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File ID	uvapub:61461
Filename	Chapter 1: Introduction
Version	final

SOURCE (OR PART OF THE FOLLOWING SOURCE):

Type	PhD thesis
Title	A better understanding of orthodontic bracket bonding
Author(s)	T.J. Algera
Faculty	ACTA
Year	2009

FULL BIBLIOGRAPHIC DETAILS:
http://hdl.handle.net/11245/1.308681

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(pagedate: 2014-11-18)

CHAPTER 1

Introduction

1.1 Historical overview

Orthodontics is the profession that concerns itself with the development and regulation of teeth and jaws. Its history goes back to the 27th century B.C. when the Chinese emperor Hoang-Ti showed interest in tooth malformations.(1) In 1723 Pierre Fauchard was the first dentist who described in detail a fixed appliance meant to create an ideal arch form.(2) From 1911 Edward H. Angle developed a series of appliances that are considered to be the prototype of the nowadays fixed appliances. They are known as the edgewise technique.

The urge to move teeth to a certain position or to fix them has been present since then. People searched for an attachment to the teeth in order to be able to transfer a load and by so doing get the teeth to move. Nowadays, attachments are adhered by materials that bond mechanically or chemically to the teeth. Around 1940 resins were introduced in dentistry. In other fields they had shown good adhesive properties when bonded to various materials like metals, wood, or glass. They had good strength properties and were chemically stable.(3) Because of the disadvantages of the materials used until that time, the resins seemed to have ideal properties for dental purposes.

In a review in 1953, Paffenbarger (4) described the physical and chemical properties of direct and indirect filling resins. Volumetric instability because of a difference in the thermal expansion coefficients of the tooth at one side and the filling resin at the other side was the major disadvantage at that time. Water uptake was reported as a factor causing this volumetric instability. Due to the fact that no adhesion to the tooth tissue was achieved, the space between the restoration and the cavity wall allowed oral fluids to enter and cause damage to the tooth. Nevertheless the prediction was made that direct filling resins should become an important material in dentistry but at that time restorations of metal and alloys were the first choice.

In an article concerning the screening of materials for adhesion to human tooth structure Rose stated in 1955 (5) that the above mentioned problems might be solved if a plastic material could be developed that adheres permanently to the structure of the human tooth. The volumetric shrinkage, as a result of the polymerization, should be controlled at the cavity walls. One of the conclusions after 5,500 tests was that no product at that time available consistently maintained adhesion after prolonged water immersion.

Almost at the same time in 1956 Bowen and Buonocore presented papers that now are considered to be the first reports on the acid-etch technique.(3, 6) Bowen found empirically that washing the bonding surface with ammonium tri-acetic acid or

with ethylenediamine tetra-acetic acid improved the bond strength. An explanation for this finding was the removal of loose calcium ions and adjustment of the polarity of the tooth.(3)

Buonocore *et al.* (6) investigated a commercially available cavity seal (Sevriton), intended for direct bonding to the tooth. This material contained a glycerophosphoric acid dimethacrylate which was claimed to have special affinity for enamel and dentin. Analysis of this material indicated that it was composed of 5-10% phosphoric acid, 5-10% methacrylic acid and 80-90% methylmethacrylate. This was probably the first acid-adhesive material available. After the application and curing of a layer of this product, the resin filling material was applied and cured. Measurements showed that the bond strength increased to a level two times higher compared to untreated controls. Also the water resistance improved, indicating a good adaptation to the tooth surface. A chemical bond of the phosphate group of the cavity seal to the organic part of the tooth was given as an explanation for the improved bonding properties.

Figure 1.1 Metal orthodontic brackets welded to metal bands, which were fixed to the tooth with phosphate cement or later by glass ionomer cement (GIC).

In the early 60's people realized that chemical adhesion to the tooth was not the major bonding factor but micro mechanical retention of the cured filling material at the roughened tooth surface.(7) In 1968 Buonocore proved the presence of resin tags in the acid conditioned enamel surface.(8) These tags arise when liquid monomer flows into the undercuts of the enamel prisms and are cured. With this form of adhesion a new era started not only in restorative dentistry, but also in other dental fields such as

orthodontics. Adhesion between the bonding material and the bracket was a new challenge.

Until this time the metal orthodontic brackets used, were welded to metal bands. These bands had to be adjusted to every single tooth which was very time consuming. Fixation to the tooth was performed with phosphate cement later followed by GIC (see Figure 1.1) Newman (9) in 1965 was the first to describe the use of adhesives for bonding plastic orthodontic brackets. One of the conclusions was that the adhesive formulation used in his research was able to bond plastic brackets to tooth surfaces and could be used for clinical purposes. Pre-treating the tooth surface by pumicing and etching with 40% phosphoric acid enhanced the bond strength.

From this point on, the number of research projects into orthodontic adhesives and direct bonding of brackets to the enamel has increased. Mitchell (10) described as one of the first in 1967 a study in which brackets with preformed bases were used *in vitro* as well as *in vivo*. Round, hat-shaped bases were stamped from 24-karat sheet gold and welded to bracket slots. The diameter of the bases was 6 mm and they were 2 mm high. The results of the *in vitro* tests showed that these brackets could withstand a load of approximately 170 g. for at least 5 months. This justified clinical testing on six patients. All treatments with this bonding technique were started and brought to an end. The conclusion was that teeth can be moved by “bandless” brackets but still a lot had to be done before this method could be adopted routinely in orthodontic practice.

The major advantages of direct bracket bonding instead of banding the teeth are the more precise placement of the brackets and the time gain. The use of “direct” indicates that the bracket positioning takes place at the moment of bonding. With the banding technique the brackets were welded previously to the bands, giving less freedom of placement to the right position of the tooth. Other advantages are the possibility for a better oral hygiene resulting in less gingival irritation, finishing of the treatment without spaces between the teeth from band material, and a more aesthetic appearance of the patient.

1.2 Bond strength testing

As Mitchell in 1967 (10) concluded, a lot of work still had to be done. The first aims were to achieve a strong and reliable bonding between the bracket and the tooth. In this period, *in vitro* bond strength testing started. The tests performed were shear, tensile, and torsion tests. From these tests, shear testing was most popular because of the clear similarity with the clinical debonding situation. Until July 2008, around 500 articles have been presented, reporting orthodontic shear bond strength data.

The tensile test is less often performed. Failure of the bracket-tooth adhesion is assumed not to be a result of pure tensile stress. The same explanation is given for the torsion test which is even less often performed. As mentioned previously, the transfer of *in vitro* results to a clinical situation is for many researchers the most important reason for choosing a shear test. The possibility of comparison with other reports is another reason for choosing this test.

The three tests are basically performed as follows: in all situations a bracket is bonded to a substrate, usually human or bovine enamel. After some time of storage a force is applied to the bracket until fracture occurs. The amount of force at the time of fracture is measured and divided by the bonding area of the bracket. The found value represents the bond strength of the material used and is presented in Mega Pascal (MPa). Directly after testing the fracture area is determined with the use of the adhesive remnant index (ARI score), first described by Årtun.(11) With this test the amount of residual cement left at the bonding surface is scored on a 4-point scale. A score of 0 indicates that no adhesive is left on the enamel, 1 indicates that less than half of the adhesive remain, 2 indicates more than half of it remain, and 3 indicates that all of the adhesive remains on the enamel surface. The scores are determined with a stereomicroscope at a magnification of 25x.

The vector of the force applied determines if shear or tensile strength is measured. When shear test measurements are performed the force applied is parallel to the bonding area. Therefore rotational forces result in shear stresses. Tensile forces originate from forces acting perpendicular to the bonding area.

In vitro bond strength testing seems an easy and clear-cut testing method. When scrutinized it appears not to be so. Ideally, studies should be performed in a standard way. This is on a detailed level very difficult because of the huge amount of variables involved in this type of testing. The bonding material, the mesh base, the storage time, or the curing methods are usually the subject of the study. Nevertheless other variables usually not investigated or controlled may easily confound the results. These variables can be:

- the substrate material (human or bovine enamel)
- the shape of the substrate (plane or curved)
- the storage medium of the substrate prior to bonding (tap water, hypochlorite solution, 0.8% NaCl solution, or formaldehyde solution)
- the storage medium and temperature after bonding but prior to testing
- the shape of the bracket base (round or rectangular)
- curvature of the bracket base

- the set up of the testing device
- the way of loading the bracket (at the wings or at the base)
- the speed of loading
- the experience and skills of the investigator

The substrate used is mostly bovine or human enamel. Extracted human teeth mimic the clinical situation best. On the other hand the age of the extracted teeth varies and the bonding surface is not usually of a standard shape. To solve these problems bovine enamel is often used as an alternative. The great advantage of a plain bovine enamel surface is the possibility to standardize the testing environment. From articles of Nakamischi, Oesterle *et al.* (12, 13) it is clear that for bond strength determination the use of bovine enamel instead of human enamel is acceptable. After extraction the teeth should be stored until testing in a humid surrounding to prevent dehydration and cracking. The storage medium used varies from plain tap water, to tap water with an addition of hypochlorite or formaldehyde. The influence on the enamel surface seems small but is still unclear.

The shape of the bracket and the mesh is of importance because of the stress distribution over the bracket when it is loaded. Knox (14) showed with finite element modeling that different mesh designs affected the stress distributions in the bracket-cement-enamel system. These changes are largely a product of the varying flexibility of the different bracket bases. Another important issue is the influence of the test set-up or design. Katona (15) calculated with finite element analysis that stresses applied on bracket-cement-enamel specimens in different directions are completely non-homogeneous. Therefore a division of the measured force by the bonding area does not give a representative value of the bond strength.

For better comparison and interpretation of the test results it is often recommended to use a standardized test protocol. Although many investigators support this recommendation, consensus about a standard procedure has still not been reached. Most investigations are not performed under identical test conditions, which probably results in different outcomes.

To gain insight into the influence of confounding factors and to show the disadvantages when comparing the outcomes, it is illustrative to screen and review the available literature.

Resin composite materials intended for orthodontic bonding, do have some disadvantages. The bonding is, as described, micromechanical. This means that prior to curing, the fluid bonding agent penetrates the etched enamel. After curing, the

formed resin tags provide retention in the undercuts of the etched enamel prisms. After treatment this hybrid layer has to be removed causing more, or less, enamel damage. Another disadvantage of resin composite is the ease of bacteria colonization on the rough surfaces. This may hamper oral hygiene. Because of these disadvantages a search for alternatives began. Glass ionomer based materials, such as conventional glass ionomer cement (GIC) and resin modified glass ionomer cement (RMGIC), seems the material of first choice as a substitute nowadays.

1.3 Glass ionomer based cements

The use of GICs as an alternative for orthodontic resin composite was first proposed in 1990.(16) These materials have the advantage that they bond chemically to enamel (17) without the necessity of etching (18). The material consists of a polyalkenoic acid and a basic glass component. The polyalkenoic acids have the ability to bond chemically to the Ca^{2+}-ions of the enamel. They also slightly pit the enamel, enabling the forming of a micro hybrid layer. Removal of this layer after removal of the brackets may shorten the chair time (19) and leads to less enamel damage compared with procedures involving resin composite cements. Another advantage of GICs is the release of fluoride over an appreciable period of time. Hallgren *et al.* (20, 21) showed that deposition of fluoride in the plaque around the orthodontic bonding area led to a decrease in Mutans Streptococcus and Lactobacillus bacteria. Furthermore Sadowsky *et al.* (22) and Marcusson *et al.* (23) reported less demineralization and white spot formation when fluoride-releasing cements were used. With regard to saliva contamination, conventional GICs are less critical than resin based cements. Beside these properties there are less favorable properties like the slow curing reaction and weak bond strength. These are the main reasons not to use conventional GIC's for orthodontic purposes.

In 1989 Antonucci *et al.* presented a GIC modified with a resin component.(24) Basically this cement consisted of a resin part and a glass ionomer part. When this material cures, both reactions run side by side until setting has taken place. The resin reaction runs fast and provides a fast initial curing in contrast to the glass ionomer reaction, which is slower. The advantage of the glass ionomer part is mainly the release of fluoride over a long period of time. The disadvantages are comparable to resin composite such as the necessity of etching.

The above shows that the ideal material for bonding brackets is not available yet. The presented research is an attempt to gain a more profound insight into the

problems of contemporary adhesives for orthodontic applications and to try to take a step forward in the clinical application of orthodontic bracket bonding.

1.4 Scope and outline of this research

The purpose of this thesis is to get a better understanding of the bonding quality of orthodontic brackets to enamel in general and with glass GICs in particular.

In **chapter 2** the bonding properties of one of the most frequent used light curing bonding agents, Transbond XT (3M Unitek, Monrovia, California, USA), is reviewed. The bond strength, bond strength *versus* curing time, and the influence of possible external variables on the bond strength are evaluated based on the available literature. In **chapter 3** the *in vitro* force to debond orthodontic brackets, bonded with three different GICs is evaluated using two techniques for faster curing. The first technique was the application of heat. The second technique was the application of ultrasonic energy. Standard cured specimens were used as controls. The topic discussed in chapter 3 continues in **chapter 4**. It concerns the influence of temperature on the working and setting times. Two conventional GICs were used for testing. Furthermore, the influence of temperature and storage medium (oil or water) on the compressive strength of the same materials is investigated at different time intervals over a period of three months. The aim of **chapter 5** is to investigate the influence of different bracket base pre-treatments, sandblasting, silicoating, and tin-plating, in relation to three different cements. The bonding properties were evaluated with the shear- as well as the tensile bond strength test. The aims of **chapter 6** were to determine the bond strengths of the separate components of the bracket-cement-enamel systems and to clarify the influence of cyclic mechanical loading (fatigue) on the strength. The bracket-cement-enamel system is used as control. Therefore the initial shear bond strength and the shear bond fatigue limit after 10,000 cycles of the bracket-cement-enamel system were measured for three different cements. Further the initial shear bond strength and shear bond fatigue limit of the cement-enamel, cement-only, and button-cement combinations were determined. In **chapter 7** a finite element model of the bracket-cement-enamel system is compared to the *in vitro* shear and tensile bond strength tests. The previous chapters are discussed **chapter 8** and summarized in **chapter 9**.

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