Original Article

Orthodontic bracket bonding without previous adhesive priming: *A meta-regression analysis*

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ABSTRACT

Objective: To determine the consensus among studies that adhesive resin application improves the bond strength of orthodontic brackets and the association of methodological variables on the influence of bond strength outcome.

Materials and Methods: In vitro studies were selected to answer whether adhesive resin application increases the immediate shear bond strength of metal orthodontic brackets bonded with a photo-cured orthodontic adhesive. Studies included were those comparing a group having adhesive resin to a group without adhesive resin with the primary outcome measurement shear bond strength in MPa. A systematic electronic search was performed in PubMed and Scopus databases.

Results: Nine studies were included in the analysis. Based on the pooled data and due to a high heterogeneity among studies ($I^2 = 93.3$), a meta-regression analysis was conducted. The analysis demonstrated that five experimental conditions explained 86.1% of heterogeneity and four of them had significantly affected in vitro shear bond testing. The shear bond strength of metal brackets was not significantly affected when bonded with adhesive resin, when compared to those without adhesive resin.

Conclusions: The adhesive resin application can be set aside during metal bracket bonding to enamel regardless of the type of orthodontic adhesive used. (*Angle Orthod.* 2016;86:391–398.)

KEY WORDS: Dental bonding; Orthodontic brackets; Shear strength

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INTRODUCTION

The spotlight in orthodontic bonding with attainment of satisfactory strengths has focused on the decrease in clinical steps and hence, the cost of materials.[1] Thus, two-step orthodontic adhesives, without prior application of adhesive resin, has appeared on the market in order to decrease the procedure time of bracket bonding.[2] These composites, called *flowable resins*, have a smaller amount of inorganic filler and therefore have low viscosity compared with conventional resins.[3] Furthermore, a previous report has shown that adhesive resins have greater cytotoxicity for gingival fibroblasts.[4]

Although proper bonding should decrease microleakage, little information is available relating microleakage and direct bracket bonding to enamel with orthodontic composites. Nevertheless, some authors[5,6] have found no association between microleakage and shear bond strength of orthodontic brackets to enamel. Moreover, absence of prior adhesive resin may diminish enamel wetness, decreasing the amount of adhesive left on the tooth after bracket removal.[3]

Several studies have reported that to achieve adhesion to enamel by mechanical retention requires prior application of adhesive resin. However, recent in vitro studies have shown that orthodontic adhesives without priming reached bond strength comparable to that found with previous primer application.[2,7] The consensus in the orthodontic literature[2,8] about the factors that might influence bracket bond strength are the base surface area, specimen storage time, enamel conditioning procedures, type of adhesive and resin used, and bracket base design. Nevertheless, many studies did not properly report significant test conditions.[9]

Several studies have evinced the bond strength success of orthodontic brackets without prior application of adhesive resin, so we wish to ascertain the necessity of using adhesive resin before bracket bonding. Furthermore, understanding the factors that play a major role in the bracket/tooth interface is essential for standardizing the experimental variables. Such knowledge could improve in vitro conditions that indeed affect bond strength outcome. Therefore, the aim of this systematic review was to evaluate the association between adhesive resin and shear bond strength of orthodontic brackets to enamel and to analyze the association among other experimental variables.

MATERIALS AND METHODS

This study was reported according to the PRISMA Statement where applicable.[10]

In vitro studies were selected to answer whether adhesive resin application influences the immediate shear bond strength of metal orthodontic brackets bonded with a photo-cured orthodontic adhesive. Studies included were those comparing a group with adhesive resin application to a group without adhesive resin application and that the primary outcome measurement was shear bond strength in MPa. There was no language or date restriction. The search limit was publication status (only studies published in journals were considered).

A systematic electronic search was performed in PubMed and Scopus databases using the following search strategy: "(Orthodontic) OR Orthodontics) AND (primer) OR liquid resin) OR bond optimizer) OR primer based system) OR adhesion promoting agent) OR bond enhancing primer) OR intermediate bond resin) OR fluid unfilled resin) OR resin sealant) OR sealant) AND (bonding system) OR adhesive) OR resin composite) OR flowable composites) AND (bond strength)." The last search was performed in August 2014. In addition, the references of the identified articles were manually searched for other relevant studies.

Two reviewers screened independently the titles and abstracts of the retrieved citations to exclude noneligible articles. Disagreement between reviewers was resolved by consensus meetings. Full texts of eligible articles were read to determine whether they met the criteria. Articles that used thermocycling as an aging process were excluded.

For each study, data on sample size, type of teeth (human premolar, human molar, or bovine), bracket base area (mm^2), bracket base design, conditioning time, photo-curing time, storage time before shear test, local force application, load type, crosshead speed of tester, bond strength (MPa) and standard deviation, year of publication, and country of included studies were obtained. Missing data were requested of corresponding authors whenever necessary.

To assess individual risk of bias of each study, 10 methodological items were analyzed: (1) citation of teeth storage medium after extraction, (2) teeth randomization, (3) screening for caries and cracks on teeth, (4) previous enamel polishing, (5) standardization of force applied on bracket during bonding, (6) using materials according to manufacturer's instructions, (7) citation of storage medium after bonding, (8) time of tooth storage before debonding, (9) citation of chisel type, and (10) crosshead speed of the testing machine. After collecting these items, we classified the studies as high, moderate, or low risk of bias. Studies that failed to report seven items or more were classified as high risk, those failing to report four to six items were classified as moderate risk, and those not reporting three items or less were classified as low risk. Studies classified as high risk of bias were excluded from the analysis.

Statistical Analysis

The pooled mean bond strength of all groups from all included studies was determined by random linear meta-analysis using the DerSimonian-Laird random-effects method. Then, because of their high heterogeneity, the data were analyzed in linear meta-regression with the restricted maximum likelihood estimator to obtain between-study variance (tau^2). P values were estimated with Monte Carlo simulation (with 1000 permutations from the 31 groups included) to obtain more precise estimates. Bivariate associations were performed, and we set the P level at $<.25$ for the variable to enter in the multivariate analysis model and a $P < .20$ to remain in the final model. Diagnostic procedures were performed to check for outliers, leverage, and normality of residuals. All analyses were performed in Stata 13.1.

RESULTS

Progress through the stages of systematic review is presented in Figure 1. A total of 808 titles and

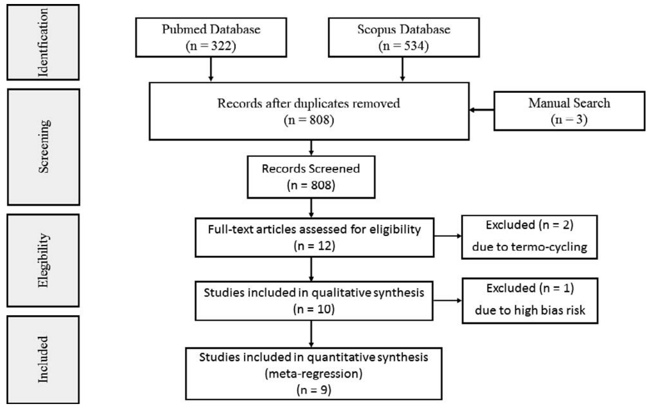

Figure 1. Systematic review flow chart of studies comparing shear bond strength of metal brackets bonded to enamel with and without adhesive resin application.

abstracts were screened after removing the duplicates. After bias risk analysis (Table 1), one study[11] was excluded due to its high risk of bias. Nine studies[2,3,8,12–17] were included; descriptive data, random-effect means, confidence interval, and weight of each study are shown in Table 2. The lowest mean for bond strength in a group was 6.42 MPa; the highest value was 34.8 MPa, with 50% of the groups' means being lower than 11.0 MPa.

Based on the pooled data and due to a high heterogeneity among studies ($I^2 = 93.3$), a meta-regression analysis was conducted. Results of the uni- and multivariate tests are presented in Table 3. Results from the nine included studies were based on the means and standard errors of 31 groups from 530 specimens.

The diagnostic of the final model showed that it explained 86.1% of the between-groups variance (if the model has a value of 100%, then the outcome can be perfectly predicted by the covariates in the model). Moreover, the within-groups variance was significant ($P < .001$). The studentized residuals were not homoscedastic or normally distributed; there were no influences of outliers or leverage.

DISCUSSION

Some factors tend to play a major role in bracket/tooth interfaces.[2,8,9] Thereby, in contrast to previous studies,[12,14,15] no significant difference of the pooled results of this meta-regression was shown between use and nonuse of adhesive resin. As heterogeneity among the included studies was high ($I^2 = 93.32$), a meta-regression analysis was performed to relate the "adhesive resin use" variable with other variables tested. Results from the meta-regression in this systematic review indicated that the laboratory conditions of photo-curing time, local force application, bracket area, adhesive resin used, and crosshead speed of the testing machine significantly influenced the bond strength of metal brackets.

The high heterogeneity within orthodontic bond strength studies had been previously shown in systematic reviews[9,18] and experimental researches.[19,20] This variation occurred mostly because of different methodological approaches used in each study ($R^2 = 83.15$). Moreover, in our multivariate model, the five aforementioned variables explained 86.1% of this heterogeneity; this result could serve as a standardization guide for further in vitro studies.

The prior application of adhesive resin to bracket bonding increased, on average, 2.1 MPa with no statistical difference when compared with no adhesive resin application. Our result corroborates other studies.[7,21,22] This might imply that after acid etching, the surface tension of enamel seems to play a major role in enhancing the mechanical interlocking between demineralized prisms and resin. Jendresen and Glantz[23] showed an increase of this superficial tension after enamel etching. Hence, the achievement of desirable shear strength does not depend on the requirement of adhesive resin wettability. This consideration may be valid for both as flowable,[24] orthodontic,[17] or restorative resins, since no significant differences in bond strength were found among them ($P = .42$), and this adhesive variable did not interfere with the ones included on the multivariate test. According to Shahabi et al.,[21] another suggestion of adhesive resin application to protect enamel against debonding force[25] is not unanimous, owing to their findings that the application had no effect on the quality or quantity of cracks whether it was applied in one or two layers. Although uncured adhesive resins have proven to have greater cytotoxicity for gingival fibroblasts,[4] they generate oxidative stress or induce a pathophysiological increase in cellular calcium level, killing their target cells by apoptosis.[26] Regarding microleakage under bonded stainless steel brackets, several studies have

Table 1. Bias Risk Analysis

Study	Teeth Storage Medium	Teeth Randomization	Teeth Free of Caries/Defects	Previous Polishing	Bonding Force	Manufacturer's Instructions	Storage Medium After Bonding	Storage TIme	Chisel Type	Testing Machine Crosshead Speed	Classification
Scribante et al., 2013	Yes	N/I	Yes	Yes	N/I	Yes	Yes	Yes	N/I	Yes	Moderate
Goracci et al., 2013	Yes	Yes	Yes	Yes	N/I	Yes	Yes	Yes	Yes	Yes	Low
Invernici et al., 2012	Yes	N/I	Yes	Yes	Yes	Yes	Yes	Yes	N/I	Yes	Low
Romano et al., 2009	Yes	Yes	Yes	Yes	N/I	Yes	Yes	Yes	Yes	Yes	Low
Ryou et al., 2008	Yes	Yes	Yes	Yes	N/I	N/I	Yes	Yes	Yes	Yes	Low
Tecco et al., 2005	Yes	Yes	Yes	Yes	N/I	N/I	Yes	Yes	Yes	Yes	Low
Uysal et al., 2004	Yes	Yes	Yes	Yes	N/I	Yes	N/I	N/I	Yes	Yes	Moderate
Tang et al., 2000	Yes	N/I	Yes	N/I	N/I	Yes	Yes	Yes	Yes	Yes	Moderate
Bradburn & Pender, 1992	Yes	N/I	Yes	Yes	N/I	Yes	Yes	Yes	Yes	Yes	Low
O'Brien et al., 1991	Yes	N/I	N/I	Yes	N/I	N/I	N/I	N/I	N/I	N/I	High

demonstrated relevant effects related to the etching method whereas the type of adhesive made no difference.[27,28]

Photo-activation time of 40 seconds increased bond strength by 8.7 MPa. Since metal brackets are opaque, polymerization of resin may not be complete.[29] The mouth has a harsh environment, and light activation for 20 seconds may not be enough to adequately convert the orthodontic resin.[30] In our study, each second of photo-activation increased bond strength by 0.43 MPa; this was more intense than the 0.077 MPa increase found by Finemma et al.[9] Nevertheless, these results suggest that longer activation cycles yield higher shear bond strengths, thus higher degrees of conversion and, consequently, higher likelihood of resin polymerization.

The third condition that significantly altered the shear bond strength was the local force application. Loading the wings resulted in an increase of 8.3 MPa on bond strength, contradicting a previous study[20] that found higher shear bond strength on the bracket base compared with the wings. One specific study,[3] in which mean values of the shear test were much higher than in other studies, might influence this finding. Another factor that might be involved is the difficulty of performing a pure shear test. Different force directions of debonding may occur as bracket bases are not all flat, so the force is easier to apply on the ligature groove or bracket wings leading to shear and tension loads.

The shear bond strength of brackets with an area between 9.5 mm^2 and 12.4 mm^2 was 3.9 MPa lower than that of brackets having $<$9.5 mm^2 of area. This might have occurred owing to the different shapes of the bracket bases. Normally, brackets with areas ranging from 9.5 mm^2 to 12.4 mm^2 are used specifically in premolars; hence, their bases are curved, leading to different resin thickness between the enamel and bracket. Increased adhesive thickness is a critical parameter that results in a weak interface due to greater polymerization shrinkage and thermal expansion of the resin matrix.[31] As reported previously,[32] different shear bond strength values were obtained when the thickness changed from 0.99 mm to 0.72 mm. A bracket base area $>$12.4 mm^2 increases the bond strength to 9.1 MPa. Bracket areas over 12.4 mm^2 are generally used on central incisors. Thus, several authors[12,33,34] have shown that bond strength obtained on anterior teeth are higher than that on posteriors.

The last condition included in the multivariate analysis was the crosshead speed of the testing machine. Our study showed an increase of 6.8 MPa for a speed increase of 0.5 mm/min. This result was similar to the findings of Finemma et al.,[9] and no clear physicochemical explanation was found for the

Table 2. Descriptive Data, Random Effects, Confidence Interval, and Weight of Studies

First Author	Year	Sample Size (Per Group)	Tooth Type	Bracket Base Area, mm²	Conditioning Time, s	Photo-Curing Time, s	Storage Time, h	Use of Adhesive Primer	Effect Mean ± SD (MPa)	95% Confidence Interval		Weight, %
Bradburn	1992	24	Human molar	9.92	90	20	24	Yes	8.87 ± 2.75	7.770	3.47	3.47
								No	7.22 ± 2.61	6.176	3.48	3.48
Tang	2000	8	Human premolar	12.5	30	20	24	Yes	20.60 ± 3.00	18.521	3.28	3.28
								No	18.00 ± 4.30	15.020	3.02	3.02
Uysal	2004	20	Human premolar	14	30	20	24	No	6.60 ± 3.20	5.198	3.42	3.42
								Yes	7.75 ± 2.90	6.479	3.45	3.45
								Yes	17.10 ± 2.48	16.013	3.47	3.47
Tecco	2005	20	Human premolar	9	30	40	72	No	34.80 ± 19.70	26.166	1.43	1.43
								No	28.80 ± 16.24	21.683	1.77	1.77
								Yes	25.52 ± 7.12	22.400	2.98	2.98
								Yes	23.23 ± 5.20	20.951	3.22	3.22
Ryou	2008	10	Human premolar	9.1	30	20	24	No	8.30 ± 1.00	7.680	3.53	3.53
								No	6.80 ± 1.20	6.056	3.52	3.52
								Yes	10.90 ± 1.70	9.846	3.48	3.48
								No	7.20 ± 0.90	6.642	3.53	3.53
								No	7.60 ± 1.40	6.732	3.50	3.50
								No	7.30 ± 1.20	6.556	3.52	3.52
Romano	2009	12	Human premolar	15.7	15	40	24	No	19.70 ± 4.70	17.041	3.12	3.12
								Yes	24.60 ± 5.20	21.658	3.03	3.03
								Yes	18.70 ± 5.50	15.588	2.98	2.98
Invernici	2012	30	Bovine	12	15	40	32	Yes	8.54 ± 1.86	7.874	3.53	3.53
								Yes	6.83 ± 2.05	6.096	3.52	3.52
								No	6.42 ± 2.12	5.661	3.52	3.52
Goracci	2013	10	Human premolar	9.15	15	20	0.5	Yes	9.80 ± 2.28	8.387	3.42	3.42
								No	11.86 ± 4.17	9.275	3.14	3.14
Scribante	2013	20	Bovine	11.2	30	20	24	No	8.31 ± 3.52	6.767	3.40	3.40
				10.7				No	10.64 ± 1.89	9.812	3.51	3.51
								No	16.10 ± 5.76	13.576	3.16	3.16
								Yes	13.78 ± 4.95	11.611	3.25	3.25
								Yes	17.67 ± 6.90	14.694	3.01	3.01
								No	11.35 ± 4.20	13.191	3.33	3.33

discrepancies with other studies.[35,36] The increase of 0.5 mm/min seems to be low to be related to the elimination of the viscoelastic response of the polymeric adhesive and a consequent induction of a stiff body response.[37] One suggestion is that, with 0.5 mm/min speed, the chisel would be in contact with the body for a longer time, increasing the strains in the bond interface, whereas the contact period of the 1.0 mm/min speed would be shorter, decreasing strain and thus increasing bond strength.

Other important variables cited in previous studies[8,17] were included solely for the univariate model. We included studies that used bovine or human teeth, with no significant difference between them. For this reason, bovine enamel has been demonstrated to be a reliable substitute for human enamel in shear bonding studies, as previously.[38] The bracket base design showed a significant difference ($P < .05$) with increased shear bond strength by 6.6 MPa with the pylon base. This difference can be explained by a discrepancy in the surface roughness between mesh and pylon bases[2] and the amount of penetration of the adhesive material.[39] It is worth mentioning that in our study the adhesive types and storage time before testing had no significant influence on the shear bond strength. The behavior of each type of adhesive has been related to its polymerization shrinkage and wettability properties.[8] Notwithstanding, lower bond strengths of the flowable composites were not because of a weak bond with the enamel, but rather a consequence of their inferior mechanical properties.[15]

Most studies presented low risk of bias, but four included studies presented moderate risk and one study was excluded due to high risk of bias. Moderate bias risk may represent a limitation of this study. On the other hand, inclusion of moderate-risk-of-bias studies did not influence results, as no outlier or leverage groups were found. In addition, exclusion of such studies would reduce the power of our study.

The current literature has been systematically reviewed for in vitro studies that either used or avoided adhesive resins. However, this study presents limitations, as heterogeneity seems to be intrinsically linked to the lack of standardization of methodological reports

Table 3. Multivariate and Univariate Analysis of All Variables with SBS as the Dependent Variable[a]

		Multivariate Analysis				Univariate Analysis			
Variable	Variable Categories	Regression Coefficient	Adjusted *P* Value*	Confidence Interval 95%		Regression Coefficient	Overal *P* Value*	Confidence Interval 95%	
Photocuring time	Control (20 s)						.004		
	40 s	8.7	<.001	5.93	11.54	7.7		2.71	12.75
Local force application	Control (base)						.078		
	Wing	8.3	<.001	5.12	11.45	4.7		−0.55	10.01
Bracket area	<9.5 mm²						.17		
	9.5–12.4 mm²	−3.9	.305	−7.51	−0.20	−3.8		−9.86	2.15
	>12.4 mm²	9.1	<.001	5.39	12.73	2.2		−4.36	8.82
Adhesive resin use	Control (no)						.247		
	Yes	2.1	.312	−0.21	4.41	3.0		−2.24	8.36
Crosshead speed	Control (0.5 mm/min)						.366		
	1.0 mm/min	6.8	.004	3.21	10.37	2.5		−3.06	8.06
Bracket base	Control (mesh)						.015		
	Pylon					6.6		1.37	11.88
Storage time before shear test	Control (<24 h)						.07		
	>24 h					5.7		−0.5	11.96
Load type	Control (flattened rod)						.111		
	Chisel tip					4.2		−3.12	11.46
	Wire loop					7.8		0.27	15.29
Type of tooth	Control (human molars)						.186		
	Bovine incisors					2.9		−8.17	14.11
	Human premolars					7.2		−3.38	17.77
Type of orthodontic adhesive	Control (orthodontic with no adhesive resin need)						.421		
	Orthodontic					4.9		−2.25	12.15
	Flow					3.2		−4.49	10.88
	Restorative					−3.6		−19.4	12.26
Conditioning time	Control (15 s)						.519		
	30 s					1.0		−5.21	7.24
	90 s					−5.1		−16.8	6.59
Study groups	Control (Bradburn et al.)						<.001		
	Tang et al.					2.7		−3.52	8.95
	Uysal et al.					−0.8		−6.32	4.76
	Tecco et al.					12.9		7.14	18.77
	Ryou et al.					−0.03		−5.00	4.93
	Romano et al.					4.7		−0.33	9.74
	Invernici et al.					11.3		4.98	17.68
	Goracci et al.					18.3		12.48	24.19
	Scribante et al.					2.4		−3.09	8.06
Year of publication	1992						<.001		
	2000					11.3		5.06	17.61
	2004					2.5		−3.02	7.99
	2005					18.3		12.5	24.1
	2008					−0.03		−4.95	4.87
	2009					12.9		7.2	18.7
	2012					−0.8		−6.2	4.69
	2013					4.2		−0.6	9.01
Country	Italy						0.08		
	South Korea					8.8		2.16	15.58
	Brazil					5.9		−1.75	13.63
	Turkey					2.4		−6.9	11.86
	Sweden					11.3		0.32	10.85
	United Kingdom					0.02		−10.8	10.85

[a] $I^2 = 90.93\%$; $R^2 = 86.12\%$.
* *F* test for overall differences among groups.

of in vitro bond strength studies. Another possible limitation of this study is that many in vitro studies of orthodontic bond strength fail to report test conditions that could affect their outcomes.[9] Furthermore, different test conditions could lead to different bond strength values as shown elsewhere.[40] Further in vitro study reports need standardization to achieve more translational and comparable data.

It is not possible to predict the clinical use of a material based only on its in vitro shear bond strength. There have been attempts to establish a bond strength value that could predict clinical outcome,[41–43] but no such value has been established. There is evidence that indicates an association of in vitro bond strength and restoration longevity.[44] Given the wide range of numerical outcomes and high variation of test parameters, it is difficult to determine values. Moreover, different forces acting on brackets may play an important role in clinical bond strength values, such as occlusal interferences and masticatory forces.[45] For all that, taking restorations as a parameter, the greater the bond strength, greater the longevity. Furthermore, in the field of dental materials is required to develop new materials and explain the mechanisms involved in the phenomena.[46]

CONCLUSIONS

- The prior application of adhesive resin does not influence the bond strength of orthodontic adhesives. Thus, this step could be set aside during metal bracket bonding to enamel regardless of the type of orthodontic adhesive used.
- The variables that significantly do influence in vitro bond strength are photo-curing time, force location, bracket area, and crosshead speed of the testing machine.

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