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Biomimetic approach in direct restoration

A Project Submitted to
The College of Dentistry, University of Baghdad, Department of Conservative in Partial Fulfillment for the Bachelor of Dental Surgery

By

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Certification of supervisor

I certify that this project entitled "Biomimetic approach in direct

restoration" Was prepared by the fifth-year student yousif alaa kareem

under my supervision At the College of Dentistry/University of Baghdad

in partial fulfilment of the graduation requirements for the Bachelor Degree in Dentistry.

Supervisor's name Mohamed T. Mohamed

Date 2023/4/26

Genesis 39:2

(And the Lord was with Joseph, and he was a prosperous man)

Dedication

I dedicate my project work to my family and many friends. A special feeling of gratitude to my loving parents, mom and dad whose words of encouragement and push for tenacity ring in my ears. My sisters noora have never left my side and are very special.

I also dedicate this dissertation to my many friends and church family who have supported me throughout the process. I will always appreciate all they have done

I dedicate this work and give special thanks to my best friend noor for being there for me throughout the entire graduation project. you have been my best cheerleaders.

Acknowledgment

First, I want to thank god for giving me the strength and ability to finish this work.

I would like to express my deep and sincere gratitude to my research supervisor, **Dr. Mohamed T. Mohamed** for providing invaluable guidance throughout this research.

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TEGDMA	triethylene glycol dimethacrylate
CAD	Computer-aided design
CAM	Computer-aided manufacturing
GIC	Glass ionomer cement
NIR	Near infrared
CRE	Caries removal end
PSZ	peripheral seal zone
ICD	Inner carious dentin
OCD	Outer carious dentin
RMGIC	Resin-modified glass ionomer cement
IDS	Immediate dentin sealing
DME	Deep margin elevation

Introduction

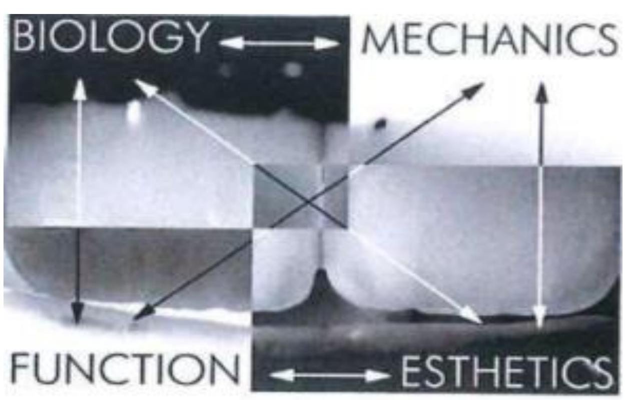
The phrase "biomimetic" was coined by biophysicist/biomedical engineer Otto Schmitt in the 1950s **(Harkness and Bhushan , 2009)** and refers to the study of multi-disciplinary mechanisms and biologically produced materials to design novel products to mimic nature **(Harkness and Kottoor , 2004).** Biomimetic is derived from Latin word "bio" meaning life, and "mimetic" is related to the imitation or mimicking biochemical process with inspiration from nature. Several biomimetic synonyms are used in the literature, for example, bionics, bioinspiration, biogenesis, biomimicry, biomimicking, and biomimetism.

Novel approaches have produced hierarchal structures by accumulating inorganic ions in a coordinated manner along with organic protein molecules analogous to biomineralization ***(Sharma et al., 2020).*** Therefore, the understanding of emerging biomimetics approaches has involved the conception of multiple ideas from biology, chemistry, materials science, and bioengineering. In addition, numerous innovations of materials at nanoscale have accentuated a major push in the fabrication of biomimetic materials using nanotechnology **(Bhushan, 2009).** It is encouraging to witness the emergence of biomimetic courses in educational sectors of robotics engineering, interdisciplinary teaching, biomaterials, and industrial design for undergraduate as well as postgraduate students ***(Cleymand et al., 2015).***

Biomimetic approaches were extensively explored across various disciplines including dentistry. Contemporary dentistry involves the minimal invasive dental management of defective or diseased tissue with bioinspired materials to achieve remineralization. The instrumental role of fluoride to control incidence and in prevention of dental caries has been widely reported in the literature for over a quarter of a century ***(Zafar et al., 2015).*** More recently, a variety of bioactive formulations such as micro- and nano-hydroxyapatite (HA), tricalcium phosphate, mineral trioxide, etc. have been advocated due to their excellent biocompatibility, biomimicry, bioactivity, and remineralization potentials ***(Donnermeyer et al., 2019).*** In clinical dentistry, biomimetics refers to the repair of affected dentition mimicking the characteristics of a natural tooth in terms of appearance, biomechanical, and functional competences ***(Bazos and Magne, 2011).*** For example, adhesive restorative materials have demonstrated tooth morphology and esthetics mimicking natural teeth ***(Tirlet et al., 2014).***

1.1Biology, Mechanics, Function, and Esthetics

It is necessary Understanding the Intact Tooth. Physiologic performance of intact teeth is the result of an intimate and balanced relationship between biologic, mechanical, and functional parameters **(Fig. 1).** Esthetics should not be the driving force of treatment but only the result of this relationship. Biology is undoubtedly the dominating element in this equation, and all efforts should go to the preservation of tooth vitality. Endodontically treated teeth, no matter how they are restored, will always present a compromised prognosis (ie. a higher risk of fracture) compared to vital teeth **(Tang and Smales , 2010).** The most educational situations supporting the complex interactions between biology, function/mechanics, and esthetics are found in cases of traumatic injuries like that illustrated in **(Fig. 1)** The price of an injury can be paid in the form of either a mechanical failure (hard tissue involvement) or a biologic failure (pulpal involvement). In both cases, the influence on the esthetic and functional parameters is observable **(Magne P. and Magne M , 1998).** A partial crown fracture might be preferable if one considers that the energy dissipated during fracture can prevent further biologic damage or root injury In consideration of the Physiologic performance of intact teeth, it is of primary importance to ask ourselves: Is it better to pursue the development of strong and stiff restorations or to find treatment modalities that reproduce the biomechanical behavior of the intact tooth? Stronger and stiffer might not always be better.



(FIG. 1) Physiologic performance of teeth, **(Magne and Belser, 2022)**

1.2 Natural Tooth Aging and Enamel Thinning

enamel and dentin exhibit different physical properties. Enamel can resist occlusal wear but is fragile and cracks easily. Dentin, on the other hand, is flexible and compliant but is not wear resistant and does not age favorably when directly exposed to the oral environment. Because of their respective shortcomings, neither enamel nor dentin independently would be considered an effective restorative material. However, they form a “composite” structure, which provides a tooth with unique characteristics ***(Kraus et al., 1969).*** The hardness of enamel protects the soft underlying dentin, while the crack-arresting effect of dentin and the thick collagen fibers at the DEJ **(Lin and Douglas , 1994)** compensate for the inherently brittle nature of enamel. This structural and physical interrelationship between an extremely hard tissue and a more pliable tissue provides the natural tooth with its original beauty but also its ability to withstand mastication, thermal loads, and wear during a lifetime.

1.2.1Anterior tooth aging/wear

The original morphology and thickness of the enamel shell **(fig. 2)** seem to have been designed to anticipate wear and function requirement **(Luke and Lucas , 1983).** Maximum wear areas are specifically those presenting higher bulks of enamel, ie, the incisal edge in the case of anterior teeth. This "preventive” architecture still allows physiologic wear to create dentin exposure in the incisal area **(fig. 2 a-c).** By the same token, teeth in the posterior region, where masticatory forces are stronger, have thicker enamel than do anterior teeth **(Macho and Berner , 1993).** the incisal edge area is the most affected by age-related alterations. **Age-related changes of the dentition are the main challenge of modern dentistry, which is faced with a population that is getting older and keeping more of its natural teeth.** Smiles can show physical and esthetic signs of aging. A sufficient and uniform thickness of facial enamel is essential to the balance of functional stresses in the anterior dentition ***(Douglas et al., 1999).***

(FIG. 2) The seasons of tooth life, (a) Anterior teeth initially present typical mamelons and surface texture. These elements are progressively eliminated by wear, (a-c) Ongoing enamel cracking and dentin exposure are linked to obvious color changes **(magne, 2002)**

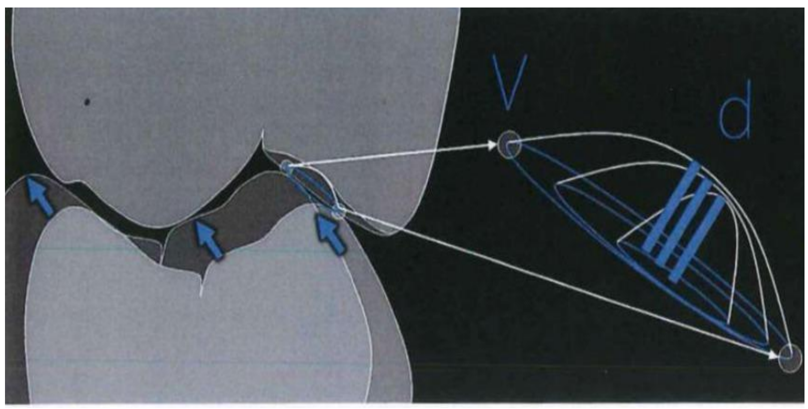
1.2.2Posterior tooth aging/wear

The natural history of posterior teeth is more complex than that of the anterior dentition. The mouth (and the occlusion) is the portal of entry to the alimentary canal and as such is a main component of the digestive system. The maxilla and the mandible meet only at the articular surfaces of the teeth, hence the significance of occlusion. In the digestive process, cusps are responsible for breaking food **(fig. 3) (Luke and Lucas , 1983).** Excursive movements generate a combined type of occlusal wear. Even though most researchers measure a qualitative depth only, there are two expressions of occlusal wear **(fig. 4):**

Volumetric wear (V) is a material property unrelated to the occlusion because a volume can assume any shape (area X depth)

Depth of wear (d) is an occlusal property because the wear is defined in one direction (usually related to facial height).

FIG. 3 Natural mandibular molar with intact cuspal features **(Magne and Belser, 2022)**



(Fig. 4) Loss of contour by articular wear can be characterized by depth wear (d) and volumetric wear (V). Volume loss is a material property and does not necessarily correlate with depth wear due to the increased contact area **(Magne and Belser, 2022)**

1.3 COPYING VS SIMULATING NATURE

It is not always possible to biomimetically emulate nature. Significant alterations of the teeth and periodontium due to disease and aging can result in irreversible losses of structure and integrity Those alterations can have complex interactions, affecting the balance between biology, mechanics, and esthetics. For instance, interdental bone loss, which starts as a biologic problem, will generate esthetic and morphologic alterations. Hence,restorative dentate cases can be classified in at least two degrees of emulation:

1-When the periodontium is intact (original scalloped architecture) and the teeth are vital and in a reasonable position, it is possible to copy nature's morphology faithfully. In these cases, the biomimetic principle can be applied in full.

2-In situations with a history of periodontal disease, in the presence of narrow roots or diastemas, or in the presence of an implant. the periodontium has lost its positive architecture and copying nature is no longer possible. In these cases, the irreversible biologic or structural loss must be compensated for by special effects included in the restorations. Those effects are not necessarily the result of the biomimetic principle. They can be in form of optical illusions, morphologic alterations ***(Belser et al., 1999)***

The two restorative situations in dentate patients are therefore:

1. **Copy-only situation**: vital teeth and periodontium intact; the biomimetic principle can be applied as a whole (no special effects needed, such as miniwings).
2. **Simulation situation**: nonvital teeth, periodontal architecture altered; the biomimetic principle is not entirely applicable and special effects must be used

1.4 MICROABRASION AND MEGABRASION

Microabrasion

For lesions caused by moderate fluorosis and involving superficial enamel, the original microabrasion technique **(Croll, 1989)** would be indicated. It consists of rubbing enamel with a mixture of abrasive particles and hydrochloric acid (HCI).

As a result, the surface texture of enamel is modified. Smooth and thinned microabraded enamel absorbs more light (increased refraction index), and, as a consequence, tooth brightness is decreased and chroma is increased. These negative side effects are easily compensated by combining microabrasion with bleaching

(Ardu et al., 2006) If a tooth exhibits mild fluorosis, however, microabrasion is usually not needed because bleaching alone is able to provide good results by decreasing the contrast between the white spots and the surrounding tissues **(table 1)**

Megabrasion

Microabrasion is ineffective and contraindicated for deep enamel defects because the opaque area would become more visible after treatment, revealing the internal aspect of the lesion. Instead, the megabrasion technique **(magne, 1997)** also called macroabrasion, ***(heymann et al., 1995)*** is a radical but predictable approach for the elimination of deep developmental white enamel lesions. The removal of enamel through megabrasion can be justified by the nature of the lesion, as it involves a disturbance in the maturation stage of the tooth mineralization ***(andreasen et al., 1971).***

The defective enamel is not an ideal substrate for bonding. Because the lesion usually does not extend into dentin, only a limited amount of enamel must be replaced with direct composite resins. Above all. the underlying intact dentin provides the natural optical effects of the tooth (color, dentin lobes, fluorescence, etc). The simple freehand application of neutral, translucent, and slightly fluorescent composite allows restoration of the enamel surface morphology without overcontouring. leading to the most natural appearance of the tooth There is no need to remove the deepest part of the lesion and risk dentin exposure. Enamel etching, resin infiltration with the adhesive, and subsequent restoration with a neutral and translucent composite will usually produce enough attenuation effect through partial recovery of the enamel refraction index. If a more conservative approach is pursued, partial megabrasion (removing only the ceiling of the lesion) can be associated with the resin infiltration technique. **(table 1).**

Clinical situation	Microabrasion[29]	Bleaching[6]	Megabrasion[19,31]	Resin infiltration[34]
Demineralization, early caries lesions	Yes*	Yes††	No	Yes
Mild fluorosis, white and brown	Yes*	Yes	No	Yes*
Mild fluorosis, white	Yes*	Yes	No	Yes*
Developmental defects, white and brown spots, and surface defects	No	Yes‡	Yes	Yes‡
Developmental defects, white and brown spots	No	Yes‡	Yes	Yes‡
Developmental defects, white spots	No	Yes**	Yes	Yes‡‡

Table 1: Ultraconservative approaches to white enamel defects and their indications **(Heymann, 1995)**

1.5Remineralization and Resin Infiltration

Other more sophisticated strategies to treat white spot lesions are to remineralize them ***(ardu et al.,2007)*** or infiltrate them with a low-viscosity monomer resin ***(paris et al., 2009).*** Remineralization This approach should be the first line of action when a noninvasive strategy is chosen. However, even for lesions found around orthodontic brackets, it has been suggested to eliminate the intact superficial hypermineralized layer of enamel first by microabrasion followed by immediate chairside and daily application of amorphous calcium phosphate (Ml Paste).

Resin infiltration

This technique originates from the idea of infiltrating non cavitated enamel caries with resin adhesives ***(gray et al., 2002)*** Infiltration with mixtures containing smaller and less viscous resin monomers such as triethylene glycol dimethacrylate (TEGDMA) proved to better penetrate the lesions ***(keltsch et al., 2007)*** TEGDMA also proved to be efficient in restoring the refractive index of enamel in white spot lesions.

A commercially available system (Icon Caries Infiltrant Smooth Surface, DMG) is

used and requires three steps:

1. Etching the enamel with 15% HCI (Icon-Etch) for 2 minutes, followed by rinsing for 30 seconds and air drying

2. Dehydrating the porous enamel with ethanol (Icon-Dry) for 30 seconds, followed by air drying

3. Infiltrating with TEGDMA (Icon-lnfiltrant) for 3 minutes, followed by light polymerization

There are two distinct resin infiltration approaches based on the clinical situation *(attal et al., 2014):*

1. Superficial lesions, developmental or originating from a demineralization process, typically such as early caries lesions and white spots around orthodontic brackets *(Staudt et al., 2004)*: The infiltrant resin can be applied directly to the existing surface of the tooth and yield excellent results without adjunct treatment ***(kim et al., 2011).***

2. Deep developmental defects: The process will usually require adjunct procedures because the ceiling of the lesion needs to be eliminated first by megabrasion or airborne-particle abrasion to facilitate the application and penetration of the infiltrate resin into the core of the lesion ***(tirlet et al., 2013)*** Similar to the megabrasion technique, enamel needs to be restored after the infiltration process **(Fig. 5).**

FIG. 5 NGVB, airborne-particle abrasion, resin infiltration, and restoration

(Clinical case and photography courtesy of Dr Gil Tirlet. Paris)

1.6ADHESIVE RESTORATIVE MATERIALS

Enamel adhesives:

Successful execution of enamel bonding provides the major retentive feature of the restoration even in the absence of another type of mechanical retention or stabilization. The effectiveness of this procedure requires the use of 35% to 37% phosphoric acid for 20 to 30 seconds, followed by thorough rinsing and drying before the application of a low-viscosity adhesive resin (to form resin tags) and subsequent polymerization **(Buonocore, 1955):**

Enamel is not isotropic, and hence the walls of the preparation should be contoured to give transverse sections of enamel prisms, which will provide significantly higher bond strength than longitudinal sections of enamel prisms ***(Munechik et al., 1984; Shimada et al., 2003)***

Dentin adhesives:

The dentin substrate is much more complex than enamel, so numerous considerations require attention during dentin bonding.

The ultimate goal of dentin bonding is the emulation of the ideal biologic "bond" between enamel and dentin at the dentinoenamel junction (DEJ). The strength of this natural assembly was evaluated at approximately 51.5 MPa in a microtensile bond test ***(Urabe et al., 2000):***

It can be explained in part by the structure of the DEJ and its rough and multi scalloped nature

The golden standard 3+1 STEPS

The demineralization resulting from the acid treatment (STEP1, etch-and-rinse) exposes collagen fibers on the dentin surface that can then be impregnated with a "cocktail" of resin monomers with affinity for collagen, calcium, and water. This is the primer (STEP 2), for which an ethanol/water based solvent is used as a carrier for the monomer cocktail. Gentle air-drying is necessary to promote evaporation of the solvent. This results in a resin-infiltrated collagen network, also known as the interdiffusion zone ***(Nakabayash et al., 1991; Nakamura et al., 1991)***

The next step is the application of a more hydrophobic resin coating or adhesive resin (STEP 3) and its subsequent light polymerization (STEP 4). Along with the adherence and diffusion into the hybrid layer, the adhesive resin forms resin tags into the open dentinal tubules, resulting in a strong micromechanical interlocking. This fourth step (light polymerization) is often not mentioned but proves critical to the successful completion of the bond.

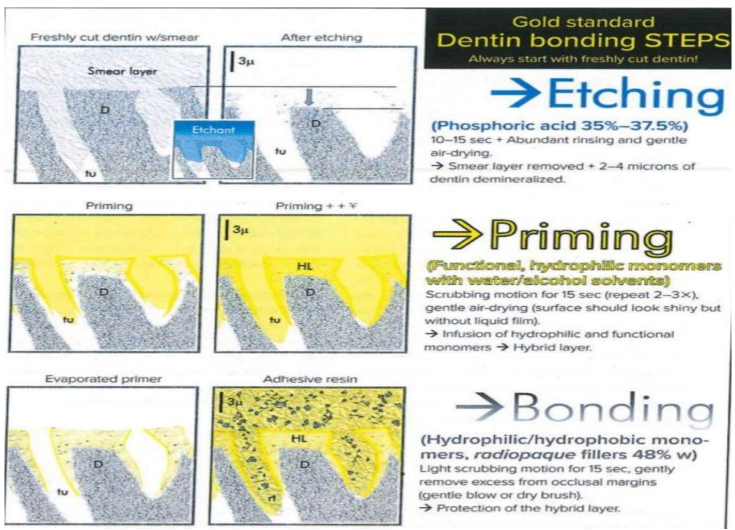


FIG. 6 Schematic transmission electron microscopic views of dentin bonding steps.

(Image courtesy of Prof Jorge Perdigao, University of Minnesota.)

Composite resin materials

The "bulk-fill" era

Bulk-fill versions of existing materials have been developed in order to simplify and accelerate the clinical procedures. Bulk-fills can be placed in a large or single increment. They are characterized by their increased depth of polymerization primarily due to their larger fillers and increased translucency ***(Munksgaard et al., 1991):***

Larger fillers produce a lower total filler-matrix inlet face, improving blue light transmittance through reduced light scattering. Laboratory results are encouraging as bulk-fills seem to be able to reduce the cusp deformation, post-gel shrinkage, and shrinkage stress and increase the fracture resistance in posterior restorations ***(Andreasen et al., 1988).***

Flowable versions of the bulk-fills have lower mechanical properties (less filler load) and usually require coverage with a regular composite to ensure the functional stability.

Fiber-reinforced composite (FRC) resins

Ever X Posterior is a unique bulk-fill dentin replacement hybrid composite resin containing E-glass fibers that are 1 to 2 mm in length. The glass fibers, however, were chopped to a very short size (60-120 microns long), and the mechanical properties were only slightly better than those of most conventional composites with traditional fillers ***(Leinfeide et al., 1999; Choi et al., 2000)***

Fiber fillers require a critical fiber length (in the millimeter scale) and aspect ratio of at least 70 (length/diameter) in order to significantly influence the overall mechanical properties. This was the goal of ever X, which is recommended for high stress-bearing areas ***(Reis et al., 2001; Shiran et al., 2012)***

Ever X Posterior proved to be worthy of consideration when restoring large defects ***(Loguercio et al., 2008)*** that would normally require a semi-direct or indirect approach but for which a direct technique is the only option due to financial limitations. As such, it is able to match the performance of CAD/CAM semi-direct inlays ***(Soare et al., 2018)*** ever X Posterior could be regarded as a possible substitute of the GIC in the sandwich approach, provided that it is covered with a sufficiently bright material to compensate for its excessive translucency.

1.7CAVITY PREPARATION AND DESIGN

Cavity preparation and design is an important step in the clinical protocol, as it determines the quality of the direct posterior composite restoration to a great extent. Nowadays, quality is a key concept in restorative dentistry. In this respect, both “hidden” and “perceived” quality should be taken into account. Whereas the final esthetic result is “perceived quality”, cavity preparation and design largely determine the “hidden quality” of the restoration. The effect of a suboptimal cavity design will become visible after some months or years of clinical functioning. Detailed guidelines of cavity preparations for direct posterior composite restorations are scarce in the literature. Some review articles merely emphasize the minimally invasive aspect of cavity preparation: only caries needs to be removed with all remaining tooth structure kept for bonding ***(Sabbagh et al., 2014).*** proper protocol of the cavity preparation and design consists of 4 steps **(Fig. 7).**

2 Create Access to the Caries Lesion

After rubber-dam isolation, access to the caries lesion is obtained with a diamond bur **(Figs 8d and 8e).** If caries is present underneath an existing restoration, the restoration is removed with a diamond bur (composite) or a multiblade tungsten carbide bur (amalgam). Next, the cavity walls and the floor of the cavity (removal of existing liner) are cleaned with a round multiblade tungsten carbide bur at a low speed (7000 rpm) to expose the carious lesion.

1. Removal of Carious Dentin

presents in two forms: infected and affected dentin. Caries-infected dentin consists of a superficial necrotic zone of severely demineralized substrate ***(Banerjee et al., 2013)*** with degenerated collagen fibrils that have lost their cross-linking. It may also be considered a bacterial biomass ***(Kellow et al., 2010).***

The consistency of this dentin is soft or leathery. Conversely, caries-affected dentin has a certain hardness and is considered to be a variation of reactionary dentin, formed in reaction to bland stimuli like caries; it presents small alterations in cross-linking of its collagen fibrils ***(Neves et al., 2011).***

Additionally, it contrasts with sound dentin by mineralized precipitates within the tubules ***(Mobarak et al.,2012).*** Some studies have shown that caries-affected dentin may be remineralize ***(Yoshihara et al., 2020)*** .Today's adhesives bond effectively to sound dentin through hybridization. Nevertheless, this bonding mechanism remains vulnerable in the long term. Incomplete resin envelopment exposes collagen to oral fluid attack and enzymatic degradation processes that may eventually lead to caries recurrence ***(Van Meerbeek et al.,2020).***

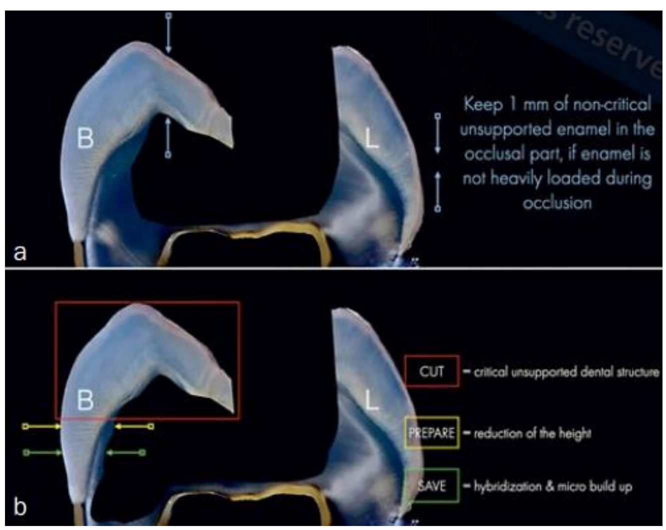
Bonding to caries-affected dentin is less predictable and durable, not only because of wider zones of unprotected collagen but also because more cracks and pores are present ***(Hsu et al.,2008)*** The bond strength to caries-infected dentin is significantly lower than that to caries affected dentin ***(Costa et al., 2017).***

A systematic review evaluating bonding effectiveness to caries-affected dentin showed that a clean, sound dental substrate is an important requisite for adhesion and adhesive dentistry ***(Isolan et al., 2017).***

Indeed, if the operator aims to obtain the best possible bond to dentin, all affected dentin should be removed during cavity preparation, resulting in a good quality hard dentin surface (Figs 5m). In a first step, a sharp hand excavator is used to check the dentin consistency and remove the soft carious dentin **(Figs 8h to 8j).** A multiblade tungsten carbide bur is not yet indicated, as the blades of the bur become compacted with the soft caries tissue, strongly decreasing the bur's cutting efficiency. In a second step, the infected/affected dentin is further removed with a multiblade tungsten carbide bur until the dentin surface is hard and clean **(Figs 8l and 8m).** The bur is used dry and at low speed (7000 rpm). The caries is removed following a centripetal approach, from the periphery to the critical points in the center, this in order to avoid possible pulp exposure. Evaluation and Removal of Undermined Enamel After removal of the existing restoration and decayed dental tissue, a second detailed biomechanical analysis is conducted and the final decision to potentially cover the cusps is made.

The following guidelines are proposed (fig. 7):

- If the remaining cusp has a thickness of 2 mm or more and enamel is supported by dentin, the cusp is kept.
- Similarly, with a cusp thickness of around 2 mm and slightly undermined enamel (on average 1 mm), the cusp can be kept if it is not heavily loaded during occlusion and articulation.
- Strongly undermined cusps (enamel not supported by dentin) should be reduced to at least 1.5 mm and capped. The more the height of the cusp is reduced, the less dentinal support is needed.



(Fig. 7) Bucco-lingual section of a molar after cavity preparation. (a) If the remaining cusp has a thickness of 2 mm or more, and the enamel is supported by dentin (lingual side: L), the cusp is kept. (b) A strongly undermined cusp (enamel not supported by dentin) (buccal side: B) should be reduced at least 1.5 mm and capped. **(Adhes, 2020)**

Other indications for cusp reduction are:

horizontal crack underneath one or more cusps, too wide (isthmus width > 1/3- 1/2) and deep cavity, MOD cavity with a longitudinal crack, MOD cavity in an endodontically treated tooth, and an endodontically treated tooth with a crack in the pulp chamber.

3. Finishing the Cavity

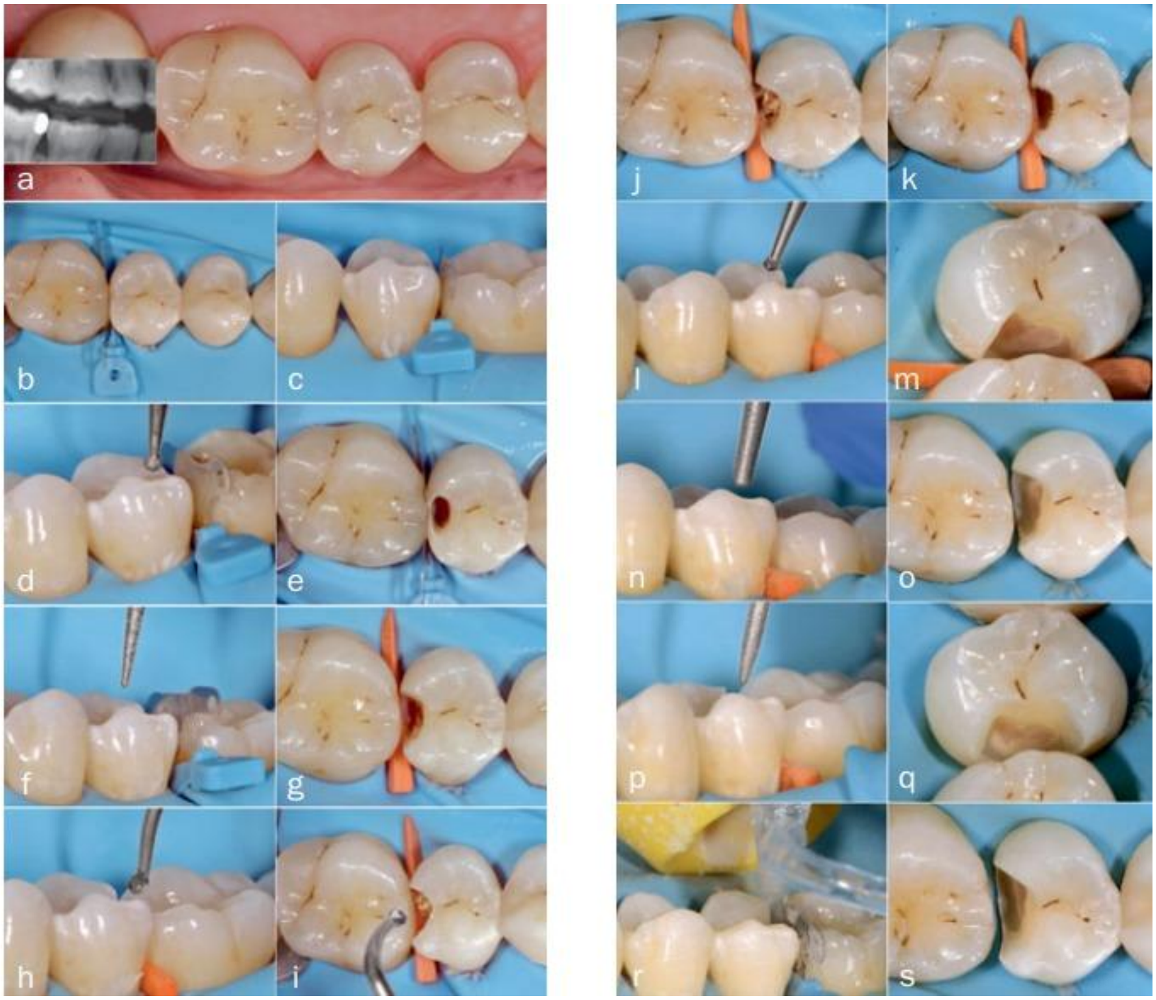
Finishing of the cavity is important, as this results in increased wettability and adaptation of the adhesive layer, improved adaptation of the composite resin, better marginal sealing of the restoration, and better adaptation of the matrix band, all to the benefit of increased longevity of restoration ***(Hayashi et al., 2018)***

The finishing protocol includes 3 steps.

1. Sharp internal angles of the cavity are rounded with a multiblade tungsten carbide bur. Rounded internal angles should be the norm, given the cusp-weakening effect of angular line- and point angles. In addition, composites tend to adapt much better in cavities with rounded rather than sharply defined internal architecture ***(Lynch et al., 2014)***.

2. To be sure that the prepared cavity is clean with a thin, light smear layer, tooth preparation is finalized by airborne-particle abrasion with Al2O3 powder (30 or 50 µm). Air abrasion is reported to increase the surface roughness and surface area available for adhesion and improve resin adaptation ***(Freeman et al., 2012)***

3. The final step in cavity preparation is finishing the enamel margins. An enamel bevel is not indicated, as this facilitates cracking the enamel at the margins ***(Soliman et al., 2016)*** In addition, the composite layer will be too thin in the region of the enamel bevel. To finish the enamel margins, the sharp, unsupported enamel prisms of the occlusal and proximal (buccal and lingual) cavity margins are removed with a flame-shaped diamond bur (40 µm grit), to be used dry at medium speed. The finished margins must not be located in demineralized enamel in order to prevent early caries recurrence.

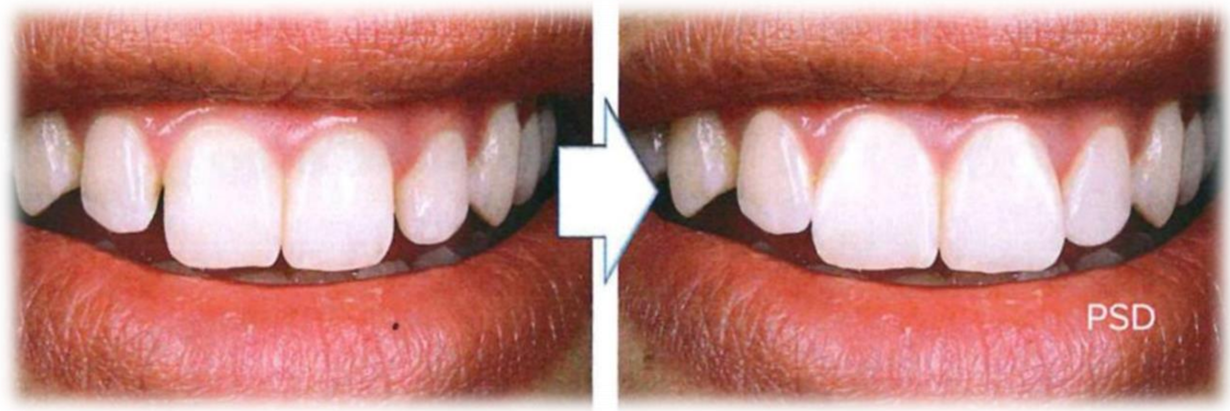


(Fig. 8) removal caries end (a) Initial situation: a deep caries lesion was present at the distal side of the upper second. premolar. (d) Access was made to the proximal caries lesion with a small round diamond bur. (e) When entering the dentin, the caries lesion is clearly visible at the enamel-dentin junction. (h) A sharp hand excavator was used to check the dentin consistency and remove the soft carious dentin. (i) Soft dentin can easily be scooped up with a sharp hand excavator with little force being required. (j) Chips of soft and leathery dentin in the cavity after using the excavator. (l) The firm carious dentin was removed with a multiblade tungsten carbide bur (Komet H1-SEM, Gebr. Brasseler; Lemgo, Germany) until the dentin surface was hard and clean. The bur is used dry and with low speed (7000 rpm). (m) The caries will be removed following a centripetal approach, from the periphery to the critical points in the center, this in order to prevent possible pulp exposure. **(Dent, 2020)**

1.8 Direct Restorations in Anterior Teeth

According to the biomimetic principle, localized missing tooth substance is not an indication for bonded ceramic restorations. Direct composite resins can be used instead, rather than partial ceramic restorations, also known as ceramic fragments or partial veneers. The latter have gained popularity through the so-called “no-prep” approach **(Kabbach et al., 2000).**

A classic example is the situation of diastema closure. Small direct composite resin additions are very simple to carry out, cost-effective, and provide outstanding results **(Fig. 9).**



(fig. 9) Small direct composite resin additions for diastemata closure **(Gresnig, 2017)**

There are two main approaches to apply the restorative material: the classic freehand method or the more contemporary guided method

1.8.1Freehand placement method

In the early 1990s, direct composites had limitations due to the fact that they were applied with the freehand method; (ie, without any help or guide for the shape of the layers). Today the freehand method is appropriate for Class 3 and Class 5 restorations. Diastema closures and Class 4 restorations can also be performed freehand, especially when intact neighboring or contralateral teeth can be used as a guide. The most popular esthetic composite resins for freehand application are multi hue systems: They are available in almost all hues (A, B, C, D) of the original VITA classical shade guide. Contemporary multihue systems include an even broader choice of shades (eg, Filtek Supreme Ultra by 3M with four opacities and 36 shades), making the selection process even more sophisticated.

Three-increment method

The freehand method can be easily applied in a simplified three-increment technique (dentin-enamel-incisal) **(Negm, 1974)** An anatomical dentin like core (Herculite XRV Dentin; or Enamel HRi dentin) is covered with translucent enamel like composite that extends onto the beveled enamel. Incisally, the dentin core is covered with transparent/translucent enamels (eg, Herculite XRV Incisal LT) or more opalescent incisal materials (eg, Enamel HRi). The incisal shape of the dentin core must be adapted according to the age of the tooth: sharp-edged for young unworn teeth, flat and thicker for worn teeth **(fig. 10),** or a combination thereof. As is the case for fragment rebonding, the esthetic and mechanical outcome of anterior direct composite resins can be greatly enhanced by augmenting the bulk of the restoration to simulate the transition line angles at the facial and proximal aspects of the tooth and, the so-called additive approach

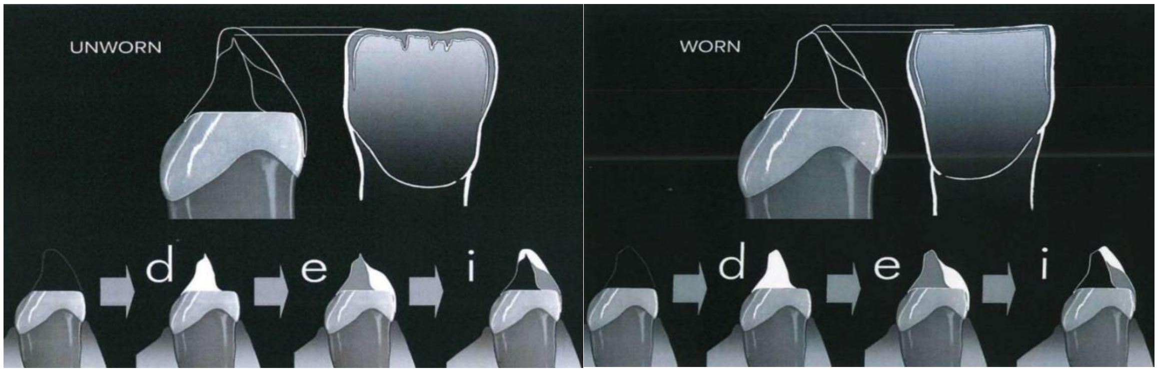


Fig. 10) Simplified three-increment stratification technique. Unworn (b) and worn (c) teeth differ by the incisal shape of the dentin core **(Magne, 1997)**

Sandwich" layering

Some particularly difficult cases can be addressed in a two-stage approach using the so-called sandwich layering technique **(Magne and Holz, 1996)**.

This technique is particularly useful to reproduce complex subsurface effects. The tooth is first restored with the freehand method using only dentin and enamel increments. The focus of this first session is to match appropriate color and shape. Following rehydration of the tooth and confirmation of shade and anatomy, a slight cutback of the restoration is carried out to place effect colors and cover them with translucent material. Because the colorants are embedded into the restoration, there will be no effect of the surface wear on the stability of the result

1.8.2Guided placement technique

It is difficult to simultaneously master marginal adaptation, form, and shade on several adjacent Class 4 restorations when using the freehand method, especially when planning alterations of the incisal edge length. these methods is to mimic more accurately the natural morphology of enamel and dentin compared to the freehand approach. They are inspired from the realm of dental porcelain. The procedure is facilitated by the use of a silicon matrix. This stent can be obtained from previous casts of the patient, an existing restoration with appropriate shape and length, or from a wax-up/ mock-up of the fractured/worn teeth. turning point in the late 1990s and early 2000s was the use of more natural or "tooth like" layering techniques. The common goal The silicon matrix allows the precise placement and polymerization of an enamel like shell of restorative material on the palatal aspect, which in turn will give support and guidance while developing the natural shape of dentin and facial-incisal enamel shell

Surface texture

the development of surface texture must always follow two consecutive steps in order to mimic the natural tooth architecture:

(1) the vertical texture formed by the three labial developmental lobes, and

(2) the horizontal texture between and across the lobes. The specific architecture of each tooth (central incisor vs lateral incisor vs canine) must be emulated accordingly

A regular diamond bur at low speed is recommended because the diamond grain will simulate the growth lines during the second step (gentle horizontal strikes). The polishing is initiated with silicon points (eg, Jiffy by Ultradent), and final gloss can be obtained with successive pastes (diamond and aluminum oxide, eg, ENA Shiny by Micerium) and brushes. It is generally recommended to exaggerate the texture in anticipation of the loss of texture that **(magne, 2020).**

1.9 CONSIDERATIONS FOR DIRECT RESTORATIONS IN POSTERIOR TEETH

Tooth preparation

Outline form of adhesive preparations should be essentially driven by the extent of the caries, demineralization of adjacent enamel, and discoloration of enamel or dentin. The principle of maximum tissue preservation should always be respected.

Marginal ridges, oblique ridges, and sound occlusal surfaces can be preserved even where enamel is not completely supported by dentin. The "adhesive preparation" should consist of a conservative round or ovoid internal shape, ***(Lutz et al., 2014)*** including beveling of enamel margins ***(Opdam et al., 2002)*.**

For existing restoration replacement, the general cavity design should be limited to the removal of the restoration and damaged tissues followed by the beveling of enamel margins. The proximal bevel should have a 45-degree angle because prism direction is at right angles to the cavosurface. Safe interdental preparation is facilitated by the use of single-sided oscillating diamond tips The prism direction in the zone of the central fossa is inclined toward the fossa. Parallel occlusal walls (or even slightly convergent) still allow a transverse cut across the prism's long axis, thereby achieving more efficient etching. Nevertheless, occlusal margins can still be smoothed (minibevel) with a fine diamond bur to remove possible weakened enamel and to enhance the esthetic blending of the composite resin n. Extensions of proximal walls can be kept as minimal as possible and can be placed in contact areas. No "extension for prevention" is needed **(fig. 11)**

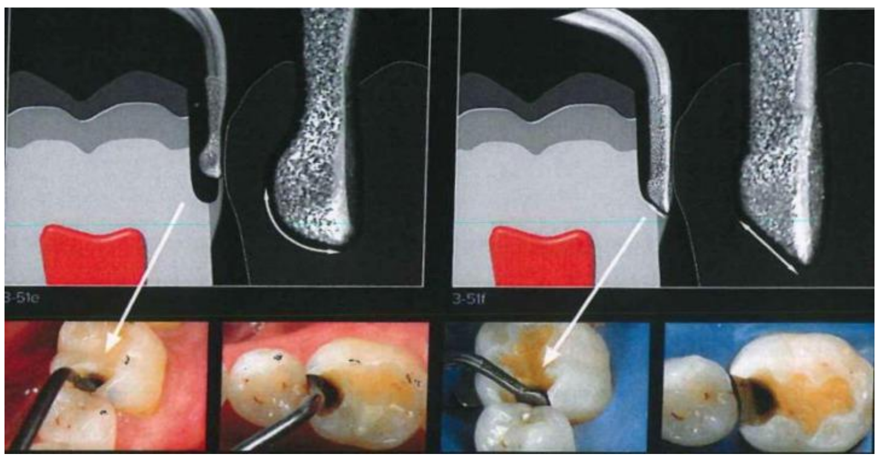


Fig. 11 Safe interdental tooth preparation.

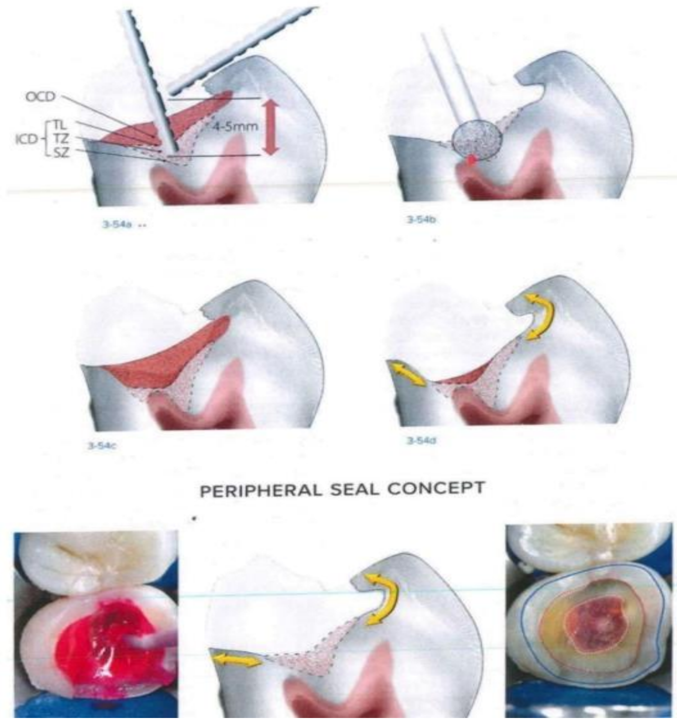
(cross polarization photography courtesy of Prof Luis N. Baratieri)

Small interproximal lesions can sometimes be accessed laterally instead of opening an intact marginal ridge. In this situation,the small oscillating hemisphere can be used as a single tool to open access, cleanthe lesion, and finish the margins.

From initial opening to deep caries removal endpoints (CREs)

For shallow lesions in the superficial dentin, complete removal of caries by the traditional visual and tactile technique is recommended. The use of fiberoptic transillumination (FOTI) can be of significant help to locate the exact entry point through the marginal ridge. The ultimate approach to transillumination is the NIR (near-infrared) DIAGNO cam device (KaVo). allowing the operator to take digital occlusal images while transilluminating the tooth from both buccal and lingual aspects. The results suggest that NIR transillumination may substitute the use of bitewing radiographs in everyday clinical practice. ***(Sochtig et al., 2014; Kiihnisch et al., 2016)*** For deeper lesions, the main challenge is to determine the ideal caries removal endpoints. More sophisticated techniques are required than traditional visual and tactile techniques For teeth with a positive pulpal vitality test, CRE determination aims at the absolute avoidance of pulpal exposure while creating a peripheral seal zone (PSZ), which acts like a highly bonded restorative"moat" **(Alleman, 2012).**

A bond strength of approximately 45 MPa can be generated by a PSZ that is 2 to 3 mm wide consisting of totally clean superficial dentin (1—2 mm), DEJ, and enamel (1-1.5 mm). There are two layers in the caries lesion **(Figure 12a).** The outer carious dentin (OCD, caries infected dentin) is highly acidic, infected, and presents denatured collagen fibrils, irreversibly damaged and demineralized. The inner carious dentin (ICD, caries affected dentin) is partially demineralized and slightly infected, but collagen fibrils have retained their structure and integrity. In ICD, whitlockite crystals (calcium phosphate precipitates from dissolved hydroxyapatite in the transparent zone) fill the enlarged tubule lumens **(ogawa, 1983),** and there is a chance for this layer to be remineralized from the surrounding dentin if the pH is neutralized. Removing the OCD only and saving the ICD for remineralization is a concept from the1960s. It is difficult, however, to clinically distinguish between these two layers. By using only visual and tactile methods for deep caries removal, the pulp may be exposed because the ICD, the normal deep dentin, and reparative dentin are all softer than superficial and intermediate dentin. Significant progress was made with the introduction of propyleneglycol solutions (eg, Caries Detector by Kuraray). It is important, however, to know that caries dye will produce a darkly stained OCD, while the ICD should remain lightly stained (pink haze) **(Alleman and Magne, 2012)**



(FIGURE 12) Caries removal endpoints, (a) Deep caries lesions are made of the outer carious dentin (OCD) and inner carious dentin (ICD), with its three layers: turbid layer (interphase with OCD). transparent zone (tubule lumens filled with whitlockite),and subtransparent zone (normal sensitive dentin). A periodontal probe should be used to assess when the excavation reaches the circumpulpal area (4-5 mm from the occlusal developmental groove),(b)In such a situation, total removal of OCD and ICD may lead to unnecessary pulp exposure,(c)In even deeper lesions with OCD (staining dark red) extending to the circumpulpal area, the goal of CRE is primarily to create the PSZ (yellow arrows), (d) Pulpal exposure should be avoided even if it means leaving a small amount of OCD on top of the ICD.(e to g) Common clinical situation with complete OCD removal but ICD (pink haze) left in the circumpulpal area. **(Reproduced with permission from Alleman and Magne.)**

Interdental contacts

Unlike amalgam restorations, the packability of composite resins, no matter how viscous they are, does not help to obtain better proximal contacts. Securing interdental contacts and contours of direct restorations may prove difficult and is dependant on the use of contoured sectional metal bands, special separation rings, and wedges ***(Peumans et al., 2001).*** When used properly, good proximal contact can be achieved consistently and predictably. In addition, the use of metallic bands improves polymerization by light reflection ***(Kays et al.,1991).*** Various interdental clearances also call for sectional bands with various curvatures and emergences.

Layering techniques

The first step in the restoration is to ensure optimal enamel-dentin bonding followed by the use of incremental layers of composite ***(Lutz et al.,1986)***. The very simple horizontal layering technique along with the use of a filled three-step etch-and-rinse adhesive (OptiBond FL) proved its efficiency in maintaining high bond strength to dentin ***(Nikolaenko et al., 2004).***

Large sandwich restorations

Polymerization contraction stress is the result of complex interactions, between polymerization shrinkage, elastic modulus, conversion degree, and cavity configuration, among other factors. McLean first introduced the sandwich restoration (SR) in the 1970s ***(McLea et al., 1985)*** as a valid solution to address the problem of shrinkage and poor dentin bond strength of earlier composite resin and adhesive formulations.

Open sandwich

The GIC can be used as a proximal margin elevation base and left exposed at the cervical margins, the so-called "open SR”. In this specific location (dentin margin), the GIC has the capacity to release fluoride and inhibit dentin demineralization lesions ***(Tantbirojn et al.,2009).*** some authors advised against this type of treatment. Low success rates were found in clinical studies investigating open SRs with traditional GIC, **(Welbury and Murray, 1990 ;Van, 1994),** which suffered from dissolution and progressive volume loss. Many fractures were found in the. open SR group because of their low flexural strength compared to composite resin materials. The replacement of GIC with RMGIC improved the performance of SRs, yielding similar results to direct composite restorations after up to 9 years of evaluation ***(Lindberg et al., 2007)***

Closed sandwich

In the closed SR, the GIC/RMGIC base is totally covered by composite resin and does not extend to the margins center **(Magne, 2000).**

When using a conventional GIC, closed SRs proved significantly superior to open SRs, which needed replacement in 75% of the cases after 6 years **(Van, 1994).**

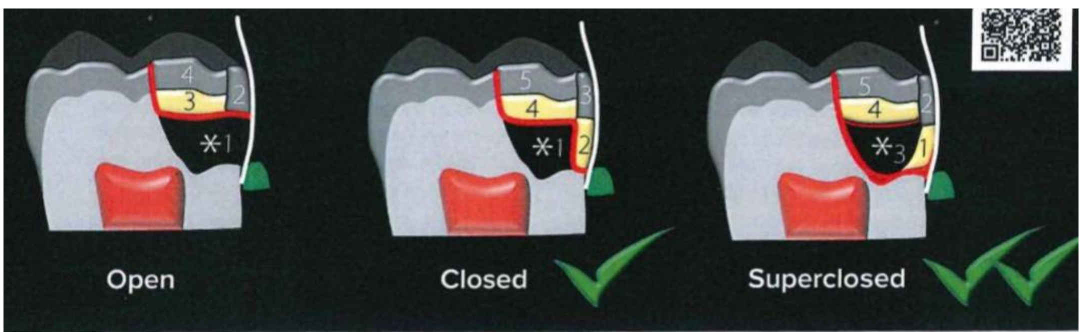
This configuration, when used with RMGIC, also demonstrated less microleakage compared to composite resin restoration alone From a clinical standpoint, cracking of the conventional GIC and internal gaps may develop as a consequence of dehydration before bonding procedures. Enamel etching can be performed prior to the application of RMGIC, but enamel can be contaminated by the conditioner or primer of the RMGIC. It was proposed that using a single adhesive system for both restorative materials would make the sandwich technique less complicated ***(Dietric***

et al., 1999; Dietrich et al., 2000) The increased viscosity of the GIC/RMGlCs (eg, compared to resin bonding agents) may also result in voids and gaps.

Superclosed sandwich

In view of the above, use of a resin adhesive before the placement of the GIC/RMGlC was suggested ***(Wieczkowsk et al., 1996; Fritz et al., 1996)***. This corresponds to the logical evolution of the closed SR technique and was presented as the "superclosed SR **(Magne et al., 2016).**

the low-shrinkage and low-thermal expansion GIC/RMGIC base is applied after sealing the tooth with an enamel/dentin bonding agent. In other words, the appropriate enamel-dentin bonding procedure is first applied to the isolated preparation before inserting the dentin-replacing GIC or RMGIC. For Class 2 super closed SRs, the layering technique must be adapted to facilitate the insertion of the GIC/RMGIC. It is advisable to start building the proximal walls of the defect with a thin layer of composite resin (converting the Class 2 defect into a Class 1), which will define a confined volume for the application of the GIC/RMGIC. At least 2 to 2.5 mm of occlusal clearance must be kept for the overlaying composite resin. Lock of occlusal thickness of composite resin may affect the overall performance of SRs.



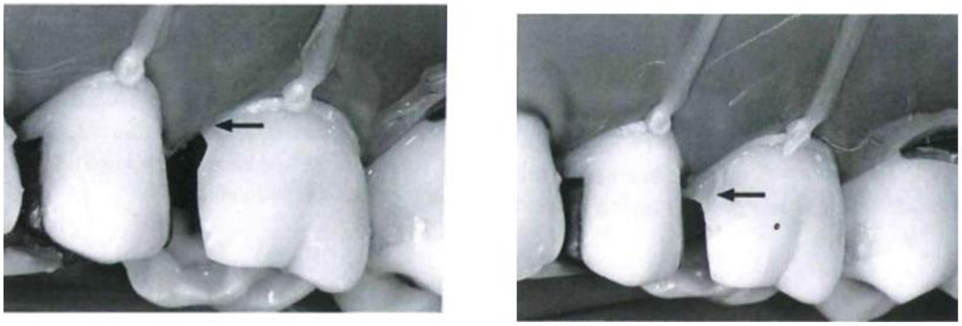
(FIG. 13) Sequence of the three different sandwich restorations **(Magne, 2000)**

Polishing and finishing

Polishing and finishing of direct posterior composite restorations follow the same steps and instruments described for anterior teeth. Following occlusal adjustments, silicon points and disks (eg. Jiffy) are used with the same sequence, finishing with a silicon bristle brush. Surface polishing and gloss can be obtained in only two steps using universal diamond-impregnated points and spiral brushes (eg, Feather Lite blue and gray, Brasseler.

1.10deep margin elevation technique

Localized subgingival margins cancomplicate the placement of both direct and indirect adhesive restorations (isolation, impression, delivery) and subsequently affect their durability and effect on the periodontium. A technique is proposed in which a modified tofflemire matrix is placed, followed by IDS and coronal elevation of the deep margin (to a supragingival position) using a base of direct-bonded composite resin **(Magne and Spreafico, 2012)** (**fig.14).** For practical and socioeconomic reasons, deep margin elevation may be a useful noninvasive alternative to surgical crown lengthening. The technique might also facilitate the placement of large direct composite resin restorations.



(FIG. 14) Deep margin elevation **(Magne, 2007)**

1.10.1Fundamentals of the DME concept

The DME concept applies to preparations for direct restorations and semi-direct and Indirect adhesive inlays and onlays (especially those generated by optical impression and CAD/CAM) when gingival margins cannot be isolated by means of rubber dam alone. DME is achieved by placing a direct composite using a modified “supercurved” circumferencial matrix (eg, Greater Curve by Greater Curve, Reel Matrix Margin Elevation by Garrison) to bring the gingival margin to a level where it can be sealed with rubber dam during the delivery of the inlay/onlay. This allows proper removal of excess luting composite resin before curing. DME should always be achieved directly after IDS, under rubber dam, and only if the margin can be isolated properly with the modified matrix. It is absolutely contraindicated otherwise e. It is recommended to make a bitewing radiograph and evaluate the proper adaptation of the composite resin in the gingival area (absence of gaps or overhangs) before proceeding with the final impression. Whenever possible, it is recommended to proceed to DME before endodontic treatment in order to benefit from the improved isolation during root canal therapy.

The following elements are fundamental for successful DME:

1. curved A matrix should be favored
2. Sufficient buccal and lingual walls of residuaI. tooth structure must be present to support the matrix
3. Matrix height should be reduced to 2 to 3 mm only
4. After placing the matrix, carefully check that the gingival marginis sealed by the matrix **(Ghezz, 2019).**
5. Before starting bonding procedures, the margin should be gently reprepared using a fine diamond bur or oscillating tips.

6. For endodontically treated teeth, one must ensure that appropriate root canal therapy has been achieved and place a GIC barrier to cover the access to the canals
7. Various types of composite resins can be used for the elevation (traditional restorative or flowable).
8. Once the elevation is completed, finishing procedures are applied as required for a direct restoration.
9. Finally, a bitewing radiograph is taken to ensure that no excesses or gaps are present
10. The “matrix-in-a-matrix” technique is a last option in case of extremely deep and localized lesions
11. Delivery of the restoration on an elevated margin requires careful cleaning of the existing composite resin base using airborne-particle abrasion,
12. DME can be used also for direct composite resin restorations.

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