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Opinion Paper

Creep as a Mechanism for Sealing Amalgams

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Clinical Relevance

Creep may be a major factor in amalgam sealing from microleakage. Creep expansion causes amalgam to fill in the tooth/amalgam interface gap and causes the restoration to extrude out of the preparation.

SUMMARY

Dental amalgam seals itself over time. The reduction of microleakage in amalgam restorations has been explained by corrosion products filling in the interface gap between amalgam and tooth structure in order to seal the restoration interface. This concept has been widely accepted; yet, curiously, there is little research supporting this theory. The creep mechanism may be a plausible alternative to explaining why microleakage is reduced over time in amalgam restorations. Amalgam restorations are confined to the fixed space of the cavity preparation; expansion of the amalgam through internal phase changes in this confined area must be relieved. The resultant creep-expansion of the amalgam restoration fills in the tooth/amalgam interface gap. Once the interfacial gap is filled and amalgam has made intimate contact with the cavity wall, the dental amalgam slides along the tooth preparation plane as predicted by classic metallurgical studies.

The results of the creep of amalgam have been observed clinically as the extrusion of amalgam from the cavity preparation. This explanation for amalgam sealing the tooth/amalgam gap fits many clinical observations and certain research data.

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INTRODUCTION

Microleakage in dentistry has been studied for more than 50 years (Buchanan, 1951; Massler & Ostrovsky, 1954). Through the use of varied techniques and different test media, such as dyes and radioactive materials, microleakage is one of the most widely studied phenomena (Cochran & others, 2004). Kidd (1976) defined microleakage as the passage of bacteria, fluids, molecules or ions along the interface of a dental restoration and wall of the cavity preparation. Hilton (2002a,b) reports that biofilm between the tooth and restoration has been associated with staining at the margins, secondary caries and a general failure mechanism of the restoration. The two papers by Hilton (2002a,b) examine the background, current status and methodology for accomplishing reduced microleakage. Part I (Hilton 2002a) specifically discusses dental amalgam and its microleakage patterns.

Studies by Swartz and Phillips (1961, 1962) indicated that restorative materials exhibited microleakage and showed that the amalgam had an unusual ability to seal itself over time. A few years later, the sixth edition of Skinner and Phillips' *Essentials of Dental Materials* (1967) suggested this ability of amalgam to dramatically reduce microleakage was a deposit of corrosion products from amalgam at the tooth/amalgam interface. The explanation of corrosion build-up to reduce the microleakage of amalgam restorations was quite logical and is widely accepted today (Ben-Amar, Cardash & Judes, 1995; Hilton 2002a). However, little research to support this concept has been published, and some data questions the accuracy of the claim that corrosion products fill the tooth/amalgam interface to reduce microleakage.

This paper presents an alternative explanation of amalgam's ability to seal itself over time through the mechanism of creep in the confining space of the cavity preparation.

ALTERNATIVE THEORY OF AMALGAM SEALING

The creep of dental amalgam may be the causative factor in sealing the amalgam restoration. The mechanical property creep is defined as the deformation of a metal (or other material) under a load that is below the proportional limit (McLean, 1966; Williams & Hedge, 1985). The rate of creep depends on applied stress, temperature and time (McLean, 1966). An essential mechanical condition required to produce creep is a continual application of monotonic, non-hydrostatic stress (Osborne, Winchell & Phillips, 1978b), and higher creep rates of metals occur at temperatures closer to their melting point (Honeycombe, 1984).

Dental amalgams have been shown to creep at mouth temperatures (Mahler & Van Eysden, 1969; Mahler & others, 1970; Espevik, 1977) and expand with internal corrosion and phase changes (Jansen & Jorgensen, 1985; Okabe & Mitchell, 1996; Taita, Lautenschlager & Marshall, 1984). The results of a creep-induced stress lie in the constraints imposed on the amalgam by the surrounding tooth structure. These constraints arise when an amalgam phase slowly deforms over long time periods. Creep-expansion occurs because of internal corrosion and/or phase changes in the amalgam restorations (Abbott, Miller & Netherway, 1986; Mahler, Adey & Marshall, 1987; Marshall, Marshall & Letzel, 1992). The dental amalgam will creep and fill in the microscopic space between the tooth-amalgam interfaces. Once the interfacial space is completely filled, the amalgam then slides at this tooth interface and extrudes at the free surface, so that the amalgam restoration protrudes out of the cavity preparation. This creep induced intimate adaptation of amalgam to the tooth cavity wall, and subsequent extrusion along the tooth preparation plane, is supported by the classic metallurgical work of deSilva and Mehl (1951) and Balluffi and Seigle (1954). The extruded amalgam at an occlusal cavosurface margin is abraded away during mastication and brushing (Suzuki, Suzuki & Cox, 1996).

DISCUSSION

The concept that corrosion-product build-up in the tooth/amalgam interface gap reduces microleakage has been around for almost 40 years. This concept has been universally accepted by the dental profession and, yet, research on its validity has not been forthcoming. The interface of amalgam restorations in extracted teeth has been examined using a scanning electron microscope, but findings have not been definitive. Examination with Rutherford backscattering techniques has found few identifiable corrosion products at the interface (Hansen & others, 1982).

The theory that creep may be a factor in reducing leakage has existed for some time. This hypothetical theory was originally proposed by Professor Peter Winchell in 1975 and published in 1978 (Osborne & others, 1978b) to explain another dental amalgam phenomenon, marginal fracture. Although this theory did contain a mechanism to partially explain the marginal breakdown of amalgam (Williams & Hedge, 1985), other concepts have expanded and given better explanations of this phenomenon (Jokstad, 1991; Williams & Cahoon, 1989; Sutow & others, 1985).

Creep is a thermally activated phenomenon that is strongly related to the melting temperature of the metal (McLean, 1966; Honeycombe, 1984). Creep occurs at temperatures closer to the melting temperature of the metallic compound, and dental amalgam is within 20% of its fusion temperature (Williams & Cahoon, 1989). The creep of dental amalgam is confined to the lower temperature phase—that is, the gamma-1 matrix (Ag_2Hg_3) (Espevik, 1977; Sarkar & Eyer, 1987; Mahler & Adey, 1991). If the matrix phase of the dental amalgam had a higher melting temperature, the creep of the amalgam would be lower, and less matrix phase in the amalgam would theoretically translate into lower creep (McLean, 1966; Honeycombe, 1984). The result of creep in the confined cavity preparation has been observed clinically (Jokstad, 1991; Mahler & Van Eysden, 1974; Osborne & others, 1978b) and resultant extrusion of different dental amalgams measured (Mahler & Van Eysden, 1974).

There are conditions that favor creep as an explanation for the time-related reduction of leakage. Among them are: 1) microleakage at the tooth/amalgam interface has been shown to reduce over time *in vitro* when the test tooth is placed in distilled water or left dry on the bench (Swartz & Phillips, 1962). Both conditions would not create an environment that would likely produce corrosion products at the tooth/amalgam interface. However, phase changes in the amalgam would continue, which would precipitate creep. 2) Most of the 25 identified corrosion products of dental amalgam are soluble (Olsson, Berglund & Bergman, 1994; Gross & Harrison, 1989) and could wash out of the tooth/amalgam interface. 3) Sealing at the occlusal margins of amalgam restorations has been shown to be significant, but not at the gingival margins (Liberman & others, 1989). A possible explanation is that the occlusal walls are opposed to each other; whereas, the gingival margin in Class II cavities is not a confined space, in that it has no opposing wall.

In addition, other data on the sealing of dental amalgam can be readily explained by the creep mechanism in a confining space. Studies have shown that low copper amalgams have greater potential for corrosion, (Lin, Marshall & Marshall, 1983) higher creep (Osborne & others, 1978a) and reduce interface microleakage faster than high copper amalgams (Ben-Amar & others, 1995; Andrews & Hembree, 1980). The higher creep rate of low copper amalgams is likely the reason these amalgams seal quickly. High copper alloys such as Dispersalloy (Dentsply Caulk, Milford, DE, USA) and Tytin (Kerr Corporation, Romulus, MI, USA) demonstrate similar corrosion rates and products in artificial saliva (Yap, Ng, & Blackwood, 2004), but Tytin takes twice as long to bring about reduced leakage (Meiers & Turner, 1998). If corrosion rates and products are similar, the sealing time should be similar. The creep of Tytin, however, is about 2 to 2.5 times less than Dispersalloy (Osborne & others, 1978a). This lower creep would create the slower sealing of Tytin as observed in the Meiers and Turner data (1998).

Because creep and its resultant stress exists in the amalgam/tooth system, concern should be raised that this phenomenon may lead to fractured teeth. First, clinical data (Wahl & others, 2004) has shown that cusps adjacent to amalgam restorations do not fracture at a greater rate than teeth with resin composite restorations. Second, photoelastic studies on amalgam alloys indicate that stress placed on the tooth structure over time is minimal (Osborne, 1999). It would appear that creep-energy is directed towards the free surface of the amalgam restoration so that the restoration extrudes.

Jokstad (1991) published a paper on the clinical behavior of amalgams using a five-year clinical trial on Class II amalgams. The analysis showed that the depth of amalgam can influence marginal deterioration but cavity volume and cusp strength did not. The amalgam restorations with greater depth showed greater extrusion from the tooth. The proposed explanation of the relationship between cavity depth and amalgam behavior was amalgam's instability caused by corrosion, temperature diffusion, reallocation of mercury and transformation of the different phases in the amalgam. The role of creep and expansion was discussed as a causative factor in amalgam marginal deterioration. Jokstad (1991) theorized that, when expansion of amalgam occurs intraorally, extrusion would be observable at all the margins, although it was pointed out that there was little data to support equal extrusion at the margins. This extrusion at all margins, in fact, may not be the case, for creep expansion is affected by cavity depth and opposing or non-opposing walls. These factors of the geometry of cavity preparation could affect the amount of extrusion in different areas of the cavosurface margins of the restoration. Jokstad (1991) also found that the potential build-up of stress at the flexible cusps was not apparent. This conclusion would support the Wahl data (2004) on the same rate of tooth fracture of amalgam and composite posterior restorations.

"Creep in Metals" is a standard course in education programs in metallurgy. Hopefully, experts in this field will help the dental profession better understand this phenomenon, and metallurgical and clinical research will be conducted to verify this theory or provide a better one for the leakage-reduced phenomenon exhibited by amalgam.

CONCLUSIONS

The reduction of microleakage at the amalgam/tooth interface via the build-up of corrosion products is universally accepted, yet has been unconfirmed. An alternative explanation of the sealing properties of amalgam is presented. The creep of amalgam may be a causative factor in reducing microleakage where the amalgam restoration is confined to a finite space. During the creep-expansion of amalgam through internal corrosion and phase change, the tooth/amalgam interface gap is narrowed and filled in with amalgam. The intimate apposition of amalgam to the tooth cavity wall will then be followed by the metallic amalgam structure beginning to slide along the plane of the tooth and out of the preparation. Corrosion products may be trapped at the interface, but since many of the amalgam corrosion products are soluble, their role is likely to be minor. The wide range of data is strong evidence in favor of creep and confined space as factors in amalgam sealing itself.

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