Evidence-based concepts and procedures for bonded inlays and onlays. Part I. Historical perspectives and clinical rationale for a biosubstitutive approach

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Abstract

This first article in the series (Part I) aims to present an updated rationale and treatment approach for indirect adhesive posterior restorations based on the best scientific and long-term clinical evidence available. The proposed treatment concept relies on the basic ideas of *(1)* the placement of an adhesive base/liner (Dual Bonding [DB] and Cavity Design Optimization [CDO]) and, when needed, *(2)* a simultaneous relocation of deep cervical margins (Cervical Margin Relocation [CMR]), prior to *(3)* impression taking to ensure a more conservative preparation and easier-to-follow clinical steps, and the use of *(4)* a highly filled, light-curing restorative material for the cementation (Controlled Adhesive Cementation [CAC]), together with restoration insertion facilitation, the application of sonic/ultrasonic energy, and/or material heating. The suggested clinical protocol will help the practitioner to eliminate the most frequently experienced difficulties relating to the preparation, isolation, impression taking and cementation of tooth-colored inlays and onlays. This protocol can be applied to both ceramics and composites as no material has been proven to be the most feasible or reliable in all clinical indications regarding its physicochemical and handling characteristics. For the time being, however, we have to regard such indirect restorations as a biosubstitution due to the monolithic nature of the restoration, with still very imperfect replication of the specific natural dentin-enamel assemblage.

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Introduction

The ideal procedures for bonded inlays and onlays remain a controversial issue, and clinical concepts are poorly standardized. The abundance of options relate first to the indication (direct or indirect), then to the fabrication method (chairside or in-lab, using conventional or CAD/CAM processing), the material choice (composite resin or various types of ceramics), and finally to the detailed clinical protocols with regard to cavity preparation, temporization and cementation.[1] It therefore still seems pertinent to review the available literature and analyze the scientific and clinical data to identify the best evidence (in terms of quantity, quality, and consistency)[2] regarding revised, optimized treatment protocols.

In the last decade, an increasing emphasis has been placed on the conservation of tissues and the respect of tooth biomechanics. More precisely, this implies the avoidance of pulpal damage and the strengthening of decayed, fragilized teeth, while providing the longest possible clinical service. The aim of such treatment may sound trivial today, yet in actuality this aim is far from being achieved in routine, daily practice due to the aforementioned absence of proper, widely accepted clinical standards. Moreover, some preparation rules inherited from former restorative materials (typically amalgam, gold, and fired porcelain) still influence the practice of many dentists, leading to the unnecessary removal of sound structure. Further, although such rules are clearly outdated, the fact that they are still applied to indirect ceramic restorations (even when using the latest generations of ceramics) suggests the need for a comprehensive revisiting of treatment protocols for bonded inlays and onlays in view of the latest technological advances, scientific knowledge, and evidence.

The terms biomimetics and bioemulation[3] are also frequently linked to such restorations, confirming the interest in and attempt to replicate natural tissue arrangement, structure, and function, with or without minimal additional tissue preparation. This latter concept, also described as “the silent revolution”, has clearly been a breakthrough in operative dentistry.[4] The legitimate yet empiric concept of following the natural model has only partially been achieved, as we still rely mostly on monolithic restorations for bonded posterior indirect restorations (using either composite or ceramics). Although of a semantic nature, it is of interest to evaluate the potential of new, evidence-based protocols aimed to emulate the natural tooth function and behavior and to validate underlying biomechanical principles.

This first article in the series therefore aims to present the best clinical and scientific evidence supporting revised treatment protocols for the preparation and adhesive cementation of tooth-colored inlays and onlays, conferring optimal biomechanical performance and behavior to the restored tooth.

Treatment rationale and clinical protocol

The most common clinical problems encountered with indirect bonded posterior restorations are related to tissue

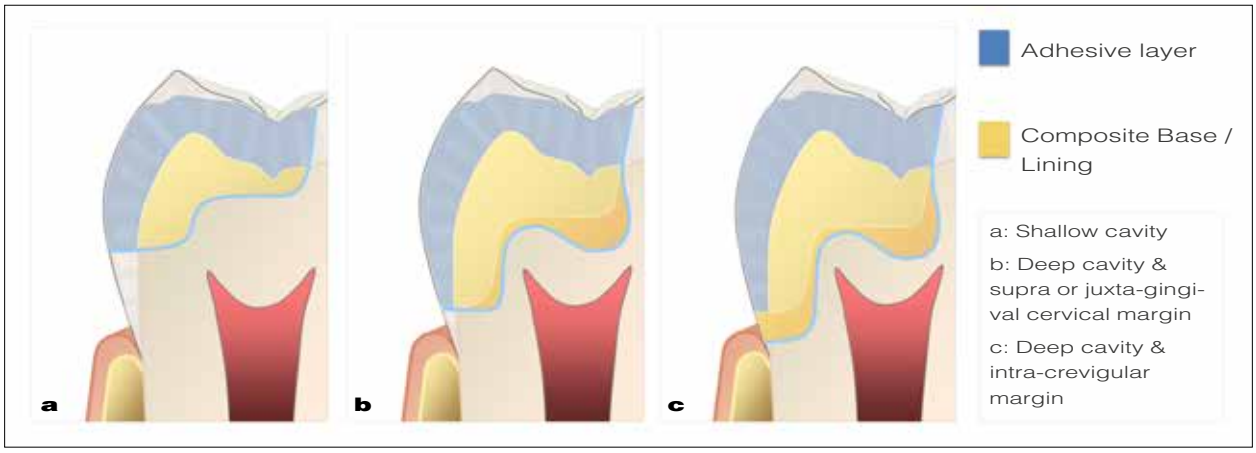


Fig 1 Diagrammatic representation of the different layers in the application of the Dual Bonding (DB), Cavity Design Optimization (CDO), and Cervical Margin Relocation (CMR) procedures. This modern treatment approach alleviates all complications encountered in indirect posterior restorations, providing reliability and increased success. **(a)** shallow; **(b)** deep; **(c)** intracrevicular cavities.

conservation (creating an appropriate cavity design may lead to significant loss of sound tissue), impression taking, adhesive cementation (deep proximal preparations are a challenge and make working-field isolation more difficult), and interim restorations (the placement of conventional acrylic temporaries is time-consuming, and the cement contaminates the interface, while simplified, "soft", light-curing temporaries are easily lost and trigger sensitivity after some time due to leakage and dentin contamination).

An original and comprehensive treatment protocol was introduced by Dietschi and Spreafico in 1997 and 1998,[5,6] which after some initial skepticism prompted much research, and then obtained verification after numerous studies had been carried out. This new treatment approach embraces various concepts that satisfactorily address the aforementioned clinical issues.

The following treatment procedures (Figs 1a to 1c) comprehensively address each clinical issue related to the classical clinical protocol (Table 1):

- Dual Bonding (DB) or Immediate Dentin Sealing (IDS).
- Cavity Design Optimization (CDO).
- Cervical Margin Relocation (CMR) or Deep Margin Elevation (DME).
- Controlled Adhesive Cementation (CAC).

The first of these four procedures, Dual Bonding (DB), relates to the treatment of substrate. It was first introduced in 1997 by Paul and Schärer for crown preparations,[7] and in 1997 and 1998 by Dietschi and Spreafico, and Dietschi and Herzfeld,[5-8] for class II restorations. This procedure was later renamed Immediate Dentin Sealing (IDS) by Magne and coworkers[9,10] with the obvious intention of offering a more meaningful term and exploring new indications of this ap-

Table 1 Development of concepts for adhesive inlays and onlays, with original references

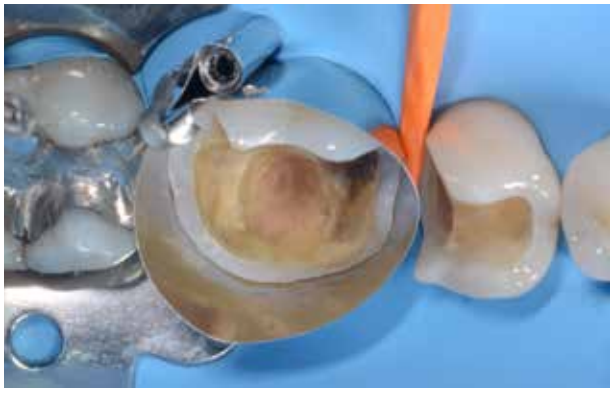
Concept and terminology	Rationale and benefits	References
Dual Bonding (**DB**) Immediate Dentin Sealing (**IDS**)	- Dentin sealing and protection before impression and provisionalization - Improved bond strength and adhesive interface quality	Paul and Schärer, 1997 Dietschi and Spreafico, 1997 Dietschi and Spreafico, 1998 Dietschi and Herzfeld, 1998 Dietschi et al, 2002 Stavridakis et al, 2005 Magne, 2005 (BPR)* Magne et al, 2005 (BPR)*
Cavity Design Optimization (**CDO**)	Application of an adhesive base/liner to: • optimize cavity geometry • fill undercuts • harmonize and limit restoration thickness • protect exposed dentin during temporary phase • improve restoration adaptation	Dietschi and Spreafico, 1997 Dietschi and Spreafico, 1998 Dietschi et al, 2003
Cervical Margin Relocation (**CMR**) Deep Margin Elevation (**DME**)	Displace supragingivally an intracrevicular cervical margin to facilitate and improve: • impression procedures • cementation procedures • cleaning and finishing of margins • restoration adaptation • rubber dam placement (for cementation)	Dietschi and Spreafico, 1998 Dietschi et al, 2003 Magne and Spreafico, 2012
Controlled Adhesive Cementation (CAC)	Luting partial restorations with highly filled, light-curing restorative composite to: • reduce luting cement wear • control excess removal of cement • extend working time	Besek et al, 1995 Dietschi and Spreafico, 1998 Dietschi et al, 2003

* BPR = Bonded Porcelain Restorations (anterior)

Fig 2 New adhesive protocol applied to CAD/CAM restoration.

Fig 2a Preoperative view of teeth 35 and 36 with defective amalgam restorations and a fracture of the mesiolingual cusp of the first molar.

Fig 2b A rubber dam is placed and amalgam restorations removed (note the deep cervical margins, particularly on the mesial aspect of the first molar).



Figs 2c and 2d A full matrix is placed around both preparations, ensuring perfect closure of deep cervical and lingual margins. Ideally, the matrix emergence profile should be divergent to allow for the development of better restoration anatomy.

Fig 2e Both cavities are sealed with an adhesive system (DB). The cervical margin is then filled up until supragingival level is reached (CMR). The composite (with flowable or restorative consistency) also serves to fill up retentive areas of the preparation to avoid additional sound tissue removal (CDO).

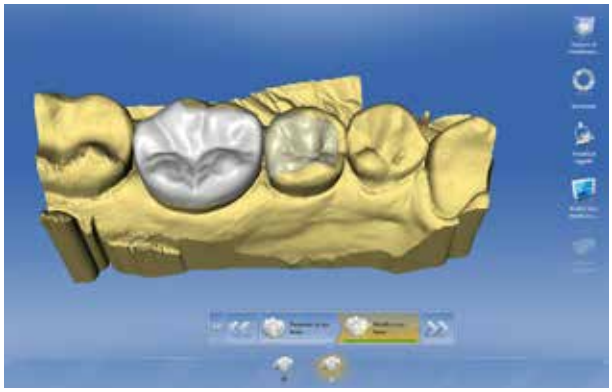


Fig 2f 3D model of the two restorations created by the CEREC CAD/CAM system, prior to milling procedure.

Fig 2g Both restorations (Lava Ultimate, 3M) are inserted and checked for occlusion and fit.

Fig 2h Occlusal characterization is performed with brown paint-on color to improve esthetic integration.

Fig 2i A rubber dam is again placed, to help control the working-field dryness and ensure optimal conditions for cementation.

Fig 2j Final restorations following the revised preparation and cementation protocol that ensures predictability and simplification, showing good esthetic and functional integration.

proach, such as veneering techniques. The idea behind this procedure is to seal the dentin surfaces with a full adhesive system while still isolating the cavity (normally with a rubber dam), which prevents further tissue dehydration (mainly when treating serial cavities) and dentin contamination. It also provides optimal tooth protection against sensitivity during the temporary phase, while improving bond strength and the stability of the adhesive interface.[5,7,12,13]

The second concept, Cavity Design Optimization (CDO)[5,6] was developed in parallel with DB/IDS to overcome unnecessary tissue removal when adapting inner-cavity design to an indirect technique (parallel or slightly tapered). Following the application of the dentin bonding adhesive (DBA) according to the DB/IDS concept, a flowable composite liner is applied to fill in all undercuts and confer an ideal geometry to the cavity. An ideal material consistency should ensure the material's stability within undercuts, while self-leveling to avoid further preparation and finishing. For this reason, highly filled flowable composites are recommended. The use of products with a high viscosity (restorative composites) or a very low viscosity (low-filled flowable composites) is feasible, although the application of these products is less practical.

The third procedure, Cervical Margin Relocation (CMR), was also introduced by Dietschi and Spreafico,[5] and renamed Deep Margin Elevation (DME) by Magne and Spreafico.[12] It is considered for deep proximal preparations (intrasulcular) that complicate impression taking and cavity isolation during cementation. In the case of deep proximal preparations, after proper positioning of a matrix in the cervical area, a first layer of flowable or restorative composite (or a combination of these materials) is applied to reposition the margin. The use of a flowable composite is recommended only up to 1 to 1.5 mm; if more material is needed, a combination of restorative and flowable composites is recommended. A highly filled flowable composite (eg, Premise Flow, Kerr), or a bulk fill flowable base (eg, SureFil SDR Flow, Dentsply) are preferable for this procedure.[14] Another critical prerequisite in order to achieve successful adhesive procedures is to perfectly isolate the cervical preparation;[5,12] indeed, when respecting the true indication of this procedure (mainly intrasulcular), the placement of a rubber dam together with a matrix is usually possible.

The fourth concept, Controlled Adhesive Cementation (CAC) refers to the use of a highly filled light-curing material for cementation to ensure optimal working time and control (which is not the case with dual-curing adhesive cement). Another major advantage of CAC in complex cavity design, and in combination with the CMR technique, is it allows for visual margin sight, offering the unparalleled advantage of facilitating the proper and uncomplicated removal of excess cement. The use of a fine microhybrid, the viscosity of which is reduced at the time of placement using a special ultrasonic or sonic cementation tip (eg, Cementation tip, EMS), greatly facilitates restoration insertion. More recent composite resin formulations, such as inhomogeneous nanohybrids (nearly all nanohybrids presently on the market) are not recommended due to their firm-

er consistency and large particle size (prepolymerized particles or clustered nanoparticles). The results of research studies on the possibility of bringing sufficient light into the cementing space for optimal composite conversion and mechanical properties have shown that proper light polymerization is feasible, and in some conditions is superior, to what can be achieved with a dual-curing material in the absence of light; in fact, proper light propagation within the luting interface is highly recommended for both types of composites (light- or dual-curing).[5-18] The CDO procedure also helps to reduce and optimize the restoration thickness, and therefore favors proper light transmission within the luting interface. An additional benefit of this technique is that, due to the dentin remaining fully protected by the base/liner, anesthesia during cementation procedures is virtually no longer required.

These procedures have to be used for both semidirect (chairside intraoral or extraoral and CAD/CAM techniques) or indirect clinical procedures (in-lab composite or ceramic)[5,6,19,20] (Figs 1 to 3).

Table 2 summarizes the comprehensive changes made to the advanced clinical protocol for bonded inlays and onlays and compares them to conventional procedures. The procedures and principles described in Table 2 (revised protocol) feature the following clinical advantages:

- The absence of tissue removal for the sake of convenience, the properties of materials, or the limitations of technology.
- The gentle treatment of the pulpodentinal complex during the preparation (and eventually the temporary phase) through the systematic use of a rubber dam and extensive water spray, and by isolating the dentin immediately after preparation with a thick layer of DBA and adhesive base/liner.
- The long-term function and resistance of the teeth due to the use of wear-resistant, strong, and rigid restorative materials (both restoration and cement).
- Strong and durable adhesive interfaces between the materials and substrate (dentin-enamel to adhesive, adhesive to base/liner, base/liner to composite cement, and composite cement to restoration).

The treatment procedures discussed in this article have been extensively evaluated *in vitro,* and there is strong positive evidence in favor of this revised treatment protocol.[21-27] In vivo, the nature of base/liners and their influence on restoration longevity and success have not been specifically investigated (no comparative, prospective, randomized clinical trial has taken place). However, these procedures have been successfully used by the authors and by many other clinicians. Long-term follow-up will be presented in Part II of this article, which may then be considered as factual clinical evidence.

Biosubstitution

The principles discussed in this article imply major differences between nature's model and an adhesively restored tooth. First, the various restoration layers and interfaces do not share the same

Fig 3 New adhesive protocol applied to semi-direct restoration.

Fig 3a Preoperative view of tooth 45 with defective cast gold onlay (cervical recurrent decay).

Fig 3b Following removal of the restoration, the cervical margin appears juxta-gingival and no enamel is present.

Fig 3c The cavity is therefore modified (as shown in Fig 1) with dentin sealing, using the DB, CMR and CDO techniques.

Fig 3d Following these procedures, the cavity is isolated using Rubber Sep (Kerr) to avoid any bonding between the resinous base/liner and restorative composite.

Fig 3e After placement of a clear full matrix, the restoration is fabricated in-mouth using a composite mass for the proximal and occlusal surfaces in addition to the central dentin increment.

Fig 3f The central groove is characterized with a brown-effect shade and, following polymerization, the restoration can be moved out of the cavity for margin refinements and luting preparation.

Fig 3g The inlay is luted with the same restorative composite (light-curing enamel mass) to ensure optimal working time and complete removal of excesses.

Fig 3h Completed restoration.

Table 2 Description of the major differences between the conventional and the revised preparation and cementation protocols for indirect adhesive class II restorations (according to Dietschi and Spreafico, 1997 and 1998)

Clinical steps	Conventional protocol	Revised protocol
Preparation	- No specific isolation - Convenient marginal and internal design is required (taper)	- Under rubber dam, mostly under water spray - Only marginal convenient design required
DBA application	At cementation	Just after preparation
Base/liner	Optional	Mandatory
Base/liner material	Composite or glass ionomer(s)	Composite only (flow mainly)
Provisional restoration	Cemented provisional temporary recommended	Non-cemented, light-curing temporary
Luting material	Dual-curing composite cement	Light-curing restorative composite
Restoration insertion	Manual	Assisted with sonic/ultrasonic tip (eventually with heated material)

configuration as a natural tooth. Second, the materials used for inlays and onlays are isotropic, while dentin and enamel are anisotropic.

The continuity of interfaces within the restoration is, however, a concept that is shared with the natural dentin-enamel junction, although this latter interface, which shows remarkable strength and stability, can unfortunately not yet be totally substituted using dental adhesives (especially at the dentin level). Using materials, and especially a combination of them, that exhibit physicomechanical properties close to natural dentin and enamel (ie, composite resins as dentin substitutes and ceramics as enamel substitutes) nevertheless remains a valid objective, although it is at present not practically feasible. What needs to be evaluated for modern ceramics is the use of a thin ceramic layer placed over a thicker composite base, a combination which has not yet proven effective with materials that have been used to date. The present reality, therefore, is biosubstitution, which is the first step towards true biomimetics or bioemulation.

Conclusion

The first article in this series (Part I) has presented a treatment rationale and related clinical procedures to be applied for indirect adhesive posterior restor-

Fig 4 New adhesive protocol applied to indirect restorations.

Fig 4a Preoperative view showing defective amalgam (teeth 46 and 47) and composite (teeth 44 and 45) restorations. The sextant also needs to be realigned to create a better curve of Spee.

Fig 4b A rubber dam is placed before removing the bulk of the restorations.

Fig 4c Preparations show deep proximal margins with no cervical enamel (teeth 44 to 46), including many undercuts. Impression taking, control of restoration proximal adaptation, and removal of excesses would complicate the next steps if such cavity configuration were to remain.

Fig 4d Thereafter, cervical margins are relocated on teeth 44 to 46 (CMR), and all retentive areas are filled up with flowable composite to improve overall cavity design (CDO). Note that an opaque composite shade is chosen for tooth 46 to cover the discolored dentin.

Fig 4e Trial of composite restorations made of a highly filled composite material (homogenous nanohybrid: Inspiro, EdelweissDR).

Fig 4f Restorations are cemented one by one, using a light-curing restorative enamel, usually a microhybrid (eg, Tetric, Ivoclar) or a homogenous nanohybrid (eg, Inspiro, EdelweissDR). Avoid selecting a conventional nanohybrid material (which contains large clusters or prepolymerized particles). This allows better control of placement and removal of excesses before curing (CAC).

Fig 4g Restoration insertion starts with manual pressure only until firm resistance is attained. Thereafter, restoration seating is achieved in a second step, using a sonic or ultrasonic handpiece and a special plastic cementation tip (KaVo or EMS).

Fig 4h Light-curing is performed for 40 to 60 s (on each restoration surface) through the tooth substrate and inlay/onlay. Not only is the light-curing efficacy shown to be sufficient, it allows for a superior quality of the physical properties of the luting material.

Fig 4i View of the composite restoration prior to cementation.

Figs 4j to 4l Final views before and after rubber dam removal, showing satisfactory esthetic and functional integration. This restorative approach facilitates clinical application and ensures more reliable results.

Fig 4k

Fig 4l

ations, based on strong scientific and long-term clinical evidence. In summary, the fundamental principles in this regard are:

- A more conservative preparation approach.
- A more respectful treatment of the pulpodentinal complex.
- A continuum of adhesive interfaces throughout the tooth-restoration system to emulate long-term strength and longevity.
- Overall, a simplification and increased predictability of all clinical procedures.

The suggested clinical protocol will help the practitioner to eliminate the most frequently experienced difficulties relating to the preparation, isolation, impression taking, and cementation of tooth-colored inlays and onlays. A cornerstone of this revised treatment approach is the placement of an adhesive base/liner be-

fore impression taking, providing (when needed) a relocation of deep cervical margins and leading to a more conservative, predictable, and improved treatment outcome. At this point in time, no material has systematically proven itself to be the most feasible or reliable regarding its physicochemical and handling characteristics. Therefore, both composites and ceramics can be successfully used for bonded inlays and onlays on vital teeth. For non-vital teeth, however, the increased rigidity and reinforcement potential of rigid, high-strength modern ceramics appears advantageous. This latter point will be discussed in the second article in this series (Part II).

Finally, practical reasons exist to limit the complexity of restorative procedures (material combinations), so that it is best to speak of biosubstitution until such time as true, evidence-based bioemulated solutions are available for class II restorations.

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