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# Immediate Dentin Sealing:

# Efficiency in indirect restorations

Georges Philippe Alfred PARIS

Dissertação conducente ao Grau de Mestre em Medicina Dentária (Ciclo Integrado)

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# Efficiency in indirect restorations.

Trabalho realizado sob a orientação de Professora Doutora Orlanda Torres e sob a coorientação da Mestre Ana Sá Góis

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# Agradecimentos

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« On rencontre quelques fois son destin, sur la route qu'on a prise pour l'éviter. »

*Mon nom est personne.*

# RESUMO

A dentina é uma estrutura dentária complexa intimamente ligada à polpa e composta por túbulos dentinários que transmitem estímulos térmicos, pressão e dor. Os túbulos dentinários podem ser expostos durante a preparação da cavidade dentária, e assim podem ser suscetíveis à infiltração de bactérias e de saliva. As restaurações indiretas apresentam várias vantagens, tais como melhor forma anatómica, contorno, estética, e resistência à fratura. A cimentação de restaurações indiretas com exposição da estrutura dentinária é considerada uma das tarefas mais desafiantes na dentisteria adesiva. O selamento dentinário imediato consiste na aplicação e polimerização duma resina adesiva diretamente após a preparação do dente e antes da impressão final. Foi proposto que o selamento dentinário imediato tem a capacidade de diminuir a sensibilidade pós-operatória e a microinfiltração bacteriana ao mesmo tempo que melhora a adesão das restaurações indiretas.

O objetivo é a abordagem da técnica de selamento dentinário imediato, as suas vantagens e a sua eficiência nas restaurações indiretas.

A pesquisa bibliográfica foi realizada na base de dados PubMed. Foram reunidos um total de 53 artigos, dos quais 20 foram considerados relevantes para este trabalho.

Os autores concluíram que a técnica de selamento dentinário imediato consiste na hibridização da dentina com um sistema adesivo. É um procedimento eficaz, que permite atingir uma melhor adesão, menor microinfiltração, e sensibilidade dentinária. Contribui para a estabilidade e redução da permeabilidade da interface adesiva em restaurações indiretas.

**Palavras-chave:** dentina, agentes de adesão dentinária, adesão a dentina, cimentos de resina, análise do stress dentário, selamento dentinário imediato.

# ABSTRACT

Dentin is a complex tooth structure closely connected to the pulp and composed of dentinal tubules that transmit thermal stimuli, pressure and pain. The dentinal tubules can be exposed during preparation of the dental cavity, and thus can be susceptible to infiltration by bacteria and saliva. Indirect restorations have several advantages, such as improved anatomical shape, contour, esthetics, and resistance to fracture. Cementation of indirect restorations with exposure of the dentin structure is considered one of the most challenging tasks in adhesive dentistry. Immediate dentin sealing consists of applying and polymerizing an adhesive resin directly after tooth preparation and before the final impression is taken. It has been proposed that immediate dentin sealing has the ability to decrease postoperative sensitivity and bacterial microleakage while improving the adhesion of indirect restorations.

The objective is to present the technique of immediate dentin sealing, its advantages and its efficiency in indirect restorations.

The bibliographic search was conducted in the PubMed database. A total of 53 articles were gathered, of which 20 were considered relevant for this work.

The authors concluded that the technique of immediate dentin sealing consists in the hybridization of dentin with an adhesive system. It is an effective procedure, which allows achieving better adhesion, less microleakage, and less dentin sensitivity. It contributes to the stability and reduction of permeability of the adhesive interface in indirect restorations.

**Keywords:** dentin, dentin bonding agents, dental bonding, resin cements, dental stress analysis, immediate dentin sealing.

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# LIST OF ABBREVIATIONS AND ACRONYMS

**IDS:** immediate dentin sealing

**DDS:** delayed dentin sealing

**DBA:** dentin bonding agent

**μ-TBS:** micro tensile bond strength

**SPP:** simulated pulp pression

**CAD/CAM:** computer-aided design/computer-aided manufacturing

**SEM:** scanning electron microscopy

**DEJ:** dentino-enamel junction

**GPa:** giga pascal

# 1. Introduction

Human tooth is composed of enamel, dentin, cement and pulp. By weight, enamel is mainly (95%) made of the mineral hydroxyapatite (which is crystalline calcium phosphate), of organic material (1–2%) and it contains virtually no water (2– 4%). Dentin is a complex hydrated biological composite structure composed in volume of 50% of inorganic matter (apatite crystals); 30% of organic matter which is largely type I collagen; and 20% of water. Dentin is composed by dentinal tubules that contains odontoblasts and transmit thermal stimuli, pressure, and pain. Dentinal tubules, peritubular dentin (or intra tubular dentin) and intertubular dentin which separates the tubules, are the three main components of dentin. Pulp and dentin are embryologically, histologically, and functionally identical tissue which leads to the believe that they must be considered as a pulp–dentin complex. (1–3) Thus, leaving dentin exposed is akin to an "open pathway" towards the pulp, which endangers tooth vitality because microorganisms can reach the pulp tissue if it is not sealed adequately. Adhesion to dentin remains a clinical challenge in clinical dentistry because of the complex composition of dentin's mineral, organic, and fluid phases. Dentin structure represents the biological basis of modern adhesive restorative treatment. Thus, interest in dentine structure is significantly correlated to contemporary understanding of the pulp-dentin complex and adhesion concepts. (4–7)

Minimally invasive dentistry and intact dental tissue conservation through adhesion are the cornerstone of the biomimetic approach in restorative dentistry. (8) Restorative dentistry took a turn in the late 20th century towards more conservative adhesive dentistry. Bonding has undergone a great evolution in recent years, particularly with the development of bonded partial restorations (inlays, onlays, overlays and veneers). These indirect restorations present several advantages, such as improved anatomic shape, contour, esthetics, and fracture resistance. (9,10) As regards disadvantages of indirect restorations, exposed vital dentin immediately after tooth preparation is susceptible to insult from bacterial infiltration and micro-leakage during the provisional phase. Bacterial and fluid penetration through the exposed dentinal tubules can result in colonization of micro-organisms, post-operative sensitivity and the potential irritation of the pulp. (11)

In the early 1990s, Japanese clinicians described the so-called "resin coating technique", which consists of the application of a resin adhesive to both enamel and dentin surfaces that were exposed after tooth preparation to protect the pulp and avoid dental surface contamination before cementation of indirect restorations. A similar idea, the so-called "dual bonding technique", was reported, which consists on the application of two layers of adhesive resin onto dentin. (4,9–12) In 2005, Magne proposed the so-called "immediate dentin sealing" (IDS) and described the technique's steps and benefits. (4,10,13,14)

The IDS generates a dentin hybrid layer and provides an integrated sealing coat on the dentin surface. The procedure consists of the application and polymerization of a "dentin bonding agent" (DBA) immediately after tooth preparation and before the final impression for the indirect restoration is taken. On the other hand, "delayed dentin sealing" (DDS) that represents a common clinical practice where the dentin adhesive is applied just before cementing the restoration in a second visit. IDS has been suggested as an alternative to improve the quality of adhesion for indirect restorative procedures since it provides numerous advantages for the patient and longevity of the restoration, with respect to the DDS. (14–17)

## 2. Objectives

The main objective is to present the technique of immediate dentin sealing, its advantages and its efficiency in indirect restorations.

Secondary objectives are:

- a global approach of fundamentals principles on dentin morphology and bonding mechanism.

- to present a clinical procedure of immediate dentin sealing for indirect bonded restorations.

## 3. Materials and methods

The bibliographic search was conducted in the PubMed database. A total of 53 articles were collected, dated between 2017 and 2022, which after being analyzed, respecting the inclusion and exclusion criteria, only 20 articles were included in the performance of this work. The total number of articles were compiled for each combination of key terms and therefore duplicates were removed using Zotero software. A preliminary evaluation of the abstracts was conducted to determine whether the articles met the objective of the dissertation. The selected articles were read and individually assessed for the objective of this dissertation. A further 10 articles were inserted as an aid to the bibliography, in order to fully develop this work.

Inclusion criteria: articles written in English; articles involving immediate dentin sealing; articles demonstrating the efficiency of the technique in indirect restorations in permanent human teeth; articles included in the last 5 years.

Exclusion criteria: articles in which the technique is compared with other materials not relevant to this review; articles that involved sealing in endodontic teeth; articles on different types of restorations; articles that do not show the scientific relevance of dentin sealing; articles with restricted access.

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| Patient, population, problem | Loss of dental tissue, caries |
| Intervention | Indirect restorations with IDS (immediate dentin sealing) |
| Comparaison | Indirect restorations with DDS (delayed dentin sealing) |
| Outcome | The application of IDS technique in indirect restorations shows better results in terms of dentin bonding than the DDS technique. |

Table 1. PICO methodology.

# 4. Results

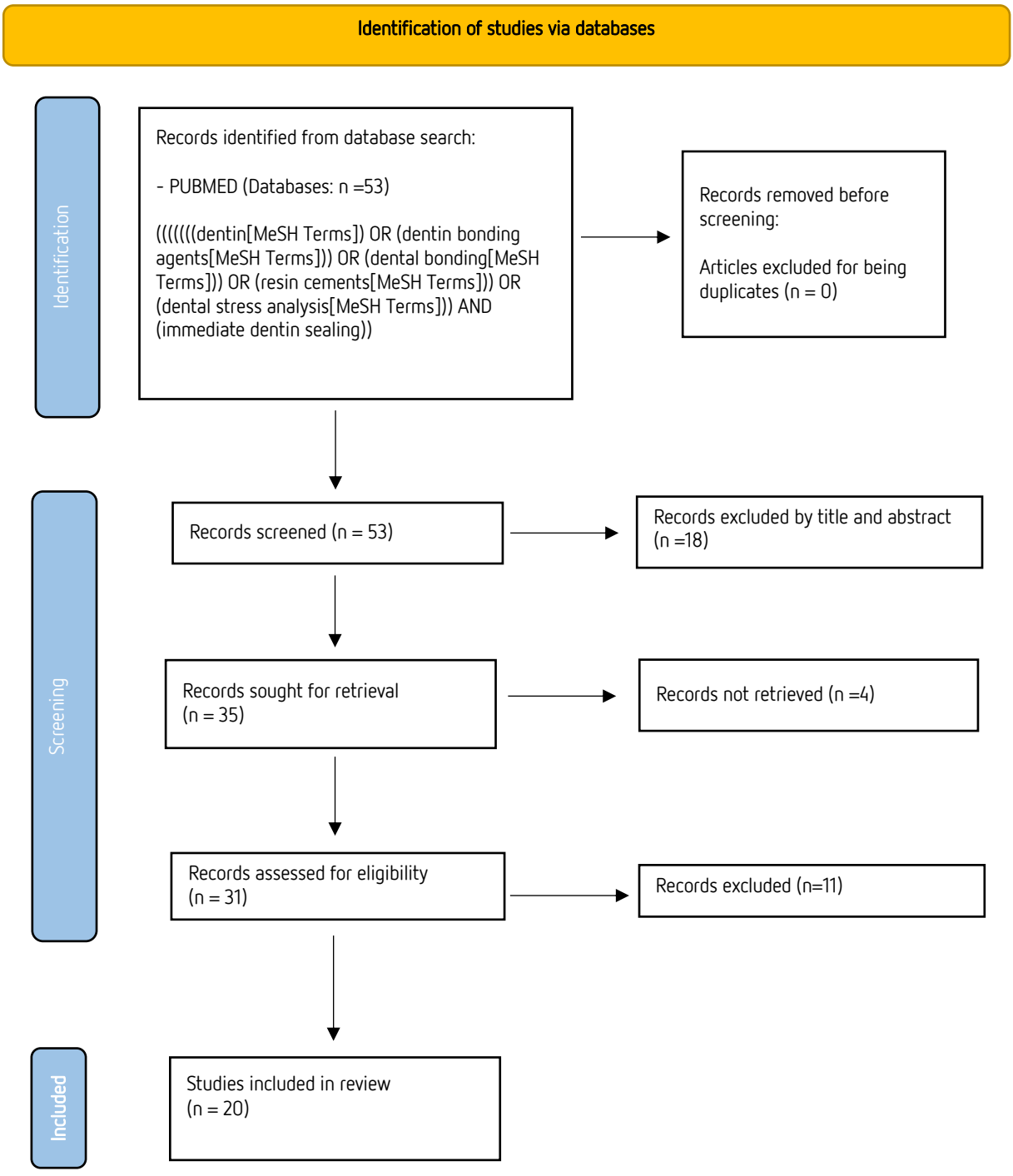


Figure 1. PRISMA 2020 flow diagram for new systematic reviews which included searches of databases.

| n° | Authors (year) | Objectives | Methods | Results | Conclusion |
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| 1. | De carvalho et al. (2021) | Evaluate the μTBS of unfilled/lightly filled DBAs compared to the golden standard filled Optibond FL with and without IDS as well as with and without reinforcement with a flowable resin coating. | 75 human molars were selected, restored/tested according the μTBS method. 5 groups were obtained from the combination of the 5 DBAs and 3 application modes: DDS, IDS and IDS with flowable resin coating. | It appears that IDS significantly improve the bond strength of all tested adhesives. The use of a flowable resin coating reinforcement after IDS increased the μTBS of all unfilled/lightly filled adhesives and maintained the performance of the 3-step golden standard adhesive. Optibond FL and Clearfil SE Bond provided the best results. | IDS improved the μTBS to dentin when a filled DBA was used. Unfilled/lightly filled DBAs should be reinforced with a flowable resin coating to improve the μTBS to dentin for IDS. |
| 2. | Gresnight et al. (2019) | In this prospective clinical trial, the survival, success rate and patient satisfaction of ceramic laminate veneers with special interest on existing restorations, IDS was evaluated. | 104 patients received 384 feldspathic ceramic laminate veneers on maxillary anterior teeth. IDS was applied when more than 50% of dentin was exposed during preparation. After adhesive cementation, restorations were evaluated. | 87 to teeth with more than 50% of exposed dentin surface. In teeth with more than 50% of dentin exposure, a significant increase in survival rate was observed when IDS was used. Patients were generally satisfied with the treatment. In this clinical trial, the ceramic laminate veneers had a relatively high survival rate. | Teeth with more than 50% of dentin exposure significantly benefit from IDS. |
| 3. | Murata et al. (2018) | Show the effect of IDS application on the bonding of CAD/CAM ceramic onlay restorations after cyclic loading were examined. | 32 extracted molars were prepared and divided into 4 groups. The intra-cavity dentin was sealed with an all-in-one adhesive and a flowable composite. CAD/CAM onlays were bonded with a resin cement system. Cyclic loading was applied, and the μ-TBS was measured. | IDS layer thickness was influenced by the IDS application. IDS application did affect the resin cement layer thickness. The μ-TBS values of the IDS restorations of groups were significantly greater than the value for the N restoration group. The stress values of the IDS restorations were significantly greater than that of the N restoration group. | IDS application improved the μ-TBS and the bonding reliability and durability of the CAD/CAM restoration. |
| 4. | Gailani et al. (2021) | Compare the μTBS of CAD/CAM specimens cemented with different pairing of adhesives and resin-cements using two IDS | 108 molars were divided into 9 groups depending on the adhesive/resin-cement (A-C) assigned. CAD/CAM blocks (Lava™ Ultimate) was cemented according to different strategies: IDS1, DDS, IDS2. Samples were sectioned and tested until failure to determine the μTBS. Failure mode was | μTBS values were equal or higher in IDS2 than DDS. Survival analysis showed that some A-Cs would significantly increase the μTBS values for IDS2. A-Cs with the highest adhesion values showed a high percentage of fractures at the LC interface, suggesting that the adhesion at the adhesive/dentin interface would be higher. IDS1 ; | Universal adhesive/resin cements values of μTBS are mainly material dependent. |

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| | | approaches in comparison with DDS. | categorized as dentin/cement (DC), at Lava™ Ultimate/cement (LC) and hybrid (H). | IDS2 both have the same performance from the statistical point of view. | |
| 5. | Abo-Alazm et al. (2021) | Investigate the effect of IDS technique using universal adhesive under SPP on μTBS of indirect resin composite restorations and dentin permeability. | 50 third molars were used. 40 specimens were used for μTBS test evaluation, those specimens were randomly assigned to 2 groups according to the dentin sealing time; IDS and DDS. Each group was further sub-divided into two subgroups according to the adhesive system used for dentin sealing. All specimens were exposed to SPP for 1 week then restored using CAD/CAM blocks. The μTBS was evaluated after 24 hours and 6 months of water storage. The remaining 10 teeth were used for the preparation of dentin discs for dentin permeability evaluation. | Statistically significant difference was recorded between μTBS mean values of both IDS and DDS techniques at 24 hours and after 6 months of water storage. Both adhesives showed a significant reduction in the Weibull characteristic strength after 6 months of water storage. Significant reduction in dentin permeability was recorded by both adhesives. | The IDS technique using universal adhesive in self-etch mode is an effective strategy for improving the final bond strength of CAD/CAM resin composite restorations and reducing dentin permeability. |
| 6. | Rigos et al. (2019) | Evaluate the shear bond strength (SBS) of pretreated monolithic zirconia surfaces bonded to human dentin following IDS using two different self-adhesive resin luting agents. | 60 third molars were used, resulting in 120 dentin specimens. Specimens were randomly assigned to eight groups depending on dentin conditioning method (IDS or DDS), zirconia surface pretreatment, and adhesive luting agent type. Bonded specimens were water-stored and subjected to SBS testing. Fracture type was evaluated with stereomicroscopy. | All factors significantly affected SBS values. Dentin conditioning method presented the greatest effect. Based on the fracture type, adhesive failures at the luting agent-zirconia interface were the least common. | Bonding strategies for monolithic zirconia restorations could potentially benefit from IDS, regardless of the adhesive luting agent system used. |
| 7. | Hayashi et al. (2019) | Examine the influences of clinical application of IDS and temporary restoration (TR) on prepared abutment surfaces on the bonding of CAD/CAM ceramic crown restorations after cyclic loading. | Standardized abutments were prepared in 60 human mandibular premolars. Dentin surfaces of half of the specimens were sealed with adhesive and flowable composite, while those of the other half were not sealed. A half of both sealed and non-sealed specimens were restored using a temporary cement and temporary crown. Each individual CAD/CAM ceramic crown was fabricated and cemented to an individual abutment. The restored specimens were subjected to cyclic loading, and the μ-TBS were measured. | The μ-TBS values in the restoration group with IDS were significantly greater than those without IDS.The Weibull modulus, PF10, and PF90 values in the IDS restoration group were significantly greater. Most of the post-test specimens exhibited mixed fractures consisting of interfacial fracture occurring at the interface between fabricated crown and resin cement and cohesive fracture occurring within the resin cement. | IDS contributed to an increase in the bond strength, whereas Temporary Restoration did not affect the bond strength. |

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| 8. | Van den breemer et al. (2019) | Evaluate the μTBS of resin-based composite (RBC) to dentin after different immediate dentin sealing (IDS) strategies and surface-conditioning (SC) methods and on two water storage times. | Human molars (n=48) were randomly divided into eight experimental groups involving 4 different IDS strategies: IDS-1L, IDS-2L, IDS-F, and DDS and 2 different SC methods. The μTBS test was performed after one week and after six months of water storage. Failure mode and location of failure were categorized. | After one week of water storage the IDS strategy and type of SC did not not produce statistical difference. However, the interaction of IDS strategy and SC methods appeared statistically significant. After 6 months of water aging, SC did not significantly affect μTBS, while IDS strategy significantly influenced μTBS. Failure was observed mainly at the adhesive-dentin interface for all the evaluated groups. | Dentin exposure during clinical procedures for indirect restorations benefits from the application of IDS, which was shown to result in higher bond strength. No significant differences were found using SC methods. |
| 9. | Hofsteenge et al. (2020) | Compare the in vitro, laboratory aging, fracture strength, failure mode and reparability of molars restored with lithium disilicate inlays and overlays in conjunction with or without IDS. | 40 extracted molars were divided into 4 groups: 1) Inlays with IDS; 2) Inlays without IDS; 3) Overlays with IDS; 4) Overlays without IDS.<br><br>The indirect restorations were luted with a heated composite. The restored teeth were subsequently challenged during aging (1.2 million cycles) and thermocycling loading. Subsequently, the fracture strength was tested, and failure analysis was performed. | Teeth restored with an onlay were stronger than those restored with an inlay restoration. Teeth with IDS were stronger overall than those without IDS. Subsequently, custom hypothesis tests showed that there was no statistically significant difference in fracture strength between inlays with IDS and overlays without IDS. | Both variables IDS and overlay preparation improve overall fracture strength. Inlays with IDS and overlays without IDS didn't differ in fracture strength. Both inlays and overlays are strong enough to withstand physiological chewing forces. |
| 10. | Hironaka et al. (2018) | Analyze the influence of IDS and interim cementation on the adhesion of indirect restorations with a dual-polymerizing resin cement. | Composite resin inlays were placed in class V cavities prepared in the buccal and lingual surfaces of 30 extracted human molars with a dual-polymerizing resin cement in 3 different ways: CG, directly on dentin; PG, after 14 days interim cementation; SG, after IDS and 14 days interim cementation. Buccal restorations were sectioned into sticks and submitted to the μTBS test. Lingual restorations were submitted to micro-Raman spectroscopy (MRS). | Significantly higher μTBS results were found for SG when compared with CG and PG, but no differences were observed between CG and PG. MRS showed that the diffusion zone in SG was significantly thicker than that of CG or PG. | The use of IDS before cementation resulted in a chemical interaction at the interface and significantly higher μTBS and diffusion zone thickness values. Interim cementation did not interfere with adhesion quality when compared with the control group. |
| 11. | Van den breemer | This study evaluated the shear bond strength (SBS) of resin cement to dentin after applying two adhesive (A) | 140 third molars were collected and randomly split between the two adhesive systems (AO; AC). The adhesive groups were further divided into 4 IDS strategies. Each strategy group was categorized into one of the two SC methods. IDS was applied, | AO groups exhibited higher mean SBS values than AC groups. Both DDS groups showed significantly lower SBS values compared with all the IDS groups. No significant differences in SBS results were found between the IDS | IDS improve the SBS compared with DDS. No significant differences were |

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| | et al. (2019) | systems with a combination of four different IDS strategies, and two surface conditioning (SC) methods. | followed by temporary restorations. These were removed after 2 weeks of water storage, and the IDS surfaces were subsequently conditioned. All specimens were subjected to thermocyclic aging. Shear force was applied to the adhesive interface. Fracture types and locations after loading were classified. | groups and between the SC methods. Dentin-cement interface failures diminished with the application of IDS. | found between the tested conditioning methods. |
| 12. | Ashy et al. (2020) | Investigate the marginal and internal adaptations of ceramic inlay restorations placed with IDS vs DDS procedures. | 12 molar teeth were randomly allocated into 6 groups of 2 teeth each. Lava Ultimate inlays were fabricated and luted to the cavities using All-Bond universal adhesive system and eCEMENT dual-curing resin cement following IDS/immediate cementation (control groups 1 and 2), IDS/delayed cementation (groups 3 and 4), or DDS/delayed cementation (groups 5 and 6) protocols. Teeth in groups 2, 4, and 6 were subjected to thermocycling after inlay cementation. The marginal and internal gap volumes were determined using microcomputed tomography images. | Marginal gap volume for DDS was significantly higher than that of IDS immediately after inlay cementation. Following thermocycling, the internal gap volume for DDS was significantly higher than that for IDS but the marginal gap volume of DDS was not significantly different from that of IDS. | Luted ceramic inlays have a superior marginal adaptation right after cementation and a superior internal adaptation after thermocycling when using the IDS technique compared to the DDS technique. However, marginal adaptation after thermocycling was not significantly different between the two techniques. |
| 13. | Van den breemer et al. (2021) | Evaluate the clinical performance of partial glass-ceramic (IPS e.max Press) posterior restorations in cinjunction with IDS. | 765 restorations in 158 patients were placed between 2008 and 2018 and evaluated in a prospective study during regular dental care visits between 2015 and 2018. The restorations were luted with a conventional photo-polymerized resin composite in conjunction with an IDS procedure. | The survival and success rates after 5 years cumulated to 99.6% and 98.6%, respectively. The condition of the vast majority of the restorations remained unaffected for 5 years. | Partial glass-ceramic posterior restorations luted by means of a conventional photo-polymerized resin composite in conjunction with the use of an IDS procedure have an excellent medium-term prognosis. |
| 14. | Brigagão et al. (2017) | Evaluate the bond strength of 2 different resin cements (conventional and self-adhesive) with or without previous dentin sealing and | 45 molars were used. 20 teeth (n=5 per group) were treated with the conventional resin cement associated with etch-and-rinse or self-etch adhesive approaches, applied before (IDS) or after (DDS) the application/removal of interim cement. Another 25 teeth (n=5, per group) were treated with self-adhesive resin cement with or without adhesive application. In | The application of adhesive before interim cement (IDS) promoted the highest values of bond strength for both resin cements. For self-adhesive resin cement, polyacrylic acid-enhanced bond strength after the application of interim cement. | The application of dental adhesive immediately after tooth preparation (IDS) and before the use of an interim cement promoted the highest values of bond |

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| | | the effect of interim cement. | the self-adhesive resin cement group, the application of polyacrylic acid for dentin etching before cementation was evaluated. μTBS was tested.The failure patterns were classified as cohesive, adhesive, or mixed. | | strength to dentin with the resin cements tested. |
| 15. | Van den breemer et al. (2019) | This prospective randomized clinical trial evaluated tooth sensitivity and patient satisfaction after the provision of partial ceramic restorations bonded using IDS or DDS on vital molar teeth through a within-subject comparison study. | Between 2013 and 2016, 30 patients received 2 lithium disilicate ceramic partial restorations on vital first or second molar teeth. The two teeth randomly received either IDS or DDS. Partial preparations were performed on all teeth and directly after tooth preparation. IDS was achieved using self-etch adhesive followed by the application of flowable resin. Partial ceramic restorations were bonded 2 weeks after preparation. The teeth were evaluated preoperatively and at 1 week, 3 months, and 12 months using a cold test and a questionnaire for perceived tooth sensitivity. Patient satisfaction was evaluated. | There was no significant difference in patient-reported tooth sensitivity between the preoperative phase and all other time points. There was also no significant difference between IDS and DDS for all items on the questionnaire. Patient satisfaction did not differ significantly between the IDS and DDS groups. No tooth sensitivity change was noticed with the application of partial ceramic indirect restorations. | This clinical study could not confirm that IDS is more advantageous than DDS in terms of tooth sensitivity and patient satisfaction at 1 year of clinical service of partial ceramic restorations. |
| 16. | Van den breemer et al. (2019) | The survival and success rate and the quality of survival of partial ceramic restorations bonded employing IDS or DDS in vital molar teeth were evaluated in a randomized clinical trial with within-subject comparison study. | 30 patients received two lithium disilicate ceramic partial restorations on vital first or second molar teeth. The two teeth randomly received either IDS or DDS. Partial ceramic restorations were luted two weeks after preparation. Evaluations were performed at 1 week, 12 months and 36 months post-operatively. Representative failures were evaluated microscopically (SEM) and by means of simplified qualitative fractography analysis. | The overall survival rate after 3 years was 98.3% and the overall success rate was 85%, with no significant difference between restorations in the IDS and DDS group. For the quality of the survival, no statistically significant differences were found between IDS and DDS restorations. | Adhesively luted partial ceramic restorations in vital molar teeth have a good prognosis, however IDS did not show any differences in success and survival rates after 3 years of function. |
| 17. | Ishii et al. (2017) | Examine the bonding state of metal-free CAD/CAM onlay restorations made from two popular resin composite blocks and a typical glass-ceramic block after cyclic loading, with and without IDS. | 24 human molars were used. The intra-cavity dentin surfaces of half of the cavities were immediately sealed with all-in-one adhesive and flowable composite, while those of the other half were not. CAD/CAM onlays were fabricated from 3 types of block and cemented with an adhesive resin cement system. The restored specimens were subjected to cyclic loading and the intra-cavity μTBS was measured. | CAD/CAM restorations with IDS had a tendency to be significantly superior in terms of bond reliability. CAD/CAM restoration with IDS tended to require a significantly greater stress to debond the adhesion than restorations without IDS. | IDS improve not only the internal bond strength, but also the bond reliability of metal-free CAD/CAM onlay restorations. |

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| 18. | Ferreira-Filho et al. (2018) | Investigate the behavior of four adhesives when used for IDS. | 4 adhesive systems were used to perform IDS. After 7 days of water storage, specimens were sectioned into beams. Half of the specimens were tested in tension after 7 days of water storage at 37°C, while the other half was stored for 3 months prior to testing in tension. The failure pattern was determined using a stereomicroscope and SEM. μTBS data were analyzed. | All groups in which IDS was performed presented higher μTBS values when compared to the control group. Found no differences in μTBS among the adhesives tested and the control group (without IDS) after 7 days/3 months of water storage. Failure mode analysis showed a prevalence of adhesive failures between the resin cement and dentin, which suggests that the dentin would still remain sealed even if interface debonding occurred. | IDS technique is recommended in order to increase μTBS during the provisional phase. |
| 19. | Van den breemer et al. (2017) | Evaluate the effect of IDS on the fracture strength and failure types of two indirect restorative materials. | Standard MOD inlay preparations were made on 40 molars (n=10 per group) and randomly divided into 4 groups to receive the inlay with and without IDS. After salinization inlays were cemented using adhesive resin cement. The specimens were thermo-mechanically aged and then subjected to load to failure. Failure types and locations of debondings were classified. | Material type and the application of IDS significantly affected the results of mean fracture strength. Neither the material type, nor the application of IDS affected the severity of the failure types. In 95% of the cases, the IDS layer left adhered on the tooth surface after fracture tests. | IDS improve adhesion, and thereby the fracture strength of inlays made of lithium disilicate but not that multiphase resin composite. |
| 20. | Yazigi et al. (2017) | Evaluate the efficiency of IDS and the effects of different bonding protocols on the fracture strength of CAD/CAM occlusal veneers bonded to exposed dentin. | 96 premolars were divided into 3 main groups with 32 specimens each: without IDS, with IDS and total etching and with IDS and selective etching. Teeth were prepared in the dentin to receive occlusal veneers. Half of the specimens of each subgroup were subjected to thermo-dynamic loading. The other half and the surviving specimens were subjected to quasi-static loading until failure. | A significantly higher fracture strength of restorations was obtained when IDS was followed regardless of the etching method. Neither the pre-cementation treatment nor the artificial aging had a statistically significant effect on the fracture strength. | IDS protocol is recommended whenever dentin is exposed during the preparation for thin glass-ceramic occlusal veneers. |

Table 2. Data and outcomes from articles

# 5. Discussion

## 5.1 Dentin bonding mechanism

The intimate association of adhesive and dentin substrate is a key element for adhesion. Considering its heterogeneous nature and physiological variations, dentin bonding will be the result of a complex interaction between dentin's structure and the adhesive system. Dentin forms the main bulk of the crown and root of the tooth. It is a living tissue susceptible to permanent adaptation by apposition or resorption of mineral matter. It is less mineralized than enamel (70%) and therefore less hard. The structure is organized of very fine canals: the dentinal tubules that make dentin a highly permeable tissue. These dentinal tubules contain the odontoblastic processes as a direct connection to the vital pulp, which move from a low concentration at the dentin-enamel junction (DEJ) to a higher concentration at the predentin surface near the pulp. Furthermore, dentinal fluid in the tubules is expose to constant external pulp pressure. A highly mineralized peritubular dentin lines the tubule lumen, containing primarily apatite crystals with little organic matrix. The tubules are separated by intertubular dentin composed of a matrix of type I collagen reinforced by apatite. The structural component of dentin will vary considerably over their course. As a consequence, dentin morphology and its important properties such as permeability, elasticity, wetness may affect bond strength, hardness and shear strength. Adhesion to dentin is challenging because of the complex composition of dentin's mineral, organic, and fluid phases. (2,5,7)

During cavity preparation, the rotary movement of instrumentation cause dentin debris, to aggregate as a "smear-layer" which covers the dentin and penetrates into the tubules to form "smear-plugs". This adherent layer is composed of shattered and crushed hydroxyapatite and denatured collagen. Besides, bacteria and saliva can contaminate the smear-layer in clinical situation. A relevant problem of keeping smear-layer, is its inherent weak bond to the underlaying dentin. As a consequence, most of adhesives systems use acid etching (acidic conditioners) to remove it entirely, in order to reach a good bonding capacity. Quality of dentin bonding depends on effective adhesive's penetration of partially demineralized dentin, and removal of adherent smear layer. To do this, etching is used in order to induce demineralization. The mineral phase of dentin is fully removed during etching,

exposing a scaffold of collagen fibrils hanging in water and nearly totally depleted of hydroxyapatite. The demineralization must be sufficient to allow penetration of the adhesive, but not too much, as not to leave a zone of weakness and collapsed collagen. In fact, a certain measure of water is crucial to prevent the collagen fibrils from collapsing. (2,3,18)

The actual superior dentin bonding mechanism is attributed as a concept of "Hybridization" proposed by Nakabayashi which consists of an "hybrid-layer" formation by infiltration of the adhesive monomers into the exposed collagen network, and subsequent polymerization. The DEJ can be regarded as a perfect fibril reinforced bond. Hybridization can generate a "structural" bond somewhat similar to the interphase formed at the DEJ. The monomers polymerization within the collagen network spaces creates a "resin-collagen composite" (the hybrid layer), which provide micromechanical retention. During the clinical procedure of hybridization, certain failures can occur, susceptibility of the hybrid layer to collapse until it polymerizes, contamination of the dentin and subsequent irritation of the pulp. For that, in case of indirect restorations, immediate dentin sealing (IDS) after tooth preparation is recommended. (5,13,18–20)

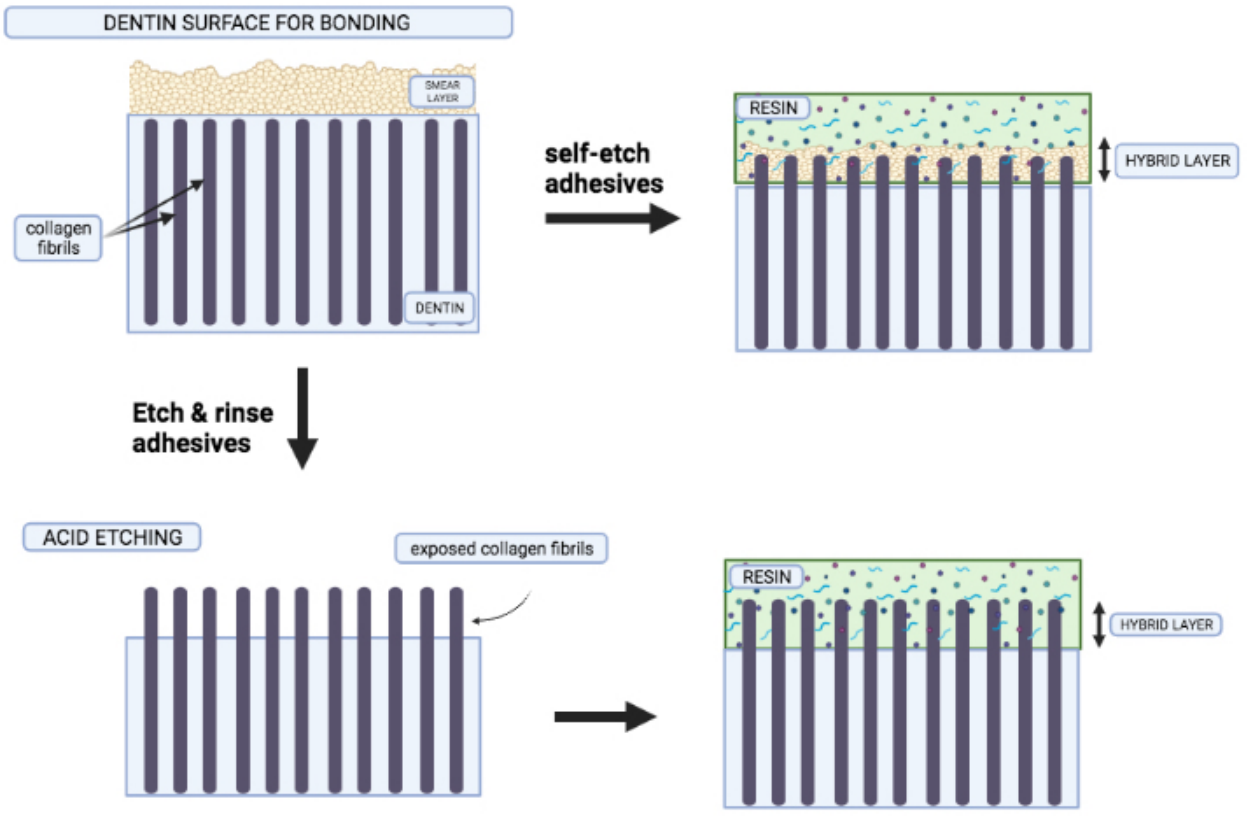


Figure 2. Schematic illustration of bond structure of a self-etching system and etch-and-rinse system (total-etch). The structure of the hybrid layer of total-etch adhesives consists of resin and collagen fibrils. The combination of resin, collagen fibrils and the smear layer are a typical hybrid layer of self-etching adhesives.

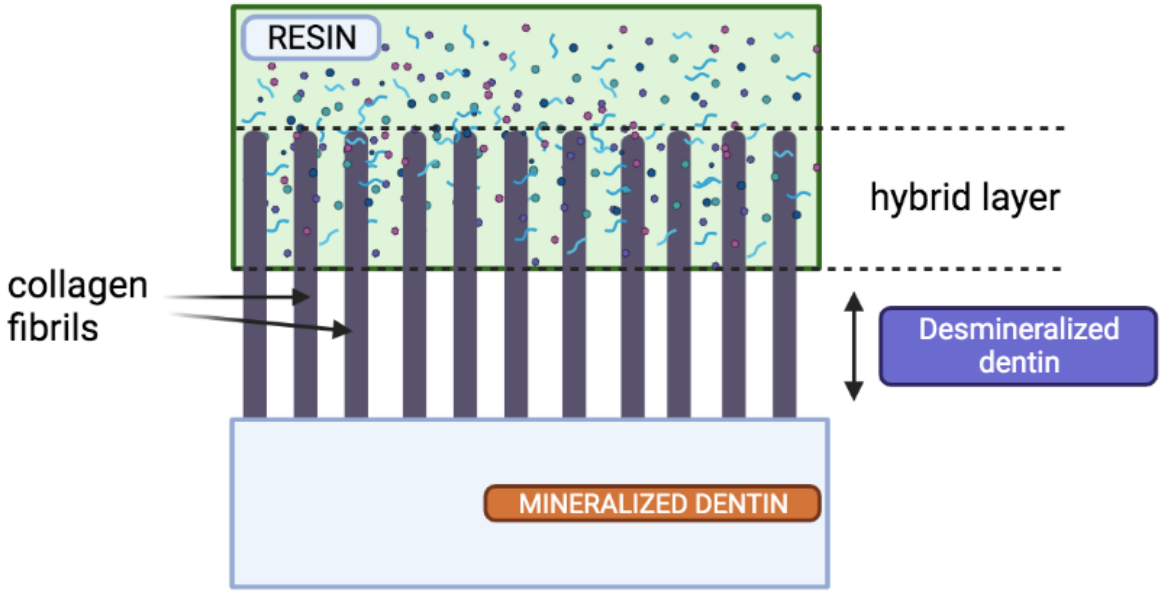


Figure 3. Schematic illustration of dentin hybridization with etch and rinse adhesives.

## 5.2 Immediate Dentin Sealing

Adhesive cementation of indirect restorations with substantial exposure of dentin structure is regarded among the most challenging tasks of bonded indirect restorations. Traditionally, application of dentin resin adhesive to exposed dentin was performed just prior to cementation, so-called "delayed dentin sealing" (DDS), where curing of the dentin bonding resin was performed together with the luting agent. Magne P. coined the term "immediate dentin sealing" (IDS) and extended its use for indirect bonded restorations. IDS has been described as the sealing of dentinal tubules with filled adhesive resin immediately after tooth preparation. The procedure includes application and polymerization of a dentin bonding agent (DBA) to freshly cut dentin directly after tooth preparation and before the final impression for the indirect restoration is taken. IDS has been assumed to result in superior bond strength, less gap formation, decreased bacterial leakage, and reduced dentin sensitivity when compared to DDS. (5,13,19–21)

The IDS technique rests upon four fundamental principles. Firstly, only fresh-cut, contaminant-free dentin provides the optimum substrate for bonding. In any other case, the bond strength is inferior. Secondly, pre-polymerization of the DBA prior to cementation ensures a hybrid layer that is not influenced by stress exerted during cementation and results in improved bond strength. The pressure of the luting resin during the seating of the restoration can create a collapse of demineralized dentin and subsequently affect adhesion. Thirdly, IDS allow stress-free dentin bond development. In fact, using indirect bonded restorations because of the delayed placement of the restorations and postponed occlusal loading, the dentin bond can increase over time and residual stresses can dissipate, resulting in significantly improved restoration adaptation. Fourthly, IDS protect dentin against fluid and bacterial leakage during the provisional phase. (5,13,19,22–24)

The first step towards IDS is to distinguish dentin from enamel. For that, a preliminary etching of 2–3 s is executed on the prepared tooth surface. After a meticulous rinsing, enamel acquires a "frosty" appearance, whereas dentin is more "glossy". Then, a fresh layer of dentin is re-exposed, re-etch and a thick layer of a DBA is applied and light polymerized. Finally, the DBA is polymerized additionally

through glycerin gel (air-blocking) to reduce the "oxygen-inhibition layer" (OIL). This layer acts as an inhibitor of the polymerization reaction but also interferes with the impression material and the adhesion of the provisional restoration material. (13,23)

Contemporary dentin bonding systems depend on how adhesives interact with the smear layer, dissolving it or making it permeable. The classification of adhesive systems in generations is obsolete. Conventional adhesive system known as "Etch-and-rinse" or "total-etch" adhesive strategy is considered as the perfect DBA for IDS. These systems are reported to achieve the highest bond strength values. The improved bond strength after dentin etching with phosphoric acid may also be due to the rinsing after the etching. In fact, rinsing removes contaminants from the interim cement, improving adhesion to dentin. Nowadays, in the quest of user-friendliness and less technique-sensitive system, some clinicians feel more comfortable using "self-etch" DBA. Self-etch adhesives do not require a separate etching step, as them monomers are acidic and simultaneously demineralize and penetrate the dentin, while incorporating the smear layer into the adhesive interface. Those adhesive systems seem to be reliable and have excellent clinical performance. (5,9,22,23,25)

Moreover, if unfilled DBA is used for IDS, it should be reinforced by a thin layer of flowable resin composite subsequent to the application of the DBA, to protect and strengthen the hybridized dentin, the so-called "reinforced IDS" approach. Likewise, a variant of IDS is the so-called "resin coating technique" that combines the DBA with the application of a flowable composite. The elastic modulus of the flowable resin composite (7-8 GPa) is smaller than the dentin (16-18 GPa) and is slightly larger than that of the adhesive resin cement (6 GPa). Consequently, the combination of DBA and flowable composite forms a stress-breaking resin layer that absorb stress resulting from polymerization contraction or functional stress. It also leads to better adaptation of deep preparations indirect restorations like inlays or onlays. Hence, the resin coating technique can minimize pulp irritation, improve the bond strength between a resin cement and tooth, and enhance interfacial adaptation of the restorations. (8,26)

## 5.3 Efficiency of IDS in indirect restorations.

a) In vitro studies

- Bond strength: μTBS

The IDS has been studied extensively in in vitro studies and obtained significantly increased μTBS compared to IDS improved the μTBS to dentin when a filled DBA was used. Unfilled/lightly filled DBA should be reinforced with a flowable resin coating to improve the μTBS to dentin for IDS. (4,5,8,9,14–16,23,24,26–28)

- Fracture strength and Failure analysis

IDS significantly improved the fracture resistance of indirect restorations like lithium disilicate inlay or occlusal veneers bonded to dentin. Mostly in the failure analysis it was noted that the IDS layer was still intact on the dentin surfaces after the fracture test. Besides most of the cases exhibited mixed fractures consisting of interfacial fracture occurring at the interface between ceramic restoration and resin cement and cohesive fracture occurring within the resin cement. This implies that adhesion to dentin was in fact more stable than the adhesion of the resin composite to the surfaces of ceramic restoration. (24–27,29)

- Enhanced adaptation

The IDS technique results in a smaller marginal gap volume at the tooth-restoration interface than the DDS technique immediately after cementation. It was found that IDS improved marginal adaptation and provided superior internal adaptation of ceramic inlays following IDS. The IDS application may smoothen the intra-cavity surfaces and round angles. Also allowing better cavity adaptation than that of a restoration without IDS. (15,21)

b) Clinical studies

- Reduced post cementation sensitivity

Some articles referred to the work of Hu and Zhu, that shows that the use of IDS can significantly reduce post cementation hypersensitivity and improve comfort during the provisional restoration period. (15,20,27) The clinical trial directed by Van den Bremer et al. revealed that no patients reported tooth sensitivity after 36 months. (6)

- Survival and success rate

Survival and success rate were evaluated in many clinical trials. Van den bremeer et al. publish in 2019, that IDS shows goods short-term survival results when bonded posterior partial crowns. After 3 years, the overall survival rate of partial restorations bonded using IDS was 98.3% and the overall success rate was 85%. The number of absolute failures was limited. (6,20)

A recent prospective clinical trial published in 2021 by Van den bremeer et al., evaluate 765 glass-ceramic posterior restorations in conjunction with IDS, the restorations presented excellent estimated survival rate (99.6%) and success (98.6%) rates after 5 years. (17) In another prospective clinical trial, the ceramic laminate veneers with IDS had a high survival rate of 95% over 11 years. (30)

## 5.4 Clinical protocol

1. Cavity preparation.
2. Identify the exposed dentin surface.
3. Etch freshly cut dentin with phosphoric acid for 15 seconds.
4. Rinse and remove excess water (depending on the type of adhesive being used).
5. Application of primer. Apply either a three-step system or the self-priming resin.
6. Application of DBA. Apply adhesive resin with a microbrush followed by removal of excess solvent using suction/gentle air drying and light polymerization for 20 seconds.
7. Air-blocking. Apply a layer of glycerin jelly (air-blocking to limit formation of "oxygen-inhibition layer") to the adhesive and slightly beyond followed by additional polymerization for 10 seconds.
8. Recommended application of a thin layer of flowable resin composite if unfilled/lightly filled DBA is used. Subsequent light polymerization.
9. Redefine the enamel margins with a diamond bur to remove any excess adhesive.
10. Gentle pumicing of the resin coating.
11. Impression.
12. Provisional restoration.
13. Removal of provisional restoration, then cleaning of the cavity in order to remove any remnant provisional material.
14. The final restoration is cemented with a resin-based cement.

# 6. Conclusion

IDS is an optimized dentin bonding mode and represents the best dentin bonding strategy when using indirect bonded restorations. Freshly cut dentin surfaces should be sealed with a DBA immediately following tooth preparation. The IDS technique has been proposed in an attempt to improve the quality of bonded interfaces in indirect restorations, in which dentin is hybridized with a two-step self-etch or a three-step etch-and-rinse adhesive system after preparation. The use of a filled DBA or the combined use of an unfilled DBA and a flowable composite liner facilitates the clinical and technical aspects of IDS. This procedure contributes to the occurrence of increased bond strength and reduces the dentin sensitivity. Several practical and clinical facts support the use of IDS as patients experience improved comfort during the provisional restoration phase and reduced postoperative sensitivity. A comprehensive knowledge of the structure of dentin and its altered properties after dentin preparation, have been presented and should enable a dentist to understand how to achieve satisfactory bonding to dentin. A detailed clinical protocol was also proposed.

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