A better understanding of orthodontic bracket bonding

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CHAPTER 8

General discussion

8.1 Introduction

Bracket bonding plays a key role in orthodontic treatment today. As a consequence premature debonding is an unfavourable side effect. It can cause a delay in the treatment time and in the daily program of the orthodontist. The majority of premature debonds is assumed to be a result of failure of the bonding material, the followed procedure, or interfering bite forces.(1)

It is the general opinion that the type of orthodontic cement is one of the main variables in the success of the bracket bonding process. Most orthodontists use resin based composite to adhesively bond their brackets to the teeth. The application of these resin composites requires etching of the enamel resulting in loss of tooth material. Due to its good bond to the enamel it is difficult to remove the remaining cement after debonding of the bracket. The use of glass ionomer cements (GICs) as an alternative orthodontic luting agent has the advantage that GIC achieves a chemical bond to the enamel without prior etching. The polyalkenoic acids slightly pit the enamel to enable the formation of a thin hybrid layer. Removal of this layer after debonding of the brackets is easy, can shorten the total chair time, and might lead to less enamel damage compared to procedures involving resin composite cements. Another advantage of GICs is the ability to release fluoride over a long period of time.

This thesis aims to provide a better understanding of the bonding quality of orthodontic brackets to enamel in general and with GICs in particular.

8.2 Orthodontic bond strength in general

The "bond strength" is defined as the strength necessary to debond one material from another and according to the International System of Units reported in Pascal (N/m^2). It is obtained when a load, measured at fracture, is divided by the bonding area. This definition assumes that the load is homogeneously applied at the specimen and that the bonding area is fully responsible for the resistance against the load. In orthodontic research bond strength is usually determined of a bracket-cement-enamel system.

The variables involved in orthodontic bond strength testing are not only the cement and the bracket. The influence of storage time, storage medium, storage temperature, temperature at the moment of testing, enamel type, preparation method of the specimens, curing technique, test set up, and test speed are all variables that might affect the test result. From the review described in the second chapter it was concluded that storage time, enamel type, and crosshead speed are unlikely to influence the bond strength significantly. The bracket-cement-enamel system is therefore the most important factor in this field.

From the literature was concluded that most bracket failures take place within the cement or at the bracket cement interface. Therefore this part of the bracket-cement-enamel system should be enhanced for a better bond. If this is possible, will the cement-enamel interface then show up to be the weakest part?

8.3 Testing method

Because of the intended similarity of the testing to the clinical situation most *in vitro* bond strength tests are performed in a shear mode. As shown in the second chapter of this thesis the variability in bond strength test results is large. This makes comparison of the found results with the literature and the interpretation difficult. Alternatives for shear testing are tensile or rotational tests. In the tensile test the bracket is pulled off the enamel perpendicular to the surface. In a rotation test a bracket is twisted of the surface. Both tests imitate the clinical situation less accurately compared to the shear test. The problem with the rotation test is the technical difficulty of performing the test. An important aspect in comparing the debonding mechanism of the rotational test, the tensile test, and the shear test is the distribution of stresses in the cement interface. In the first two tests the stress application is more uniform, leading to a more homogeneous stress distribution over the bracket-cement-enamel system during testing. This makes the bonding area “more responsible” for the resistance against the load application and therefore the results are more precise.

In general, another problem of *in vitro* testing is its predictive value for the clinical situation and often its lack of standardization. Only few clinical reports of bond strengths are known. These reports, which are considered as the gold standard of clinical bond strength, do not match the *in vitro* results. Standardization of bond strength testing may solve the problem of not comparable test results reported in the literature. It should be clear, that if the aim is to test a material or curing method by comparing the obtained data with already published results in literature, then the method of testing should be identical. If an *in vitro* study claims to be clinically predictive it should be checked with *in vivo* experiments.

8.4 The bracket-cement-enamel system

The purpose of this thesis is to provide a better understanding of the bonding quality of orthodontic brackets to enamel in general and of GICs in particular. The focus of bond strength testing in general is mainly on an increase of bond strength sought in a tensile or a shear mode. After the bond strength testing the weakest link of the bracket-cement-enamel system is usually determined using the adhesive remnant index (ARI score) described by Årtun.(2) The involved main variables are the enamel, the bracket, and the cement. In this study the enamel was no topic of research. The focus of this thesis was on the cement and the bracket.

The results of chapter 5 of this thesis suggest that the proposed improvement of the adhesion at the weakest part of the bonding, between the bracket and the cement, did not lead to a higher bond strength of a bracket to enamel. An explanation for this finding is a possible insufficient bracket pre-treatment. Another possible explanation can be that not the alteration of the mesh influences the bond strength, but other mechanisms like the elasticity of the bracket, cement, or the combination.

In chapter 6 and 7 this was studied more in detail. In chapter 6 the separate components of the bracket-cement-enamel system were investigated. The total system was used as control. The results showed that the bond between the bracket and the cement was the strongest part. The total system provided the weakest bond strength results for two of the three cements. The cement-enamel bond was slightly higher. Taking into account that most failures take place between the bracket and the cement this is surprising. One of the explanations can be that the local stresses vary in the different components when combined. This is due to the fact that the different components, enamel, cement, and bracket, have completely different E-moduli. Altering the design of the bracket is directly related to the stiffness of the system and therefore influences the bond strength. Also the material of the bracket, e.g. stainless steel, plastic, or ceramic, and the E-modulus of the components of the bracket-cement-enamel system can have an influence on the bond strength and failure rate.(3)

Not only the initial bond strength was determined in chapter 6, also the influence of fatigue was investigated. Reason for this was the assumption that in the clinical situation the cement is vulnerable to fatigue as a result of the forces acting on it. This turned out to be true. Similar to results of the sparsely available literature on this topic the bond strength dropped with approximately 50%.(4) This indicates that the bond strength found *in vitro* tests needs to be twice as high compared to the clinical needs.

To visualize the lack of homogeneous stress distribution during an orthodontic bond strength test a finite element model (FEM) was composed in chapter 7. It revealed the non-homogeneous stresses present during testing, when a specimen was loaded in different directions. During loading peak stresses are produced leading to an initial fracture of the cement. Because of the brittle property of the cement, the fracture propagates until full debonding. These results led to the theory that not only the elasticity of the bracket-cement-enamel system but also the angle of loading plays a key role in the resistance against different loads. Improvement of the bond strength might therefore be found in enhancement of these properties.

8.5 Enhancement of glass ionomer bond strength

Bonding brackets with resin composite has next to a rather predictable, acceptable bonding also some disadvantages. The bonding is due to the procedure time consuming, vulnerable to water contamination, invasive into the enamel and a preference location for bacteria. Therefore an alternative is requested. The most appropriate alternative seems to be GIC. GICs consist of an acid and a base and mainly bind chemically to enamel. Resin modified glass ionomer cement (RMGIC) possess two bonding mechanisms. As well as the chemical bonding of the conventional glass ionomer part, the resin part of the material binds micromechanically with enamel. The main advantages are the minimal invasive bonding and the release of fluoride. The main disadvantage is the low bond strengths of both materials, which is for GIC lower than for RMGIC.

In 2001, Towler *et al.* (5) found an improvement of the GIC curing reaction when ultrasound was applied to the setting material. The reason for this improvement was not completely clear. Several explanations were proposed; the influence of a setting acceleration as a result of heat generation was one of the possibilities. In the same report a benefit for orthodontic purposes was suggested. The practical performance and the influence of the application of ultrasound or heat to the initial setting reaction bracket cement was therefore investigated and described in chapter 3. The results showed that the application of ultrasound or heat to the setting material enhances the initial bond strength. No clear difference was found between the two processes. The ideal application temperature and its effect in the long term remained unclear. The ability of achieving a setting on command for glass ionomer cement was not known either. These properties were investigated in chapter 4. In this chapter it was shown that a setting on command could be achieved when a temperature between 60 and 70°C was applied. As a result of the faster setting the materials reached the maximum strength earlier. It should be noticed that ideal environmental conditions, e.g. curing in oil, positively influence the effect of the heat application. If curing took place under water conditions the faster setting did not result into spectacularly higher long term strengths. This makes the GIC still unusable for orthodontic purposes. If water uptake can be prevented a significant bond strength rise might be expected, high enough for clinical use. It is worthwhile testing this *in vitro* as well as *in vivo*.

8.6 Conclusions

In conclusion, the present study showed in detail the complexity of a seemly simple problem, the adhesion of bracket to a tooth. The findings clearly showed that:

- Taking into account that Transbond XT is a clinical well performing composite, an *in vitro* shear bond strength of 9.3- 15.4 MPa is sufficient (chapter 2).
- Accelerated setting by means of heat or ultrasound results in significantly higher tensile bond strengths for glass ionomer cements (chapter 3).
- Heat application and curing in a water-free surrounding improves the strength of conventional glass ionomer cement significantly. Also an “on command” setting can be achieved with the application of sufficient heat, however the material is not useable for bracket bonding purposes because of the inappropriate bond strength (chapter 4).
- To improve the bond strength, alteration of the elasticity of the different components of the bracket-cement-enamel system might be more successful than searching for improvement of the weakest link determined by the adhesive remnant index (chapters 5 and 6).
- In vitro experiments showed that fatigue has a significant reducing influence on the bond strength (chapter 6).
- None of the applied loading directions on a bracket-cement-enamel system resulted in a homogeneous stress distribution within the cement layer. Therefore the value of presenting bond strengths in Pascal should be discussed. In this view performance of tensile tests instead of shear tests is recommended (chapter 7).

8.7 Future prospects

As recommended by many authors a standardized bond strength test protocol is desirable but probably not realizable. Therefore the approval for clinical use of luting cements is in the hands of manufacturers. To omit possible prejudicial opinions, studies comparing *in vivo* results with *in vitro* results are of great value.

This research showed clearly that the bond strength of brackets cemented with GIC is lower than when RMGIC or resin composites are used. Because of the favourable properties of the GIC and with the knowledge that ideal curing circumstances improve the strength, future research should focus on further improvement of the strength of the cement. Therefore, a clinical *in vivo* testing, using a proper study design, may hopefully be justified in the near future.

8.8 References

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