties of CR and DBS. In addition, as the main bulk of restoration will be CR, further understanding on the bonding of CR may be useful. The bonding system and CR placement technique used affect the microleakage at dentine margins. These relate to factors that contribute to microleakage of the restoration especially shrinkage stress. Methods proposed to reduce polymerization shrinkage and subsequent microleakage had been developed, including incremental placement of CR and DBS with stronger bond strength. Prati et al. (1992) reported that there exists an inverse relationship between dentine bond strength and microleakage of restorations [82], while Kim et al. (1999) demonstrated similar results of significant negative correlation between bond strength and microleakage values [83]. Reduction of microleakage at dentine margins is a primary objective in the development and further improvement in DBS technology and CR placement techniques.

DENTINE BONDING SYSTEMS (DBS)

In 1955, Buonocore proposed the use of phosphoric acid for enamel etching. By demineralization of hydroxyapatite on enamel surfaces, microporosities are created which allow resin tag formation and micromechanical interlocking between resin-based materials and enamel surface [32]. In 1969, Wilson and Kent invented self-adhesive GIC by mixing aluminosilicate glass powder and polyacrylic acid. In 1977 when the sandwich technique was developed, DBS were not yet available. It was only until 1979 that Fusayama reported the use of phosphoric acid conditioning enamel and dentine resulted in better adhesion of resin-based adhesives. Later, it was ensued by discovery of dentine hybrid layer by Nakabayashi in 1982 [32]. Nakabayashi's research team also highlighted the use of both hydrophobic and hydrophilic monomers in adhesive systems. In 1984, the debut of methacryloyloxydecyl dihydrogen phosphate (MDP) monomer in dental adhesive was brought upon by Kurakay [32].

These decades-old adhesion concepts laid the foundation for modern DBS. Although there had been simplification in newer DBS, the contemporary systems mainly comprise of an acidic etchant, hydrophilic primer and hydrophobic bonding resin. Manufacturers had sought to reduce clinical steps by combining two or all three components into one. The current systems can be categorized to etch-and-rinse or total-etch, self-etch, and the recently-introduced universal adhesive.

(i) Total-etch bonding system

Total-etch bonding system involves a separate etching step, prior to placement of primer and bonding agent. The initial protocol introduced was using three individual agents and steps in etching, priming and bonding agent application respectively. The etching step involves a 35-37% phosphoric acid that demineralizes superficial tooth structure to produce microporosities and remove smear layer on dentine, followed by the primer which is a hydrophilic solution that improves wettability to the dentine surface. Lastly, the bonding agent containing hydrophobic resin forms resin tags within the microporosities. Despite the simplification with a two-step total-etch system combining the primer and bonding resin, the preceding three-step system is still considered the gold standard among all other adhesive systems [32].

Least microleakage was detected in CR restorations bonded using a total-etch system when compared to CR restorations lined with resin-modified GIC and flowable composite using sandwich technique [16]. As explained by the author, this finding was due to the use of resin-modified GIC with higher viscosity and probe placement instead of injection technique from a capsule. The drawbacks of total-etch systems are more clinical steps hence increased chairside time and more technique sensitive than self-etch [84]. Furthermore, there is increased risk of desiccation of dentine surface when clinicians air dries the bonding surfaces after application and rinsing of the acidic etchant.

(ii) Self-etch bonding system

Self-etch bonding system combines both etching and priming into a single step, utilizing an acidic primer, thus eliminating the separate etching procedure. This system may present in two-step or one-step formulations. This simplification obviously reduces the clinical procedures and hence its technique sensitivity and clinical time. However, simplification of clinical steps may not accompany clinical efficacy in reducing microleakage. Studies investigating the microleakage of dentine bonding interface concluded that total-etch bonding system had better results than self-etch bonding system [85,86]. This is due to the higher acidity of separate acidic etchant than the acidic primer used in self-etch systems, resulting in more microporosities in enamel by demineralization for large surface area and removes smear layer in dentine more thoroughly. Notwithstanding, Gupta et al. (2017) reported that self-etch and total-etch bonding systems showed comparable microleakage results on dentinal surfaces due to chemical interaction between functional monomers in the self-etch bonding system and the composition of dentine [17].

As a result of lower acidity of the acidic primer when compared to phosphoric acid, selective enamel etching technique is reported to improve the bonding of CR to enamel. On an eight-year clinical evaluation, restorations using two-step self-etch adhesive systems with selective enamel etching scored better in enamel and dentine marginal defect and discoloration than those without [87]. Meerbeek et al. (2004) reported more marginal defects at non-selectively etched enamel margins when compared to those selectively etched with 40% phosphoric acid, but emphasized that it was clinically negligible and does not require any intervention [88].

The disadvantages of self-etch bonding system is mainly due to its less effective acidic primer in demineralization of enamel and incomplete removal of smear layer and smear plugs on dentinal surfaces, which ultimately compromises the effectiveness of resin tag formation [89]. The acidic primer also results in degradation of the bonding system overtime and leads to water uptake and plasticization [84]. The simplified self-etch bonding system was found to be more hydrophilic and permeable even after polymerization, which allowed fluid penetration into the bonding interface, leading to degradation of resin-dentine interface by hydrolysis.

(iii) Universal bonding system

Universal adhesive or bonding system was introduced in 2011. In addition to the simplicity as observed in one-step self-etch system, the one-bottle bonding system also provides versatility in adhesion strategies, that is clinician can use it with either total-etch or self-etch technique. Furthermore, universal adhesives can be applied in direct and indirect restorations. The universal bonding system includes functional carboxylate or phosphate monomers that are capable to ionically bond with calcium present in the hydroxyapatite.

One of the commonly used monomers is MDP which is included in modern adhesives. MDP-Ca salts were found deposited at the hydroxyapatite-resin interface, forming a nanolayer structure that promotes strong adhesion to the tooth surface [84]. However, universal adhesive should be used in self-etch mode on dentine due to the depletion of calcium ions necessary for chemical bond with MDP by phosphoric acid [32].

Kermanshah and Khorsandian (2017) reported that the universal bonding system showed better microleakage results in dentine when compared to self-etch bonding system [90]. With regards to dentine bond strength, universal adhesive had shown superior results over self-etch bonding system. [91]. Cuevas-Suarez et al. (2019) reported that the dentine bond strength of universal adhesive was stabilized by the presence of 10-MDP monomer [92]. The bond strength of three universal bonding system all containing 10-MDP was reported to be ranging from 5.61 to 7.86MPa compared to 3.53MPa of self-etch bonding system [93]. The limitation of the current universal bonding system is somewhat similar to the self-etch bonding system, that is although the formulation had been simplified to one bottle to ease clinical steps, additional selective enamel etching is often recommended to improve bond strength to enamel. Similar to self-etch systems, universal bonding systems bear the brunt of having a semi-permeable property, leading to water uptake and subsequent hydrolytic degradation.

PLACEMENT METHODS AND THICKNESS OF THE MATERIALS

As polymerization shrinkage was found to be directly related to microleakage [94], strategies in reducing the shrinkage stress should also be put in clinical consideration when restoring tooth structure. For instance, incremental placement of CR reduces polymerization shrinkage by reducing the volume of material polymerized at a time, lowers C-factor and minimizes contact with the opposing cavity walls during polymerization. Incremental technique is further divided into horizontal and vertical layering, wedge-shape, centripetal build-up, split-increment horizontal layering and more [94].

A study comparing bulk, oblique, centripetal and split-incremental horizontal layering techniques (Figures 3-6) [95] in restoring Class II cavities using nanohybrid CR concluded that all incremental techniques resulted in better marginal seal than bulk technique, and among the incremental techniques used, split-increment horizontal layering technique showed the best outcome. The above techniques split each horizontal increment into two, which reduces the shrinkage stress acting on the cavity wall by lowering the cavity C-factor during light polymerization [95]. However, incremental placement is found to increase clinical time and technique sensitivity due to more placement and polymerization steps involved [11].

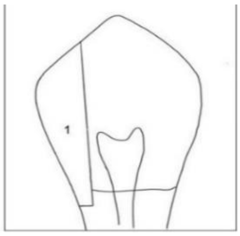

Figure 3 Bulk technique (Proximal view)

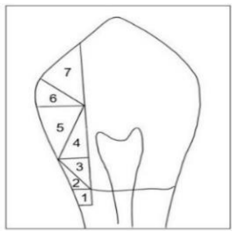

Figure 4 Oblique technique (Proximal view)

Bulk-fill composite for posterior restorations was introduced by manufacturers recently, and proclaimed to have superior depth of cure up to 5mm, when compared to conventional composite, eliminating the necessity of incremental placement [98]. Polymerization modulators had been added to the formulation to reduce polymerization shrinkage stress, eg. incorporation of modified urethane dimethacrylate with photoactive groups in SDR™ Posterior Bulk Fill Flowable Base [14,15]. Bulk-fill composite is also available in low viscosity base similar to flowable composites, which was said to improve marginal adaptability, whereas SonicFill (Kerr, Orange, CA, USA) is ultrasonically dispensed to reduce its viscosity by 84% for the same reason [96]. Swapna et al. (2015) demonstrated that SonicFill showed better microleakage results than other bulk fill composites [97]. Flowable bulk-fill composite restorations did not show difference in microleakage when compared to conventional composite restorations using incremental placement [98,99].

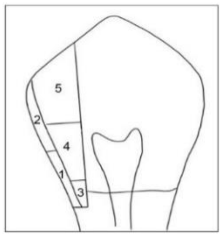

Figure 5 Centripetal technique (Mesio-distal section)

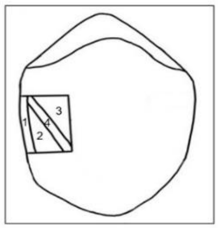

Figure 6 Split-incremental horizontal technique (Occlusal view)

Studies investigating the effect of thickness of lining in sandwich technique and composite increments found that thinner layer materials led to reduced microleakage for both resin-modified GICs and CRs [100-102]. Application of thin layers of lining material resulted in lower volume of material for polymerization, hence reducing the polymerization stress exerted on the adhesive interface. Although both Moosavi et al. (2018) and Natasha and Suprastiwi (2017) concluded that effect of thickness of lining on microleakage was insignificant for both resin-modified GIC and flowable composite respectively, the authors reported that the thicker material showed poorer sealing ability than the other [103-104]. Moosavi et al. (2018) explained that the thicker liner using resin-modified GICs produced more micro-gaps and porosities, leading to increased microleakage [103]. Further investigations need to be done on the effect of thickness of increments and light-curing methods of bulk fill CRs on microleakage and marginal adaptation.

Snowplow technique (Figure 7) is another variation of sandwich CR placement method where flowable composite of thickness around 0.25mm to 0.5mm [105-106] is placed as an intermediate layer on the cavity floor up to the cavosurface margin, followed by placement of packable CR.

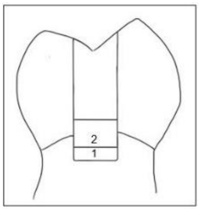

Figure 7 Snowplow technique (Proximal view). Increments 1 (flowable composite) and 2 (packable composite) are light-cured simultaneously [109]

Both materials are then cured simultaneously. This technique was proposed to be better than light-curing each layer separately by reducing the thickness of flowable CRs which exhibits more shrinkage due to its lower filler content (37%-53% by volume). Snowplow technique was found to be more effective in reducing microleakage than open-sandwich technique using flowable and packable Beautifil II giomer [107]. In contrast, Nematollahi et al. (2017) reported that snowplow technique resulted in more microleakage than closed-sandwich technique with resin-modified GIC and flowable composite as liner [108]. The author explained that the displacement of uncured flowable composite into the overlying bulk of composite led to increased resin contents of the bulk of restoration, thus increasing polymerization shrinkage and microleakage.

SUMMARY

This paper highlighted the factors to consider in choosing the appropriate technique and materials in sandwich restoration. As of now, there is neither a standardized procedure nor the best restorative material for the technique. Sandwich technique had been proven by some but not all to be clinically successful in reducing microleakage. In addition, the *in vitro* settings of many studies may not entirely reproduce the clinical environment. For instance, most of the laboratory studies utilize samples of non-carious extracted teeth, while in reality restorations are placed on tooth substrate that had been altered due to the disease process. On the other hand, *in vitro* studies allow the parameters to be scrutinized explicitly, while limited access is allowed in clinical settings and can often be subjective. The treatment prescribed for the patient therefore lies in the discretion of the clinician tailoring to the needs of the patient while supported by a high level of evidence, knowledge and skills.

None of the restorative materials and techniques discussed are capable of eliminating microleakage in sandwich restorations. High caries risk patients benefit more from sandwich restorations using fluoride-releasing GICs than solely CR restorations. Closed-sandwich technique or lining with flowable composite may be preferred for patients with a highly acidic diet. Resin-modified GICs provide marginal seal better than flowable composites as a liner, and even better with ultrasonic agitation. More investigations need to be conducted on tricalcium silicate-based biodentine which was proven to have superior microleakage over resin-modified GICs in several existing studies. Etch-and-rinse remains the gold standard among bonding systems for enamel and dentine margins for composite restorations, but self-etch with simpler steps can be used during time constraints and in situations where it is difficult to attain moisture control. Thin lining material and incremental placement of conventional CR both reduce polymerization shrinkage stress and microleakage.

Sandwich technique had been proven valuable in clinical applications in lowering microleakage and improving adhesion of restorations. Deep margin elevation for instance helps clinicians in placing margins of indirect restorations at a position more favourable for subsequent bonding procedures. While the use of sandwich technique may yet be superseded in the future by the introduction of an ideal restorative material superior in all aspects, clinicians should have sandwich technique well-equipped within their knowledge and skills.

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DECLARATION OF INTEREST

The authors of this article certify that they have no proprietary, financial, or other personal interest of any nature or kind in any product, service, and/or company that is presented in this article.

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