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Review Article

Methods for determining the bond strength between different materials and hard dental tissues

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Abstract

The strength of the adhesive bond is a critical determinant of the longevity of indirect restorations. Prior to the clinical introduction of new restorative materials and luting agents, it is essential to evaluate their bonding performance to hard dental tissues. This literature review aims to examine the various tests used to measure adhesive bond strength and to identify the factors that influence laboratory outcomes. Bond strength tests are classified as static or dynamic, and further subdivided into macro- and micro-tests according to the bonded surface area. Static methods include macro-shear, macro-tensile, macro-push-out, micro-shear, micro-tensile, and micro-push-out tests. Dynamic methods comprise macro- and micro-shear, macro- and micro-tensile tests, three- and four-point micro-bending techniques, and micro-rotation tests. Factors affecting test results are associated with the substrate, the sample characteristics, and the test protocol itself. Laboratory methods for assessing adhesive bond strength are highly valuable for clinicians, as they support informed selection of restorative materials, adhesive systems, and cementing agents. When choosing an appropriate testing method, researchers must consider the specific properties of the hard dental tissues, restorative materials, and cements under investigation.

Keywords

adhesion, bond strength, static tests, dynamic tests

Introduction

Achieving a reliable adhesive bond is essential not only for counteracting the stresses generated by polymerization shrinkage, but also for resisting changes associated with the oral environment, such as masticatory load, temperature and pH fluctuations, as well as hydrolytic and enzymatic degradation [1]. Adhesive bond strength plays a critical role in determining the longevity of restorations, and it can be measured through a variety of in vitro tests designed to approximate clinical conditions. Because clinical studies require long-term observation and thus delay the introduction of new materials, laboratory tests are commonly used as predictors of clinical durability [2]. Their outcomes are considered informative for clinicians when selecting appropriate luting agents. Numerous quantitative methods have been described in the literature, differing according to the magnitude of force applied and the adhesive interface area under evaluation. Bond strength is typically calculated as the maximum load required to produce failure, divided by the geometrically defined

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cross-sectional area of the bond [2]. Test outcomes may be influenced by factors related to the materials being examined, the characteristics of the hard dental tissues (HDT), and the specific testing conditions employed.

Types of tests

Bond strength tests are generally classified into two major categories: static and dynamic [3–5]. Static tests, which are more widely used, involve the application of a unidirectional force to a stationary specimen. They are further subdivided into macro- and micro-tests, depending on the size of the bonded area. Macro tests involve adhesion areas larger than 3 mm^2, whereas micro tests typically assess areas smaller than 3 mm^2 [5] or even less than 1 mm^2 [3]. Although static tests are convenient, their ability to simulate clinical conditions is limited [3]. Historically, macro-tests were predominant; however, advances in sample preparation and experimental design have shifted preference toward micro tests due to their increased precision. Macro tests include macro-shear, macro-tensile, and macro-push-out protocols.

Macro-shear bond strength (SBS) test

First introduced by Bowen, the macro-shear test remains one of the most employed methodologies. It measures the maximum force required to disrupt the bond via shear stresses at the interface between two materials [4].

Macro-tensile bond strength (TBS) test

Although used less frequently, the macro-tensile test offers a more uniform distribution of stresses compared to SBS, which contributes to improved reliability. Tensile forces are applied to both ends of the specimen until failure occurs [4].

Push-out (PO) test

This method assesses the adhesion between an adhesive or cement and dentin [4], and it is particularly suitable for evaluating the retention of fiber posts in root canals. During testing, force is applied to the post until it is displaced from the dentin [4].

Micro-tests—comprising micro-shear, micro-tensile, and micro-push-out methods—offer higher precision and reduced variability.

Micro-Shear Bond Strength (μSBS) Test

Developed by Shimada [2], the μSBS test allows assessment of shear strength in small specimens without the need for preliminary sectioning, in contrast to μTBS testing. This minimizes the risk of introducing microcracks during preparation. The test is suitable for enamel and brittle materials such as glass-ionomer cement [4] and may be performed using the wire-loop technique [6]. Its small bonding area permits evaluation of dentin with varying thicknesses, and multiple specimens can be obtained from a single tooth [2, 7].

Micro-tensile Bond Strength (μTBS) Test

Introduced by Sano et al. in 1994 [2], the μTBS method involves cementing a material onto a flat enamel or dentin surface, followed by sectioning into small sticks using a diamond instrument [2, 8]. Although microcracks may form during cutting, μTBS offers several advantages over TBS, including more efficient use of tooth structure, control over dentin/enamel depth, improved stress distribution, and reduced incidence of cohesive failures within the substrate or adhesive interface [2, 8].

Micro-Push-out (μPO) Test

The μPO test is analogous to the macro-push-out method but is performed on smaller specimens, often less than 1 mm thick [4].

Dynamic tests more accurately simulate the clinical environment by subjecting specimens to variable loading conditions [5]. Their primary limitations are extended testing time and increased technical sensitivity. From a clinical standpoint, these tests are highly relevant because they reflect functional stresses. Dynamic methodologies include macro and micro shear, macro and micro tensile, three- and four-point micro-bending, and micro-rotation tests. Procedures such as the Push-Out Fatigue Test (POFT) replicate masticatory forces, enabling evaluation of interfacial durability under cyclic loading [3, 9].

Factors related to the substrate

Tooth type

The type of tooth used influences reported values of bond strength. Both human and bovine teeth are used in experimental research. Most studies report no significant differences; however, some authors suggest that the larger dentinal tubules in bovine teeth may affect results [5]. Additional variability may arise depending on whether third molars or premolars are used, the presence of caries, and the age of the donor. Superficial dentin layers generally exhibit higher bond strength [5].

Type of hard dental tissue

Enamel is brittle and prone to cracking, especially along prism boundaries [8]. For this reason, μSBS is generally preferred over μTBS when testing enamel, because sample sectioning in the latter increases the risk of microcrack formation. Achieving strong adhesion to dentin is more challenging, and bond strength varies with dentin depth [8]; deeper dentin contains wider tubules and increased moisture content, both of which influence bonding.

Influence of different materials

Studies of adhesive performance in indirect restorations typically involve two material categories: the restorative material and the luting agent. Restorative materials include composite, ceramic, and zirconia options used in digitally fabricated restorations. Composites may be produced via milling or additive manufacturing. A review by Kagaoan et al. reports that crowns fabricated using additive technologies exhibit higher bond strength values than milled counterparts [10].

Factors related to the samples

Adhesive bond area

Bond strength decreases as the bonded surface area increases [5, 8]. Numerous studies report lower strength values for macro tests compared to micro tests [2], likely due to the increased presence of defects in larger specimens.

Sample shape

μTBS specimens may be prepared in stick, cylindrical, hourglass, or dumbbell shapes [1]. Research by Sanches et

al. suggests that the dumbbell configuration provides the most accurate representation of true adhesive strength [1].

Aging methods

Several protocols have been proposed for simulating intraoral aging, including storage in water or sodium hypochlorite (NaOCl) solutions and thermal cycling [11]. Evidence remains inconclusive regarding the optimal method. Some authors report that thermal cycling significantly reduces bond strength, and that NaOCl storage may increase it [11], while others indicate that NaOCl decreases bond strength [12]. These discrepancies may be attributed to variations in adhesive systems, cements, and test methodologies.

Factors related to the type of test

Test settings

Testing parameters substantially influence measured bond strength. According to a review by Sirisha et al., factors such as test design and the distance between the loading point and the bonded interface are critical [13].

The speed at which the force is applied

The rate at which force is applied affects bond strength measurements. Sadek et al. demonstrated that increasing the cutting speed during μTBS preparation significantly reduces measured strength [14]. However, most authors report that cutting speed does not greatly influence μTBS outcomes [15, 16].

Operator skills

Operator experience is another factor influencing test results. Studies show that more experienced operators consistently record higher bond strength values [17].

Types of fractures resulting from adhesion testing

During adhesion testing, the measured bond strength may result in three distinct types of fracture: adhesive, cohesive, and mixed [18]. An adhesive fracture occurs at the interface between the tooth structure or restorative material and the bonding agent. A cohesive fracture is observed within the tested material itself or within the hard dental tissues. A mixed fracture represents a combination of adhesive and cohesive failure modes. From a clinical perspective, cohesive fractures are considered preferable, as they indicate that the adhesive bond strength exceeds the internal strength of the bonded substrate.

Conclusion

Bond strength is essential for predicting the long-term success of restorations. Accurate assessment of bond strength supports clinicians in selecting appropriate restorative materials, adhesive systems, and luting agents. When comparing outcomes across studies, it is crucial to consider the type of test employed and the conditions under which it was conducted.

Additional information

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Ethical compliance

Not applicable.

Conflict of interest

The authors declare that they have no conflict of interest and no affiliation with or involvement in any organization or entity with any financial interest in the subject matter or materials discussed in this manuscript.

Author contributions

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