Sealing and retentive ability of dental luting cements

Summary and Review

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I Linear dimensional change during setting of a zinc phosphate cement. A methodological study. J. Oral Rehabil. 1975, 2, 179–185

II Linear dimensional changes during setting of two polycarboxylate cements. J. Oral Rehabil. 1976, 3, 161–166

III Linear dimensional changes of three luting agents. J. Oral Rehabil. 1977, 4, 395–399
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IV Adaption of luting cements to enamel, dentin and restorative material. Acta Odontol. Scand. 1978, 36, 149–156

V Extent of slits at the interface between luting, cements and enamel, dentin and alloy. Acta Odontol. Scand. 1978, 36, 257–261

VI Adhesive bonding of dental luting cements: Influence of surface treatment. Acta Odontol. Scand. 1978, 36, 263–270

VII Stress/strain behaviour of some dental luting cements. Acta Odontol. Scand. 1978, 36, 45–49
Co-author: S. Espevik

VIII The influence of surface roughness on the retentive ability of two dental luting cements. J. Oral Rehabil. 1978, in press
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These papers are referred to as Papers I–VIII in the present summary. Other papers are referred to in normal manner.

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INTRODUCTION

Inlays, crowns and bridges are fixed permanently to remaining teeth with a luting cement. The cement is located in a narrow gap between the restoration and the prepared tooth surfaces. The desired width of this gap should be somewhere above the maximum grain size of the cement powder, i.e. 25 μm (International Standard ISO/R 1566–1970), and below 50 μm which has been shown to

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be an acceptable width for gaps adjacent to amalgam fillings (16). By selection of appropriate materials and techniques these requirements can be achieved (18). However, in practice these gaps often exceed 100 μm (22, 30). The mechanical and chemical properties of the materials luting this gap are very different from those used for the restoration. Nevertheless, it is essential that the cement layer should maintain its functions as long as the restoration itself.

The luting layer has three prime functions:

1. To secure a lasting retention of the prosthesis to the tooth
2. To seal the gap against penetration of fluids and bacteria from the oral cavity
3. To act as an insulating barrier against thermal conduction.

When a restoration is accepted in the mouth, the sealing and retentive abilities are to be the main properties of the cement which may influence the lifetime of the restoration, and the present investigations have plased emphasis on certain problems related to these functions of the luting layer.

Sealing ability

Several in vitro and in vivo studies have demonstrated that no cement can seal completely against a penetration of fluids from the oral cavity (1, 11). These studies have been performed by different permeability tests and are often difficult to interprete (11). A penetration of liquids may occur through a porus cement as well as along the interfaces between the cement and the neighbouring materials. Physical and biological problems related to such penetration will not be studied in the present investigation.

However, in some cases bacteria may invade the cement/tooth interface (3). These observations and some of the penetration tests (11) indicate that the contiguity of the interfaces is incomplete. The present investigation will therefore deal with some technological aspects of the ability of the luting materials to fill the gap between the tooth and the restoration.

One of the main factors determining the adaption of the cement film to the adjacent tooth or restoration would be a shrinkage of the luting material during setting. Several previous investigations have shown that some of the luting cements contract during setting (8, 23, 31). The total dimensional change, however, from an early stage of the setting when the cement is in a viscous phase, has not been determined. This aspect has therefore been studied in the present investigation, i.e. a comparison of the total dimensional change of different luting agents (Papers I, II, III).

Some recently published leakage studies have indicated differences between the sealing abilities of various cements (1, 3), and these differences could be related to variations in the adaption of the cements to adjacent surfaces. The presence of slits at the interfaces was therefore studied for different cements (Papers IV, V).

The creation of slits at the interfaces could be a result of an interplay between the tensile forces due to shrinkage of the materials and the adhesive forces to the adjacent tooth and restoration surfaces (2). The bond strength of various luting materials to dentin with different surface treatments was therefore studied (Paper VI).

Retentive ability

The retentive function of dental luting cements has been studied in several investigations. It has been shown that the mechanical properties of the luting medium (5, 20) as well as the geometrical relations of the prepared tooth surfaces (4, 19) are of importance for the retention of a cast restoration. Every load on a restoration from mastication, gravity or any other force, results in a transmission of forces through the luting layer and a development of stresses in the

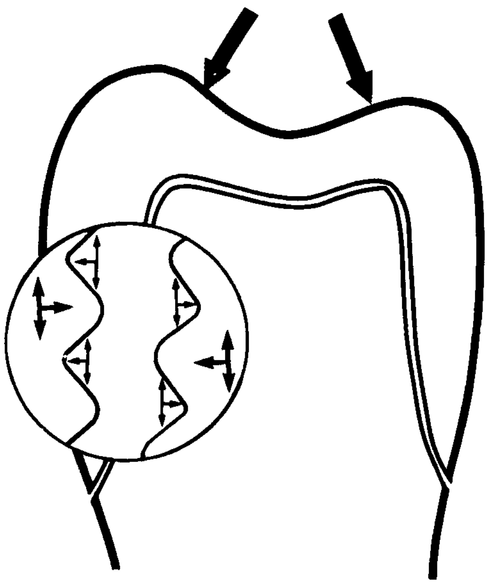

Fig. 1. Transmission of forces through the cement layer based on the interlocking effect of the cement.

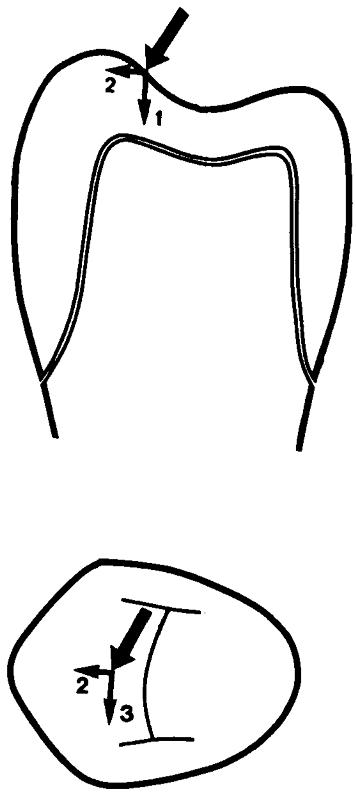

Fig. 2. The load on an artificial crown divided in three force components:
1. Force acting parallel to the central axis of the preparation.
2. Force acting perpendiculare to the central axis trying to tip the crown around an axis at the gingival margin.
3. Force acting perpendiculare to the central axis trying to rotate the crown in relation to the central axis of the preparation.

cement. Compressive forces, acting perpendicularly to the cement layer, lead to normal stress. A tension, however, can not occur as the most commonly used luting materials except polycarboxylate cement, do not have adhesive properties of importance (29). A transmission of forces other than compressive must therefore be based on the interlocking effect of the luting material. When the cement flows into and sets in minor irregularities at the prepared tooth surface and the fitting surface of the restoration, a development of shear stress is possible in the cement layer (Fig. 1).

The load on a restoration from masticatory forces can be divided in three main components:

1. Forces parallel to the long axis of the tooth
2. Tipping type forces
3. Rotating type forces

The force components are illustrated in Fig. 2. The tooth and the corresponding crown are constructed to give maximum areas where these forces can be transmitted as normal or shear stresses in the cement layer. This is obtained by following the main guidelines of maximal height and minimal inclination of the axial walls of the preparation (13, 18). Normal and shear stresses will then occur in the cement along the axial walls both by the axially directed (32) as well as by the tipping- and rotating type of loads (Fig. 2). To loosen the restorations from the tooth, the forces must be sufficient to deform or fracture the cement that has set in interlocking positions. The strength of the cement is therefore an important factor for the mechanical interlocking. An assessment of the compressive strength of the different cements and their dependence on testing conditions was therefore carried out (Paper VII).

However, the cement is submitted to loads lower than those causing fracture of the material. An elastic and/or a plastic deformation of the cement tags could also be of importance for the retentive ability of the luting layer. Accordingly, the elastic and plastic properties of luting cements were included in the study of mechanical properties (Paper VII).

It is also possible that the structure of the prepared tooth surface as well as of the fitting surface of the restoration could be of importance for the retentive function. The influence of surface roughness on the retentive ability of two different luting cements has therefore been assessed (Paper VIII).

The utilization of the minor irregularities on the surfaces for retention requires an intimate contact between the cement and the alloy as well as between the cement and the tooth substance. The present investigation includes studies of the adaption of cements as well as of several factors of importance for the adaption of cements to restorative material and to the prepared tooth (Papers I, II, III, IV, V, VI).

MATERIALS AND METHODS

Four different commercially available dental luting cements (zinc phosphate, polycarboxylate, EBA and composite resin cements) were used in the present investigation on strength, contraction, adhesion and adaption (Papers I, II, III, IV, V, VI, VII). Only two of these cements were used for the study of the influence of surface roughness on retentive ability (Paper VIII).

The dimensional stability of different cements was assessed on a mercury bath using a two dimensional measuring microscope (Papers I, II, III). The cements were setting at 37 °C under wet and dry oonditions.

The adaption of cements to tooth substance and casting alloy was assessed by means of a replica technique using a scanning electron microscope (Papers IV, V).

The bond strength of various cements to dentin was evaluated in a universal testing machine (Paper VI), using a crosshead speed of 1 mm/min. The surface structure of dentin treated in different ways was also studied in a scanning electron microscope and with an electronic surface tracer (Paper VI).

The stress/strain behaviour of the different cements was evaluated using a universal testing machine (Paper VII). The tests were performed at 23 °C and 37 °C with two different crosshead speeds (0.1 mm/min and 2.0 mm/min).

The roughness of dentin and metal surfaces was evaluated with an electronic surface tracer (Paper VIII) and the force necessary to break the cement seal was evaluated on a tooth/crown model mounted in a mechanical testing machine (Paper VIII).

RESULTS

Dimensional changes during setting (Papers I, II, III)

The linear dimensional changes varied depending on the type of cement employed and the environmental conditions during setting. All cements with the exception of the EBA cement, exhibited a rapid contraction during the first 10 to 20 minutes of setting. A slow but continued contraction was found under dry conditions, whereas only small changes were observed after the initial phase, when the cements were setting under wet conditions. The EBA cement had a small initial contraction which occurred later than that of the other cements. Under wet conditions the initial contraction was followed by an expansion which compensated or was larger than the contraction.

Adaption of cements to adjacent materials (Papers IV, V)

The inspection of replicas in the scanning electron microscope revealed that the cements did not have a complete adaption at both sides of the cement film. The slits varied in extent and localization. The polycarboxylate cement exhibited the best adaption with a small extent of slits only on the metal side. The zinc phosphate cement had a moderate extent of slits at both sides of the cement film. The EBA cement had a small extent of slits where the cement film was thin, but their extent increased significantly with increased film thickness. The slits were mainly located at the cement/tooth interface. The composite resin cement exhibited a large extent of slits at the cement/tooth interface independent of the cement film thickness.

Adhesion of cements to dentin (Paper VI)

Only polycarboxylate cement exhibited adhesion to smooth, but otherwise untreated dentin. The strength of the bond (3.8 MN/m^2) seemed to be limited by the tensile strength of the cement as the rupture mostly occurred cohesively in the cement. Zinc phosphate and EBA cements had a slight bond to polished dentin, but no measurable bond was found for the composite resin cement. All cleaning procedures and the application of varnish or liners to the dentin seemed to reduce the bond for zinc phosphate, polycarboxylate and EBA cements, whereas that of the composite resin cement showed a slight increase. Etching with citric acid, however, resulted in an increased bond between this cement and the dentin with a strength approaching that of the polycarboxylate cement (1.8 MN/m^2).

Strength and deformation (Paper VII)

Compression tests showed that large differences existed in strength, elastic and plastic properties between the different luting cements. Zinc phosphate cement had a high strength, high modulus of elasticity and a small plastic strain at fracture. These properties were not significantly affected by variations of the crosshead speed nor by the temperature during testing. The composite resin cement had a higher strength than the zinc phosphate cement, but exhibited large elastic and plastic deformations. The influence of the testing variables was limited. The polycarboxylate and EBA cement showed low values of strength combined with high values of elastic and plastic strain. The mechanical properties of these cements were markedly improved with an increased crosshead speed, but decreased when testing at a higher temperature (37 °C).

Influence of surface roughness (Paper VIII)

The measured retentive force was increasing when the roughness of the adjacent surfaces was enhanced. The retention of zinc phosphate cement increased more than that of the polycarboxylate cement and it was also larger at the cement/alloy interfaces than at the cement/dentin interfaces.

DISCUSSION

Dimensional stability

Previous investigations have shown that some of the luting materials shrink during setting, and more under dry than under wet conditions (8, 23, 31). The contractions measured in the present study were larger (Papers I, II, III). It was also demonstrated that the first minutes of setting are important when evaluating the stresses that will occur in a setting material which is prevented from contraction (2, 7). In other restorative work, a contracting, but still viscous material, can be supplied from a reservoir of excess material and thereby some of the stresses may be avoided (17). This is seldom possible when cementing cast restorations.

Adaption and sealing

Localization of slits

The two studies on localization and extent of slits (Papers IV, V) showed that none of the cements had a complete adaption on both sides of the cement film. However, there is reason to believe that the tooth substance would be somewhat better protected against bacteria if the slits were to be located at the cement/alloy interface than when located at the cement/tooth interface.

Extent of slits

A small extent of slits, as observed in the present study, could be interpreted as a few small areas where the adaption was lacking. These areas were scattered over the entire interface. If few slits were found a communication between them would probably not occur (Fig. 3). As the extent increased, the length of each slit or the number of slits increased, and the possibility that some areas with lacking adaption were anastomosing would increase (Fig. 3). A large extent of slits could thus mean that the bacteria could find a continuous pathway from the restoration margin to deeper parts of the interface through anastomosing slits. For the polycarboxylate cement which exhibited a good adaption, such communications would not very likely occur. At the interface between composite resin cement and tooth, however, such communication would probably be the rule rather than the exception.

The extent of slits could not be related to the amount of contraction measured in vitro, and with one exception, not to the cement film thickness. These findings indicate that slits occurred mainly as a result of inadequate wetting of the surface by the cement. However, the width of the slits was also varying independent of the cement film thickness. A rupture of an adhesive bond due to contraction stresses cannot therefore be excluded as an explanation for some of the slits.

Adhesion to dentin

The bond strength of several luting cements have been evaluated with different methods in previous investigations (5, 9). The results in the present study (Paper VI) confirmed the previous findings on adhesion to dentin. It also demonstrated the importance of the microstructure of the dentin surface for the wetting with dental cements. Any practical procedures to increase the bond strength beyond that which existed at smooth, but otherwise untreated dentin, was not revealed. On the contrary, the results indicate that a layer of grinding debris could be favourable to some cements in the establishment of a bond.

It was not clarified, however, if the positive influence of the layer of grinding debris was related to the sealing of the tubules and a reduced flow of water on the dentin surface (4) or if the debris that was dissolved in the cement liquid could be part of an intermediate layer in the establishment of a bond.

A surface treatment with citric acid, which has been shown to give some resins an increased bond to bovine and human dentin (9, 21, 28, Paper VI), is not biologically acceptable (10). Various observations indicate that the wettability increasing effect of this acid (8) could in part be related to a sealing of the tubules (Paper VI).

The bond strength of various luting materials to dentin and alloy showed a good correlation to the localization of slits. The zinc phosphate cement had a small bond strength to both dentin (Paper VI) and casting alloy (26), and slits were observed at both interfaces. The polycarboxylate cement had 6 times greater adhesion to both dentin (Paper VI) and alloy (26) than zinc phosphate cement. The main adhesion,

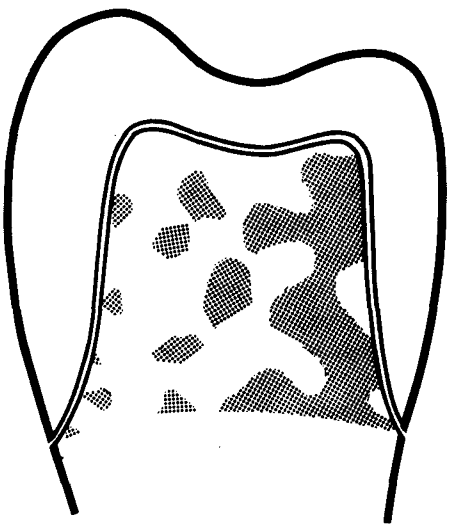

Fig. 3. Areas (shaded) with lacking adaption at the cement/tooth interface. Increasing extent of slits from left to right.

however, was to the dentin surface where no slits were found. The composite resin cement exhibits some adhesion to casting alloys (21), but no adhesion was found to dentin (Paper VI), and the slits were observed at the cement/dentin interface (Papers IV, V).

Strength and retention

It has been shown that the compressive strength of a cement is of great importance for the retentive ability (15, 20). It has also been indicated that a tensile strength could be of importance for retentive ability of the polycarboxylate cement which adheres to the tooth substance (12, 24, 25). The compressive strength of this cement, however, was less than half of that of the zinc phosphate cement at 37 °C (Paper VII). The results from the retention tests (Paper VIII) and the adhesion tests (Paper VI) indicate that the tensile strength of this material, though greater than that of the zinc phosphate cement (27), is too low to compensate for the lower compressive strength.

The prepared surfaces are relatively rough (7), and it must be concluded that a high compressive strength is the most important strength property with regard to the retention of a restoration.

Deformation and retention

An inspection of the cement surface that had been loosened from a metal surface (Paper VIII) showed that the cement tags were fractured or compressed. The studies of the stress/strain behaviour of the different cements showed that some cements exhibited extensive plastic deformation at 37 °C (Paper VII). It might therefore be speculated that a small but repeated loading could lead to a slow deformation of the cement tags and thus limit the lifetime of the retentive function.

Large differences were also observed in the moduli of elasticity, e.g. four times larger for the stiff material than for the most elastic material. It might be assumed that tags of cement with low elastic modulus could be elastically deformed and eventually slip out of the interlocking position during loading.

Surface roughness and retention

It has been conclusively shown that increased roughness can improve the retentive ability of different cements (Paper VIII). However, the utilization of an increased interlocking is obviously better for a stiff and brittle material than for a more ductile, but less strong, cement. An increase in the maximum roughness value from 5 µm to 50 µm resulted in an increase by a factor of 10 for the retention of zinc phosphate cement at the metal surfaces and by a factor of 3 at dentin surfaces. The retentive force of the polycarboxylate cement was barely doubled under the same conditions. One must assume, however, that the influence of surface roughness will decrease with increasing inclination of the *axial walls*.

Adaption and retention

The adaption of various cement films to alloy and tooth structures differed considerably (Papers IV, V), but slits at the interfaces were observed for all cements. These slits did not only represent a possible source for marginal leakage, but they also reduced the area of contact where stresses could be transmitted from one material to the other. With increasing extent of slits, an increased stress concentration could be expected at the remaining retention area. Variations in the retentive ability of different cements could thus probably partly be explained as a difference in the adaption.

CONCLUDING REMARKS

The present investigations have demonstrated the complex nature of the retentive and sealing functions of dental luting cements. It involves both physical and chemical properties of the cements and the alloys employed as well as of the prepared tooth surfaces. In addition, the microstructure of the prepared tooth surfaces may have a considerable influence on the functions of the cement.

A lasting retention requires a good combination of strength, adaption and amount of luting material in interlocking positions. Clinically, this can be obtained by cements with high strength and modulus of elasticity such as the zinc phosphate cement. The polycarboxylate and EBA cements should only be used where the prepared tooth offers maximum of retentive area and probably not for bridge retainers where increased stresses are expected.

In addition, the tooth and metal surfaces should have a roughness comparable to that produced by a coarse diamond cutter. The advocated procedures to smoothen, clean or cover the dentin with other materials prior to cementation will not enhance the retention but rather reduce it. When using resin cement on non vital teeth, however, a pretreatment with cleaning agents containing citric acid would be preferable. Metal surfaces should be cleaned by sand blasting. Smooth surfaces such as pre-fabricated posts, should be roughened prior to cementation. The use of an extra "cement lock" can be of advantage in certain cases provided the cavities can be prepared without weakening the tooth or restoration.

Materials which allow the retention to be based on adhesive bonding and a sufficient tensile strength of the cement are not yet available. However, some materials do show promising properties and future research may give other concepts for the retention of cast restorations.

The present investigations also revealed that wetting properties, adaption and adhesion of the luting materials, with exception of the polycarboxylate cement, were insufficient for an optimal sealing effect in the gap between a cast restoration and the tooth. A cleaning procedure to remove the debris layer or a deposition of a protective linere seems dubitable when using zinc phosphate or polycarboxylate cements as luting materials. However, a demonstration of the factors which could influence bacterial ingrowth is required in order to evaluate the clinical implications of insufficient sealing. Further research on new materials and techniques to enhance the adhesion to tooth structures and restorative materials may also improve the sealing effect of luting cements.

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