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Influence of Repeated Bonding on the Shear Bond Strength of Orthodontic Resin Cements: A Systematic Review and Meta- analysis

Abstract

Background: Successful orthodontictreatment depends on achieving optimal shear bond strength (SBS) between brackets and enamel, ensuring durability while preventing enamel damage. Repeated bonding procedures is required to prevent bracket failure or repositioning which may alter enamel morphology or even compromise bond strength making their orthodontic treatment tidious.

Aim: To assess the influence of repeated bonding procedures on the shear bond strength of orthodontic resin cements and to identify effective rebonding strategies that maintain bond integrity alongside minimizing enamel damage.

Material and Method:A systematic search was conducted across PubMed, Scopus, and Web of Science for studies published between 2010 and March 2026. The systematic review is registered upper PROSPERO with id CRD420261326015. Following the set inclusion and exclusion criteria, in vitro studies evaluating SBS after at least one rebonding cycle were included. Data extraction and risk of bias assessment were performed independently by the authors. A meta-analysis using a fixed-effects model was conducted on comparable studies, and heterogeneity was assessed.

Results: Four studies met the inclusion criteria. The studies demonstrated a reduction in SBS following rebonding compared to primary bonding. However, most values remained within clinically acceptable limits (6–10 MPa). Surface reconditioning techniques such as sandblasting and tungsten carbide burs improved SBS compared to untreated groups. The meta-analysis revealed a small but statistically significant difference (mean difference=0.54; p=0.04) favoring primary bonding, with moderate heterogeneity observed.

Conclusion: Repeated bonding reduces shear bond strength but generally maintains clinically acceptable levels. Appropriate enamel and bracket surface preparation can mitigate this reduction. Further standardized and long-term clinical studies are required to strengthen evidence and optimize rebonding protocols

1. Introduction

During orthodontic treatment, the success of fixed appliances depends on establishing a stable bond between orthodontic brackets and tooth enamel necessitating tooth movement and overall treatment efficacy (1,2). This bondbetween the bracket and enamel must withstand orthodontic forces and mastication and also allow debonding without enamel damage (3). The bond integrity can be compromised by various factors, including adhesive type, surface preparation techniques, and rebonding challenges. Adequate bond strength is crucial (6 - 10 MPa) to ensure bracket retention and prevent premature failure.. However, if the SBS is more than 10 MPa, it may negatively affectthe enamel surface upon removal of orthodontic brackets (4,5). Despite these advancements, failures can still occur due to factors such as the bonding procedure, patient compliance, or extreme occlusal forces (6). Rebonding of the bracket is often necessitated by premature bracket detachment or repositioning.This may introduce further complexities such as residual adhesive removal and potential enamel surface alterations that influence subsequent bond strength (7). The implications of repeated bonding procedures on the shear bond strength of orthodontic resin cements are crucial for optimizing clinical protocols and ensuring predictable treatment outcomes (5).

The application of orthodontic brackets is a multi-step procedure beginning with meticulous enamel surface preparation to ensure optimal adhesion (8). Bonding often includes prophylaxis to remove plaque and debris, followed by etching with phosphoric acid to create a microporous surface for mechanical interlocking (9). This traditional approach was pioneered by Buonocore, significantly enhances enamel surface energy and wettability, enabling superior resin penetration and bond formation (10). However, concerns persist regarding potential enamel damagesuch as demineralization and etching beyond the bracket footprint particularly with 37% phosphoric acid (11). The conventional acid-etching has been linked to iatrogenic effects like increased surface porosity and cavity susceptibility due to loss of the fluoride-rich layer (12). Consequently, alternative conditioning methods and self-etching primers have been developed to moderate these issues by reducing etching time and acid concentration for achieving clinically acceptable bond strength with more conservative enamel preparation (13).

Resin cements also play a pivotal role in orthodontic bonding due to their favourable mechanical properties and aesthetic appeal. These materials provide superior bond strength compared to traditional cements, which is essential for resisting complex orthodontic and masticatory forces (14). Cement comprises of resin matrix, fillers, and photoinitiator system. These enable effective microchemico-mechanical interlocking between etched enameland treated bracket bases, ensuring durable retention (15). Moreover, specific monomers and fillers can enhance theresin cement properties such as fluoride release, viscosity, and fracture toughness, contributing to bond longevity (16). Nonetheless, optimal use requires justifying risks such as enamel damage during debonding and managing adhesive remnants (17). The versatility of resin composites, with their sufficient SBS and acceptable failure rates makes them highly suitable for orthodontic applications across diverse clinical scenarios (18).

The bracket base characteristicssuch as surface roughness and mesh design also play a crucial role in micromechanical retention with the adhesive (19). Similarly, the etching protocol (including etchant type, concentration, and duration), instrumentation also profoundly affects enamel morphology and bonding capacity (20-23). Patient-specific factors like age, diet, and oral hygiene further introduce variability underscoring the need for anall-inclusive approach to optimize outcomes. All these factors count in for successful bonding of a bracket to the enamel surface. Material properties including SBS and tensile bond strength (ideally 7–9 MPa), are also critical for appliance longevity (24).

Repeated bonding, common due to bracket debonding or repositioning, introduces complexities that can compromise enamel integrity and subsequent bond efficacy. It often requires meticulous re-preparation and careful agent selection to restore adequate strength while minimizing cumulative tooth damage (25). The challenges include maintaining clinically acceptable SBS (typically 6–8 MPa), as values exceeding 20 MPa risk enamel damage, and balancing retention against iatrogenic harm during debonding (16,26). With ceramic brackets, debonding can cause significant enamel trauma like chipping or cracking due to high forces and material rigidity (17). Residual adhesive post-debonding further complicates rebonding, often necessitating additional surface preparation that may exacerbate damage (27). Thus, this review evaluates and combines the evidence of how repeated bonding affects SBS of orthodontic resin cements, considering various enamel conditioning methods and adhesive system characteristics.

Methods

This systematic review was done with a comprehensive search strategy to identify relevant studies investigating the influence of repeated bonding on the shear bond strength of orthodontic resin cements. The review is also registered with PROSPERO (CRD420261326015). Only studies identifying the primary and secondary bond strength were included after careful selection amongst the present literature.

Focused Question

This review is based on focused question: What is the impact of repeated bonding procedures on the shear bond strength of orthodontic resin cements, and which re-bonding techniques or material modifications demonstrate superior performance in maintaining bond integrity and minimizing enamel damage?

Search Strategy

A systematic search was conducted across several electronic databases including PubMed, Scopus, and Web of Science, utilizing pre-selected keywords combined with Boolean operators to identify all relevant studies. The search terms included combinations of "repeated bonding," "rebonding," "shear bond strength," "orthodontic adhesives," "resin cement," "enamel reconditioning," and "bracket failure" to ensure a broad yet targeted retrieval of literature. The search was limited to human studies published in English, with year of publication limiting from 2010 till march 2026 to ensure a comprehensive overview PRISMA guidelines were followed (Figure 1). Additionally, manual searches of the reference lists of included articles and relevant review papers were performed to identify any further studies that might have been missed by the electronic database search.

Eligibility Criteria

Studies were included if they investigated the shear bond strength of orthodontic brackets after at least one debonding and rebonding cycles on human enamel. Studies that focused exclusively on initial bond strength, different adhesive types and instrumentation used. Furthermore, studies evaluating the efficacy of various enamel surface reconditioning techniques post-debonding were also considered, provided they quantified the resulting shear bond strength. The exclusion criteria comprised of other review articles, animal studies, conference proceedings, case reports, and studies published in languages other than English.

Data Extraction

The search was performed systematically by two independent reviewers to minimize bias and ensure thoroughness. Any discrepancies in study selection were resolved through discussion with a third reviewer to reach a consensus. Data extraction subsequently involved compilation of information from the selected articles, including study design, sample size, type of orthodontic bracket, adhesive system used, enamel conditioning methods, number of bonding-debonding cycles, shear bond strength values (mean and standard deviation), and methodologies for bond strength measurement and tabulation in an excel sheet.

Risk of Bias Assessment

The methodological quality and potential for bias in the included studies were evaluated using established tools appropriate for the study designs, such as the QUIN Risk of Bias tool for in-vitro studies. A total of 12 domains were analysed and included Clearly stated aims and objectives, Detailed explanation of sample size calculation, Detailed explanation of sampling technique, Details of comparison or control groups, Detailed explanation and standardization of methodology, Operator details (e.g., how many and their qualifications), Randomization of samples/specimens, Method of outcome measurement (validity and reliability), Outcome assessor details, blinding of the operator or assessor, Statistical analysis (appropriateness and details), Presentation of results. Each criterion is scored as follows: 2 for adequately specified, 1 for not adequately specified, 0 for not specified, and NA if not applicable. The scores for all criteria are summed to calculate the final score for each study. This score is then used to classify studies into three categories of bias risk: low risk (>70%), medium risk (50–70%), and high risk (<50%), using the formula: Final score=(Total score×100)/(2×number of criteria applicable). This assessment facilitated an understanding of the internal validity of the included research and informed the synthesis of findings.

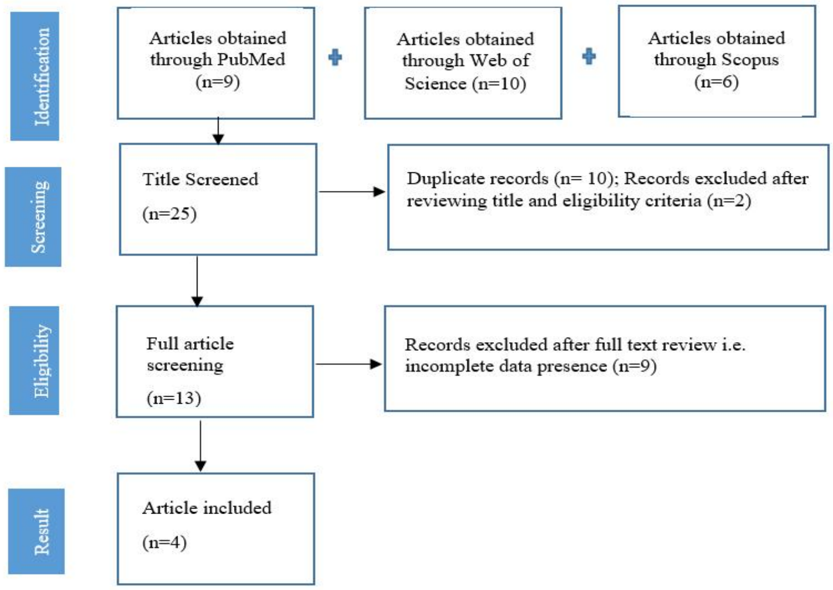
Data Synthesis

A narrative synthesis approach was employed to consolidate findings from diverse study designs, focusing on quantitative shear bond strength data and qualitative observations regarding enamel integrity and adhesive performance. Meta-analysis was performed where appropriate, using a fixed-effects model to pool shear bond strength data from studies with similar methodologies and outcome measures to determine overall effect sizes and their associated confidence intervals. The heterogeneity of study designs and outcome reporting necessitated a careful approach to statistical pooling, with subgroup analyses conducted to explore potential sources of variability such as adhesive type, reconditioning protocol, and debonding force application methods. This systematic approach ensured a robust synthesis of evidence, enabling the identification of optimal strategies for maintaining shear bond strength during repeated bonding procedures in orthodontic practice.

Results

The search strategy from the databases lead to25 articles total across all databases. After removing duplicates and checking the eligibility criteria, 13 articles were screened for relevance based on their titles and abstracts, leading to the retrieval of 4 full-text in vitro studies. (Figure 1)

Figure 1: PRISMA FLOWCHART



Characteristics of Included Studies

The reviewincludes in vitro studies, evaluating shear bond strength of orthodontic bonding agents under diverse simulated clinical conditions. The studies range between 2010to 2026 and investigate extracted human premolars as samples (sample sizes: 45–79 per study) and compared enamel surface treatments, conditioning protocols, rebonding strategies, and intervals between debonding and rebonding (13,20-22). (Table 1)

A variety of bonding agents (predominantly light-cured resins like Transbond XT) and enamel preparation techniques were assessed, including conventional acid etching, self-etching primers, and other surface modifications, often with standardized protocols via universal testing machines (13). One study incorporated both in vitro testing and a randomized controlled clinical trial, evaluating enamel preparation alongside clinical failure rates and SBS values (13).

Findings indicated SBS variability based on protocols and treatments. Most systems achieved clinically acceptable values [6-10MPa], with certain techniques demonstrating superior performance (20-22). Simple mechanical treatments like aluminum oxide sandblasting or tungsten carbide burs produced SBS comparable to initial bonding, outperforming untreated controls or less effective (21-22). Statistical analyses revealed significant intergroup differences and frequent adhesive failures at the bracket-adhesive interface in untreated rebonds (20,22). Delaying rebonding or artificial saliva immersion yielded minimal benefits, emphasizing immediate, thorough adhesive remnant removal (22)

S.NO	Author	Title	Sample size	Bonding agent		Shear bond strength		Overall Result
				Sample	Agent	Primary debonding	Secondary debonding	
1	Guarita MK; 2015 (13)	Effect of Different Surface Treatments for Ceramic Bracket Base on Bond Strength of Rebonded Bracket	75	15	Transbond XT resin without acid etching	30.41		The result shows that all treatments, except Rocatec, were effective in fulfilling the main purpose of surface treatment, i.e., to remove the remaining adhesive from the accessory and to expose the bracket surface again for bonding.
				15	Transbond XT resin without acid etching + sandblasting with aluminum oxide	24.52		
				15	Transbond XT resin without acid etching +	27.53		

					sandblasting + silane			Thus, it is possible to obtain a good result by using a simple method such as aluminum oxide sandblasting.
				15	Transbond XT resin without acid etching + silica coating + silane	28.12		
				15	Transbond XT resin without acid etching + silicatization performed in a laboratory (Rocatec system)	14.22		
2	Ishida K; 2011 (20)	Shear bond strength of rebonded brackets after removal of adhesives with Er,Cr:YSGG laser	79	19	Untreated	10.97	3.91	The mean initial bond strength was significantly higher than the mean rebond strength in untreated group but there was no significant difference between other groups. Failures at the bracket-adhesive interface occurred frequently at second debonding in untreated group
				19	Er,Cr:YSGG laser	10.7	9.86	
				19	sandblaster	10.7	9.05	
				19	Er,Cr:YSGG laser/sandblaster.	10.93	9.39	
3	Ahrari F; 2012 (21)	Early versus delayed rebonding of orthodontic brackets	60	15	Residual composite was removed by a round bur	9.4	8.1	Postponing rebonding to the next visit does not improve the SBS significantly. It is recommended to use a tungsten carbide bur or a green rubber wheel and not round bur for removing adhesive remnants following debonding of orthodontic brackets
				15	Residual composite was removed by a green rubber wheel.	9.17	9	
				15	: Residual composite was removed by a tungsten carbide (TC) bur.	9.51	9.74	
				15	Residual composite was removed by a tungsten carbide bur and the teeth were immersed in a Fuzayama Meyer artificial saliva solution for 1 month at 37oC.	9.21	10.06	
4	Dirie AR; 2011 (22)	Evaluation of sandblasting with acid etching versus acid	45	15	rebonding using sandblasting followed by acid etching	19.38	22.37	The differences in the bond strength were significant between the IB group and the SBE group, as well as
				15	rebonding	19.38	17.37	

		etching alone in the preparation of enamel for rebonding orthodontic brackets: An in vitro study and a randomized controlled trial			using acid etching			between the SBE group and the Egroup. The clinical failure rate for bonded brackets was 10% in the SBE group, and 25% in the E group and this difference was statistically significant
				15	Intial Bond (control)	19.38	NA	

Risk of Bias in Included Studies

QUINtool was used to assess the quality of the included articles. A comprehensive detail of the quality assessment is provided in Figure 2. Among the 4 included article, 3 reported with medium risk of bias whereas one reported low risk. (Figure 2)

DOMAINS	REFERENCE NO.			
	13	20	21	22
D1: Clearly stated aims and objectives	2	2	2	2
D2: Detailed explanation of sample size calculation	0	0	0	0
D3: Detailed explanation of sampling technique	2	2	2	2
D4: Details of comparison or control groups	0	0	0	2
D5: Detailed explanation and standardization of methodology	0	1	0	1
D6: Operator details (e.g., how many and their qualifications)	2	2	2	2
D7: Randomization of samples/specimens	0	0	0	0
D8: Method of outcome measurement (validity and reliability)	2	2	2	2
D9: Outcome assessor details	2	2	2	2
D10: Blinding of the operator or assessor	0	0	0	0
D11: Statistical analysis (appropriateness and details)	1	1	1	2
D12: Presentation of results	2	2	2	2
TOTAL SCORE	**13**	**16**	**13**	**17**
RESULTS	MEDIUM RISK	MEDIUM RISK	MEDIUM RISK	LOW RISK

Figure 2: Risk of bias assessment using QUINTool

Meta-analysis:

On plotting forest plot for shear bond strength, the variation for sandblastingamongst thetwo studies (20-22), a heterogeneity could not be clearly defined. The combined pooled analysis shows a difference of 0.73 amongst the primary and secondary shear bond strengths for the rebonded brackets. The confidence interval does not cross 0 indicating a statistically significant effect in favor of the primary rebonding stating the secondary shear bond strength is 0.73 times less compared to the primary shear bond strength for a rebonded bracket and not significant (p ≈ 0.69) (Figure 3).

Study or Subgroup	Primary Events	Primary Total	Secondary Events	Secondary Total	Weight	Odds Ratio M-H, Fixed, 95% CI
Dirie AR (Sandblast+ AE)	19	15	22	15		Not estimable
Ishida K (sandblasting)	10	15	11	15	100.0%	0.73 [0.15, 3.49]
Total (95% CI)		30		30	100.0%	0.73 [0.15, 3.49]
Total events	29		33			
Heterogeneity: Not applicable						
Test for overall effect: Z = 0.40 (P = 0.69)						

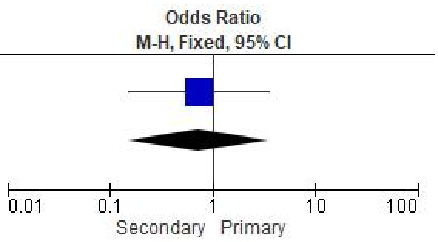


Figure 3: Comparison of primary and secondary shear bond strength

The funnel plot shows a less heterogeneous distribution as most of are enveloped into the cone and follow similar methodology for shear bond assessment. Thus, the risk of bias states equal.

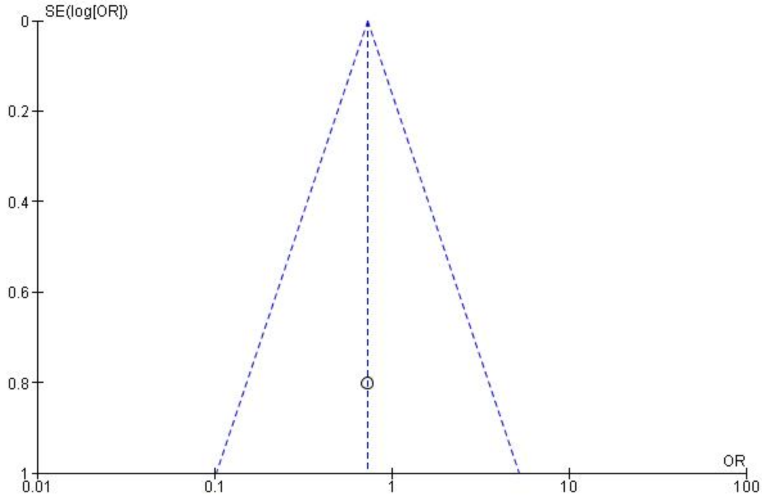


Figure 4: Publication bias amongst included studies

Discussion

The systematic review demonstrates that repeated bonding cycles exert a substantial impact on the shear bond strength of orthodontic resin cements, which vary for different studies (5, 20-22). Initial bonding procedures commonly achieve SBS values of 16 to 18 MPa (13). Following rebonding, these values typically decline. Nevertheless, majority of brackets sustain SBS levels within the clinically acceptable range of 6-10 MPa (20,22). This observation is particularly pertinent as the Reynolds threshold of 5.9-7.8 MPa is widely accepted as the minimum requisite to resist masticatory forces (17,24). Moreover, accounting for the approximately 40% reduction in bond strength under intraoral conditions relative to laboratory simulations, an in vitro rebonding SBS of at least 9.83-13 MPa is advocated to promote clinical durability (24). An exception was noted in one of the included studies where the secondary SBS is elevated more than the primary SBS and near 20 MPA, which is already an established value for enamel damage (22).

The observed reduction in SBS upon rebonding stems primarily from micromorphological alterations to the enamel surface. Post-initial debonding, residual resin tags persist within the enamel prisms, extending to depths of up to 50 µm (25-26). These occluded porosities hinder the infiltration of fresh resin during subsequent bonding, yielding fewer and shorter resin tags than in primary applications (27). The exception in Dirie AR et al. can be due to methodology or the invitro model requisite as both the surface and bracket surface are conditioned (22).

Enamel and bracket surface preparation is an important factor influencing rebonding efficacy (7). Although slow-speed tungsten carbide burs or silicone polishers proficiently eliminate adhesive remnants from enamel, they compromise surface conservation. Evidence suggests that such mechanical abrasion induces enamel loss averaging approximately 19 µm (28). Given that resin tags can penetrate far deeper than this abraded layer, exhaustive removal of adhesive residues proves histologically unattainable without incurring substantial iatrogenic enamel damage (25).

Regarding bracket reconditioning, sandblasting and Er:YAG laser irradiation effectively reinstate mechanical retention on bases of both metallic and ceramic brackets (21). In particular, Er:YAG laser application can restore retention exceeding 26 MPa for metal brackets sans structural compromise (21). While sandblasting is more common, it poses a greater risk of impairing the fragile microcrystalline architecture of ceramic bracket bases, thereby yielding inferior subsequent bond strengths relative to laser irradiation (20).

Adhesive selection profoundly modulates rebonding performance. Conventional etch-and-rinse regimens employing 35-37% phosphoric acid invariably produce the highest SBS owing to their characteristic deep "honeycomb" etch morphology (8,11,28). Nonetheless, self-etching primers are being preferred for their milder etch patterns, which mitigate decalcification risks inherent to phosphoric acid (8). Self- etch primers generally deliver SBS values of 10-12 MPa which is prerequisite for adequate retention while curtailing enamel fracture and cracking risks during debonding, safeguarding compromised enamel substrates (10,14).

Clinically, enamel undergoes irreversible modification post-initial bonding (5). A compensatory benefit arises from "resin-to-resin" interfacial bonding where residual intraporous tags fuse chemically with novel adhesives and offset the absence of etched surfaces (5). In this scenarios, moisture contamination typical to posterior regions or in noncompliant patients, the use of moisture-tolerant primers or resin-modified glass ionomers exhibit superiority due to resilience against isolation lapses (9,18). Nevertheless, for standard applications, a meticulous mechanical debridement followed by judicious re-etching constitutes the benchmark protocol (16,23). This strategy harmonizes robust retention imperatives with enamel preservation, particularly as recurrent bonding-induced roughness may exacerbate bacterial colonization if inadequately addressed (25,30). All the factors combined when taken into consideration can lead to an elevated SBS of resin cements and provide a base for a successful orthodontic treatment.

Limitations of the Review

A significant limitation identified in this review is the lack of standardization in SBS testing methodologies across the included studies. Variations in crosshead speeds, the location of force application, and the storage conditions of samples (e.g., thermocycling vs. water storage) contribute to the heterogeneity of the results. Furthermore, the majority of the data is derived from in vitro models, which cannot fully replicate the complex oral environment characterized by fluctuating pH levels, temperature changes, and the presence of saliva and oral enzymes. These "aging" factors can significantly degrade the resin-enamel interface over the typical two-year treatment duration, a variable often missing in laboratory assessments.

Recommendations for Future Research

Future research should focus on developing standardized protocols for bond strength testing to allow for more accurate comparisons between different materials and techniques. There is also a critical need for long-term clinical trials that evaluate the failure rates of rebonded brackets over the entire course of orthodontic treatment. Additionally, the emergence of bioactive composites and remineralizing etchants warrants further investigation. These materials could potentially mitigate the enamel demineralization and iatrogenic damage associated with repeated bonding, leading to a more biological approach to orthodontic adhesion.

Conclusion

Repeated bonding procedures result in a measurable reduction in the shear bond strength of orthodontic resin cements compared to primary bonding. Although this reduction is statistically significant, most rebonded brackets still demonstrate bond strengths within clinically acceptable limits. The findings highlight that appropriate enamel and bracket surface reconditioning techniques can effectively mitigate the loss of bond strength. However, the presence of moderate heterogeneity and reliance on predominantly in vitro studies necessitate cautious interpretation of the results. Further standardized protocols and long-term clinical studies are required to validate these findings and optimize rebonding strategies.

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Data Availability Statement: The data supporting the findings of this systematic review and meta-analysis are available within the article and its supplementary materials. The data extraction sheets and data pooling files are available from the corresponding author upon reasonable request.

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