A Review of Failure Modes in Teeth Restored with Adhesively Luted Endodontic Dowels

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Abstract

Purpose: Previous clinical studies indicated loss of retention between dowel and tooth was a major cause of failure for passive endodontic dowels. Advances in luting cement technology may have improved the retention of dowels. The purpose of this systematic review was to determine the clinical failure modes for dowel/core/crown restorations luted using resin-based cements that are either self-etching or used in conjunction with a bonding agent.

Materials and Methods: PubMed was searched for English language, peer-reviewed clinical research following restorations for 2 years or longer. For inclusion, a study group must have followed more than 50 permanent teeth restored using a dowel luted with resin cement and a bonding agent. Furthermore, more than 80% of the restorations must have received a nonresin crown.

Results: Fifteen studies met the inclusion criteria and reported a total of 187 failures from 3046 restorations. The commonly reported causes of failure were dowel debonding (37% of all failures and primary cause in 8 of the 17 reporting study groups) and endodontic lesions (37% of all failures and primary cause in 6 of the 11 reporting study groups).

Conclusions: Loss of retention remains a major mode of failure even for passive, nonmetal dowels luted by resin cements with a bonding agent. The exact nature and underlying causes of debonding have not been adequately investigated.

Endodontic dowels were traditionally luted using zinc phosphate cement. Although this cement has a long history of clinical use, its properties are not ideal. Of primary concern are its high solubility[1-5] and weak adhesion.[1,2,6-9] Other traditional materials include polycarboxylates and glass ionomer cements. Although these cements offer improved adhesion[1,6-9] and reduced solubility,[1-5] their compressive and tensile strengths remain mediocre.[1,10,11] As a result, it is not surprising that clinical trials[12-24] often report the major mode of failure for metal dowel and core restorations luted with these traditional cements is debonding of the dowel from the canal. Out of 13 clinical trials, 12 reported at least one failure due to dowel debonding, and 7 reported it was the primary mode of failure.

Resin-based luting cements, whether self-adhesive or used in conjunction with a bonding agent, promise superior properties. Laboratory studies generally report that they produce superior retention of the dowel,[25-36] though nonsuperior[37-41] and inferior[42-46] performance has also been observed. Laboratory studies[47-49] have also suggested that bonded resin luting cements enhance the ability of the restoration to withstand functional forces. This concept is further supported by finite element models.[50,51] The laboratory performance of resin luting cements, along with their easy handling, have lead to their widespread clinical acceptance for dowel and core cementation.

It is difficult to assess if resin-luting cements yield any measurable improvement in clinical outcome. A properly controlled clinical trial would require thousands of patients to have sufficient statistical power. It is quite understandable that no one has yet attempted this task. A less onerous task would be to perform a metaanalysis of published success rates. Unfortunately, the enormous number of clinical variables in dowel and crown restoration largely prevents direct comparison between different clinical trials. For example, zinc phosphate cements were usually tested in conjunction with cast metal dowel and cores, while bonded resin cements were usually tested with prefabricated fiber-composite dowels and resin cores.

With these limitations in mind, the scope and ambitions of this systematic review were narrowed. Rather than comparing the clinical success rates of different luting systems, this systematic review will focus on the clinical failure modes for dowel/core/crown restorations luted using resin-based cements that are either self-etching or used in conjunction with a bonding agent.

Materials and methods

PubMed was queried using the search string "(post OR dowel) AND (retrospective OR prospective OR longitudinal OR clinical) AND (failure OR success) AND tooth." The search results were assessed for suitability, and full-text articles were obtained. The references cited by each full-text article were skimmed to identify relevant articles that may have been missed by the PubMed search.

The retrieved articles were then subjected to the inclusion and exclusion criteria. Only clinical studies that followed restorations for at least 2 years on average and documented the mode of restoration failure were considered. Studies that did not include at least one group of more than 50 permanent teeth restored using a dowel luted with resin cement and bonding agent were ignored. Only those groups that were frequently (>80%) restored with resin cores and had received a nonresin crown were considered. If failure data for such subgroups were not published, the corresponding author was emailed to request detailed data. Failures of the interim restoration were not included. If more than one study reported on a given patient set, for example, one study after 5 years of observation and another after 10 years, the one presenting data closest to 5 years was chosen.

Results

The initial PubMed search returned 326 results. After review of these results and their references, a total of 45 articles were subjected to the selection criteria. Fifteen studies[52-66] met the selection criteria (Table 1): six tested glass fiber dowels, six tested carbon fiber dowels, three quartz fiber, one zirconium ceramic, one polyethylene fiber dowels, and none tested metal dowels. Altogether, the studies reported 187 failures from 3046 restorations (Table 2). The most commonly reported causes of failure were dowel debonding (37% of all failures, primary cause in eight study groups) and endodontic lesions (37% of all failures, primary cause in six study groups).

Discussion

Studied dowel materials

The study groups that met the inclusion criteria did not span all the dowel varieties available on the market. The many varieties of cast dowel and prefabricated metal dowels were not represented at all. Threaded, active dowels were also not represented. Of the 17 study groups, 16 used passive fiber-composite dowels and one used zirconium ceramic dowels. Of the fiber-composite dowel groups, six used glass fiber, three quartz fiber, six carbon fiber, and one polyethylene fiber.

The dowel materials with the greatest contemporary acceptance are glass fiber and quartz fiber. Carbon fiber dowels were the original fiber-composite dowel, but have fallen out of common use due to their fiber's black color. Zirconium ceramic dowels enjoy some measure of clinical acceptance due to their high modulus, but are some of the most expensive dowels currently in the market. Polyethylene fiber composites are a recent development that has not yet gained widespread clinical adoption. Laboratory studies on polyethylene fiber dowels report that they have a slightly lower failure strength[78-80] and a significantly lower modulus[78] than glass fiber dowels.

Studied luting cement systems

Of the resin luting cement systems used in the various studies, all used a bonding agent. Of the 17 study groups, one used only a self-etch bonding agent, two sometimes used a self-etch bonding agent, other times a total-etch bonding agent, one used a citric acid etch bonding agent, and 13 used a phosphoric acid total-etch bonding agent. Total-etch bonding systems are known to provide superior results to self-etch systems due to their reduced water sorption.[81]

Studied core and crown materials

The core restorations were generally prepared from special-purpose resin core materials. In a few study groups, universal composites such as Z-100 (3M ESPE, St. Paul, MN) or flowable composites such as Æliteflow (Bisco, Inc., Schaumburg, IL) were used to create the core.

Metal-ceramic restorations were the most popular crown. All-ceramic and all-porcelain crowns were also used. All-gold crowns appeared in only one study group.

Other variables

Most other details of the restoration were not reliably reported. This includes details of the endodontic instrumentation, endodontic obturation, remaining tooth structure, or dowel space preparation.

Overall failure rate

The reported failure rates ranged from a low of 0.0% to a high of 29.6% with a median of 7.0%. The mean failure rate obtained by pooling the studies was 6.1%. The failure modes reported in clinical studies included apical lesions, periodontal lesions, secondary caries, loss of adhesion between crown and core, loss of adhesion between core and tooth, loss of adhesion between dowel and canal, root fractures, dowel fractures, and core fractures. The only combination failures reported were dowel debonding in a tooth with apical lesions. The two major modes of failure commonly present in clinical studies were debonding of the dowel from the tooth and endodontic lesions.

The criteria used to categorize failures were not universally accepted. Although most studies counted asymptomatic periapical lesions as a failure, Mannocci et al[55] explicitly excluded them, while Hedlund et al,[56] Paul and Werder,[59] and Piovesan et al[63] are unclear as to whether such failures were counted. Since periapical failure was not reliably reported, the present study cannot accurately assess its prevalence. Other potential discrepancies in the definition or identification of failure modes could further skew the results. For example, secondary caries and periodontal failures were only reported in one study each, which is lower than otherwise expected.

Table 1 Experimental details of those clinical studies matching the inclusion criteria

Study	Experimental design	Duration (years)	Dowel material	Acid etching	Bonding agent	Luting cement	Core material	Crowns	Samples meeting criteria
Fredriksson et al[52]	Retrospective	2 to 3	Carbon	Phosphoric*	All-Bond 2	Unspecified Resin	Resilient	PFM/AC	236
Ferrari et al[53]	Retrospective	4	Carbon	Phosphoric*	All-Bond 2	C&B	Biscore	PFM	97
Glazer[54]	Prospective	4	Carbon	Citric*	C&B	C&B	Core Paste	PFM	52
Mannocci et al[55]	Prospective	3	Carbon	Phosphoric	All-Bond 2	C&B	Z-100	PFM	57
Hedlund et al[56]	Retrospective	2	Carbon	None	Panavia Primer	Panavia	Z-100/Clearfil	PFM/AC	65
Malferrari et al[57]	Prospective	2.5	Quartz	Phosphoric	All-Bond 2	C&B	Core-Flo	PFM/AC	180
Monticelli et al[58]	Prospective	2 to 3	Glass	None/Phosphoric	One-Step/Excite DSC	Duo-Link/MultiLink	Tetric Flow/Æliteflow	AP	150
			Quartz	Phosphoric	Excite DSC	MultiLink	Æliteflow	AP	75
Paul and Werder[59]	Retrospective	1 to 10	Zirconium	Phosphoric*	All-Bond 2	Panavia 21	Core Paste/Empress	PFM/AC	87
Cadigiaco et al[60]	Prospective	2	Glass	Phosphoric	Prime & Bond NT	Prime & Bond NT	X-Flow/Ceram X	AC	121
Ferrari et al[61]	Prospective	2	Glass	Phosphoric	Prime & Bond NT	Calibria	Core Paste	PFM	120
Ferrari et al[62]	Retrospective	7 to 11	Carbon	Phosphoric*	Multiple	Multiple	Multiple	Mostly PFM	615
			Quartz	Phosphoric*	Multiple	Multiple	Multiple	Mostly PFM	370
Piovesan et al[63]	Retrospective	8	Ribbon	Phosphoric	Scotchbond Multipurpose	Enforce	Z-250	PFM/AC	68
Cagidiaco et al[64]	Prospective	3	Glass	Phosphoric	Prime & Bond NT	Calibria	X-Flow/Ceram X	PFM	120
Mehta and Millar[65]	Retrospective	2 to 4	Glass	None/Phosphoric	Panavia Primer/Calibria NT	Panavia F/Calibria	ParaCore	PFM/Gold	108
Signore et al[66]	Retrospective	5	Glass	Phosphoric Acid	All-Bond 2	Luxa-Core Dual	Ecusit Composite	AC	526

*Etching not explicitly stated but implied by the choice of luting cement.
PFM = porcelain fused to metal; AC = all ceramic; AP = all porcelain.

Table 2 Reported failure modes for the study groups meeting the inclusion criteria

				Number of failures due to						
Study	Dowel material	Included dowels	Observed failures	Failure rate	Dowel debonding	Apical lesions	Crown dislodgement	Dowel breakage	Root fracture	Other
Monticelli et al[58]	Glass	150	8	5.3	**5**	3	0	0	0	
Cagidiaco et al[60]	Glass	121	12	9.9	**7**	5	0	0	0	
Ferrari et al[61]	Glass	120	11	9.2	**9**	2	2	0	0	2 debonding with lesions
Cagidiaco et al[64]	Glass	120	11	9.2	**11**	0	0	0	0	
Mehta and Millar[65]	Glass	108	32	29.6	3	9	0	0	2	**12** core fractures, 6 secondary caries
Signore et al[66]	Glass	526	7	1.3	**5**	3	0	1	0	1 core fracture, 3 debonding with lesions
	Sub-total	1145	81	7.1	**40**	22	2	1	2	
Fredriksson et al[52]	Carbon	236	5	2.1	0	**1**	0	0	2	2 periodontitis
Ferrari et al[53]	Carbon	97	2	2.1	0	**2**	0	0	0	
Glazer[54]	Carbon	52	4	7.7	0	**2**	1	0	0	1 core debonding
Mannocci et al[55]	Carbon	57	3	5.3	**2**	*	0	0	0	1 marginal gap
Hedlund et al[56]	Carbon	65	2	3.1	**2**	**	0	0	0	
Ferrari et al[62]	Carbon	615	43	7.0	13	**19**	10	1	0	
	Sub-total	1122	59	5.3	17	**24**	11	1	2	
Malferrari et al[57]	Quartz	180	0	0.0	0	0	0	0	0	
Monticelli et al[58]	Quartz	75	6	8.0	**3**	**3**	0	0	0	
Ferrari et al[62]	Quartz	370	36	9.7	8	**20**	7	0	1	
	Sub-total	625	42	6.7	11	**23**	7	0	1	
Paul and Werder[59]	Zirconium	87	0	0.0	0	**	0	0	0	
Piovesan et al[63]	Polyethylene	67	5	7.5	1	**	0	**4**	0	
	Total	3046	187	6.1	69	69	20	6	5	

*A study group that explicitly ignored apical lesions; **A study group for which it is unclear if apical lesions would be counted as failure.
The numbers in bold are the major modes of failure.

The type of dowel material did not noticeably influence the overall failure rate. A mathematical metaanalysis of the data is not warranted due to the considerable variation in clinical conditions. There did not appear to be any obvious association between study duration or design and reported success rate.

Effect of dowel material on failure mode

The composition of the dowel appears to affect the primary mode of failure. Debonding was the most common mode of failure for glass fiber dowels, while endodontic lesions were the most common failure mode for carbon and quartz fiber dowels. To be more specific, dowel debonding was responsible for 49% of glass fiber dowel failures but only 29% and 26% of carbon fiber and quartz fiber failures, respectively. It is not clear how the choice of dowel fiber influences the retention of the dowel.

Endodontic lesions

Only 11 of the 15 studies explicitly recorded failures due to endodontic lesions. Of the 2770 teeth reported in these studies, 69 failed due to endodontic lesions. This corresponds to a failure rate of 2.5%, far lower than the rates typically reported for root canal therapy alone. Literature reviews[67,68] have reported that the success rate of endodontic treatment is about 75% when success is defined as total resolution of the apical lesion and 85% when success is defined as partial resolution of the apical lesion. The de facto definition of endodontic success used in the dowel-and-crown studies is likely even looser, as clinicians may hesitate to re-treat a tooth with significant restorative work. Treatment selection bias is also likely to be a factor, as clinicians defer crowning high-risk endodontially treated teeth until signs of resolution are seen. Another factor skewing the success rates is the fact that all the teeth in the dowel-and-crown studies have received a proper coronal restoration. Metaanalysis[68] of the role of the coronal restoration found that the odds ratio for teeth with satisfactory coronal restorations versus unsatisfactory was 1.8 with a 95% confidence interval of 1.48 to 2.25. Finally, it may be possible that the adhesive interface between the luting cement and dentin reduces the amount of leakage through the root canal. In vitro evidence for this effect is lacking, with one study[69] reporting a nonsignificant reduction in leakage versus an extended sealer/gutta-percha filling.

Dowel debonding

Dowel debonding was the most common mode of failure for 8 of the 17 groups and accounted for 37% of all reported failures. The pooled odds that a restoration will fail due to debonding

Table 3 Reported failure modes for clinical studies on passive dowel and cores (primarily cast) luted with zinc phosphate or glass ionomer cements

				Number of failures due to					
Study	Included dowels	Observed failures	Failure rate	Dowel debonding	Apical lesions	Crown dislodgement	Dowel breakage	Root fracture	Other
Balkenhol et al[12]	802	90	11.2	**39**	14	0	3	14	9 periodontal, 6 caries, 4 crown fracture, 1 other
Bergman et al[13]	96	16	16.7	6	7	0	0	**2**	1 periodontal
Ellner et al[17]	40	1	2.5	0	0	0	0	1	
Ferrari et al[53]	98	14	14.3	0	3	2	0	**9**	
Creugers et al[14]	127	7	5.5	3	*	0	0	**4**	
Torbjorner et al[24]	788	72	9.1	**45**	*	0	6	21	
Fokkinga et al[19]	118	19	16.1	**7**	3	0	0	2	4 periodontal, 3 "crown replacement"
Salvi et al[23]	82	8	9.8	**4**	1	0	0	3	
Ottl and Lauer[22]	230	18	7.8	0	**12**	0	0	1	5 periodontal
Total	2381	245	10.3	104	40	2	9	57	

*A study group that explicitly ignored apical lesions.

are 2.3%. As previously mentioned, many factors prevent a proper comparison of the debonding rate for dowels luted with adhesive resin cements and traditional cements. The closest comparison that can be made with published data is to passive dowel and cores luted with zinc phosphate or glass ionomer cements. Nine clinical studies[12-14,17-19,22-24] investigated a total of 2381 such restorations and found 245 failures, 104 of which resulted from debonding (Table 3). This corresponds to a 4.3% chance that a given restoration will fail due to debonding. Therefore, resin-luted prefabricated dowels with resin cores appear 50% less likely to fail via debonding compared to traditionally luted passive dowels. Based on this data, adhesive luting cements appear to have succeeded in lowering the incidence of failure due to debonding; however, there are many reasons to be skeptical of this comparison. Studies using traditional luting techniques followed restorations for twice as long as those studies on adhesively luted dowels. Furthermore, the studies using traditional luting techniques often included bridge restorations, which were largely excluded from the studies on fiber dowels. Finally, there seems to be a treatment selection bias towards use of nonmetal dowels only in the anterior regions of the mouth where the occlusal forces are different than the posterior regions.

Although dowel debonding is a common mode of failure, few studies have elaborated on the exact nature of the debonding. The evaluated clinical studies generally reported debonding happens sporadically during the lifetime of the restoration with no noticeable tendency for immediate failure. None of the clinical studies mentioned any significant association between debonding and other failure modes such as secondary caries. The only study that commented on the mechanics of debonding[57] reported that two of three debondings occurred at the dentin/cement interface and one occurred cohesively within the cement near a bubble. Failure at the dentin/cement interface has also been commonly reported by in vitro studies[70-76] on the retention of fiber dowels luted with resin cements, although other failures have been reported.[70,76,77] None of the clinical studies reported if the loss of retention began at the crown/dentin interface or at the dentin/resin interface.

If initial failure at the crown/dentin interface was common, one would expect that in a certain number of restorations, the debonding interface would continue to propagate in a nearly straight line and follow along the crown/core interface rather than turn to follow the core/dentin interface. Of the clinical investigations considered by this study, 20 restorations failed by loss of crown retention, and 70 restorations failed by loss of dowel retention. Therefore, it seems more likely that failure begins with a decrease in retention at the dentin/resin interface.

Because loss of retention remains a major mode of failure, clinicians should consider taking additional measures to maximize dowel/tooth retention. Such strategies include ferrules, undercuts, antirotational boxes, and active dowels. A ferrule is a well-known preparation technique usually reported to improve the fracture resistance,[82] and to a lesser extent the retention, of a dowel core restoration.[64,82] Undercuts and antirotational boxes are techniques for allowing even nonbonded materials to be retained via macromechanical retention. Finally, active dowels have been shown in laboratory testing to be more retentive than passive dowels.[82]

Crown dislodgement

Dislodgement of the crown was reported in four study groups and accounted for 11% of all reported failures. It is interesting to note that 19 of the 20 dislodgements were reported in just two studies, both performed by similar research groups. In those studies the incidence of dislodgement, 1.7%, was far greater than in other studies, 0.05%. The cause of this discrepancy is unknown, but case selection may have had some influence; the authors claimed[62] that "dislodgement of the crowns occurred simultaneously with partial or total fracture of the abutments, in teeth with little remaining coronal tooth structure and with natural dentition and heavy occlusion."

Dowel breakage

Breakage of the dowel was the dominant mode of failure reported by the one study group investigating polyethylene fiber dowels (Ribbond). Otherwise, it was responsible for 1% of all reported failures. Laboratory studies on polyethylene fiber dowels report that they have a slightly lower failure strength[78-80] and a significantly lower modulus[78] than glass fiber dowels.

Root fracture

Root fracture was reported in three studies and accounted for less than 3% of all failures. This is markedly less than the rate from previously mentioned studies on traditionally luted passive metal dowels, 23%. Such a reduction is not unprecedented, as numerous computational[50,51,83-86] and laboratory[86-91] studies report that low-modulus fiber dowels reduce the risk of root fracture. It should be noted; however, that the laboratory studies are not all in agreement, with several reporting no difference[92-94] or increased[95-98] risk of root fracture.

Other failure modes

Uncommon modes of failure included secondary caries, periodontitis, core fracture, core debonding, and marginal gap formation. Core fracture was the major mode of failure in one study, but was only reported once in all other studies. Clearly some unique factor must have affected the one study that reported 12 core fractures. Perhaps the core material, ParaCore Handmix (Coltène/Whaledent, Inc, Cuyahoga Falls, OH), has inadequate properties or was not properly used.

Conclusions

Within the scope of this systematic review, loss of retention is a major mode of failure for passive fiber dowels luted by bonded resin cements. The exact nature and underlying causes of debonding have not been adequately investigated. The other major mode of failure was recurring endodontic lesions. The incidence of endodontic failure in dowel and core restorations was lower than in minimally restored endodontically treated teeth.

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