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Review Article

Delayed Versus Immediate Placement of Direct Resin Composite Restorations Following Vital Pulp Therapy with ProRoot® Mineral Trioxide Aggregate or Biodentine™: A Review of the Literature

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Abstract

The quality of final restoration is one among other important factors that should be considered for a successful outcome of vital pulp therapy (VPT) because an inadequate coronal seal can allow bacterial penetration reaching to the pulp tissue, resulting in failure of VPT. Resin composite has been one of the most commonly used direct intra-coronal permanent restorations, whereas calcium silicate-based cements (CSCs), especially ProRoot® MTA and Biodentine™, are currently recommended as the pulp dressing materials of choice for VPT. However, resin composites cannot be immediately and directly placed as final restorations following VPT with ProRoot® MTA or Biodentine™ because of their prolonged setting time. Moreover, the suitable time elapsed for the placement of resin composites over these two cements is still controversial. This review aimed to gather current information regarding the immediate or delayed placement of resin composite restoration following VPT with ProRoot® MTA or Biodentine™. In addition, a practical approach for resin composite placement has also been discussed.

Keywords: Biodentine™, delayed versus immediate placement, direct resin composite restorations, ProRoot® MTA, vital pulp therapy

Introduction

With an increased understanding of pulp biology and the development of bioactive endodontic materials, vital pulp therapy (VPT) has demonstrated very promising results lately.[(1)] Bioactive endodontic materials, such as calcium silicate cements (CSCs), are capable of forming calcium hydroxide during their hydration process. As a result, they yield calcium and hydroxyl ions, forming an apatite layer when in contact with biological fluids. Moreover, they can induce a release of biologically relevant ions potentially acting as epigenetic signals that further stimulate a positive biological response.[(2)] Effective sealing of coronal restoration was found to be another significant factor influencing the successful outcome of VPT-treated teeth.[(3,4)] However, unlike for the root canal treated teeth, there is limited information available for the VPT-treated teeth regarding appropriate restorative techniques following VPT procedures, particularly with CSCs.

Resin composites have been one of the most commonly used direct intra-coronal permanent restorations[(5-7)] whereas CSCs, such as ProRoot® MTA and Biodentine™, are currently recommended as pulp dressing materials of choice for VPT.[(8,9)] However, the major drawback of ProRoot® MTA is its prolonged initial setting time (2 hours 45 minutes); hence, resin composites could not be immediately and directly placed as final restorations following VPT. Conversely, for Biodentine™, as its initial setting time is 12 minutes, shorter than that of ProRoot® MTA[10], thus making it possibly for immediate placement of resin composite within a single visit. Nevertheless, controversies exist regarding the appropriate elapsed time for resin composites that should be placed over both ProRoot® MTA and Biodentine™.

Therefore, the purposes of this literature review are 1) to explore *in vitro* and clinical studies relating to immediate or delayed placement of direct resin composite restorations following VPT with ProRoot® MTA or Biodentine™, and 2) to discuss a practical restorative approach in this clinical scenario. However, the importance of VPT and the basic knowledge of the commonly used CSCs, ProRoot® MTA and Biodentine™, will be briefly described first to lay basic knowledge for the readers.

Vital pulp therapy procedures in young permanent teeth with cariously exposed vital pulp

Traditionally, permanent teeth with cariously exposed vital pulp have been treated with root canal treatment (RCT).[11] However, the survival rate of root canal filled teeth is not as good as that of vital teeth, especially in molars.[12] RCT is the procedure that devitalizes the treated teeth, leading to the loss of proprioceptive sensation[13] and damping property[14] that may consequently decrease the tooth strength. Therefore, when indicated, VPT should be considered as an alternative treatment to RCT in permanent teeth with cariously exposed vital pulp.[5,6,15] Based on the concept of complete or non-selective caries removal, there are three VPT techniques: direct pulp capping (DPC), partial pulpotomy (PP), and coronal pulpotomy (CP). From the systematic review by Aguilar and Linsuwanont[1], DPC provided a less predictable outcome than PP and CP because DPC does not involve the removal of inflamed pulp tissue underneath the carious lesion. It is assumed that the completion of the inflamed pulp tissue removal is critical to the success of VPT. However, other factors that may affect VPT success include the type of pulp dressing materials used and the effective sealing of coronal restoration. Both factors will be discussed in greater detail in the respective order.

Calcium silicate cements used as a pulp dressing material in vital pulp therapy

CSCs are bioactive materials commonly used in VPT and there are many commercially available CSCs on the market.[16,17] However, this article will mainly focus on ProRoot® MTA and Biodentine™

ProRoot® MTA

ProRoot® MTA (Dentsply Tulsa Dental, Tulsa, OK, USA) was first introduced by Torabinejad in 1990 and was approved for use in endodontic treatment by the U.S. Federal Drug Administration in 1998.[18] In 1999, ProRoot® MTA was the first commercial mineral trioxide aggregate (MTA) product introduced in the United States.[19] This cement has been recommended for various applications, as it can be used to seal off pathways of communication between the root canal and the external surface of the tooth such as filling the root canal, creating an apical barrier in apexification, repairing root perforations, and treating internal root resorption. Moreover, it has been used successfully as a pulp dressing material in VPT.[8,20]

ProRoot® MTA has two main compositions including powder and liquid, as shown in Figure 1 and Table 1. In preparation, the powder is mixed with distilled water in a 3:1 ratio on a glass slab; the material has a grainy and sandy consistency, thus making it difficult to handle.[8,21]

Figure 1: ProRoot® MTA

The setting reaction of this cement is a hydration process of tricalcium silicate and dicalcium silicate that occurs when these particles react with sterile water. The main products from this reaction are calcium silicate hydrate gel and calcium hydroxide, that can produce the alkaline pH environment.[22] The initial setting time of ProRoot® MTA is approximately 2 hours 45 minutes and complete setting time may be up to 21 days.[8,18] The delayed setting time of ProRoot® MTA can increase risk of material loss[8,23]; thus, is considered the major drawback of this material.

Biodentine™

Biodentine™ (Septodont, Saint-Maur-des-Fossés, France) is a new calcium-silicate based material developed by Septodont in 2011[10] and has been advocated to be used in different clinical applications such as temporary filling, permanent dentin replacement, a root-end filling material, repair of root perforations, apexification, and a pulp dressing material in VPT.[10,24,25]

Biodentine™ has two main components consisting of the powder in a capsule and the liquid in a pipette, as shown in Figure 2 and Table 1. In preparation, this cement is created by adding 5 drops of liquid to the powder in the capsule and the combined components are mixed with an amalgamator for 30 seconds at 4000 rpm leading to the formation of cement.[10,24)

Figure 2: Biodentine™

The setting reaction of Biodentine™ is a hydration process that produces the hydrated calcium silicate gel and calcium hydroxide. This cement has a shorter initial setting time compared to ProRoot® MTA because of the addition of calcium chloride as a setting accelerator in liquid part of this material.[25] The initial setting time according to the manufacturer is 12 minutes; however, the final setting time of 45 minutes has been reported.[10,26] Moreover, in one study, the final setting time of Biodentine™ was estimated to be 85.66 minutes, almost double the setting time described by the manufacturer.[27]

Resin composite restorations following vital pulp therapy in young permanent teeth

One of the most important post-operative factors affecting the long-term successful outcome of endodontic treatment is the quality of the final restoration where effective sealing of a suitable coronal restoration was found to be a significant factor influencing the survival rate of VPT-treated teeth.[3,4]

Resin composite has been one of the most commonly used direct intra-coronal permanent restorations in dentistry. In a VPT procedure, the quality of coronal seal is dependent on the bond strengths between restorative materials and the remaining tooth structure as well as between restorative materials and pulp dressing materials, the former can be found elsewhere and the later will be emphasized in this review. Currently, controversies exist regarding the most appropriate restorative protocol for resin composite following CSC placement, including time elapsed before placing restoration, type of base materials, and type of adhesives used.

Restorative approaches for resin composite placement over ProRoot® MTA

Regarding direct resin composite restoration following VPT with ProRoot® MTA, there are generally two clinical approaches: delayed (multiple-visit) and immediate (single-visit) approaches.

Resin composite placement over ProRoot® MTA: Delayed placement or multiple-visit approach

Since ProRoot® MTA is a hydrophilic CSCs that has an initial setting time of 2 hours 45 minutes[28]; the resin composite could not be placed immediately and directly over freshly-mixed ProRoot® MTA. Etching of the unset ProRoot® MTA layer could affect its physical properties and rinsing could dislodge the material.[29-31] Moreover, because of their hydrophilic nature, all CSCs usually require water for their complete maturation.[28] A moist cotton pellet has traditionally been recommended to be placed over freshly mixed ProRoot® MTA, followed by a temporary restoration which is further replaced by a permanent restoration in a subsequent visit.[8] Interestingly, several *in vitro* studies demonstrated that the appropriate elapsed time for resin composite placement should be at least 4 days after the mixing of ProRoot® MTA to avoid the adverse effects of acid etching on its surface and to allow this cement to have optimal physical properties.[29,30,32]

Inevitably, the type of adhesives used for bonding between ProRoot® MTA and resin composite should also be discussed. There were several *in vitro* studies that evaluated and compared the shear bond strength (SBS) values between ProRoot® MTA with different setting times (0 hour to 7 days) and resin composites, as shown

Table 1: Composition and setting time of ProRoot® MTA and Biodentine™ (Modified from Kaup M, Schafer E, Dammaschke T. An *in vitro* study of different material properties of Biodentine™ compared to ProRoot® MTA. *Head Face Med* 2015; 11:16.[27])

Calcium silicate cement (Manufacturer)	Chemical composition				Setting time	
	Component	Constituent	Function	Content (wt%)	Initial	Final
ProRoot® MTA (Dentsply®)	Powder	Tricalcium silicate	Portland cement (Main component)	75	165 min	21 days
		Dicalcium silicate				
		Tricalcium aluminate				
		Tetracalcium aluminoferrite				
		Bismuth oxide	Radiopacifier	20		
		Calcium sulfate dihydrat	Gypsum	5		
	Liquid	Distilled water	Solvent	100		
Biodentine™ (Septodont®)	Powder	Tricalcium silicate	Main core material	>70	12 min	45 min (up to 85 min)
		Dicalcium silicate	Second core material	<15		
		Calcium carbonate	Filler	>10		
		Iron oxide	Coloring agent	<1		
		Zirconium oxide	Radiopacifier	5		
	Liquid	Water	Main liquid	N/A		
		Calcium chloride	Accelerator	>15		
		Hydrosoluble polymer	Water-reducing agent	N/A		

in Table 2. Although most studies concluded that total-etch adhesive is superior to self-etch adhesive, conclusions regarding the appropriate type of adhesives that should be used over ProRoot® MTA could not be drawn. There is a wide variation in setting time intervals, brands of adhesive and resin composite, and methodologies used between studies. Furthermore, the SBS value has mainly been obtained from laboratory studies, as such there may be some limitations for its clinical application.

Regarding the base materials that should be used, conventional glass ionomer cement (GIC) was one of the base materials recommended to be layered over the partially set ProRoot® MTA, after 45 minutes of ProRoot® MTA mixing.[31,39,40] However, GIC should not be placed over freshly mixed ProRoot® MTA because GIC may absorb water from it, resulting in increased porosity and incomplete hydration of ProRoot® MTA.[41]

Several clinical studies adopted the delayed placement approach of resin composites over ProRoot® MTA, as shown in Table 3. However, this delayed restorative protocol increases cost, chair time, and risks of failure of the endodontic procedure.[42] Moreover, second dental visit is needed for final restoration and may not be suitable, especially for pediatric patients.[43]

Resin composite placement over ProRoot® MTA: Immediate placement or single-visit approach

Contrasting the traditional recommendation[8], several *in vitro* studies showed that ProRoot® MTA can absorb water from tissue moisture to enhance its maturation[44-46], thus resin composite restorative procedure may be completed within a single visit. Furthermore, several authors have inexplicably and conveniently placed different types of base materials on top of the ProRoot® MTA layer, without a wet cotton pellet or waiting for its complete setting.[6,47,48]

From an *in vitro* study's results, Camilleri[41] has demonstrated that a non-setting calcium hydroxide paste can be applied on a freshly mixed ProRoot® MTA without any effects on the hydration of this cement. Moreover, Eid *et al.*[49] have also demonstrated that resin-modified glass ionomer (RMGIC) can be used as a base material, covering on the freshly mixed ProRoot® MTA, before the placement of the final restoration. RMGIC does not affect the ProRoot® MTA-RMGIC structural interface[49] and has the lowest hydrophilic interaction energy, thus allowing for sufficient hydration for the setting of ProRoot® MTA.[50] Similarly, the manufacturer of ProRoot® MTA has recently recommended that a flowable compomer or an equivalent light-cured RMGIC can be used to cover the cement before placing the routine resin composite restoration.[51]

Table 2: *In vitro* studies showing the shear bond strength (SBS) between ProRoot® MTA at different setting time intervals and resin composites using different types of adhesives

Author, year	Type of adhesives	Brands of resin composite	MTA setting time interval	SBS values Mean ± SD (MPa)	Conclusions
Total-etch adhesive is superior to self-etch adhesive					
Tunç *et al.*, 2008[33]	Single Bond 2 (2-step total-etch)	Filtek™ Z250	48 hours	13.22±1.22	Single Bond 2 showed significantly higher SBS values than Prompt L-Pop
	Prompt L-Pop (1-step self-etch)			10.73±1.67	
Atabek *et al.*, 2012[34]	All-Bond SE (1-step self-etch)	Aelite	4 hours	5.06±0.42	If a longer waiting time can be practiced after MTA mixing, higher SBS values can be obtained Among all time intervals, One-Step Plus showed a significantly higher SBS to MTA than other groups
			24 hours	7.39±1.69	
			48 hours	9.42±0.77	
			72 hours	14.44±2.11	
			96 hours	14.93±1.86	
	All-Bond 3 (3-step total-etch)	Aelite	4 hours	5.14±0.85	
			24 hours	7.99±1.92	
			48 hours	10.82±1.63	
			72 hours	15.24±1.47	
			96 hours	15.09±2.35	
	One-Step Plus (2-step total-etch)	Aelite	4 hours	5.80±0.53	
			24 hours	9.53±1.38	
			48 hours	13.50±2.09	
			72 hours	18.25±1.34	
			96 hours	18.42±1.07	
	No adhesive system	Aelite	4 hours	N/A	
			24 hours	0.19±0.43	
			48 hours	0.24±0.67	
			72 hours	0.53±0.87	
			96 hours	0.78±0.57	
Tyagi *et al.*, 2016[35]	Prime & Bond NT (2-step total-etch)	Brilliant Flow	45 minutes	5.2±1.54	Among all time intervals, Prime & Bond NT is significantly higher SBS than other groups
			24 hours	7.3±1.49	
	All bond 7 (Self-etch)	Brilliant Flow	45 minutes	3.8±1.25	
			24 hours	4.8±0.98	
	Dyad flow (Self-adhering flowable composite)		45 minutes	3.4±1.17	
			24 hours	4.2±1.32	
Sulwinska *et al.*, 2017[36]	Single Bond Universal® (Total-etch mode)	Filtek™ Ultimate	Immediately	1.52±1.22	The highest SBS was obtained when the adhesive was used after 24 hours in a total-etch
			24 hours	6.89±5.25	
			72 hours	5.19±3.66	
	Single Bond Universal® (Self-etch mode)	Filtek™ Ultimate	Immediately	0.74±0.39	
			24 hours	3.81±3.79	
			72 hours	2.74±2.15	
Self-etch adhesive is superior to Total-etch adhesive					
Shin *et al.*, 2014[37]	Scotchbond Multipurpose (3-step total-etch)	Filtek Flow	7 days	6.98±2.37	AdheSE One F showed the highest bond strength between MTA and resin composite
	Single Bond 2 (2-step total-etch)			6.96±2.15	
	Clearfil SE Bond (2-step self-etch)			5.29±1.37	
	AdheSE One F (1-step self-etch)			8.25±1.89	
Total-etch and self-etch had equal results					
Oskoee *et al.*, 2014[38]	Single Bond (2-step total-etch)	Gradia Direct	48 hours	4.65±2.38	No significant differences in the SBS values in relation to the type of the adhesive system
	Clearfil SE Bond (2-step self-etch)			3.08±1.10	

N/A: Not available

Clinically, several authors have anecdotally placed RMGIC as a base layer over the ProRoot® MTA without a wet cotton pellet or waiting for its complete setting, as shown in Table 3 and Figure 3. Although these clinical studies showed success of VPT outcome, the restorative outcome of this protocol has never been reported. Interestingly, there has been no clinical studies regarding CP with ProRoot® MTA, using this immediate placement approach. It may be assumed that clinicians may be uncertain of the setting reaction of the thick MTA layer in CP; thus, a moisten cotton pellet was often placed to ensure adequate hydration, and restoration was often performed in the subsequent visit in these teeth.

Moreover, although the acid etching and rinsing of freshly mixed ProRoot® MTA can dislodge this cement, Neelakantan *et al.*[52] have demonstrated in their *in vitro* study that when resin composites were immediately placed on the freshly mixed ProRoot® MTA, the highest bond strength was achieved when using a one-step self-etching adhesive, compared to when using the total-etch and two-step self-etch adhesives. Further studies are recommended to confirm these results.

Table 3: Clinical studies showing ProRoot® MTA restorative protocol of resin composite after vital pulp therapy in permanent teeth

Author, year	Study type	VPT	Age of patients (years)	Follow-up periods	Successful outcome of VPT (%)	ProRoot® MTA restorative protocol				
						Thickness of MTA (mm)	Moist cotton pellets	Temporary restoration	Time elapsed between VPT and resin composite restoration	Base material used
Delayed placement of permanent restoration (Two-visit approach)										
Aunianu *et al.*, 2010[53]	Prospective study	DPC	18-35	12 months	87.5	N/A	Not used	Ketac Molar	1 week	Not used
Marques *et al.*, 2015[54]	Prospective study	DPC	8-86	3.6 years	91.3	1.5	Not used	Coltosol® F	4-12 weeks	Not used
Linu *et al.*, 2017[55]	Retrospective study	DPC	15-30	1-18 months	84.6	1.5-3	Not used	Fuji II LC	1 week	Vitrebond
Cho *et al.*, 2013[47]	Retrospective study	DPC	N/A	3 years	67.4*	N/A	Used	IRM or Fuji II LC	2 months	Not used
Bogen *et al.*, 2008[56]	Observational study	DPC	7-45	Up to 9 years	97.9	1.5-3.0	Used	Clearfil Photocore	5-10 days	Not used
Kundzina *et al.*, 2016[57]	RCT	DPC	18-55	6-36 months	85.0*	2.0	Used	Fuji IX	1 week	Not used
Çalışkan & Güneri, 2017[58]	Retrospective study	DPC	14-55	24-72 months	85.9	N/A	Used	Kemdent	2-7 days	Vitrebond
Farsi *et al.*, 2016[59]	Prospective study	PP	9-12	6-24 months	93.0	N/A	Used	IRM	2 weeks	Not used
Taha and Khazali, 2017[60]	RCT	PP	20-52	6-24 months	83.0	3.0	Used	IRM	1 week	Vitrebond
Özgür *et al.*, 2017[61]	RCT	PP	6-13	6-24 months	97.3	1.0	Used	IRM	1 day	Vitrebond
El-Meligy and Avery, 2006[62]	RCT	CP	6-12	3-12 months	100.0	N/A	Used	IRM	1 week	Not used
Linsuwanont *et al.*, 2017[63]	Retrospective study	CP	7-68	8-62 months	87.3	2	Used	Used (N/A)	1 month	Not used
Alqadeli *et al.*, 2014[64]	Prospective study	CP	10-15	1-47 months	90.0	2.0-4.0	Used	IRM	1 day	Vitrebond
Taha *et al.*, 2017[65]	Prospective study	CP	11-51	3-36 months	92.7	2-3	Used	IRM	1 week	Vitrebond

Immediate placement of permanent restoration (Single-visit approach)										
Miles *et al.*, 2010[66]	Retrospective study	DPC	21-85	12-27 months	56.2	N/A	Not used	Not used	Immediate	Vitrebond
Mente *et al.*, 2010[67]	Retrospective study	DPC	8-75	12-80 months	78.0	N/A	Not used	Not used	Immediate	Vitrebond
Mente *et al.*, 2014[3]	Cohort study	DPC	7-77	Over 10 years	80.5	N/A	Not used	Not used	Immediate	Vitrebond
Cho *et al.*, 2013[47]	Retrospective study	DPC	N/A	3 years	67.4*	N/A	Not used	Not used	Immediate	Fuji II LC
Brizuela *et al.*, 2017[68]	RCT	DPC	7-16	3-12 months	86.4	N/A	Not used	Not used	Immediate	Vitrebond
Parinyaprom *et al.*, 2017[5]	RCT	DPC	6-18	6-44 months	92.6	1.5	Not used	Not used	Immediate	Vitrebond
Barriesh-Nusair and Qudeimat, 2006[69]	Prospective study	PP	7.2-13.1	12-26 months	82.1	2-4	Not used	Not used	Immediate	Vitrebond
Qudeimat *et al.*, 2007[70]	RCT	PP	6.8-13.3	25-45 months	93.0	N/A	Not used	Not used	Immediate	Vitrebond
Chailertvanitkul *et al.*, 2014[48]	RCT	PP	7-10	3-24 months	99.8	2-3	Not used	Not used	Immediate	Vitremer
Uesrichai *et al.*, 2019[6]	RCT	PP		7-55 months	92.0	1.5-3	Not used	Not used	Immediate	Vitrebond

RCT: randomized clinical trial; VPT: vital pulp therapy; DPC: direct pulp capping; PP: partial pulpotomy; CP: coronal pulpotomy; IRM; intermediate restorative material, N/A: Not available
**Cumulative survival rate of VPT-treated teeth*

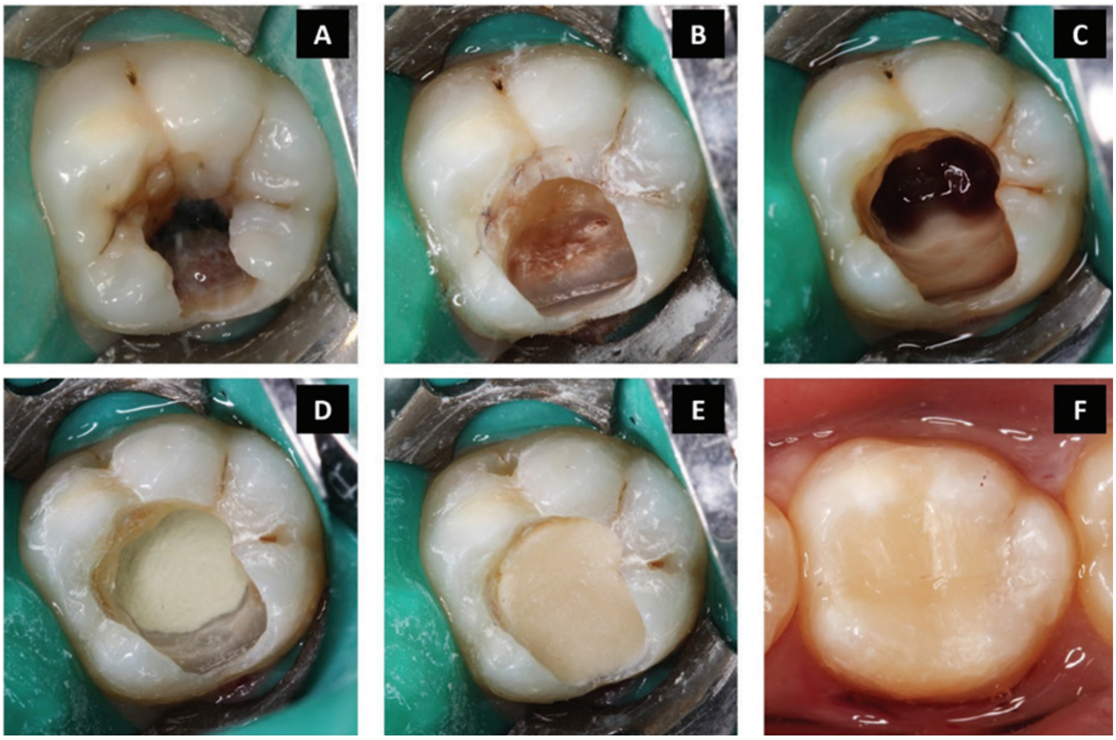

Figure 3: Step-by-step approaches for immediate placement of resin composite following coronal pulpotomy by using ProRoot® MTA on young permanent molar; initial clinical appearance (A), pulpal exposure during complete caries removal (B), after pulp tissue removal and hemorrhage was controlled (C), a 1.5-mm thickness of ProRoot® MTA was placed in the cavity (D), Vitrebond™TM was placed immediately over the ProRoot® MTA as a base material (E), and a resin composite was used as a final restoration (F).

Restorative approaches for resin composite placement over Biodentine™

Similar to ProRoot® MTA, there are generally two clinical approaches for composite placement over Biodentine™, including delayed (multiple-visit) and immediate (single-visit) approaches.

Resin composite placement over Biodentine™: Delayed placement or multiple-visit approach

Biodentine™, a new generation of CSC, has an initial setting time of 12 minutes, shorter than that of ProRoot® MTA. Nevertheless, the manufacturer suggests delaying the placement of the final restoration for at least one week for the complete crystalline formation of Biodentine™.[71] Moreover, when Biodentine™ was allowed to set for one week, its compressive strength was not affected by acid etching.[71,72] Similarly, Hashem *et al.*[73] suggested that the placement of resin composite restoration should be postponed for two weeks after Biodentine™ placement because there was a significant increase in µSBS values in the delayed setting phase (≥ 2 weeks) compared to that in the early setting phase (≤ 24 hours). It was assumed that Biodentine™ was a weak restorative material in its early setting phase.

Table 4: Clinical studies showing BiodentineTM restorative protocol of resin composite after vital pulp therapy in permanent teeth

Author, year	Study type	VPT	Age of patients (years)	Follow-up periods (months)	Successful outcome of VPT (%)	Biodentine™ restorative protocol		
						Temporary restoration	Time elapsed between VPT and resin composite restoration	Base material used
Delayed placement of permanent restoration (Two-visit approach)								
Katge and Patil, 2017[75]	Split mouth Study	DPC	7-9	6-12	100.0	Biodentine™	3 months	Biodentine™*
Linu *et al.*, 2017[55]	Retrospective study	DPC	15-30	1-18	92.3	Biodentine™	2 weeks	Biodentine™*
Lipski *et al.*, 2018[76]	Prospective study	DPC	11-79	12-18	78.4	Biodentine™	2-3 months	Biodentine™*
Owittayakul and Chuveera, 2016[77]	3 case reports	PP	22-50	12-30	100.0	Biodentine™	2 days, 6 days, 1 month	Biodentine™*
Chinadet *et al.*, 2019[78]	Case report	PP	9	60	100.0	Biodentine™	2 days	Biodentine™*
Immediate placement of permanent restoration (Single-visit approach)								
Brizuela *et al.*, 2017[68]	RCT	DPC	7-16	3-12	86.4	Not used	Immediately	Biodentine™†
Parinyaprom *et al.*, 2017[5]	RCT	DPC	6-18	6-54	96.4	Not used	Immediately	Biodentine™†
Lipski *et al.*, 2018[76]	Prospective study	DPC	11-79	12-18	85.7	Not used	Immediately	Biodentine™†
Uesrichai *et al.*, 2019[6]	RCT	PP	6-18	7-69	87.0	Not used	Immediately	Biodentine™†
Abueliniell *et al.*, 2021[79]	RCT	CP	7-8	6-18	80.0	Not used	Immediately	Biodentine™†
Taha and Abdelkhader, 2018[15]	Prospective study	CP	9-17	6-12	95.0	Not used	Immediately	Vitrebond
Taha and Abdelkhader, 2018[80]	Prospective study	CP	19-69	6-12	98.4	Not used	Immediately	Vitrebond

RCT: randomized clinical trial; VPT: vital pulp therapy; DPC: direct pulp capping; PP: partial pulpotomy; CP: coronal pulpotomy

**Biodentine™ was reduced to a base material before the placement of resin composites.*

†Biodentine™ was used as a pulp dressing as well as a base material.

Controversies exist regarding the type of adhesives that should be used for bonding between resin composite and aged Biodentine™. Odabas *et al.*(74) demonstrated in their *in vitro* study that among all groups, the highest SBS values was obtained from Clearfil SE Bond (self-etch adhesive) at a 24-hour period. Conversely, Hashem *et al.*(73) demonstrated that there was no significant difference between time intervals when using Scotchbond™ Universal adhesive in either total-etch or self-etch mode. However, all studies were *in vitro*. Therefore, more clinical studies are required to resolve these discrepancies. Clinically, several authors have delayed the placement of restorations over Biodentine™, as shown in Table 4. However, the clinical evidence regarding the restorative outcome of this protocol is scarce.

Resin composite placement over Biodentine™: Immediate placement or single-visit approach

Biodentine™, with its reduced setting time, may possibly allow for resin composites to be placed over the set Biodentine after 12 minutes, within a single-visit procedure. Palma *et al.*(81,82) have demonstrated in their two *in vitro* studies that the bond strength of resin composites placed on the 12-minute Biodentine™ group was similar to that of the 7-day group. They further concluded that this cement might allow for the immediate approach of permanent restoration.

Moreover, the bond strength between resin composite and Biodentine™, depending on the different types of adhesive used, is important for the coronal sealing of the restorations. However, discrepancies exist regarding the appropriate type of adhesives (total-etch versus self-etch adhesives) for bonding between Biodentine™ and resin composites in a single-visit approach, as shown in Table 5.

Interestingly, several clinicians have conveniently placed resin composites as permanent restorations over Biodentine™ after 12 minutes, as shown in Table 4 and Figure 4. However, the restorative outcome of this approach has never been reported. Moreover, this approach is contrast to the *in vitro* study by Deepa *et al.*(88), which reported that cohesive failures were found within Biodentine™ when resin composite was placed over Biodentine™ after 12 minutes of mixing. However, this study was an *in vitro* evaluation, thus further clinical studies are required.

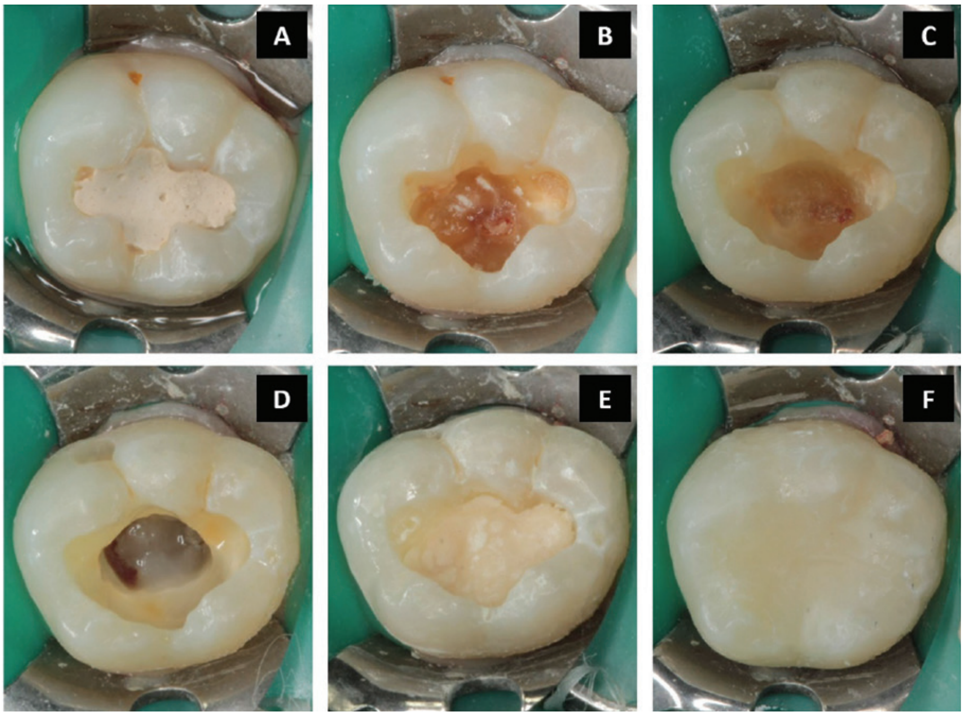

Figure 4: Step-by-step approaches for immediate placement of resin composite following vital pulp therapy with Biodentine™ on young permanent molar: initial clinical appearance (A), temporary filling was removed (B), pulpal exposure during complete caries removal (C), after pulp tissue removal and hemorrhage was controlled (D), Biodentine™ was placed as a pulp dressing as well as a base material and allowed to set, usually in 12 minutes (E), and a resin composite was used as a final restoration (F).

Table 5: *In vitro* studies showing the shear bond strength between initially set Biodentine™ and resin composites using different types of adhesives

Author, year	Type of adhesives	Brands of resin composite	Aging periods of Biodentine™	SBS values Mean ± SD (MPa)	Conclusions
Total-etch adhesive is superior to self-etch adhesive					
Cengiz and Ulusoy, 2016[83]	Vertise Flow (Self-adhering flowable composite)		12 minutes	8.99±2.11	
	Scotchbond Universal (Total-etch mode)	Filtek Bulk-Fill		13.25±2.72	Filtek Z250 applied with Prime & Bond NT and Filtek Bulk-Fill Posterior Restorative applied with Scotchbond Universal exhibited the highest SBS
	Prime & Bond NT (2-step total-etch)	Filtek™ Z250		13.99±3.48	
	Clearfil SE Bond (2-step self-etch)			11.45±1.07	
Meraji and Camilleri, 2017[84]	Excite F (Total-etch)	Evetric	15 minutes	Not available	Resin composite with AdheSe One F was lost from all the Biodentine™ samples during thermocycling
	AdheSe One F (Self-etch)			0	
Self-etch adhesive is superior to total-etch adhesive					
Colak *et al.*, 2016[85]	Prime & Bond NT (2-step total-etch)	Filtek™ Z250	9 minutes	12.95	No statistically significant difference between the 9-minute group and the 48-hour group and the highest SBS values were observed in Clearfil S3 Bond
			48 hours	11.77	
	Adper Prompt L-Pop (1-step self-etch)	Filtek™ Z250	9 minutes	9.82	
			48 hours	9.82	
	Clearfil S3 Bond (1-step self-etch)	Filtek™ Z250	9 minutes	13.32	
			48 hours	15.09	
Nekoofar *et al.*, 2018[86]	Adper Single Bond 2 (2-step total-etch)	Filtek™ Z350 XT	12 minutes	9.26±2.66	All-Bond Universal showed the highest SBS to 12-minute aged Biodentine
			1 week	25.41±2.55	
			1 month	25.02±8.93	
	Clearfil SE Bond (2-step self-etch)	Filtek™ Z350 XT	12 minutes	5.72±3.23	
			1 week	18.52±1.82	
			1 month	15.69±1.23	
	All-Bond Universal (Self-etch mode)	Filtek™ Z350 XT	12 minutes	62.49±16.39	
			1 week	31.29±3.94	
			1 month	19.59±4.38	
	No adhesive system	Filtek™ Z350 XT	12 minutes	2.76±0.62	
			1 week	8.12±2.29	
			1 month	3.15±1.29	
Keles and Simseh Develioglu, 2019[87]	Prime & Bond NT (2-step total-etch)	Clearfil Majesty	12 minutes	10.65±1.74	Peak SBS values were obtained in the Clearfil SE groups
	Clearfil SE Bond (2-step self-etch)			14.10±2.83	
	Clearfil Universal Bond (Self-etch mode)			11.52±2.77	

Although less than that of MTA, the 12-minute initial setting time of Biodentine™ is still considered too long in clinical practice.[43] To reduce chair time, a base material may possibly be placed on a partially-set Biodentine™ before placement of permanent restoration, similar to the method performed in ProRoot® MTA. Schmidt *et al.*[89] demonstrated in their *in vitro* study that different light-curing flowable base composites could be placed directly over Biodentine™ after the 3 minutes of mixing, noting that a longer waiting time did not improve the bond strength of these flowable base composites to Biodentine™. However, some studies showed that GIC should not be used for the restoration of teeth in which Biodentine™ is used as the pulp dressing material[83,84] because the bond strength between GIC and Biodentine™ was shown to be lower than those between direct resin composite and Biodentine™ after the 12-minute initial setting time of this cement.

Discussion

Prevention of coronal leakage is necessary for the long-term successful outcome of VPT; hence, the effective bonding between pulp dressing materials and resin composite restorations could not be overemphasized. This review demonstrated that there are several factors affecting this bonding includes time elapsed before placing a restoration, type of base materials, and type of adhesives used.

The objective behind the delayed placement of resin composite is to allow for the complete maturation of the CSCs, thus gaining the maximum physical properties of these cements. Delayed placement of resin composite restorations over these cements has potential benefits on the increasing SBS values between two materials. A previous study reported that a minimum bond strength value of 17-20 MPa was sufficient to resist the contraction of resin composite.[(90)] However, from this review, the bond strength values between CSCs and resin composites, regardless of its setting time, varied considerably between protocols and were often lower than the value recommended. Thus, it may be suggested that clinicians should rely considerably on the bond strength between the remaining tooth structure and resin composite for the restoration retention. However, there is no evidence of the threshold value that can affect the clinical significance. Moreover, this approach is inconvenient for both patients and practitioners because it increases the cost, chair time, and the risk of VPT failure.

On the other hand, the immediate placement approach of resin composite restorations on the CSCs layer may be considered as a practical alternative because a single visit is only required. While the appropriate choices of base material recommended to be placed over different types of CSCs have been recommended there are discrepancies, including the appropriate initial setting time, type of base materials, and type of adhesive that should be placed over initially set CSCs, that still exist for this immediate approach. Another possible practical option is to choose the type of CSC with decreased setting time. There are currently several CSCs on the market that have been reported as having even shorter setting time than Biodentine™. Some examples of recent generation CSCs with improved physical properties are Neo MTA and Retro MTA.[(91)]

Unfortunately, it seems like there are more questions than answers to this review. Most gathered data are derived from *in vitro* studies with different protocols and this information may not be directly transferred to effective clinical practice. Moreover, this review only covers two types of CSCs while there are many more types of CSCs available on the market. Besides, the existing clinical studies mainly focus on the pulpal outcome without providing any clinical data on restorative outcome. Thus, the authors urge for clinical studies on these issues to set the foundation of the appropriate restorative protocol that should be used following VPT with CSCs.

Conclusions

There is no consensus regarding the restorative protocols (delayed or immediate approach) for resin composite placement over ProRoot® MTA or Biodentine™, as a majority of the existing information is derived from *in vitro* studies, thus limiting their clinical relevance. Therefore, clinical studies regarding different resin composites restorative protocols over CSCs should be further investigated.

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