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Review Article

Comparison of Bond Strength Among Three Direct Bonding Systems for Metal Brackets in Orthodontics: A Systematic Review and Meta-Analysis

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Abstract

Background: Direct bonding of metal brackets is a fundamental procedure in orthodontics and the bonding efficacy of the system employed is critical for treatment success. There are three main types of adhesive systems: etch-and-rinse, self-etching and universal. However, there is no consensus in the current literature on which of these systems provides the highest adhesive strength, justifying this review to guide clinical selection based on updated evidence.

Methods and findings: A comprehensive search was conducted in databases including PubMed, Cochrane Library, Science Direct and Google Scholar, including studies published from 2014 onwards. Search strategies were developed using specific terms related to orthodontic bonding and types of adhesive systems.

The inclusion criteria were *in-vivo* and *in-vitro* randomized controlled studies that evaluated the shear bond strength of adhesive systems in metal brackets. Studies had to be published in English or Spanish from 2014 onwards and with a sound methodology and low risk of bias. Studies with a high risk of bias, those not relevant to the objective or with differing methodological designs were excluded.

The methodological quality of the studies was assessed using the Cochrane Collaboration's risk of bias tool. Data on bond strength, type of adhesive system and tooth characteristics were collected. Meta-analyses were performed using RevMan Web, generating forest plots and evaluating heterogeneity with the I^2 statistic. SPSS was employed to identify potential publication bias.

Etch-and-rinse systems demonstrated the highest bond strength compared to self-etching systems, which were advantageous in reducing clinical time. Universal adhesives demonstrated comparable bond strength to conventional systems when combined with acid pre-etching. Variability in results indicating that factors such as application technique and substrate conditions (e.g., moisture and enamel quality) influence adhesive effectiveness.

Conclusion: Etch-and-rinse systems provide the greatest bond strength, but universal adhesives offer a versatile and clinically favorable option when balancing efficacy and simplicity. The high heterogeneity among studies and variability in protocols limit the generalizability of the results. Additionally, the predominance of *in-vitro* trials may not fully reflect clinical conditions.

Orthodontists should select the adhesive system based on the specific characteristics of each case and clinical technique. This review contributes valuable information for clinical decision-making in orthodontics, supporting the selection of the most suitable adhesive system to enhance treatment outcomes and patient satisfaction.

Keywords: Etch and Rinse; Self-Etch; Universal; Metal Brackets; Bond Strength

Introduction

Orthodontics is a specialized field of dentistry focused on achieving dentofacial harmony through the alignment and movement of teeth, thereby improving both aesthetics and masticatory function. One of the essential procedures in orthodontic treatment is the direct bonding of brackets, in which small metallic components are adhered to the tooth surface and subsequently connected by archwires that generate the necessary forces for tooth movement [1]. The success of orthodontic treatment depends significantly on the strength of the bracket-tooth bond, as insufficient adhesion can lead to bracket debonding, patient discomfort, treatment delays and increased clinical costs [2].

Various adhesive systems are available for bonding metallic brackets, each with distinct advantages and limitations. The choice of the most suitable adhesive system depends on various factors, including the clinician's expertise, bracket type, tooth characteristics and patient preference [3]. Conventional etch-and-rinse adhesive systems involve an acid-etching step followed by rinsing, creating a microporous enamel surface that enhances adhesive penetration and bond strength [4]. However, this technique is technique-sensitive and requires precise handling to avoid enamel damage. In contrast, self-etch adhesive systems simplify the bonding procedure by combining etching and priming in a single step, eliminating the need for separate acid etching [5]. This simplification reduces chair time and technique sensitivity, but some studies suggest that self-etch systems may provide lower bond strength compared to etch-and-rinse adhesives [6]. More recently, universal adhesive systems have gained popularity due to their versatility and ease of application, demonstrating bond strengths comparable to or even superior to conventional adhesives, though long-term evidence is still needed [7].

Despite the diversity of adhesive systems, no consensus exists regarding which offers the highest bond strength for direct bracket bonding. While some studies suggest that etch-and-rinse systems yield the strongest adhesion, others indicate that self-etch or universal adhesives are equally effective or superior [8]. These inconsistencies in the literature highlight the need for a systematic review to compare the available scientific evidence on the adhesive strength of etch-and-rinse, self-etch and universal adhesive systems in direct bracket bonding. This study aims to provide orthodontists with evidence-based insights to optimize adhesive selection, enhance treatment outcomes and improve patient experience. By critically evaluating the literature and identifying trends in adhesive performance, this review will contribute to a deeper understanding of adhesive systems in orthodontics. The findings will offer valuable guidance for clinical decision-making and future research, ensuring that orthodontic treatments continue to evolve based on robust scientific evidence.

Ethics Approval

This study was approved by the Ethics Committee of Navodaya Dental College and Hospital, Raichur (IEC/NDC/RCR/2023-2024/SSO025).

Methodology

This research consisted of a systematic review and meta-analysis of Randomized Controlled Trials (RCTs) evaluating adhesive systems used for the direct bonding of metal brackets. The PRISMA 2020 guidelines were followed to ensure a rigorous and reproducible selection of studies. The PICO strategy (Population, Intervention, Comparison, Outcome) was used to define the scope of the review and structure the bibliographic search.

PICO Strategy:

Population (P): Teeth with metallic brackets bonded using a conventional, self-etching or universal adhesive system.

Intervention (I): Direct bonding system for metallic brackets.

Comparison (C): Comparison of different bonding systems (conventional, self-etching and universal) for direct bonding of metallic brackets.

Outcome (O): Identify which bonding system is the most suitable for the direct bonding of metallic brackets.

Research Question

Which bonding system exhibits the highest bond strength in the direct bonding of metallic brackets?

Information Sources and Search Strategy

A systematic search was conducted in PubMed, Cochrane Library, Science Direct and Google Scholar on June 17, 2024. MeSH terms and Boolean operators were used with the following search strategy: "Bond strength and orthodontic brackets and self-etching adhesives or conventional adhesives or universal adhesives." No restrictions were applied to maximize the retrieval of relevant studies.

Eligibility Criteria

RCTs published in English or Spanish from 2014 onwards were included, evaluating the adhesion of metal brackets using etch-and-rinse, self-etch or universal adhesive systems and reporting shear bond strength as the primary outcome. Studies with methodological designs other than RCTs, those not reporting shear bond strength as the primary variable, studies in other languages or those without an available abstract were excluded.

Study Selection and Data Extraction

Study selection followed a two phases process: 1, title and abstract screening to exclude irrelevant studies and 2, full-text reading of preselected studies to determine eligibility. The PRISMA tool was used to document the selection process. Data extraction was performed in Microsoft Excel using a structured form, recording the author, year of publication, study design, type of adhesive system, comparison group, evaluation method and main results. A second reviewer verified the accuracy of the extraction.

Risk of Bias Assessment

The methodological quality of the included studies was assessed using the "Cochrane Collaboration's Risk of Bias Tool," which analyzes five domains: randomization, deviations from interventions, incomplete outcome data, outcome measurement and selective reporting. Studies were classified as having low, moderate or high risk of bias. In case of discrepancies, a third evaluator resolved disagreements.

Statistical Methods

Statistical analysis was performed using RevMan Web and SPSS v.29. Mean differences were calculated to evaluate shear bond strength among different adhesive systems. A random-effects model was used due to the expected heterogeneity among studies. Heterogeneity was assessed using the I^2 statistic and the Chi-square test. Publication bias was evaluated using funnel plots and Egger's test. Confidence intervals of 95% were reported, avoiding the exclusive use of p-values to determine statistical significance.

Results

Study Selection and Risk of Bias Assessment

A total of 3,292 titles were identified from the database searches (Fig. 1). After removing 1,822 duplicate articles, 1,470 unique studies remained. A preliminary screening of titles and abstracts resulted in the selection of 272 studies that met basic relevance criteria. However, 203 were excluded for being unrelated to the research topic, involving ceramic brackets or using rebonded brackets.

Of the 69 full-text articles assessed, 31 were excluded as they did not employ metal brackets or did not directly address the study objective. This resulted in 38 eligible studies. Using the Risk of Bias (RoB 2.0) tool, five studies were excluded due to high risk of bias, resulting in a final selection of 33 randomized clinical trials for the systematic review.

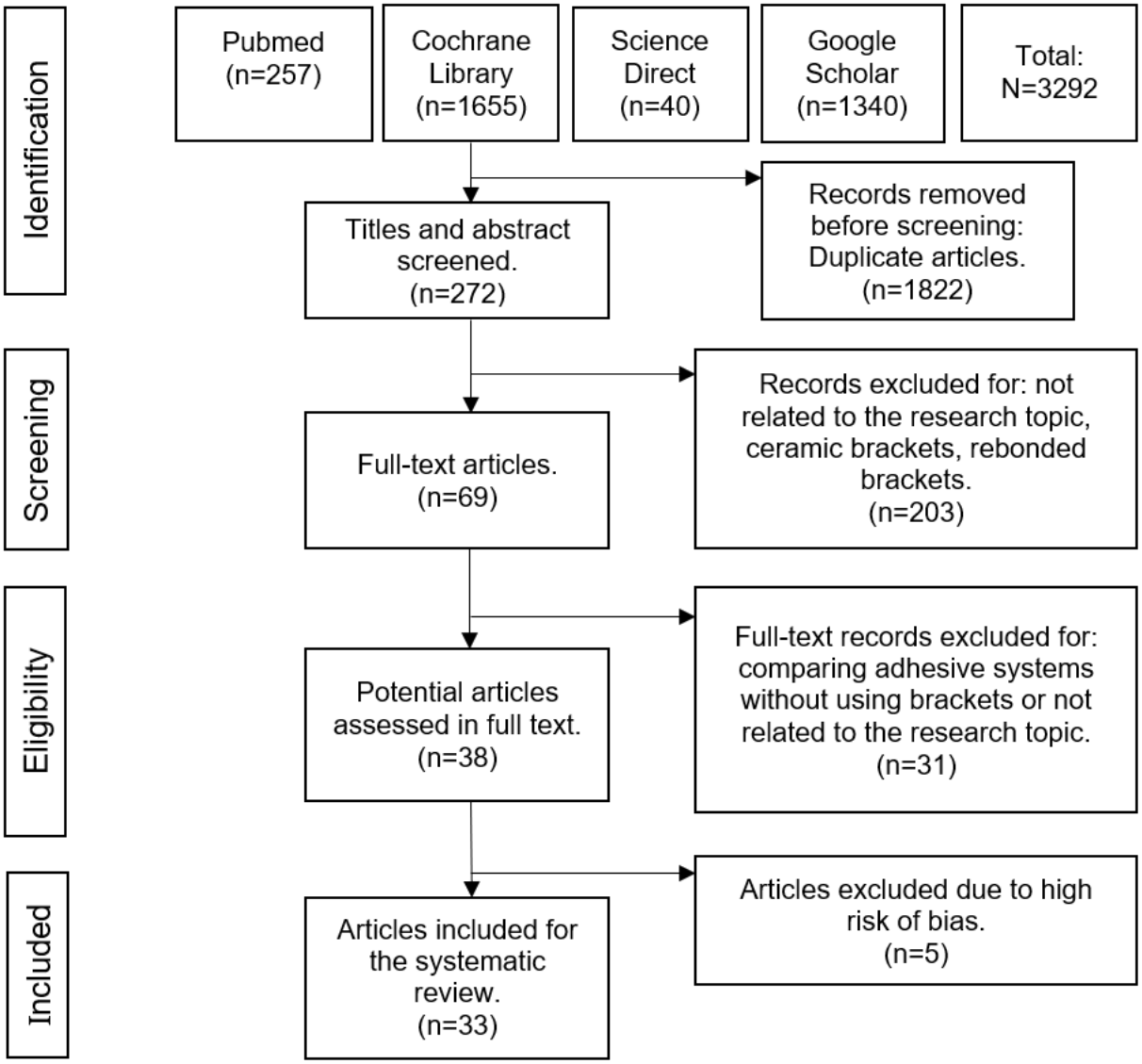

Figure 1: PRISMA flow diagram.

Out of the 33 included studies, five had a low risk of bias, whereas the remaining 28 had "some concerns." Of these, four *were in-vivo* trials and 29 were *in-vitro* studies.

Comparison of Adhesive Systems

Of the 33 included studies, 30 evaluated shear bond strength, while three investigated the percentage of bracket debonding. Regarding sample type, 29 studies used human teeth, whereas four used bovine teeth (Table 1).

Author/Year	Study Design	Type and Number of Teeth	Adhesive System	Evaluated Groups	Assessment Method	Results
Lahcen Ousehal 2016(9)	RCT (in-vivo)	400 premolars	Etch and rinse vs self-etching	100 patients, brackets were cemented on teeth 14 and 25 with self-etching adhesive and on teeth 15 and 24 with conventional adhesive.	Percentage of brackets debonding	There was no significant difference.

Mete Ozer 2014(10)	RCT (in-vivo)	1140 teeth 57 patients with full arches	Etch and rinse vs self-etching	57 patients, for each patient, brackets were cemented using both the conventional system and the self-etching system alternately by quadrant.	Percentage of brackets debonding	There was no significant difference.
Shaza M. Hammad 2016(11)	RCT (in-vitro)	96 premolars	Etch and rinse vs self-etching vs Universal (passive)	Four randomly assigned groups Group 1: n=24 brackets cemented with Transbond XT and 37% Phosphoric Acid for 15 seconds Group 2: n=24 brackets cemented with Transbond Plus Group 3: n=24 brackets cemented with Futurabond DC Group 4: n=24 brackets cemented with Optibond All-in-One	Shear bond strength (Sbs/Mpa)	There was no significant difference at 12 hours. At 24 hours, the mean Sbs of the conventional adhesive was statistically higher than that observed for the Optibond All-in-One adhesive.
Qasim Khalid 2023(12)	RCT (in-vitro)	60 premolars	Etch and rinse vs Universal (passive)	Two randomly assigned groups: Group 1: n=30 Brackets bonded with Transbond and phosphoric acid. Group 2: n=30 Brackets bonded with Futurabond DC.	Shear bond strength (Sbs/Mpa)	The mean SBS of universal adhesives was statistically higher compared to that of conventional adhesives.
Andreas Hellak 2016(13)	RCT (in-vitro)	60 premolars	Etch and rinse vs self-etching vs Universal (passive)	Three randomly assigned groups: Group 1**:** n=20 brackets bonded with Transbond XT and 37% phosphoric acid for 20s Group 2: n=20 brackets bonded with Prompt-L-Pop Group 3**:** n=20 brackets bonded with Scotchbond Universal	Shear bond strength (Sbs/Mpa)	There was no significant difference.
Ines Dallel 2019(14)	RCT (in-vitro)	120 premolars	Etch and rinse vs self-etching	Four randomly assigned groups: Group 1**:** n=30	Shear bond strength (Sbs/Mpa)	The mean SBS of conventional adhesives was

				brackets bonded with Optibond FL (Kerr-Hawe) and 37.5% phosphoric acid for 15s, light-cured with a 1500 mW/cm² lamp. Group 2**:** n=30 brackets bonded with Retensin® Plus (Spofadenta) and phosphoric acid, light-cured with a 1500 mW/cm² lamp. Group 3: n=30 brackets bonded with Bond 008 (Spofadental), light-cured with a 1500 mW/cm² lamp. Group 4**:** n=30 brackets bonded with Bond 008 (Spofadental), light-cured with an 800 mW/cm² lamp.		statistically higher compared to that of self-etch adhesives.
Alexandra R. Vinagre 2014(15)	RCT (in-vitro)	90 premolars 180 Hemi premolars	Etch and rinse vs self-etching	Four randomly assigned groups: Group 1**:** n=45 brackets bonded with Concise. Group 2: n=45 brackets bonded with Transbond XT and 37% phosphoric acid for 30s. Group 3: n=45 brackets bonded with Transbond Plus. Group 4**:** n=45 brackets bonded with Heliosit.	Shear bond strength (Sbs/Mpa)	There was no significant difference.
Emire Aybüke Erdur 2017(16)	RCT (in-vitro)	100 mandibular third molars	Etch and rinse vs self-etching	Five randomly assigned groups. In all groups, the mesiobuccal and distobuccal surfaces were randomized: one received the experimental adhesive, while the	Shear bond strength (Sbs/Mpa)	The mean SBS of conventional adhesives was statistically higher in all groups compared to that of self-etch adhesives.

				other received the control adhesive. The control adhesive was Transbond XT with 37% phosphoric acid for 15s. Group 1: n=20 brackets bonded with Transbond Plus SEP. Group 2**:** n=20 brackets bonded with Clearfil S3 Bond Plus. Group 3: n=20 brackets bonded with Clearfil S3 Bond. Group 4: n=20 brackets bonded with Ortho Solo. Group 5: n=20 brackets bonded with AdheSE.		
Mukundan Vijayan 2023(17)	RCT (in-vitro)	20 premolars	Etch and rinse vs self-etching	Two randomly assigned groups: Group 1**:** n=10 brackets bonded with Transbond Plus SEP. Group 2**:** n=10 brackets bonded with Transbond XT and 37% phosphoric acid for 30s.	Shear bond strength (Sbs/Mpa)	The mean SBS of conventional adhesives was statistically higher compared to that of self-etch adhesives.
Elsanuse Saied 2021(18)	RCT (in-vitro)	30 premolars	Etch and rinse vs self-etching	Two randomly assigned groups: Group 1**:** n=15 brackets bonded with Transbond XT and 37% phosphoric acid for 15s. Group 2**:** n=15 brackets bonded with Transbond Plus.	Shear bond strength (Sbs/Mpa)	There was no significant difference at 24 hours and 30 days. The mean SBS of conventional adhesives was statistically higher at three months compared to that of self-etch adhesives.
Nasrin Farhadian 2019(19)	RCT (in-vivo)	22 patients 44 premolars	Etch and rinse vs self-etching	22 patients, with brackets bonded using the	Shear bond strength (Sbs/Mpa)	There was no significant difference.

				conventional system and the self-etch system alternately by quadrant for each patient. Two months later, the premolars were extracted.		
May Anny Alves 2021(20)	RCT (in-vitro)	80 bovine incisors	Etch and rinse vs self-etching vs Universal (passive)	Four randomly assigned groups: Group 1: n=20 brackets bonded with Transbond XT and 37% phosphoric acid for 15s. Group 2: n=20 brackets bonded with Transbond Plus. Group 3: n=20 brackets bonded with Single Bond Universal for 20s. Group 4: n=20 brackets bonded with Single Bond Universal for 40s.	Shear bond strength (Sbs/Mpa)	The mean SBS of conventional and self-etch adhesives was higher compared to that of universal adhesives.
M. J. Ravindranath 2015(21)	RCT (in-vitro)	60 premolars	Etch and rinse vs self-etching	Three randomly assigned groups: Group 1: n=20 brackets bonded with Transbond XT and 37% phosphoric acid for 15s. Group 2: n=20 brackets bonded with Transbond XT and 37% phosphoric acid for 30s. Group 3: n=20 brackets bonded with Transbond Plus.	Shear bond strength (Sbs/Mpa)	The mean SBS of conventional adhesives etched for 30s with 37% phosphoric acid was higher than that of self-etch adhesives and conventional adhesives etched for 15s.
Sudhir Sharma 2014(22)	RCT (in-vitro)	80 premolars	Etch and rinse vs self-etching	Four randomly assigned groups: Group 1: n=20 brackets bonded with Rely-a-Bond. Group 2: n=20 brackets bonded with Transbond XT and 37% phosphoric acid for 30s.	Shear bond strength (Sbs/Mpa)	The mean SBS of conventional adhesives was higher compared to that of self-etch adhesives.

				Group 3: n=20 brackets bonded with Transbond Plus. Group 4: n=20 brackets bonded with Xeno V.		
Aman Sachdeva 2017(23)	RCT (in-vitro)	150 premolars	Etch and rinse vs self-etching	Three randomly assigned groups: Group 1: n=50 brackets bonded with Transbond XT and 37% phosphoric acid for 15s. Group 2: n=50 brackets bonded with Transbond Plus. Group 3: n=50 brackets bonded with G-BOND.	Shear bond strength (Sbs/Mpa)	The mean SBS of conventional adhesives was statistically higher compared to that of Transbond Plus, but no significant difference was found with G-Bond.
Ezgi Atik 2018(24)	RCT (in-vivo)	63 patients, full arches 1260 teeth	Etch and rinse vs self-etching	Four randomly assigned groups: Group 1: n=15 brackets bonded with Transbond XT and 37% phosphoric acid for 15s. Group 2: n=16 brackets bonded with APC brackets and 37% phosphoric acid for 15s. Group 3: n=16 brackets bonded with Transbond Plus. Group 4: n=16 brackets bonded with APC brackets and self-etching enamel.	Percentage of brackets debonding	There was no significant difference.
Handan Bayar Bilen 2020(25)	RCT (in-vitro)	144 premolars	Etch and rinse vs self-etching	Six randomly assigned groups: Group 1: n=24 brackets bonded with Transbond XT and 37% phosphoric acid for 15s. Group 2: n=24 brackets bonded with Transbond Plus. Group 3: n=24 brackets bonded	Shear bond strength (Sbs/Mpa)	There was no significant difference.

				with GC Ortho Connect and 37% phosphoric acid for 15s. Group 4: n=24 ceramic brackets bonded with Transbond XT and 37% phosphoric acid for 15s. Group 5**:** n=24 ceramic brackets bonded with Transbond Plus. Group 6: n=24 ceramic brackets bonded with GC Ortho Connect and 37% phosphoric acid for 15s.		
Bhogi Siddarth 2022(26)	RCT (in-vitro)	100 premolars	Etch and rinse vs self-etching	Two randomly assigned groups: Group 1: n=50 brackets bonded with Transbond XT and 37% phosphoric acid for 15s. Group 2**:** n=50 brackets bonded with Optibond eXTRa.	Shear bond strength (Sbs/Mpa)	There was no significant difference.
Shaheen Hamdani 2016(27)	RCT (in-vitro)	200 premolars	Self-etching Vs self-etching (active)	Four randomly assigned groups: Group 1**:** n=50 brackets bonded with Transbond Plus without pre-etching. Group 2**:** n=50 brackets bonded with Transbond Plus and 37% phosphoric acid for 10s of pre-etching. Group 3: n=50 brackets bonded with Transbond Plus and 37% phosphoric acid for 30s of pre-etching. Group 4**:** n=50 brackets bonded	Shear bond strength (Sbs/Mpa)	The mean SBS for the self-etch adhesive conditioned with 37% phosphoric acid for 10s was statistically higher compared to that of the self-etch adhesives that were either not conditioned or conditioned for 30s and 60s.

				with Transbond Plus and 37% phosphoric acid for 60s of pre-etching.		
Kartikaya Verma 2019(28)	RCT (in-vitro)	80 premolars	Etch and rinse vs self-etching	Four randomly assigned groups: Group 1: n=20 brackets bonded with Transbond XT and 37% phosphoric acid for 30s. Group 2: n=20 brackets bonded with Heliosit and 37% phosphoric acid for 30s. Group 3**:** n=20 brackets bonded with Transbond Plus. Group 4: n=20 brackets bonded with Optibond All-In-One.	Shear bond strength (Sbs/Mpa)	The mean SBS for the conventional adhesive was statistically higher compared to that of the self-etch adhesives.
Junaid Ahmed 2018(29)	RCT (in-vitro)	100 premolars	Etch and rinse vs self-etching (active)	Four randomly assigned groups: Group 1**:** n=25 brackets bonded with Transbond XT and 37% phosphoric acid for 15s. Group 2**:** n=25 brackets bonded with Transbond XT and 37% phosphoric acid for 15s and contaminated with saliva. Group 3**:** n=25 brackets bonded with Transbond Plus and 37% phosphoric acid for 15s. Group 4**:** n=25 brackets bonded with Transbond Plus and 37% phosphoric acid for 15s and contaminated with saliva.	Shear bond strength (Sbs/Mpa)	There was no significant difference; Transbond Plus performed better in a wet environment than the conventional adhesive.
Nishad A Vaheed 2018(30)	RCT (in-	60 premolars	Etch and rinse vs	Three randomly assigned groups:	Shear bond strength	The mean SBS for the self-etch

	vitro)		self-etching	Group 1**:** n=20 brackets bonded with Transbond XT and 37% phosphoric acid for 15s. Group 2: n=20 brackets bonded with Xeno V (self-etching). Group 3: n=20 brackets bonded with Filtek Z350 XT.	(Sbs/Mpa)	adhesive (7th) was statistically higher compared to that of the conventional adhesive.
Amit Zope 2016(6)	RCT (in-vitro)	100 premolars	Etch and rinse vs self-etching	Five randomly assigned groups: Group 1: n=20 brackets bonded with Transbond XT and 37% phosphoric acid for 40s. Group 2**:** n=20 brackets bonded with Transbond Plus. Group 3: n=20 brackets bonded with Xeno V. Group 4: n=20 brackets bonded with G-Bond. Group 5: n=20 brackets bonded with One-Coat.	Shear bond strength (Sbs/Mpa)	The mean SBS for the conventional adhesives was statistically higher compared to that of the self-etch adhesives.
Isabella-Saraiva 2023(31)	RCT (in-vitro)	100 bovine incisors	Etch and rinse Vs Universal (active)	Five randomly assigned groups: Group 1: n=20 brackets bonded with Transbond XT and 37% phosphoric acid for 15s. Group 2: n=20 brackets bonded with Ambar and 37% phosphoric acid for 30s. Group 3: n=20 brackets bonded with Ambar Universal and 37% phosphoric acid for 30s. Group 4: n=20	Shear bond strength (Sbs/Mpa)	After 24 hours, there were no significant differences. After 12 months, only Single Bond Universal was statistically superior compared to Transbond XT.

				brackets bonded with Single Bond Universal and 37% phosphoric acid for 30s. Group 5: n=20 brackets bonded with Adper Single Bond and 37% phosphoric acid for 30s.		
Chandrashekhar Yadala 2015(32)	RCT (in-vitro)	60 premolars	Etch and rinse vs self-etching	Four randomly assigned groups: Group 1: n=15 brackets bonded with Transbond XT and 37% phosphoric acid for 15s. Group 2**:** n=15 brackets bonded with Adper™ Prompt. Group 3: n=15 brackets bonded with Xeno III. Group 4: n=15 brackets bonded with Transbond Plus.	Shear bond strength (Sbs/Mpa)	There was no significant difference.
Angelica Iglesias 2020(33)	RCT (in-vitro)	72 premolars	Etch and rinse vs self-etching	Six randomly assigned groups: Group 1: n=12 brackets bonded with Transbond XT and 37% phosphoric acid for 30s directly. Group 2: n=12 brackets bonded with Beauty Orthobond II directly. Group 3**:** n=12 brackets bonded with GC Ortho Connect and 37% phosphoric acid for 30s directly. Group 4**:** n=12 brackets bonded with Transbond XT and 37% phosphoric acid for 30s	Shear bond strength (Sbs/Mpa)	The mean SBS for the conventional adhesives was statistically higher compared to that of the self-etch adhesives.

				indirectly. Group 5**:** n=12 brackets bonded with Beauty Orthobond II indirectly. Group 6: n=12 brackets bonded with GC Ortho Connect and 37% phosphoric acid for 30s indirectly.		
Senkutvan Rathnam 2014(34)	RCT (in-vitro)	36 premolars	Etch and rinse vs self-etching vs Universal (active)	Three randomly assigned groups: Group 1: n=12 brackets bonded with Transbond XT and 37% phosphoric acid. Group 2**:** n=12 brackets bonded with Prompt L-Pop. Group 3**:** n=12 brackets bonded with Nano bonding agent and 37% phosphoric acid.	Shear bond strength (Sbs/Mpa)	There was no significant difference.
Muhittin Ugurlu 2021(35)	RCT (in-vitro)	75 premolars	Etch and rinse vs Universal (active)	Five randomly assigned groups: Group 1: n=15 brackets bonded with Scotchbond Universal and 37% phosphoric acid for 15s. Group 2: n=15 brackets bonded with Scotchbond Universal (double application) and 37% phosphoric acid for 15s. Group 3**:** n=15 brackets bonded with Prime&Bond Universal and 37% phosphoric acid for 15s. Group 4: n=15 brackets bonded with Prime&Bond	Shear bond strength (Sbs/Mpa)	The average SBS of the Scotchbond Universal adhesive was statistically higher compared to the conventional adhesives and the Prime&Bond Universal adhesive.

				Universal (double application) and 37% phosphoric acid for 15s. Group 5: n=15 brackets bonded with Transbond XT and 37% phosphoric acid for 15s.		
Michael Schauseil 2016(13)	RCT (in-vitro)	32 bovine incisors	Etch and rinse vs self-etching	Two groups were randomly assigned: Group 1: n=16 brackets cemented with Transbond XT and 37% phosphoric acid for 30s Group 2: n=16 brackets cemented with Tectosan	Shear bond strength (Sbs/Mpa)	There was no significant difference.
Julia H. Seeliger 2017(36)	RCT (in-vitro)	40 bovine incisors	Etch and rinse vs self-etching	Four groups were randomly assigned: Group 1: n=10 brackets cemented with sample primer Group 2: n=10 brackets cemented with Opal Seal and 35% phosphoric acid for 30s Group 3: n=10 brackets cemented with Transbond Plus Group 4: n=10 brackets cemented with Transbond XT and 35% phosphoric acid for 30s	Shear bond strength (Sbs/Mpa)	There was no significant difference.
Fereshteh Shafiei 2019(37)	RCT (in-vitro)	84 premolars	Etch and rinse Vs Universal (active y passive)	Seven randomly assigned groups: Group 1: n=12 brackets bonded with Transbond XT and 37% phosphoric acid for 30s. Group 2: n=12 brackets bonded with Transbond XT and laser. Group 3**:** n=12 brackets bonded with Scotchbond	Shear bond strength (Sbs/Mpa)	The mean SBS for active universal adhesives (5, 10 and 15s) was statistically higher compared to that of conventional adhesives. No significant difference was found between passive universal adhesives and conventional

				Universal and 37% phosphoric acid for 15s. Group 4**:** n=12 brackets bonded with Scotchbond Universal and 37% phosphoric acid for 10s. Group 5: n=12 brackets bonded with Scotchbond Universal and 37% phosphoric acid for 5s. Group 6: n=12 brackets bonded with Scotchbond Universal (passive). Group 7: n=12 brackets bonded with Scotchbond Universal and laser.		adhesives.
George Sam 2021(38)	RCT (in-vitro)	60 premolars	Etch and rinse vs self-etching	Three groups were randomly assigned: Group 1: n=20 brackets cemented with Transbond XT and 37% phosphoric acid for 15s Group 2: n=20 brackets cemented with One-Coat Group 3: n=20 brackets cemented with Adper Easy One	Shear bond strength (Sbs/Mpa)	The mean SBS for conventional adhesives was statistically higher compared to self-etching adhesives.

Aslıhan Zeynep Oz 2018(39)	RCT (in-vitro)	68 premolars	Etch and rinse vs self-etching Vs Universal (active and passive)	Four groups were randomly assigned: Group 1 (n=16) consisted of brackets cemented with Transbond XT and 37% Phosphoric Acid for 10s, Group 2 (n=16) consisted of brackets cemented with Transbond Plus, Group 3 (n=16) consisted of brackets cemented with Clearfil Universal Bond and 37% Phosphoric Acid for 10s and Group 4 (n=16) consisted of brackets cemented with Clearfil Universal Bond (passive).	Shear bond strength (Sbs/Mpa)	There was no significant difference.

Table 1: Characteristics of the included studies.

A total of 28 comparisons between conventional and self-etch adhesive systems were reported. Of these:

- Eleven studies indicated that the conventional system had superior adhesion
- One study favored the self-etch system
- Sixteen studies found no statistically significant differences

For the nine comparisons between conventional and universal adhesive systems:

- One study showed superior adhesion for the conventional system
- Four studies favored the universal system
- Four studies reported no statistically significant differences

For the five comparisons between self-etch and universal adhesive systems:

- One study favored the self-etch system
- Four studies found no statistically significant differences

Meta-Analysis

A meta-analysis was conducted to quantitatively analyze the data. The primary comparison focused on shear bond strength in brackets bonded with conventional and self-etch adhesives. A total of 24 randomized controlled trials were included, with 22 conducted on human teeth and two on bovine teeth (Fig. 2).

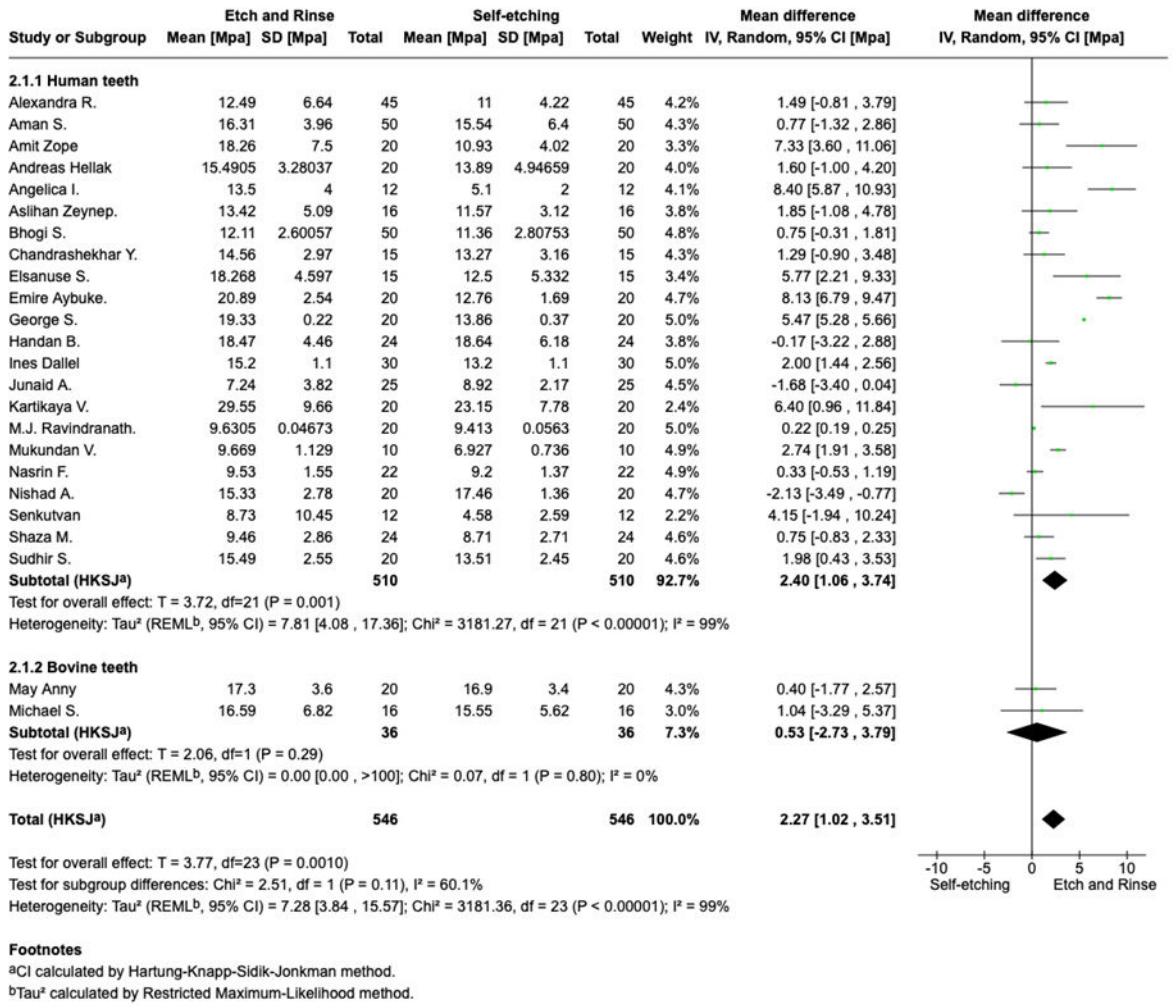

Figure 2: Summary of findings from the meta-analysis: Etch and Rinse vs. Self-etching adhesives.

The results indicate that conventional adhesive systems exhibit significantly higher bond strength (2.27 MPa, 95% CI: 1.02-3.51) compared to self-etch systems (P=0.001). Sensitivity analysis confirmed the robustness of the findings, as the exclusion of individual studies did not alter statistical significance (P<0.05). However, substantial heterogeneity was observed (I_2=99), likely due to differences in adhesive brands and tooth characteristics among the studies.

Publication bias assessment using a funnel plot revealed asymmetry, suggesting potential underreporting of negative or non-significant results. Egger's regression test showed no statistically significant evidence of publication bias (P = 0.285), indicating that the findings should be interpreted with caution.

A comparative meta-analysis of nine trials (seven on human teeth, two on bovine teeth) was conducted to evaluate shear bond strength between conventional and universal adhesives. The overall effect size was not statistically significant (P = 0.33), with high heterogeneity (I^2 = 97% for human teeth, I^2 = 96% for bovine teeth), suggesting similar performance between these adhesive systems (Fig. 3).

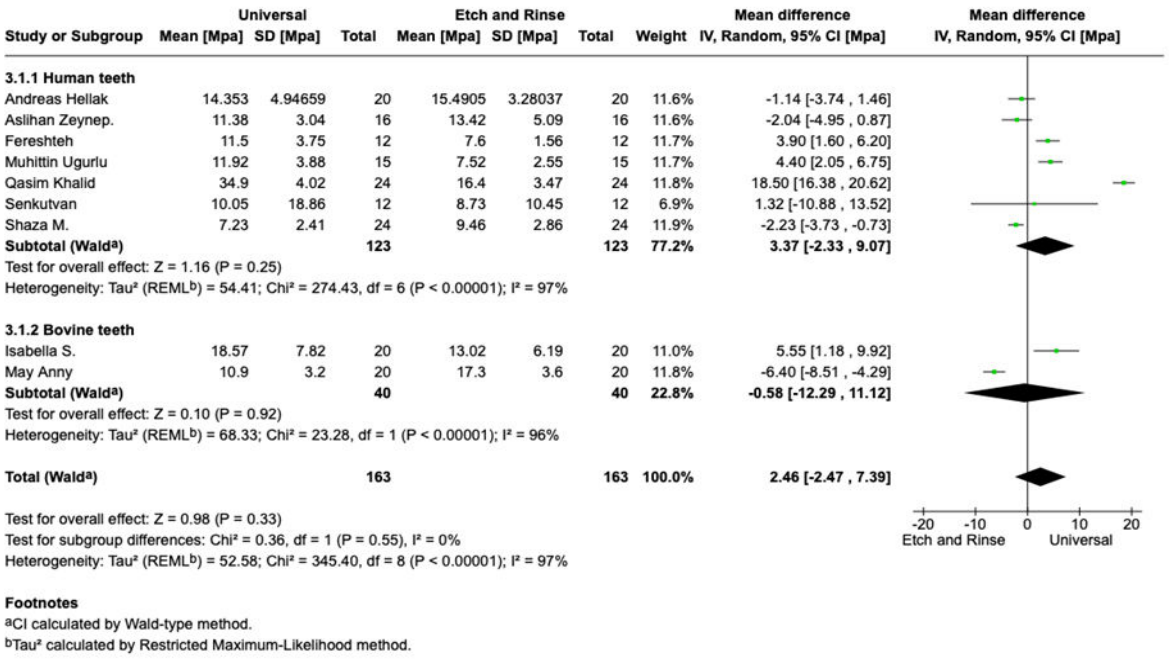

Figure 3: Summary of findings from the meta-analysis: Universal vs Etch and Rinse adhesives.

Additionally, a meta-analysis of four studies comparing self-etch and universal adhesives revealed no statistically significant difference in bond strength (difference of means: 0.75 MPa; 95% CI: -0.34 to 1.84; P = 0.18). Sensitivity analysis confirmed the consistency of results, with no significant impact observed upon study exclusion (Fig. 4).

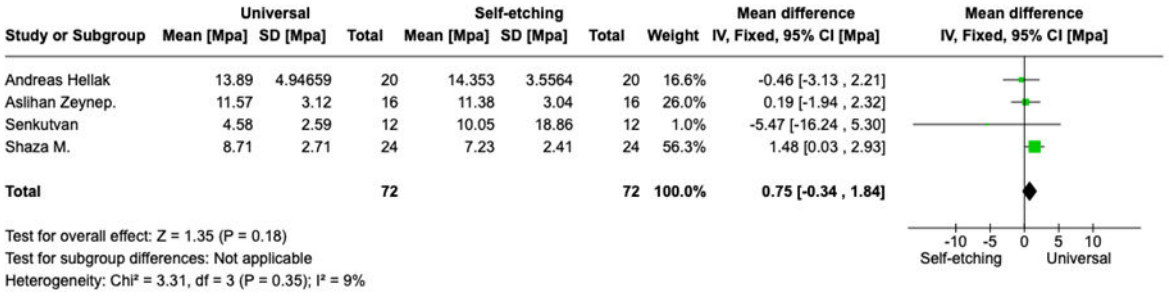

Figure 4: Summary of findings from the meta-analysis: Universal vs Self-etching adhesives.

A final meta-analysis of three *in-vivo* trials compared bracket debonding rates between conventional and self-etching adhesives. No significant differences were found in clinical failure rates. Sensitivity and heterogeneity assessments confirmed the reliability of these findings (Fig. 5).

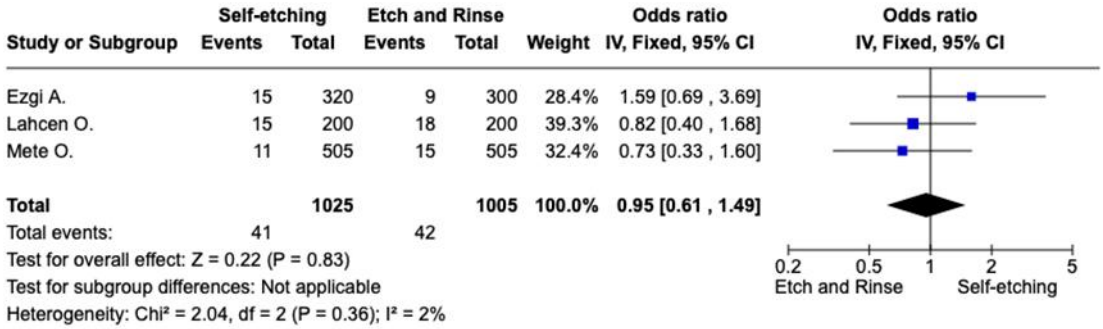

Figure 5: Summary of findings from the meta-analysis comparing brackets debonding rates between etch and rinse and self-etching adhesive systems.

The systematic review and meta-analysis indicate that conventional adhesive systems generally demonstrate superior shear bond strength compared to self-etch adhesives. However, comparisons between conventional and universal adhesives, as well as between self-etch and universal adhesives, yielded no significant differences. The overall quality of the included studies was moderate, with considerable heterogeneity observed in meta-analyses. Further research with standardized methodologies is recommended to validate these findings.

Discussion

This systematic review and meta-analysis compared the adhesive effectiveness of conventional, self-etch and universal bonding systems for the direct bonding of metal brackets. Our findings indicate that conventional adhesive systems, employing etch-and-rinse techniques, demonstrated significantly higher shear bond strength compared to self-etch adhesives. Universal adhesives, when used with a total-etch approach, exhibited comparable performance to conventional systems, whereas their self-etch mode resulted in lower bond strength. These results suggest that etch-and-rinse systems remain the gold standard in achieving optimal adhesion in orthodontic treatments.

The findings of this review are clinically relevant as they provide evidence-based insights into the selection of adhesive systems for direct bracket bonding. The superior performance of etch-and-rinse adhesives suggests their continued use in cases requiring maximum bond strength. Universal adhesives offer versatility and ease of application, making them a promising alternative when used with prior acid etching. Self-etch adhesives simplify the bonding process; however, they may not always achieve adequate bond strength, particularly in highly mineralized enamel. It is important to interpret these findings with caution given that the majority of included studies were in-vitro, which may not fully reflect intraoral conditions.

Strengths and Limitations

Strengths

- The systematic review adhered to PRISMA guidelines, ensuring methodological rigor and transparent reporting
- The inclusion of randomized controlled trials enhances the reliability of the findings
- The study applied advanced statistical techniques, including meta-analysis, sensitivity analysis and heterogeneity assessment, strengthening the robustness of the conclusions

Limitations

- A significant proportion of the included studies were *in-vitro*, which may not fully capture intraoral conditions such as moisture, salivary enzymes and patient variability
- Considerable heterogeneity was observed in the included studies, likely due to variations in adhesive brands, application techniques and sample types

Implications for Existing Knowledge

These findings reinforce existing evidence that etch-and-rinse systems provide the highest bond strength, particularly in high-demand orthodontic applications. The study also highlights the growing relevance of universal adhesives, which, when applied with a selective-etch approach, can achieve bond strengths comparable to conventional adhesives. However, the results challenge the assumption that self-etch adhesives can fully replace conventional systems, emphasizing the need for careful adhesive selection based on clinical requirements.

Future Research Directions

- Clinical Trials: Future research should focus on well-designed clinical trials comparing adhesive performance in real-world conditions to account for factors like salivary contamination and enamel variations
- Longitudinal Studies: Investigations assessing long-term bracket retention and failure rates in different adhesive systems could provide a better understanding of their durability
- Material Innovations: Research into novel adhesive formulations that enhance self-etch performance while maintaining simplicity of application could bridge the gap between etch-and-rinse and self-etch systems
- Subgroup Analyses: Further studies should explore adhesive effectiveness in specific patient populations, such as those with fluorotic enamel or younger patients with immature enamel

Conclusion

This study confirms that etch-and-rinse adhesives remain the most effective for direct bracket bonding, while universal adhesives represent a viable alternative when used with prior acid etching. Self-etch adhesives, despite their ease of use, generally result in lower bond strengths, limiting their application in high-demand clinical scenarios. Future research should focus on validating these findings through clinical trials and exploring innovations to enhance adhesive performance across all systems.

Conflict of Interest

The authors have no conflict of interest to declare.

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