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Operative Dentistry publishes articles that advance the practice of operative dentistry. The scope of the journal includes conservation and restoration of teeth; the scientific foundation of operative dental therapy; dental materials; dental education; and the social, political, and economic aspects of dental practice. Review papers and letters also are published.

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EDITORIAL

Should Specialists Be Required to Take a General Dentist's State Board Examination?

Historically, state dental board examinations were developed because of a perceived need to protect the public, as most dental schools were proprietary, and an even larger number of dentists were trained in a private practice preceptorship. Originally dental boards examined only operative dentistry procedures and full dentures. State and regional board examinations are still given with the stated purpose of "protecting the public." But do they?

There is certainly one group of candidates that examining boards cannot justify requiring to take the examination by stating that it is protecting the public. No rational, thinking individual can justify having board-certified specialists take a general dentistry clinical examination and say that the examination is required to protect the public.

Having specialists such as periodontists, oral pathologists, and oral and maxillofacial surgeons take an examination that includes clinical procedures on live patients such as gold inlays, crowns, amalgams, root canals, or denture set-ups is, in my estimation, nothing less than ludicrous.

In fact, having board-certified specialists take a general dentistry examination does just the opposite of protecting the public. The treatment provided by many of these candidates is substandard and amounts to patient abuse, not patient protection. In my estimation, examining boards that conduct such exams for candidates who will not be doing any of the procedures they are being tested on should be looked at by the state's legal authorities to determine the legality of such an examination.

The usual response to challenging the necessity of these exams is that you cannot depend on specialists to limit their practice to the specialty, and therefore they must be tested in all areas to protect the public. That is just an excuse! Looking back at all of the oral surgeons I have known over the years, I have yet to know of one who made dentures, gold inlays, or amalgams. I can also say the same for the periodontists, endodontists, and oral pathologists I have known. I have, however, known a lot of them who came to me for advice and instruction on how to do these procedures and who then practiced them prior to challenging a particular state board examination.

Having specialists take general dentistry examinations can be construed only as "gate-keeping." It is my understanding that just a few years ago the state board of dental examiners contacted the various specialty groups in the state to allow consideration of specialty licensure. Their response was to turn down such a proposal, so the state board continues to require specialists to take the general dentistry examination. It is time that, on a national basis, we consider specialty licensure, and then in all states licensure by credentials be granted. It is long overdue. I feel that all board-certified specialists should be granted their licenses by credentials. As for new specialists, as yet not board-certified, they should be given a provisional license for a specified period of time, such as five years. At the completion of that time, if they did not have their specialty board certification, they would lose their license to practice dentistry. All specialists would thus become board-certified. The impact of this would be to enhance patient care; I am convinced that certified specialists, overall, deliver a higher level of care.

As to the concerns of those who worry about specialists practicing dentistry, there should be no such concerns, as specialists who do not limit their practice to their specialty would lose their specialty licenses.

It is time to have examining boards examine the candidates that they should be examining and license by credentials the bona fide specialists. In doing so the public's interest would be protected. State and regional boards do serve the profession well, but not by "gate-keeping" for the specialists. It is time for action on the part of our profession.

DAVID J BALES
Editor

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ORIGINAL ARTICLES

Parameters of MOD Cavity Preparations: A 3-D FEM Study, Part II

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R C S CHEN • S A GURUSAMI

Summary

Stresses induced by the influence of variations in the dimensions of three different parameters of MOD cavity preparations were studied using the finite element technique. The parameters studied were the depth, isthmus width, and the thickness of the remaining interaxial dentin. A total of eight different cavity designs, divided into three groups, were compared with the normal (unprepared) tooth and other cavity designs in the same group. Enamel and dentin experienced large regional variations in compressive stresses even in normal teeth. Teeth with prepared cavities showed even more variation, and stress combinations became critical from a tooth fracture point of view. It was seen that narrow but deep cavity preparations and wide and equally deep cavity preparations experienced a similar, damaging combination of stresses. It was deduced from the stress patterns observed in this study that the depth of the cavity preparations is the most critical factor in fracture of the tooth or cusps, whereas the width of the isthmus alone is the least critical.

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INTRODUCTION

Fracture of posterior teeth, including the "cracked tooth syndrome," is a frequent dental problem. Many factors, including large restorations and/or carious lesions, have been associated with fractures (Cameron, 1964 & 1976; Gher & others, 1987).

Recent surveys (Cavel, Kelsey & Blankenau, 1985; Eakle, Maxwell & Braly, 1986) suggest that isthmus width in MOD amalgam restorations is directly related to cuspal fractures and that frequency of fracture increased as the isthmus width increased. Lagouvardos, Sourai and Douvitsas (1989) reported that vital teeth with three surface restorations fracture more frequently than those with one or two surface restorations. Nonvital teeth, when restored with three surface restorations, fractured even more frequently than those with two surface restorations. These reports seem to support the concept that with the loss of marginal ridges, fracture of the remaining cusps would occur frequently if the MOD cavity preparations were wide (Larson, Douglas & Geistfeld, 1981). Christensen (1971) suggested that when the isthmus exceeds one third of the intercuspal distance, onlays should be designed to prevent cusp fracture.

Vale (1956 & 1959) demonstrated that cavity preparations with wide isthmus widths markedly reduced the fracture resistance of the teeth when compared to cavity preparations with narrow isthmus widths and intact teeth. Many other studies have also demonstrated that the wider isthmus increases the potential for cuspal fracture (Mahler, 1958; Craig & others, 1967; Shillingburg & Fisher, 1970; Holland, 1971; Rodda, 1972; Fisher & others, 1975; Bell, Smith & DePont, 1982; Landy & Simonsen, 1984). Nadal (1962) proposed a cavity preparation with a narrow occlusal outline and a shallow cavity floor. Mondelli and others (1980) demonstrated that in MOD cavity preparations with an isthmus width equal to 1/4 of the intercuspal distance, the remaining tooth was significantly weakened, particularly at the buccopulpal and linguopulpal line angles. When more dentin was removed in approximal boxes, the tooth became even weaker. Larson and others (1981) also found a similar pattern of fracture of teeth with MOD cavity preparations. In contrast, Re and Norling (1981) and Re, Draheim and Norling (1981) demonstrated that the fracture resistance of the teeth was not reduced in wide but shallow class 1 cavity preparations. Re, Norling and Draheim (1982) also demonstrated that wide MOD cavity preparations did not significantly reduce the fracture resistance of the tooth when compared with narrow MOD cavity preparations or intact teeth. Blaser and others (1983) found that narrow or wide isthmuses of MOD cavity preparations did not significantly weaken the teeth if the pulpal depth was shallow. However, the damage to the remaining tooth structure was very significant, even with a narrow isthmus, when the pulpal depth was increased. Landy and Simonsen (1984) demonstrated that in an MOD slot preparation (with no interaxial dentin), if the depth was greater than the isthmus width the fracture potential of the remaining tooth structure increased significantly.

A recent study (Khera & others, 1988) demonstrated the presence of compressive and tensile stresses in wide and deep MOD cavity preparations. Tensile stresses were present in dentin at the pulpal floor at the buccopulpal line angle with heavy compressive stresses in the immediately adjoining areas. This combination was suggested to be a major factor in the fracture potential of teeth with wide and deep cavity preparations.

There is controversy in literature regarding the effects of MOD cavity preparations on the remaining tooth structure. The critical factors and their effects, individually or collectively, in MOD cavity preparations and the remaining tooth structure were not examined or compared. The critical and repeatedly measurable factors affecting the teeth with MOD cavity preparations are isthmus width, the depth at the pulpal floor, and the thickness of interaxial dentin between mesial and distal walls. There are many other factors, such as the extent of decay, occlusal relationship, and cuspal morphology, which are equally, if not more, critical. However, the factors that are the only measurable parameters which can be applied as a guideline in most MOD cavity preparations in a clinical situation are the width of the isthmus and the depth and thickness of the remaining interaxial dentin. The present study was undertaken to determine which of the three parameters is more critical in MOD cavity preparations. The stresses and the effect of each parameter, individually and collectively with other parameters, were analyzed to provide a basis for drawing clinical guidelines in order to minimize cuspal fractures.

The finite element technique has been used to investigate stresses in complex structures like the human tooth (Farah, Craig & Sikarski, 1973; Thresher & Saito, 1973; Yettram, Wright & Picard, 1976; de Vree, Peters & Plasschaert, 1984; Williams, Edmundson & Rees, 1989). The validity of the computed results has been confirmed in the biomechanics literature and more specifically in dental applications (Khera & others, 1988). Among these, a number of two-dimensional and three-dimensional finite element studies have reported stress distribution patterns for normal and restored tooth models.

Due to their proven reliability, this study, which is a part of ongoing research, used three-dimensional finite element models.

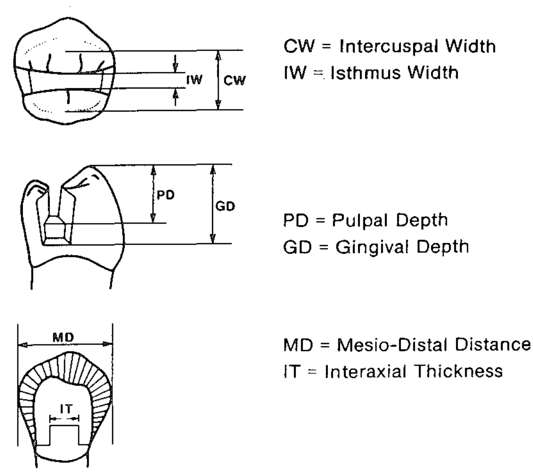


FIG 1. *Landmarks used to determine various dimensions*

MATERIALS AND METHODS

The models for this three-dimensional investigation are based on the actual geometric data for the tooth and eight cavity preparation designs derived from the serial photography technique described in earlier reports (Goel & others, 1985; Khera & others, 1988). This approach allows an understanding of the regional stress variations related to all designs of cavity preparation. A short description of the development of the three-dimensional finite element model of the normal tooth and eight cavity preparations follows.

From a pool of 10 human mandibles, one was selected on the basis of tooth morphology, level and contour of the aveolar bone, and the alignment of the dentition. From this specimen, a section extending from the mesial of the first premolar to the distal of the third molar was obtained. Duplicates of this section were made using die-cast material, and eight different MOD inlay cavity preparations of known dimensions were made, one in each of the duplicates. The landmarks used to determine the dimensions and the definition of the parameters in the cavity preparations are illustrated in Figures 1 and 2. The original mandibular specimen and the duplicates were embedded in an epoxy resin block in a known orientation. Using grinding and photographing techniques, serial photographs of this complex were obtained at approximately

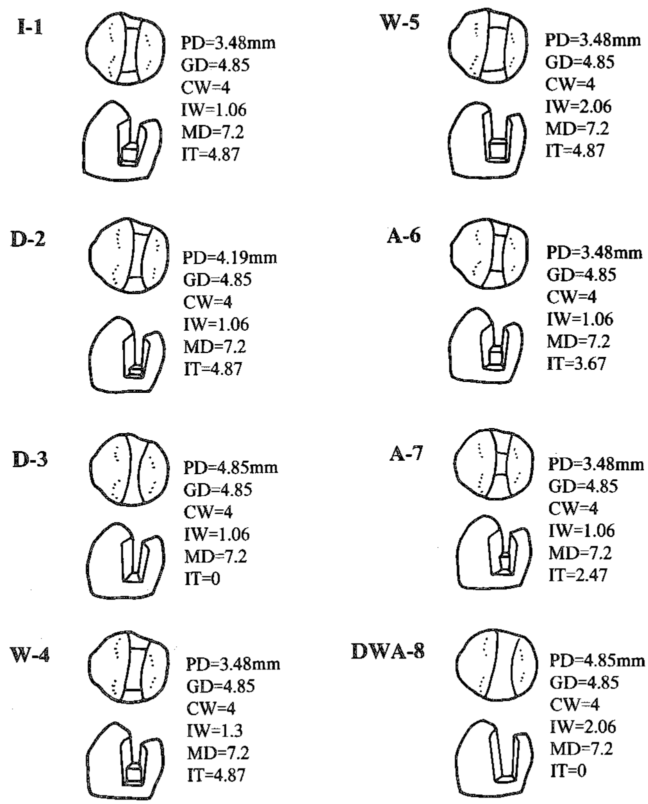


FIG 2. *Dimensions of various cavity preparations investigated*

0.5 mm intervals (Fig 3). Tracings from these sections were then divided into a number of discrete rectangles (elements) connected to adjoining elements at the nodes. Thus, the geometry of each section was closely duplicated. These elements were eight nodal linear isoparametric elements joined with corresponding nodes in successive sections. In this manner, three-dimensional finite element models of the unprepared tooth and the cavity preparations were developed (Fig 4). The coronal portion of the tooth was represented by 381 elements and the radicular portion by 341 for a total of 722 elements.

Isotropic material properties of enamel, dentin, periodontal ligament and alveolar bone assigned in this model were the same as described by Atmaram and Mohammed (1981).

A vertical load of 17 kg (170 Newtons) was evenly distributed on the entire occlusal surface to simulate the presence of food on the entire occlusal surface during mastication. In this phase of the investigation, vertical load was applied.

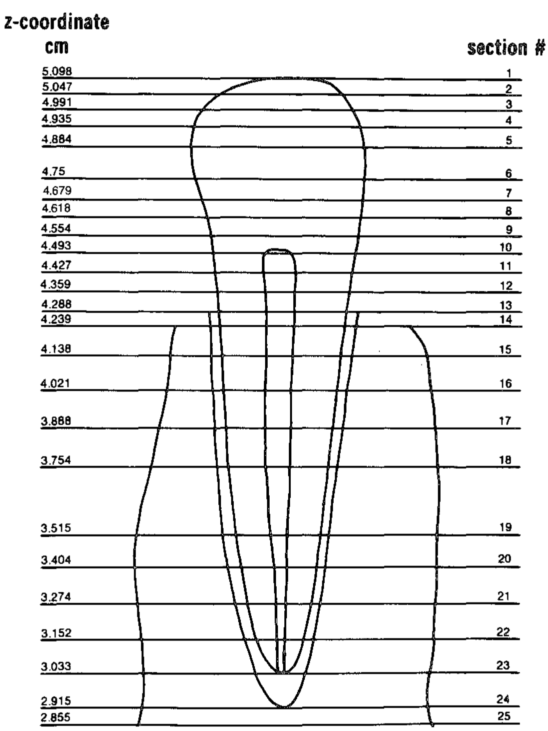


FIG 3. *Level of various sections made during serial sectioning*

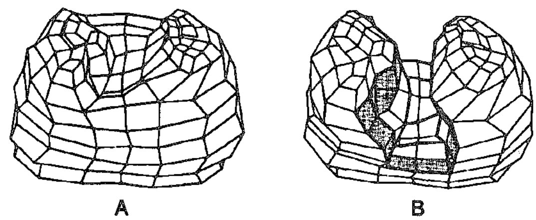


FIG 4. *3-D FEM models of (A) the normal tooth and (B) the tooth with W-5 cavity design. (Dot-screened elements represent enamel inside the cavity preparation).*

Further studies investigating the influence of +30° and -30° angles are currently in progress. The most apical section was fixed to prevent rigid body displacement or movement. The 17 kg load was deduced by calculating the maximum biting force and normal chewing force (1/3 of the maximum biting force) as presented in an earlier report (Khera & others, 1988).

In this report, cavity preparation designs were labelled as follows:

I-1: Minimal (ideal) cavity preparation,

D-2: Same as I-1 but with slightly deeper pulpal floor,

D-3: Same as I-1 but with pulpal floor being at the same level as the gingival wall,

W-4: Same as I-1 except for slightly wider isthmus width,

W-5: Same as I-1 except for even wider isthmus width,

A-6: Same as I-1 except for narrower interaxial dentin between mesial and distal axial walls,

A-7: Same as I-1 except for very narrow interaxial dentin, and

DWA-8: Cavity preparation very wide (as in W-5) and very deep (as in D-3).

DATA ANALYSIS

Basic data were analyzed for each group as compared to the normal tooth in the following comparisons:

1. Highest maximal principal (compressive) stress compared in the prepared teeth with the same in the "normal" and intact tooth at the same location in all section levels,

2. Percentage change in the highest stress values in enamel and dentin at the pulpal floor level compared with the normal tooth and as influenced by isthmus width, pulpal depth, thickness of interaxial dentin, and combined effect of lack of interaxial dentin and width, and

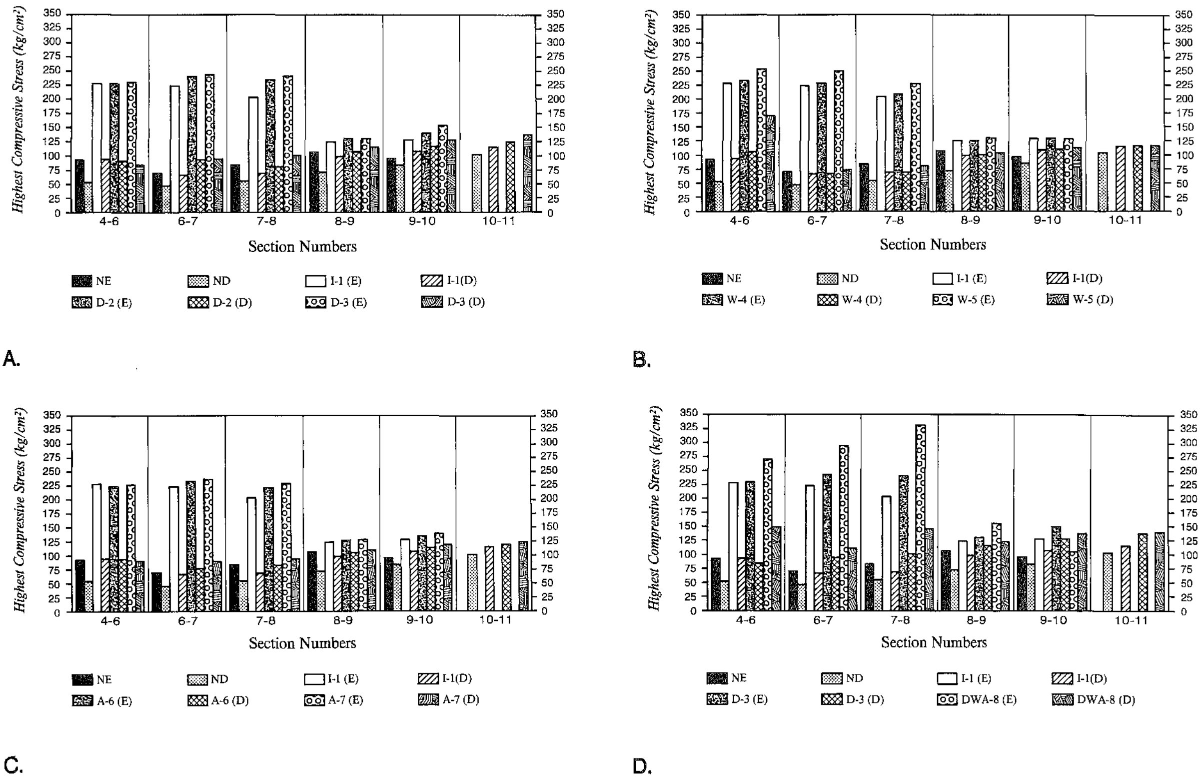


FIG 5. *Comparison of highest compressive stress in enamel (E) and dentin (D) in normal tooth and cavity designs: (A) I-1 (ideal), D-2 and D-3; (B) I-1, W-4 and W-5; (C) K-1, A-6 and A-7; (D) I-1, D-3 (narrow but deep) and DWA-8 (wide and deep)*

3. Comparison of stress values in cavities in a buccolingual direction immediately below the pulpal wall with the normal tooth, as affected by width of cavity preparation, depth of cavity preparation, thickness of interaxial dentin, and width of cavity preparation and the absence of interaxial dentin.

The stress values in the prepared teeth were compared with the stress values in the same area of the normal tooth so that the stresses at the pulpal floor level, for example, in design I-1 were compared with the stresses at the same level as in the normal tooth. However, stresses for the pulpal floor level in design D-2 were compared with stresses in the normal tooth at the deeper section since the pulpal floor in design D-2 was deeper than in design I-1. Each parameter was evaluated as normal tooth versus a group of cavity preparations with one variable. Thus, each parameter was compared with the normal tooth and with two other dimensions of the same parameter. The comparison for each parameter is reported separately as the influence on enamel and dentin at different levels. No statistical analysis was done on these data because in theoretical models such an analysis is not applicable, especially when loading conditions and physical properties are constant.

RESULTS AND DISCUSSION

Comparison of Highest Maximal Principal (Compressive) Stress

The normal tooth demonstrated the highest compressive stress in the distolingual line angle area. This is perhaps due to the anatomy of the tooth in the area and concurs with previously reported data (Khera & others, 1988). All models with different designs of cavity preparations demonstrated the highest maximal principal stress in the same general area.

Comparative analysis in all eight cavity designs demonstrated high levels of maximal principal stresses in enamel in the area immediately below the pulpal floor level (Figs 5A-D). This was at the level of section 4-6 for cavity preparation design numbers I-1, W-4, W-5, A-6, and A-7. In cavity design D-2 it was observed at section 6-7; in cavity design numbers D-3 and DWA-8 it was observed at section 7-8.

Variation in stresses in enamel in all designs were not as large among different designs, except for design DWA-8 (Figs 5A-D). This preparation was both very deep and very wide and did not have any interaxial dentin. However, these values in the enamel were the same as in the normal tooth in the sections immediately below the gingival wall, as is evident in sections 8-9, 9-10, and 10-11. In other words, stresses in enamel immediately below the pulpal floor level were much higher than those in the normal tooth but were close to stress values in the normal tooth just below the gingival wall. This pattern was similar to earlier findings and was true for all eight cavity preparation designs.

Dentin, however, showed a unique pattern. In general, dentin exhibited slightly higher maximal principal (compressive) stresses for all designs when compared with the normal teeth (Figs 5A-D) except in cavity designs W-5 and DWA-8 (Figs 5B, 5D). These designs demonstrated an unusually high level of maximal principal stress in dentin at section level 4-6, the section closest to the area of occlusal surface. But in sections 6-7 and 7-8, only cavity design DWA-8 showed much higher compressive stress values in all sections of dentin. Other cavity designs demonstrated a pattern where stress values were closer to those for the normal tooth in sections 6-7 and 7-8. In sections cervical to these, all of the dentin, including that in the normal teeth, demonstrated a much higher level of stress values than in the extreme occlusal level. Essentially, only cavity design DWA-8 demonstrated any major deviation from the normal tooth.

A critical issue in this analysis is the phenomenon that compressive stress values showed a large increase in enamel immediately below the pulpal floor but were close to the normal values in the area just cervical to it or at the level of the gingival wall. On the other hand, dentin showed a much higher value of compressive stress in the area close to the pulpal floor and immediately cervical to the pulpal floor, except for cavity design DWA-8. This different behavior of these two tissues at different levels as influenced by different designs of cavity preparation could be attributed partly to the difference in physical properties (such as the modulus of elasticity of the two tissues) and partly to the amount of these tissues remaining.

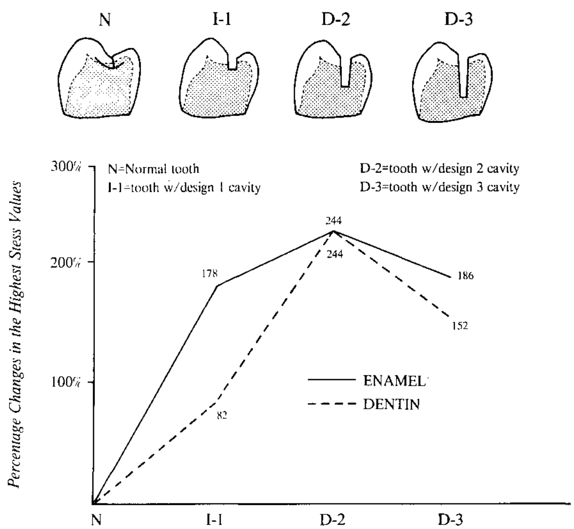
Comparison of Percentage Changes in the Highest Stress Levels in Enamel and Dentin at the Pulpal Floor

This comparison in the compressive stress values exhibited a unique effect in enamel and dentin. Even with the most ideal cavity preparation design, I-1, there was an increase in stress values when compared with the normal tooth (Fig 6A). Design D-2 showed an even higher percentage change, an almost 250% increase from the normal tooth in both enamel and dentin. Design D-3, a narrow and deep cavity preparation, however, demonstrated slightly lower values for both enamel and dentin than for design D-2, but much higher values when compared to design I-1. Yet, design D-3 reflects a change of 186% for enamel and 162% for dentin compared to the normal tooth.

Even though compressive stress values demonstrated a very high percentage change for enamel compared to the normal tooth structure as influenced by varying isthmus widths, these values were not much higher for design W-4 and W-5 compared to design I-1 (Fig 6B). Dentin, however, demonstrated less percentage change than enamel in cavity preparation designs I-1 and W-4 when compared to normal teeth. These values were much higher for designs W-5 and DWA-8 (Fig 6B). This was not surprising since the isthmus width for design W-5 was much greater than that for designs I-1 and W-4. When all of these cavity preparations (I-1, W-4, or W-5) were compared with design DWA-8, both enamel and dentin demonstrated a much higher level of stress values for DWA-8. This illustrates that the width in itself is not as critical a factor as the combination of the width and the depth.

The effect of varying thicknesses of interaxial dentin did not show large increases in compressive stress values in enamel when compared to those in the ideal cavity preparation, I-1 (Fig 6C). Designs A-6 and A-7 demonstrated that reducing interaxial dentin exhibited similar stress values for enamel. But in dentin, the stress values for both designs A-6 and A-7 were twice those in design I-1, and were about 180% greater than in the normal tooth. When designs A-6 and A-7 were compared with design D-3, both enamel and dentin demonstrated a similar pattern. Both these values were much higher than those seen in the ideal cavity preparation (design I-1). In wide and deep cavity preparation (design DWA-8), both enamel and dentin demonstrated a much larger increase in stress values for design DWA-8 than the normal tooth and other cavity designs (Fig 6C).

This analysis suggests that the thickness of interaxial dentin does influence the stress values for both enamel and dentin. When the thickness of interaxial dentin was reduced, as in designs D-3, A-6, A-7 and design DWA-8, the effect on the remaining tooth structure was much greater compared to other designs.



A.

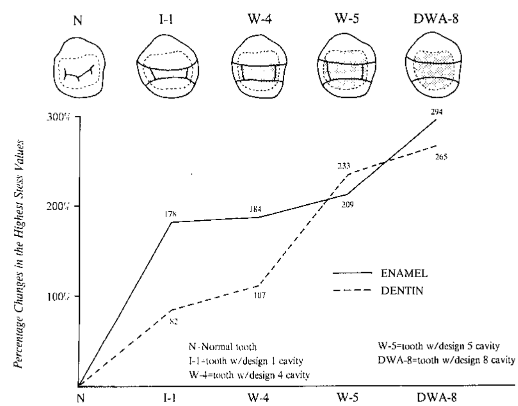
Comparison of Stress Values in Cavity Preparations in Buccolingual Direction at the Pulpal Floor

This comparison demonstrated that in the normal tooth both compressive and tensile stresses varied dramatically occlusogingivally and buccolingually. This observation agreed with earlier reports that there is regional variation in both enamel and dentin (Khera & others, 1988; Goel, Khera & Singh, 1990). Enamel exhibited higher compressive tensile stress values in buccal and lingual areas than dentin and also demonstrated greater regional variation occlusogingivally (Fig 7).

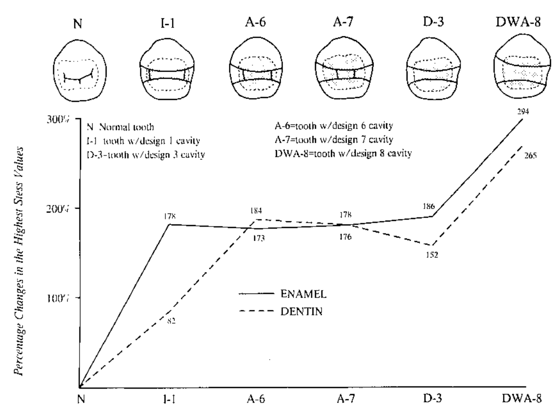
Analysis of Three Parameters

CAVITY DEPTH

When cavity design I-1 was compared to the normal tooth, it was seen that dentin in the center of the pulpal floor experiences a noticeable change in the form of higher compressive stress values, whereas the buccal and lingual



B.



C.

FIG 6. *Comparison of percentage change in the highest compressive stress values in enamel and dentin at the pulpal floor of normal tooth (N) and cavity preparations with varying (A) pulpal depth, (B) isthmus width alone and in combination with depth (DWA-8), and (C) thickness of interaxial dentin alone and in combination with a narrow cavity preparation with no interaxial dentin (D-3) as well as wide preparation cavity with no interaxial dentin (DWA-8)* enamel does not (Fig 8A). In cavity design D-2, dentin in the middle of the pulpal floor showed compressive stress values lower than in the area immediately adjacent to it (Fig 8B), projecting a tendency towards a change in the character of stresses in the middle of the pulpal floor which could, in time, have effects similar to the deeper cavity preparation design D-3. In cavity design D-3, the stresses in dentin in the middle of the pulpal floor changed in character from compressive to tensile (Fig 8C) with very high values of compressive stress in the areas immediately adjacent to it. Enamel on the buccal side also experienced very high compressive stress when compared to the normal tooth at the same level. Among the three designs comparing the effect of the depth of the cavity preparation, this change in character was seen only in D-3, although design D-2 exhibited a tendency towards the same, and though the width of the isthmus in design D-3 was the same as in I-1 and D-2, only the depth was greater. Earlier observations showed a similar pattern in wide and deep cavity preparations (Khera & others, 1988). It is this combination, tensile stress in the middle of the pulpal floor

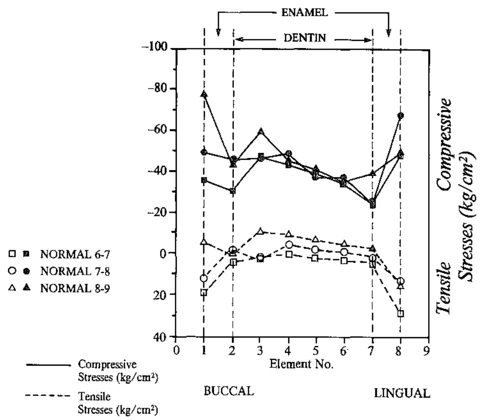


FIG 7. *Regional variation in compressive and tensile stress values in a normal tooth occlusogingivally (sections 6-7, 7-8, 8-9, etc) and buccolingually (element 1-8)*

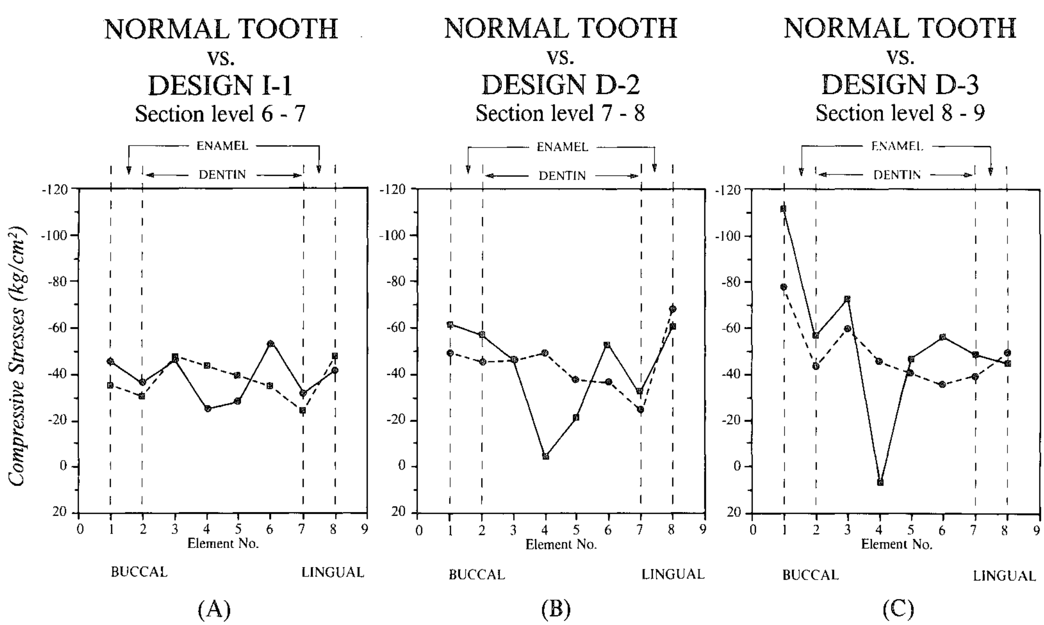


FIG 8. *Comparative analysis of compressive stresses between cavity preparations of varying depths (solid line) in buccolingual direction at the level of the pulpal floor and normal tooth (N, broken line): (a) I-1, (b) D-2, (c) D-3. Note the change in character of compressive strength to tensile in (c).*

and heavy compressive stresses on either side of it, that could be playing a role in cuspal fracture clinically. This observation seems to suggest that the depth of the MOD cavity preparation is a critical factor.

WIDTH OF THE ISTHMUS

The observations of stress patterns as affected by isthmus width demonstrated that the width of the isthmus in itself does not have a major effect on the remaining tooth structure. All preparations (I-I, W-4, W-5), when compared to each other, demonstrated a similar stress pattern (Fig 9), and these values exhibited no change in character, though there was a slight tendency similar to that observed in design D-3 in all cavity preparations. Except for the middle of the pulpal floor, the stress pattern was quite similar to that in the normal tooth itself, especially in the buccal and lingual areas. This does not suggest that the width of the cavity preparation has no detrimental effect on the remaining tooth structure. The depth of the cavity preparation, however, appears to influence the stress values and character more critically than the width of the isthmus.

THICKNESS OF INTERAXIAL DENTIN

Comparison of the changing thickness of interaxial dentin in cavity designs A-6 and A-7 from I-1 demonstrated high compressive stress values in the middle of the pulpal floor. All other areas experienced stress levels that were quite similar. Tensile stresses, however, demonstrated a very different pattern (Fig 10). As the thickness of the interaxial dentin was reduced from 1/2 (I-1) to 1/3 (A-6) to 1/4 (A-7) of the mesiodistal dimension of the tooth, the location of the highest tensile stress changed. This change was seen as a shift from the middle of the pulpal floor (I-1) to the buccal dentinoenamel junction (A-6) to the lingual dentin immediately adjacent to enamel (A-7), possibly due to further separation of cusps caused by the reducing interaxial dentin. The character of stress, however, did not change. Tensile stresses by themselves, in general, had very low values in all models and appear to have little clinically critical impact. But the variation in stress values as influenced by cavity designs, as seen in A-6 and A-7 (Fig 10), may contribute to cuspal deflection, especially of cusps that are weak to begin with. In time, this may lead to cuspal fracture. The level and the complexity of this fracture would be influenced by both the thickness of remaining interaxial dentin as well as the depth of the pulpal floor.

It appears from the comparison between cavity designs I-1, D-3, A-6, A-7 and DWA-8 that the presence of any amount of interaxial dentin prevents the change in the character of compressive stresses to tensile stresses as seen in

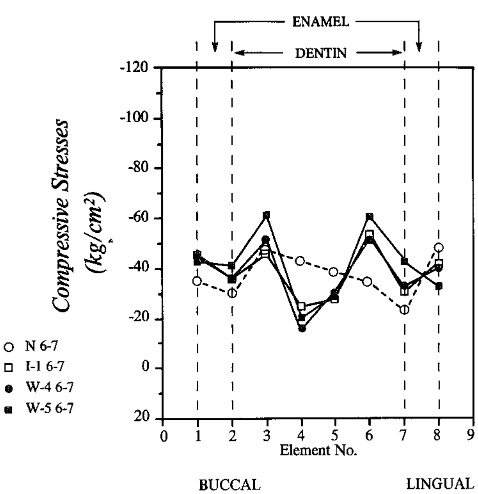


FIG 9. *Comparative analysis of compressive stresses between normal tooth (N) and cavity preparations of varying isthmus widths (I-1, W-4, W-5) in buccolingual direction at the level of the pulpal floor*

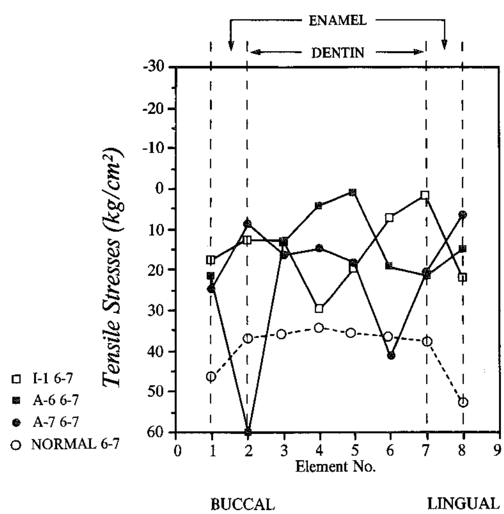


FIG 10. *Comparative analysis of tensile stresses between normal tooth (N) and cavity preparations of reducing thickness of interaxial dentin (I-1, A-6, A-7) in buccolingual direction at the level of the pulpal floor*

designs D-3 and DWA-8. Thus this parameter appears to be more critical in MOD cavity preparations than the width of the isthmus.

COMBINED EFFECT OF DEPTH, WIDTH, AND THE THICKNESS OF INTERAXIAL DENTIN

This analysis was made when the ideal cavity preparation (I-1, Fig 8A) was compared with narrow but deep preparation (D-3, Fig 8C) and wide and deep preparation (DWA-8, Fig 11). These preparations (D-3 and DWA-8) had no interaxial dentin. As reported earlier (Khera & others, 1988), the compressive stresses in dentin in the middle of the pulpal floor in wide and deep preparation (DWA-8) demonstrated a change in character to tensile with heavy compressive stresses in the area immediately adjacent to it (Fig 11). When narrow and deep preparation (D-3) was examined, a similar pattern was seen (Fig 8C). This combination seen in designs D-3 and DWA-8, in time, could lead to the fracture of the remaining cusps as illustrated in Figure 12. Narrow and only slightly deeper cavity preparation (D-2) showed a similar tendency but no actual change in the character of stresses (Fig 8B). Additionally, wide cavity preparations (W-4 and W-5) also showed a similar pattern but no change in the character of stresses (Fig 9). These comparisons suggest that:

a. depth of cavity preparation is the most critical factor in MOD cavity preparations,

b. interaxial dentin alone plays an important part in preventing the change in character of stresses, and

c. although width of the isthmus of the cavity preparation alone is an important and critical factor in MOD cavity preparations, it alone is not as critical as the other two parameters.

CLINICAL IMPLICATIONS

Restoring teeth severely damaged due to caries or fracture always presents a challenge to the clinician. Not only must the damaged tissue be removed while protecting the pulp, but the remaining healthy tooth structure must also be preserved. The relative unpredictability of the integrity of the remaining tooth structure

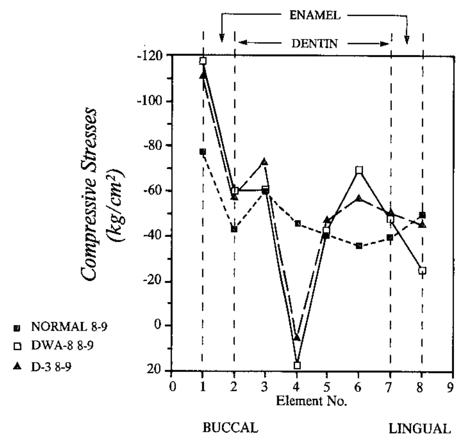


FIG 11. *Comparative analysis of compressive stresses between the normal tooth (N) and deep cavity preparations with narrow isthmus width (D-3) and wide isthmus width (DWA-8) in buccolingual direction at the level of the pulpal floor. Note and compare the change in character of compressive stresses to tensile for both D-3 and DWA-8 in the middle of the pulpal floor accompanied by heavy compressive stresses in the area immediately adjacent to it.*

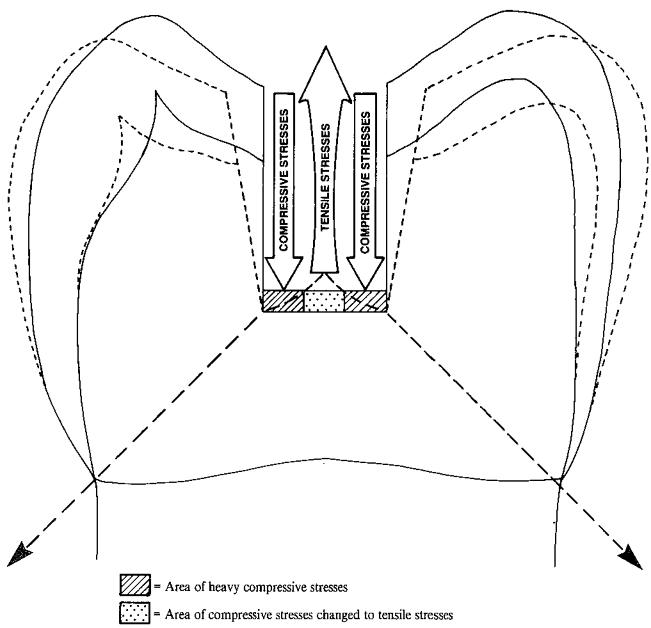


FIG 12. *A composite of the effect of tensile stresses and compressive stresses on the pulpal floor and how this could lead to cuspal fracture*

and the varying functional requirements of each individual tooth present further complications. Clinically, the variations may be so many that a general rule or specific set of guidelines may be difficult to establish. One guideline based upon the isthmus width alone is not universally applicable. As observed in surveys reported earlier (Eakle & others, 1986; Cavel & others, 1985), even the narrow widths of the isthmus in class 2 cavity preparations were involved with cuspal fractures, as were single surface restorations. What is missing, perhaps, is the information regarding the effect on the remaining tooth of varying dimensions of cavity preparations.

Isthmus width is perhaps an easy parameter that could be applied in the majority of the situations, but it also may be the most misleading parameter in large cavity preparations. The other two parameters seem to play a more critical role as far as the stresses on the remaining tooth structure are concerned. As demonstrated in this study, the most important factors in large cavity preparations are depth of the prepared cavity and the thickness of the remaining interaxial dentin. Cavity preparations with even narrow widths of the isthmus demonstrated very high stress levels when compared to the normal tooth. The other two parameters, however, did exhibit effects with potentially damaging results in the long run due to the character of stresses developed at or just below the pulpal floor (Fig 12). These parameters appear to be involved in the prevention or development of tensile stresses at or just below the pulpal floor whereas the width of the isthmus alone is not. These observations suggest the following:

(1) Isthmus width of the prepared cavity, in itself, does not affect the remaining tooth structure in an adverse manner as long as the depth of the prepared cavity is shallow. This is in agreement with Nadal (1962), Re and Norling (1981), Re and others (1981), Re and others (1982), and Blaser and others (1983).

(2) The thickness of remaining interaxial dentin is critical in MOD cavity preparations in terms of preventing cuspal fractures. In the present study, it was clearly seen that the presence of even small amounts of interaxial dentin (design A-7) present between mesial and distal axial walls prevents the development of tensile stresses at or just below the pulpal floor. This perhaps prevents the fracture of the remaining tooth structure. This is in agreement with the findings of Mondelli and others (1980) and Larson and others (1981) that removal of minimal amounts of tooth structure from approximal boxes did not severely increase tooth fracture potential and with the viewpoint of Tucker (1989), who suggested that in the presence of a "good stock of dentin between buccal and lingual cusps, an inlay should be alright" (*sic*).

(3) The depth of the cavity preparation is perhaps the most critical parameter when compared to the other parameters. This study clearly demonstrated that depth alone could cause development of tensile stresses at the pulpal floor even if the isthmus width of the prepared cavity is narrow (design D-3), and may lead to the fracture of the remaining tooth structure due to the fatigue factor or the cumulative effect of the stresses over a long period of time. This also agrees with the viewpoint of Tucker (1989), Shillingburg, Jacobi and Brackett (1985), and Shillingburg (1989), who suggested respectively that "if not enough stock of dentin is present between buccal and lingual cusps," or where "there is significant loss of tooth structure in the central core of the tooth," the restoration designed should provide cuspal protection to prevent cuspal fractures. Both of these clinicians have, in their own way, referred to the depth of the prepared cavity as a very critical parameter in preventing cuspal fractures.

From a clinical standpoint, one can thus see the importance of all three parameters in an MOD cavity preparation and prepare the teeth for cuspal protection by restoring them with either onlays, 3/4 crowns, 7/8 crowns or full veneer crowns, when the pulpal depth of the prepared cavity approaches the cervical area of the tooth and when there is a very insignificant or biologically compromised (demineralized) amount of dentin present between the buccal and lingual cusps. The depth of the prepared cavity has also been linked to cuspal deflection (Assif, Marshak & Pilo, 1990). This in turn may contribute to recurrent decay further weakening the remaining tooth structure and ultimately leading to fracture of the cusps (Anusavice, 1989).

There are other factors, such as the size of the cusps, thickness of enamel of the cusps, cuspal inclines (Khera & others, 1990), occlusal harmony, masticatory habits and loads, and perhaps aging, which will also influence the fracture potential of cusps. This was demonstrated by Salis and others (1985), who found that intact mandibular first premolars had significantly higher fracture resistance, as compared to other premolars, when vertical impact load was applied on the buccal cusp. Most likely, the size of the cusp and other factors mentioned above played a critical role in these observations. Many of the above-mentioned factors are either not controllable or not correctable by the clinician. As cavities are being prepared, the clinician has to make a judgment based upon the dimensions of the prepared cavity, and this is dictated by the spread depth of the carious lesion or other pathology. This decision should be based upon examining all parameters of the prepared cavity, the integrity and health of the remaining tooth structure, and the functional requirements of the tooth and the restoration. Protecting the cusps from fracturing in deep cavity preparations, as discussed earlier, will offer patients the best care they seek from the clinician.

CONCLUSIONS

Fracture of teeth associated with MOD cavity preparations has been generally related to isthmus width of the cavity preparations. However, the physiologic behavior of enamel and dentin, which varies dramatically occlusogingivally, buccolingually, and mesiodistally, has not been taken into account in determining the relationship between fracture frequency/potential and the dimensions of the prepared cavity. This behavior of enamel and dentin can be evaluated in detail easily by using the finite element technique.

The finite element technique was employed in this investigation to study the effect of cavity preparation depth, isthmus width, and interaxial dentin thickness on the potential for tooth fracture. Results obtained in this study, as well as findings from clinical surveys and other experimental studies, suggest that the depth of the prepared cavity alone plays the most significant role in the fracture of teeth prepared for MOD restorations, whereas the isthmus width alone is the least significant contributing factor. Thus, clinical decisions regarding the choice between intracoronal versus onlay type restoration for MOD cavity preparations should be based on the following in decreasing order of importance: depth of cavity preparations, thickness of interaxial dentin present, and width of the isthmus.

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Retention and Resistance Provided by Nine Self-threading Pins

J O BURGESS • J B SUMMITT

Summary

Extracted molar teeth, reduced to a flat surface approximately 3 mm coronal to the cementoenamel junction, were notched and embedded in acrylic. Nine types of pins were tested for retention in dentin and for resistance provided to complex amalgam restorations. Pins of each type were inserted into dentin and removed in tension with a constant load applied by an Instron Testing Machine (six pins per tooth). Minim and PPS pins provided significantly better retention in dentin than the other pins. Pins of each type were inserted into flattened teeth. Amalgam was condensed around the pins, allowed to set, and loaded in compression at 45°. Pure titanium pins and heat-softened stainless steel pins provided significantly less resistance than titanium alloy or stainless steel pins.

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INTRODUCTION

Self-threading pins have provided supplemental resistance form for restorations for over 150 years (How, 1839). Whaledent began marketing self-threading stainless steel pins in the late 1960s. These pins and others were tested by numerous laboratory studies over the next two decades (Wing, 1969; Moffa, Razzano & Doyle, 1969;

Eames & Solly, 1980). When introduced, self-threading pins were made of stainless steel only; however, manufacturers now market pins in various metals and designs, so that a variety of pins is available to the practitioner.

One necessary factor for the clinical success of pins is adequate retention in dentin. Recently pin manufacturers have made several modifications in thread design and as a result have claimed improved dentin retention and less crazing. These new designs consist of a decreased number of threads per unit length, a shoulder to prevent the pin from contacting the bottom of the prepared dentin channel, and a reverse buttress thread design. The Max Pin (Whaledent) has this thread design (Fig 2). The reverse buttress thread design reportedly decreases stress during placement and increases retention of the pin into dentin.

Self-threading pins are now produced from titanium or a titanium alloy in addition to the traditional stainless steel. As a material, titanium is very biocompatible, with a tough surface oxide which provides immunity to many acids and other corrosives. However, titanium has a lower modulus of elasticity than most stainless steels, and therefore pins made of titanium could provide less retention and resistance for amalgam restorations than stainless steel pins (Taira, Moser & Greener, 1989).

A titanium alloy (Ti-6A1-4V) used by Brasseler USA, Inc (Savannah, GA 31419) and Whaledent International (New York, NY 10001) for their self-threading pins is composed of approximately 90% titanium, 6% aluminum and 4% vanadium. This alloy has an increased modulus of elasticity compared to pure titanium and produces pins that are stiffer than those made from commercially pure titanium.

This study tested the resistance and retention provided by nine different pin systems made from three different alloys by five manufacturers.

MATERIALS AND METHODS

Extracted molar teeth, free of caries and restorations, were selected and stored in tap water except during specimen preparation and testing. The occlusal surface of each molar was reduced with a model trimmer to provide a flat surface approximately 3 mm above the cementoenamel junction. The roots of each tooth were notched for retention and embedded in acrylic which extended occlusally to approximately 2 mm below the cementoenamel junction.

Nine types of pins (Figs 1 & 2) manufactured by five companies were selected for evaluation on

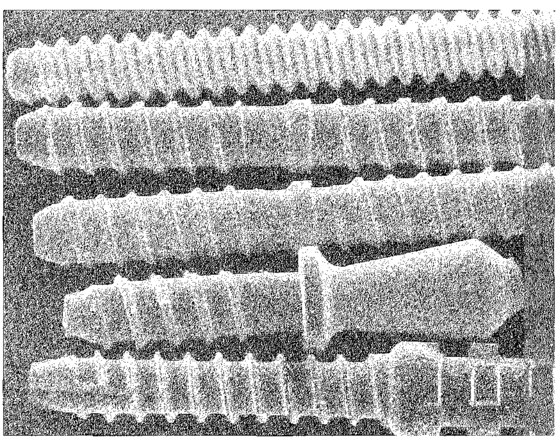

FIG 1. *SEM of five threaded pins tested in this study, from top to bottom: Minim (conventional thread), Link Plus Titanium alloy (buttress thread), Link Plus stainless steel (buttress thread), Max titanium alloy (reverse buttress thread)*

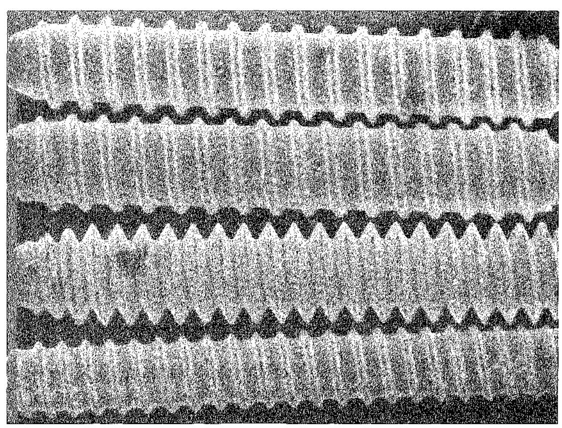

FIG 2. *SEM photomicrograph of the remaining four pins tested in this study, from top to bottom: Stabilok stainless steel, Stabilok titanium, Denlok heat-softened stainless steel, and Filpin titanium. All these pins have the conventional thread design.*

the basis of having similar diameters (Table 1). Four of the pins tested were made by Whaledent and included the TMS Minim stainless steel pin with gold plating, the Link-Plus stainless steel pin with gold plating, and the Link-Plus and Max titanium pins made from the Ti-A1-V alloy. Also tested were Brasseler's PPS (Parapulpal Pin System) pins also made of Ti-A1-V alloy. Fairfax Dental's Stabilok pins (Fairfax Dental Inc, Coral Gables, FL 33134) of both stainless steel and pure titanium were included, as were Vivadent's titanium Filpins (Vivadent USA, Inc, Tonawanda, NY 14150) and Denovo's stainless steel Denlok pins (Denovo, Arcadia, CA 91006). Note that each of these nine pins had an advertised diameter of approximately 0.6 mm.

Although the diameters of the pins selected were as close to 0.60 mm as possible, several of the mean pin diameters varied slightly. The mean diameters of the pins of each system tested were determined by measuring 20 of each pin using MAX-CAL Electronic Digital Calipers (Ted Pella, Inc, Redding, CA 96003). Means and standard deviations for these measurements are shown in Table 1 in Newtons. Newtons may be converted to pounds by multiplying by a factor of 0.2248.

Resistance Test

Ninety mandibular molars were rank-ordered by buccolingual dimension and distributed among nine groups of 10 teeth, producing a similar mean buccolingual dimension in each group. Six pins from each system were inserted into each molar. Pin channels were prepared with the twist drills provided by the manufacturers. Each drill was driven by an American Midwest Tru-Torque Shorty low-speed handpiece (Midwest Dental Products Corp, Des Plaines, IL 60018), with a latch-type contra-angle. The drill was aligned parallel to the external surface of the tooth adjacent to the proposed channel location. Channels were prepared at least 0.5 mm inside the dentinoenamel junction, to a depth of 2 mm. Six pins, three on the facial and three on the lingual, were inserted into each molar by the method recommended by the manufacturer. The pins were cut after insertion with cutting pliers so that 2 mm of each pin extended above the surface of the tooth preparation.

Annealed copper band matrices were adapted to the tooth and reinforced with green modeling compound. Amalgam (Dispersalloy, Johnson & Johnson Dental Products Co, East Windsor, NJ 08520) was triturated according to the manufacturer's instructions and condensed into the preparations using hand and mechanical (Condensaire, Densco, Denver, CO 80207) condensation. The matrices remained in place at least 10 minutes after completion of condensation. Amalgam flash was trimmed from the margins, and the "occlusal" surface of each specimen was trimmed flat using a Supermet Polisher-Grinder (Buehler, Evanston, IL 60204) so that the amalgam extended 4 mm above the prepared surface of the tooth.

Seven days later, each specimen was inserted into a fixture which positioned it at a 45° angle. A 1 mm bevel was prepared on the line angle at the junction of the occlusal and the facial surfaces of the amalgam. The bevel was cut with a separating disk mounted horizontally in a straight handpiece held vertical by a Ney surveyor (J M Ney Co, Bloomfield, CT 06002).

While positioned in the same fixture, each specimen was tested in an Instron Testing Machine (Instron Corp, Canton, MA 02021). The specimens were loaded in compression to fracture using a 1/4-inch

Table 1. Pin Composition and Diameters

Manufacturer	Pin Name	Composition	Mean Diameter (mm)	SD
Brasseler	PPS	titanium alloy	0.57	0.009
Denovo	Denlok	stainless steel	0.57	0.010
Fairfax	Stabilok	stainless steel	0.60	0.010
Fairfax	Stabilok	titanium	0.62	0.009
Vivadent	Filpin	titanium	0.59	0.008
Whaledent	Max	titanium alloy	0.58	0.008
Whaledent	TMS Link Plus	stainless steel	0.60	0.010
Whaledent	TMS Link Plus	titanium alloy	0.60	0.010
Whaledent	TMS Minim	stainless steel	0.60	0.009

diameter flat rod at a crosshead speed of 1.27 mm (0.05 inches) per minute (Fig 3). The mean load data and the failure mode were recorded.

Retention Test

Twenty-three molars embedded in acrylic were used to test the retention of the nine pin types in dentin. Ten of each pin type were inserted by hand into channels prepared as described in the resistance test methods. Only four pins were inserted into each molar to allow space for each pin to be attached to the Instron Testing Machine for tensile loading. A Jacobs Chuck (Jacobs Chuck Manufacturing Co, Clemson, SC 29633) was used to grasp each pin (Fig 4), and the pin was loaded in tension on an Instron Testing Machine at a crosshead speed of 2 mm/min. Peak failure load was recorded.

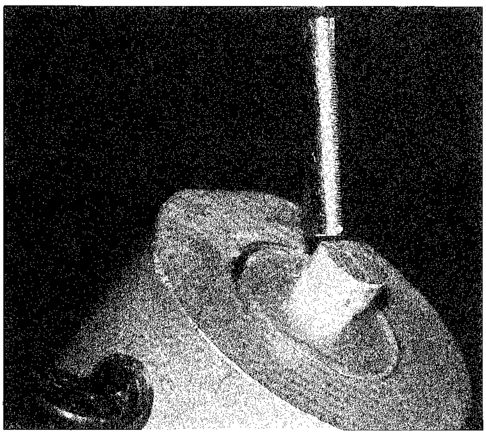

FIG 3. *Positioning specimen for compressive loading in the Instron Universal Testing Machine*

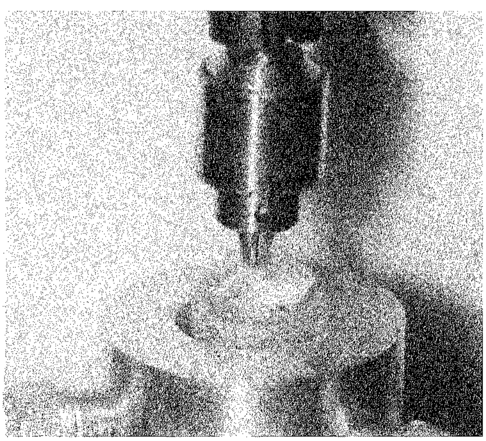

FIG 4. *Pin grasped for tensile loading*

RESULTS

Resistance Test

Means and standard deviations for the loads required to cause failure of the resistance form in each of the groups are shown in Table 2. Data were analyzed using a one-way analysis of variance (ANOVA). A Duncan Multiple Range Analysis was used to determine intergroup differences.

Statistically, pins were grouped as shown by the lines adjacent to the means in Table 2. The means are presented graphically in Figure 5. Whaledent Minim and Link-Plus stainless steel pins provided the most resistance; Link-Plus stainless steel and Link-Plus titanium alloy pins composed the next most resistant group, and Brasseler PPS (titanium alloy) pins were in the third most resistant group. The Link-Plus and Max titanium alloy pins made up the next most resistant group, the Max and PPS the next, and the Stabilok, Filpin, and Denlok pins were not significantly different from each other and provided significantly less resistance than the Whaledent and Brasseler pins.

Table 2. Resistance Failure Loads

Pin Type	Metal	Mean Load (N)	SD
Minim	SS	1827	192
Link-Plus	SS	1745	235
Link-Plus	TVA	1590	195
Max	TVA	1515	291
PPS	TVA	1382	202
Stabilok	SS	1154	237
Stabilok	TI	1147	162
Filpin	TI	1094	217
Denlok	SS	1092	94

The mode of failure for each pin type was determined (Fig 5).

Retention Test

Means and standard deviations for the loads required to cause retention failure are shown in Table 3. Again the data were analyzed with a one-way ANOVA; a Duncan Multiple Range analysis was used to determine differences among the groups. The greatest retention was exhibited by the PPS and TMS Minim pins.

Table 3. Retention Failure Loads

Pin Type	Metal	Mean Load (N)	SD
PPS	TVA	176	32
Minim	SS	161	59
Link-Plus	SS	143	39
Max	TVA	138	32
Filpin	TI	125	5
Link-Plus	TVA	122	42
Denlok	SS	121	11
Stabilok	TI	116	20
Stabilok	SS	83	28

DISCUSSION

The resistance and retention provided by various pins of similar diameters varies considerably. This is probably due to differences in thread design, to variations in the pin-to-channel mismatch, to variations in the metal constituents, and to the heat treatment of stainless steel. The softening heat treatment applied to the Denlok and Stabilok (SS) pins produces a more flexible pin, which may aid insertion and self-alignment of the pin when it is inserted. However, that treatment produces a pin which does not provide as much resistance as the stiffer stainless steel and titanium alloy pins. The pure titanium and the heat-softened pins failed more frequently by shearing through the pin. Neither the buttress nor the reverse buttress thread appear to offer any advantage for retention or resistance compared to the standard thread used with the Minim pin. The desirable properties for metal pins have not been definitively established, and a completely reliable test has not been developed to test resistance form. The resistance form test used in this study, loading the restoration at a 45° angle from the occlusal plane, has been employed by several researchers to determine the resistance provided by various resistance features (Buikema & others, 1985; Outhwaite, Garman & Pashley, 1979; Davis & others, 1983).

If a pin is used to retain a restoration, the pin providing the greatest resistance and retention form should be used. The number of pins needed for any given clinical situation has not been determined; however, Buikema and others (1985) compared the resistance provided for complex amalgam restorations when the numbers and sizes of stainless steel pins (Whaledent TMS) were varied. They reported that the force required to cause failure increased as the number and size of pins increased. It would follow then that more of the titanium or heat-softened pins should be used to obtain the same resistance provided by the stainless steel or the titanium alloy pins.

It is interesting to note that the PPS pins provided significantly less resistance than the Minim pin, though the PPS pin was not significantly different from the Minim pin in retention. When the failure patterns of the pins were examined, it was noted that the PPS-retained amalgams fractured through the amalgam most frequently, possibly due to the head design of the PPS pin, which may concentrate stress and lead to amalgam fracture (Fig 5).

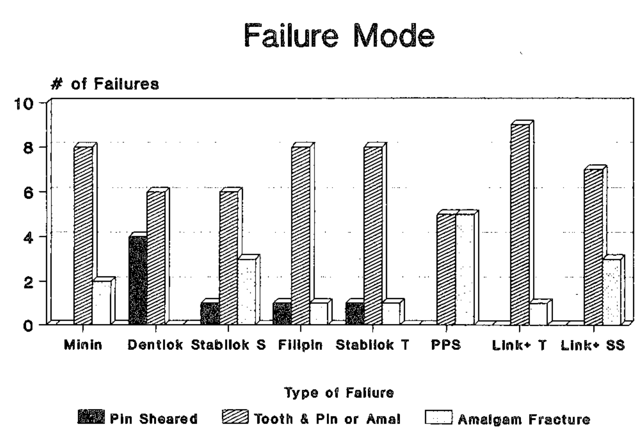

FIG 5. *Pin failure modes*

CONCLUSIONS

On the basis of this in vitro study, Whaledent stainless steel pins (Minim or Link-Plus) and titanium alloy pins made by Whaledent and Brasseler provided similar resistance. These five pins provided significantly more resistance than the other four pins. Brasseler's PPS and Whaledent's Minim pin systems provided excellent retention in dentin.

Pins made with the Ti-6A1-4V titanium alloy provided more resistance than pure titanium pins. Pins made from the titanium alloy may be the best alternative if titanium pins are to be used. Even though heat-softened stainless steel pins may be easier to insert than conventional stainless steel pins, the heat-treated pins provided less resistance.

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In Vivo Occlusal Wear of Posterior Composite Restorations

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Summary

The available and proposed methods for determining the in vivo occlusal wear values of classes 1 and 2 restorations made of resin-filled composite materials are critically reviewed. A methodology to be used to address the fundamental question of the link between the wear of the in vivo restorations and the relevant mechanical properties of the materials is outlined. For the four commercial formulations of composite materials which are currently "fully acceptable" to the American Dental Association (Estilux Posterior, Ful-Fil, Occlusin, and P-10), analysis of the published clinical wear values versus time data is performed.

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Introduction

There is a continuing dedicated search for creditable, affordable, and clinically acceptable alternatives to dental amalgams for use in classes 1 and 2 posterior teeth restorations. The most promising contenders to date are composite materials, which are composed of a resin, usually bis-phenol A glycidyl methacrylate, typically filled with particles or filaments of barium glass, strontium glass, or fumed silica, and cured with either visible light or a suitable chemical. These "posterior composites" have thus been the subject of numerous fundamental and clinical studies, particularly since 1985 (Lambrechts, Braem & Vanherle, 1985; Wilson & Phillips, 1989).

There is some ambivalence regarding the suitability of these materials: they have an array of attractive properties, but there is widespread uncertainty, in the practicing dental community, about the magnitude of the long-term in vivo occlusal wear values of posterior teeth restorations made of them. It is suggested here that this uncertainty is the one factor which mitigates against their being unreservedly recommended by dentists today. It is disappointing that, in spite of the fact that there is a large body of clinical data on the occlusal wear of these restorations (Table 2), this sense of uncertainty persists. It is argued here that this is because of two reasons. First, there is a dearth of critical appraisals of available and proposed occlusal wear determination methods. Second, there has been no systematic collation and statistical treatment of all the available clinical wear data on posterior restorations made of specified posterior composite(s).

It is therefore the main objective of the present work to correct these deficiencies in the literature. The first part of the work consists of a critique of methods of determining occlusal wear in these restorations. In the second part, an analytical treatment of available clinical data is presented with respect to four commercially available posterior composites only, namely Estilux Posterior, Ful-Fil, Occlusin, and P-10 (Table 1). Consideration is limited to these materials because, as of mid-1990, they are the only composites that are classified as "fully acceptable" by the American Dental Association.

Table 2. Summary of Clinical Evaluations of Classes 1 and 2 Restorations Made of Commercial Formulations of Dental Posterior Restorative Composite Materials, Selected Results 1985-1990

Materials	Clinical Trial Period (y)	References
Miradapt, Estic Microfill, and Adaptic	4	Lambrechts, Braem & Vanherle (1985)
Visio-Fil, Visio-Dispers, Nimetic, Nimetic-Dispers, and Visio-Radiopaque	5	Heymann & others (1987)
P-10, P-30, Ful-Fil, Occlusin, Visio-Fil, Visio-Dispers, Visio-Radiopaque, Nimetic, Nimetic-Dispers, Uvio-Fil, Nuva-Fil, Nuva-Fil PA, Estilux Posterior, and Profile	0.5-5	Roberson & others (1988)
P-30, Ful-Fil, Heliomolar, and Estilux Posterior	0.75	Dietschi, Ciucchi & Holz (1989)
Adaptic II, Heliomolar, Marathon, and P-30	3	Freilich & others (1990)

Critique of Occlusal Wear Determination Methods

In this section, the relative merits and demerits of the available or proposed methods for determining the occlusal wear of posterior restorations are presented. These methods may be classified into five groups.

In the first category is a method which enjoys the widest currency today and involves

Table 1. Suppliers of the Commercial Formulations

Supplier	Commercial Formulation
The L D Caulk Div, Dentsply International, Inc Milford, DE 19963	Ful-Fil Nuva-Fil Nuva-Fil PA
ESPE-Premier Sales Corp Norristown, PA 19404	Nimetic Nimetic-Dispers Uvio-Fil Visio-Dispers Visio-Fil Visio-Radiopaque
ICI Dental Division Macclesfield, England, and Coe Labs, Inc, Chicago, IL 60658	Occlusin
Johnson and Johnson Dental Products Co, East Windsor, NJ 08520	Adaptic Adaptic II Miradapt
Kulzer, Inc, Irvine, CA 92714	Estic Microfill Estilux Posterior
S S White Co, Harrow, Middlesex, England	Profile
Vivadent, Schaan, Liechtenstein	Heliomolar Compocap
3M Dental Products St Paul, MN 55144	Concise P-10 P-30
Kuraray, Osaka, Japan	Clearfil Posterior
SDI, Australia	Concept
Dental Fillings Ltd London, England	TD 71
Den-Mat Corp Santa Maria, CA 93456	Marathon

evaluation of the restoration by two or more clinicians (usually working in different dental establishments) using the United States Public Health Service scores (Cvar & Ryge, 1971). While this method has the attraction of being simple to use, it suffers from being exclusively evaluator-subjective in its estimation of occlusal wear values. In addition, this method has a serious technical limitation in that the boundary between the categories of wear are not discriminating enough in terms of discerning small early surface changes. This is a consequence of the difficulty of obtaining reliable intraoral landmarks from where the wear measurements may be made. One solution to this problem is to quantify the Alpha-to-Bravo transition as the point where the restoration has developed a step at the cavosurface margin of, say, 200 μm in height.

The methods in the second category are used to obtain indirect assessments of in vivo occlusal wear values through a comparison between die stone casts of restored teeth and a set of calibrated standards. Examples of such methods are those introduced by Goldberg and others (1981), Leinfelder (1983), Lugassy and Moffa (1985), and Leinfelder, Wilder and Teixeira (1986). The main drawbacks of these methods are the need for fabricating casts of the restorations, and the poor spatial resolution of such casts. Thus, the accuracy of the eventual wear estimates are no better than 100 μm. In a recent development, Adams and Wilding (1988) reported the use of a reflex microscope to determine the average depth lost in a restoration replicated on a lead cast. The attraction of this approach is that the reflex microscope allows such depth measurements to be made in three dimensions without photography.

In the third category are methods which may be used to give direct in vivo occlusal wear values. Some recent examples of such methods are presented in Table 3. As of mid-1990, most of these methods are untried and/or unproven in clinical evaluations. Thus, no comments can be made at this time regarding the accuracy of the wear measurements that may be obtained using them.

In the fourth category, use is made of artificial mouth machines. In such a machine, (a) the reaction between the simulated saliva solution and the test material, (b) the temperature, aeration, and humidity fluctuations, and (c) the forces and movements during mastication all closely resemble those found in vivo. On the whole, the results obtained using these machines have shown excellent correlation with clinical test data (Wilson, 1990). The drawbacks of these artificial mouths is that they are complex and very expensive, placing them beyond the reach of many researchers.

The methods in the fifth category may be employed to deduce in vivo wear values based on results from in vitro tests which have been carried out on restorations or test material specimens subjected to a combination of mechanical forces and aqueous media that closely match those experienced in vivo. Three recent examples of these methods are now given. In the first, a cylindrical stainless steel wheel containing samples of the test posterior composite placed in rectangular grooves is rotated clockwise against a second wheel in a bowl containing the third-body medium, namely suspensions in water of pulverized millet seed, of polymethylmethacrylate beads, mixtures of the two, and water alone (de Gee, Pallav & Davidson, 1986). In the second example, Leinfelder, Beaudreau and Mazer (1989) described a test device comprising a cyclic loading mechanism, a polyethylene tape-advancing system, a rapid-response thermocycling system, and a variable-speed power source for controlling the rate of specimen loading. The specimen is an extracted human molar in which a restoration made of the test posterior composite had been made on the occlusal surface. In the third example, Hengchang and others (1990) described a test machine which has a rubber

Table 3. Direct Methods of Measuring in Vivo Occlusal Wear from Posterior Restorations, Selected Examples

Method	Reference
Precision occlusal mapping	Roulet, Reich & Lutz (1983)
Laser interferometry	Williams & others (1983)
Three-dimensional digitalization of the occlusal surfaces	Delong & others (1988)
Digital micrometry	Lugassy, Moffa & Ellison (1988)
Profilometry	Söderholm & others (1988)

plate grinder and an abrasive material consisting of a slurry of fluorite powder and carboxymethyl cellulose mixed with water. The specimen, made of the test posterior composite, 10 mm in diameter and 6 mm in height, is made to move up and down against the grinder, with the slurry between the specimen and the grinder.

In spite of numerous difficulties in the construction and operation of devices that are utilized in this category of methods, they continue to be popular. Thus, it is germane to comment on two important aspects of studies that utilize these methods. First, the results are not generally given in terms of detailed statistical descriptors of the dependence of wear values or rates on relevant experimental variables, such as the contact stress or relative speeds of counter-rotating wheels, or the nature and/or concentration of the slurry (when these are used). Second, these methods have had only very limited success in terms of the closeness between predicted in vivo wear values or rates and actual in vivo results (Finger & Thiemann, 1987; Leinfelder & others, 1989). This poor track record is not surprising, given the complex nature of the in vivo wear processes.

An alternative approach to the prediction of in vivo wear values from in vitro test results involves the correlation of clinical wear results obtained on posterior restorations with the values of some relevant mechanical properties of posterior composites used in making these restorations. However, for two main reasons, even this approach has not been successful so far. First, in many studies only a few mechanical properties are used in the correlation exercise. Three such properties are hardness (Tillotson, Craig & Peyton, 1971), compressive deformation at fracture (Jørgensen, 1980), and fracture toughness, K_{IC} (Truong & Tyas, 1988). Second, the mechanical properties used in the correlation analysis are almost invariably obtained in air (for example, see Table 4 for values of K_{IC} of six posterior composites). One exception is the work by Truong and Tyas (1988) on the determination of K_{IC} of 11 posterior composites in dry, water-saturated, and ethanol/water (3:1 v/v) saturated states.

Outline of a New Approach

The proposed approach has the same philosophical foundation as the methodology described in the preceding paragraph while correcting the two deficiencies referred to. Thus, for a given posterior composite, a large collection of mechanical properties that are considered relevant (such as hardness, modulus of elasticity, transverse strength, percentage strain to fracture, modulus of resilience, fracture toughness, fatigue strength, and ultimate compressive strength) would be measured in an appropriate oral cavity medium (such as saliva and/or plaque solutions) following various times of exposure. In addition, the most reliable body of clinical occlusal wear data of the material would be assembled from as many sources as possible. An example of such a data-set is that generated by Wilson and others on Occlusin (Table 2). Finally, a detailed statistical analysis of the correlation between the two bodies of data (in vivo mechanical properties and clinical occlusal wear values) would be carried out. The results will show which individual or collection of material properties are most significantly correlated with clinical wear value for the composite under consideration. Once these "most significant correlation relations" are available for a large number of commercially available posterior composites, it will become evident which material properties are the most significant. These are defined as the ones that feature in the "most significant correlation relations" for each of the materials studied.

The results from the exercise outlined above will constitute a major contribution to a fuller evaluation of posterior composites. There are two reasons for this contention. First, one valid

Table 4. Fracture Toughness, K_{IC} of Seven Commercial Formulations of Dental Posterior Restorative Composite Materials, Measured in Ambient Air

Commercial Formulation	K_{IC} (MPa m)	References
Compocap	1.40	Lloyd & Iannetta (1982)
TD 71	1.15	
Concise	1.38	Pillar, Vowles & Williams (1987)
Clearfil Posterior	1.34	
Occlusin	1.55	
P-30	1.02	

and rapid screening method for these materials would have become available. In other words, prediction of the in vivo occlusal wear of posterior restorations made of such a material need only involve determination of the values of some relevant material properties in vitro. This proposed approach would thus obviate or reduce the need for clinical trials which are expensive, time-consuming, and produce results that many times are not amenable to full statistical analysis (McCann, 1990). Second (and perhaps more important), by identifying the main mechanical properties that affect the occlusal wear of a posterior composite, some light would have been shed on the significance of the various interactive phenomena and/or mechanisms which are relevant to the restoration wear process. Such phenomena include abrasive wear caused by occlusal contact, fatigue failure caused by cyclic stress from opposing teeth or restorations, and chemical effects on the resin and filler in the material. The methodology described herein thus has the potential to make contributions to both the fundamentals of the subject and the search for materials that would be used to make restorations with long, stable life and low wear rate in the oral environment. As Draughn, Bowen and Moffa (1985) have remarked, "... the central problem of insufficient clinical durability (of dental composite restorative materials) must be attacked at the basic research level. A principal need is to define the material parameters that control wear ... "

Analysis of Clinical Wear Results

A complete collection of the published clinical wear results on posterior restorations made of Estilux Posterior, Ful-Fil, Occlusin, and P-10 composite materials is given in Table 5. The best

Table 5. Clinical wear (in µm) of Classes 1 and 2 Posterior Restorations Made of Estilux Posterior, Ful-Fil, Occlusin, and P-10 Composite Materials

Material	Clinical Trial Period (y)							Reference
	0.5	1.0	2.0	3.0	4.0	5.0	8.0	
Estilux		56						Braem & others (1986)
Posterior	43	89	175	245				Braem & others (1987)
							152	Wilder, May & Leinfelder (1987)
		33	59					Tyas, Truong & Goldman (1989)
Ful-Fil	47	86	86	101				Leinfelder, Wilder & Teixeira (1986)
		57	104	145				Derkson & Richardson (1986)
				135	163	220		Boksman & others (1987)
	61	100	119	145		158		Sturdevant & others (1988)
		22	66					Tyas, Truong & Goldman (1989)
Occlusin	37	56						Leinfelder, Wilder & Teixeira (1986)
				70				Robinson, Rowe & Maberley (1988)
				76				Norman & others (1988)
				48	85	160		BSDR (1988)
						154		Wilson & others (1988)
					97			Wilson, Wilson & Smith (1988)
						129		Rowe (1989)
P-10			64[a]					Hörsted & Borup (1984)
	38		150					Lutz, Imfeld & Phillips (1985)
			40					Leidal, Solem & Rykke (1985)
				215				Mitchem & Gronas (1985)
		38						Braem & others (1986)
	81	111	140	149				Leinfelder, Wilder & Teixeira (1986)
	37	58	104	143				Braem & others (1987)
	72	108	121	145				Brunson & others (1989)
		20	38					Tyas, Truong & Goldman (1989)

[a]Clinical trial period = 2.5y

fit to these results is found to be of the form

Clinical wear value (μm) = aT^b (1)

where a and b are material constants, and T is the clinical trial period in years. The implication of this relationship is that the wear rate decreases with time up to an asymptotic value which may be regarded as the "equilibrium" or "steady-state" wear level.

The results, using the data in Table 5 and equation (1), are given in Figures 1-4. The values of the correlation coefficient, r, for the fit in the case of Estilux Posterior, Ful-Fil, Occlusin, and P-10, are 0.72, 0.78, 0.82, and 0.56 respectively. Although all the calculated fits are statistically significant at at least the 5% level, the moderate values of r (especially in the case of P-10) reflect the wide scatter in the reported clinical wear values. This, in turn, is a consequence of the lack of uniformity and/or consistency of the methods used by various clinicians to determine wear values. This observation highlights the urgent need for the introduction of a "standard" clinical wear determination method. The preceding remarks mean that the values of the coefficients a and b, in equation (1), obtained in the present work for each of the materials considered (Figs 1-4), should be taken as approximate. With this caveat, it is estimated that the wear values of restorations made of Estilux Posterior, Ful-Fil, Occlusin, and P-10 would be about 290, 290,

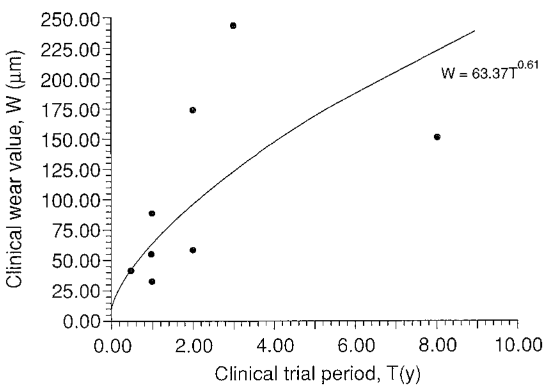

FIG 1. *The dependence of clinical wear of posterior restorations on clinical trial period for restorations made of Estilux Posterior composite material*

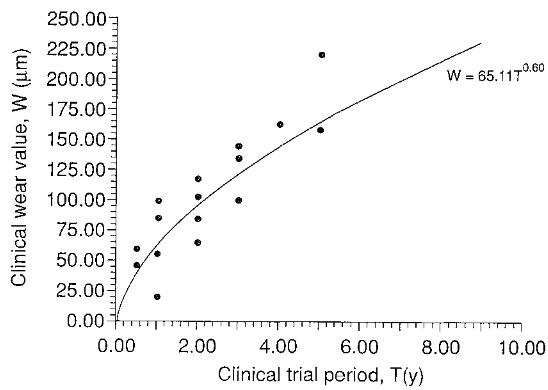

FIG 2. *The dependence of clinical wear of posterior restorations on clinical trial period for restorations made of Ful-Fil composite material*

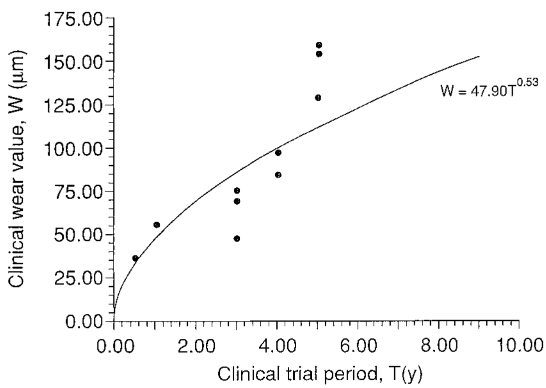

FIG 3. *The dependence of clinical wear of posterior restorations on clinical trial period for restorations made of Occlusin composite material*

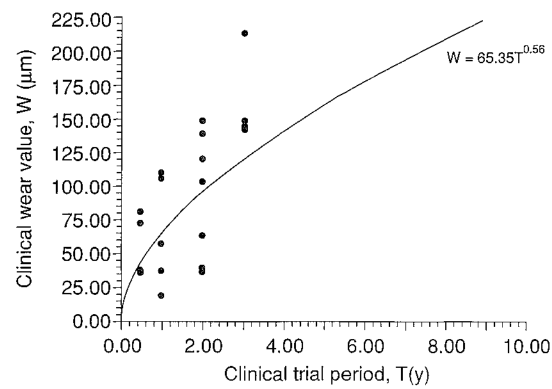

FIG 4. *The dependence of clinical wear of posterior restorations on clinical trial period for restorations made of P-10 composite material*

180, and 260 μm respectively, after 12 years' service in the oral environment. These values are comparable to those obtained from posterior restorations made of dental amalgam (Rowe, 1989) after this same time period, which is generally regarded as the median life of these restorations (Maryniak & Kaplan, 1986).

Conclusions

Three main conclusions emerge from the present review.

First, the most popular method of determining clinical wear of posterior restorations made of composite materials continues to be the one that is evaluator-specific, and hence subjective and inaccurate. This is disappointing, given the plethora of methods that have been suggested in recent years. Clinicians should be encouraged to use more of these methods in clinical trials, thereby contributing to the evaluation of these methods.

Second, the usual approach of attempting to predict clinical wear values from in vitro wear test results has so far proved unsuccessful, on the whole. An alternative approach, as outlined in the present work, would involve correlating clinical wear results with values of a collection of relevant mechanical properties obtained in a simulated oral medium. This would then indicate which of these material properties could be used as indices of wear resistance.

Third, it has been shown that the clinical wear value of restorations (made of any one of the four commercial formulations of posterior composites that are currently "fully acceptable" to the American Dental Association) bears a semilogarithmic relationship to the clinical test period. The "nominal long-term" wear rate of such restorations is estimated to be 21 $\pm$ 4 μm per year.

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The Effect of Cross-sectional Area on Transverse Strength of Amalgapin-retained Restorations

A J CERTOSIMO • R C HOUSE • M H ANDERSON

Summary

The transverse strength of large amalgam restorations retained by amalgapins of varying diameter and number was evaluated. Restorations with amalgapin retention fractured with greatest frequency parallel to the pulpal floor through the amalgapin at the amalgam-tooth interface. The findings indicate that the geometric configuration and number of amalgapins was of greater importance to the transverse strength of amalgapin-retained restorations than the total cross-sectional area.

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INTRODUCTION

Silver amalgam is retained in a cavity preparation through mechanical means. Providing auxiliary retention for extensive amalgam restorations can be technically challenging and time-consuming.

Markley (1958) discussed the use of cemented threaded pins for retention in large amalgam restorations. Subsequent development of numerous pin techniques has contributed significantly to amalgam retention. Concomitant mechanical and physical disadvantages have been noted. These include weakened restorations due to decreasing transverse and compressive strength (Wing, 1965; Going, 1966; Welk & Dilts, 1969; Going & others, 1968), cracking and crazing of tooth structure (Dilts & others, 1970; Standlee, Collard & Caputo, 1970), pulpal and periodontal involvement through perforation (Schuchard & Reed, 1973; Birtcil & Venton, 1976; Seng & others, 1980), fractured and lodged pin drills (Shavell, 1980), and additional time for placement (Shavell, 1980; Seng & others, 1980; Garman & others, 1983). Other authors have cast doubt on the validity of some of these purported disadvantages (Going & others, 1968).

In 1979 and 1982, Outhwaite and others published laboratory studies on an alternative technique of auxiliary (direct) retention that used dentinal slots prepared with an inverted-cone bur. Seng and others (1980) introduced the concept of slot depth by advocating individual

1.4 mm deep amalgam inserts. Shavell (1980) coined the term "amalgapin" and suggested a 1.5 - 3.0 mm deep channel prepared with a #1156, 1157, or 1158 round-nose bur. Research by Outhwaite and others (1979), Seng and others (1980), and Davis and others (1983) demonstrated no significant difference in retentive value between amalgapins and retentive pins. However, amalgapins offered the following advantages: they eliminate the purported decrease in compressive and transverse strength of the amalgam associated with pin techniques; no special equipment is required; no stresses are induced into dentin during slot/amalgapin placement (Seng & others, 1980; Garman & others, 1983; Outhwaite & others, 1979); they do not require the same amount of occlusal reduction that has been suggested for pins (Davis & others, 1983); there is decreased clinical time for placement (Shavell, 1980); and they are less costly. On the down side, volumetric considerations of tooth structure removed strongly favor retentive pins.

A review of the literature reveals studies on how the ultimate strength of amalgapin restorations is affected by depth (Shavell, 1980), number (Seng & others, 1980), condensation procedures (Garman & others, 1983), and beveling (Davis & others, 1983; Roddy & others, 1987). Plasmans, Welle and Vrijhoef (1986) reported a significant difference in tensile strength between restorations with amalgapins and restorations with the more retentive circumferential amalgam slot. Roddy and others (1987) examined the effect of channel depth and diameter on the transverse strength of the amalgapin. There are currently few experimental data relating the cross-sectional area of the amalgapin to the transverse strength of the amalgam restoration.

The purpose of this study was to determine the transverse strength of large amalgam restorations retained with amalgapins of different diameter and number.

METHODS AND MATERIALS

Fifty unrestored extracted human molars with similar crown dimensions and shape were stored in a humidor (95-100% relative humidity) at room temperature until used. The occlusal surface of each specimen was reduced with a conventional model trimmer using copious amounts of water and polished with a fine sandpaper disc (200-grit, L D Caulk Co, Milford, DE 19963) to a smooth, flat dentinal surface 3 mm above the cementoenamel junction. The roots of each tooth were notched for retention and embedded in an aluminum mounting ring (20 mm deep and 16 mm in diameter) filled with a standardized mix of polymethyl methacrylate (Plastodent, Inc, Bronx, NY 10461). A depression machined in the same location on all mounting rings ensured standardized placement of the mounting rings in a machined holding block used later in the experiment (Fig 1). A machined mounting jig was used to orient all teeth perpendicular to the long axis at a standardized height in the center of the mounting ring (Fig 2).

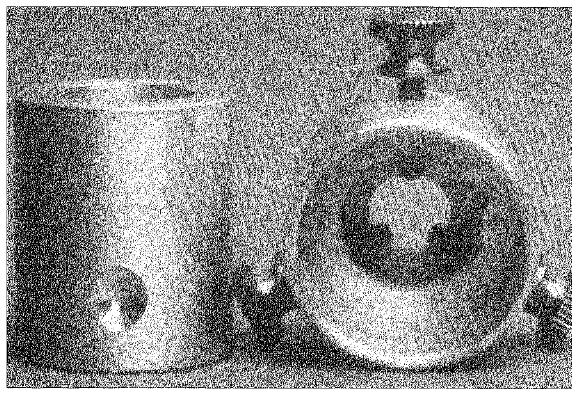

FIG 1. *Mounting rig to hold each specimen*

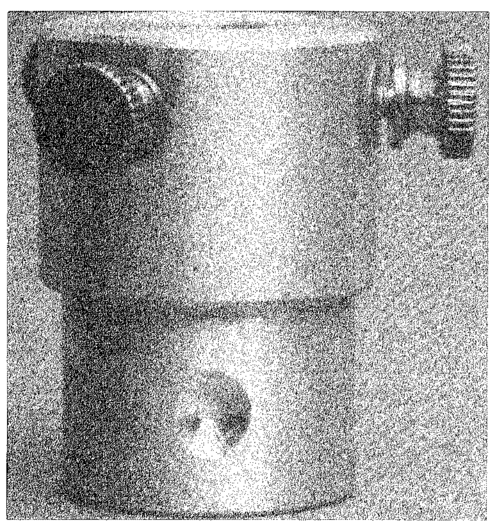

FIG 2. *Jig to orient teeth in mounting ring*

The 50 teeth were allocated to five groups of 10 teeth each according to the bur size and number of amalgapins used (Table 1). Amalgapin channels were prepared with #2 or #4 round burs (S S White Dental Products International, Philadelphia, PA 19102) modified to ensure a depth of 2.0 mm by adding an autopolymerizing resin sleeve stop to the bur. A customized paralleling device ensured amalgapin replication and minimized variance of amalgapin placement (Fig 3). Amalgapins were placed 1.5 mm from the external surface of the tooth, equidistant from each other, and at a 90° angle to the occlusal plane.

Table 1. Test Sample Grouping

Group	Number of amalgapins	Bur size/ diameter (mm)
1	1	2/1.0
2	2	2/1.0
3	3	2/1/0
4	4	2/1.0
5	3	4/1.4

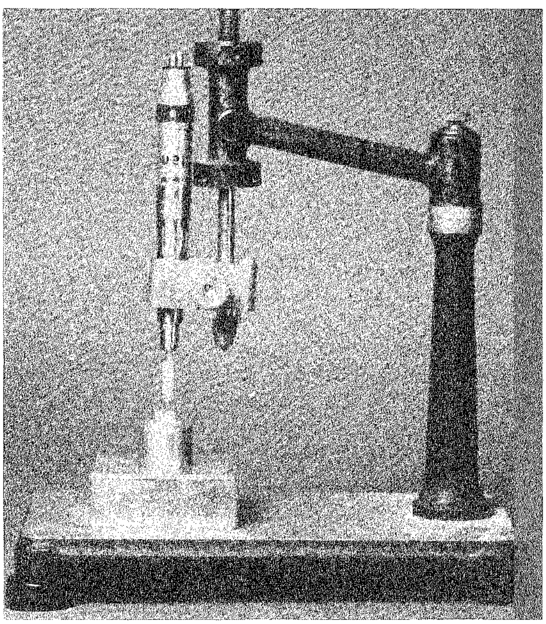

FIG 3. *Custom paralleling device*

Amalgapin entrances were not beveled (Roddy & others, 1987). Each bur was discarded after 10 amalgapin preparations. Two layers of copal varnish (Plastodent) were applied to all teeth. A tight-fitting copper matrix band was adapted, placed, and securely reinforced with red modeling compound. Silver amalgam (Tytin, Kerr/ Sybron, Romulus, MI 48174) was prepared according to the manufacturer's recommendations, triturated in an amalgamator (Vari-Mix III, L D Caulk Co) at M setting for nine seconds, and condensed into each restoration. The amalgapin channels were condensed by hand, and a mechanical condenser (Condensaire, Teledyne Densco, Denver, CO 80207) was used to complete the restoration. The copper matrix band was removed after 72 hours. The amalgam crowns were trimmed so that the amalgam extended 4 mm above the cavosurface margin. A 45° bevel, with a width of 1.0 mm, was placed at the occlusal-axial line angle of the amalgam (Fig 4).

An aluminum block was used to hold the cylindrical mounting ring. The holding block contained a spring-loaded ball that engaged the depression on the mounting ring so that all rings were consistently mounted. The samples were

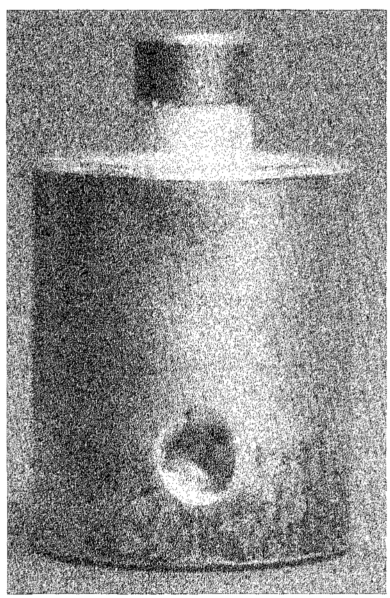

FIG 4. *Mounting ring and 4 mm amalgam restoration*

mounted on an inclined plane so that the load was applied at a 45° angle to the prepared surface (Fig 5). The samples were mounted on a testing instrument (United Calibration Corp, Garden Grove, CA 92642), and the test load was applied to each specimen at a constant crosshead speed of 0.5 mm/min until the specimen fractured (Fig 6). The highest kilogram force recorded before the first deflection of the recording pen toward the baseline was termed fracture force. Statistical analysis was performed with an analysis of variance (ANOVA) and Scheffé's test ($P = 0.01$). Multiple t-tests were used to compare adjacent groups for pin cross-sectional area, strength, and total area.

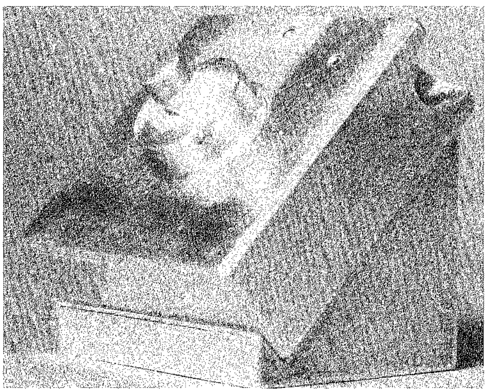

FIG 5. *Holding block on 45° inclined plane for sample orientation*

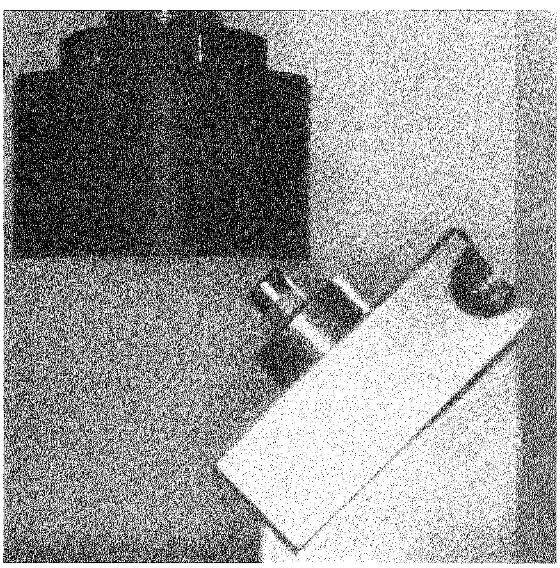

FIG 6. *Completed restoration oriented in the United testing instrument just before fracture*

To determine cross-sectional area, the fractured amalgapin-tooth margins of all experimental specimens were photographed at X10 at a constant focal distance with a stereomicroscope (Stereo Zoom 7, Bausch and Lomb, Rochester, NY 14604) equipped with a camera body (Pentax K-1000, Pentax Corp, Englewood, CO 80150). A machined millimeter rule was photographed at the same X10 setting and focal distance. The resulting slides were projected onto a grid paper, with 1 mm on the projected rule equalling 18.9 mm on the grid paper. The amalgapin outlines were traced onto the grid paper. The cross-sectional area of the amalgapins was quantified in square millimeters using a Bioquant System IV program and graphics tablet (R & M Biometrics, Inc, Nashville, TN 37209) with a personal computer (IBM Corporation, Armonk, NY 10504). To ensure reproducibility, 10 tracings of the same amalgapin were made, and the corresponding cross-sectional area was determined. The relationship of cross-sectional area to transverse strength of amalgapin-retained restorations was examined.

RESULTS

All restorations failed before the tooth fractured. The mean transverse strength of amalgapin-retained restorations, cross-sectional area, and the calculated force to fracture per unit area measurements are shown in Table 2. Statistical comparisons between mean strength values and cross-sectional area of the amalgapin groups showed each to be significantly different ($P < .01$, ANOVA) with the single exception that the cross-sectional area of groups 3 and 4 are not different. Scheffé's test was used for discrimination. Additionally, the force to fracture per unit area is significantly different between groups.

Generally, the strength of amalgapin-retained restorations increased progressively as the number of amalgapins and the total amalgapin surface area were increased. The exception to this finding was with group five, where the strength decreased slightly (145 ± 8 kg) with a reduction in the number of amalgapins, yet the amalgapin surface area was significantly increased compared to other groups.

Examination of the fractured amalgapins under the stereomicroscope showed the diameter of all amalgapins to be larger than that of the bur used in the preparation. All but four of the 130 amalgapins tested fractured parallel to the amalgapin-tooth interface. The aberrant fracture patterns occurring with the four separate samples of group four resembled triangular configurations, with the apex pointing toward the direction of force. These fractures occurred with amalgapins located farthest from the applied load and were 0.5-1.0 mm above the occlusal plane. Fractures like these have been attributed to creep of the amalgapin resulting from high fracture forces (Rupp, 1987).

Figure 7 depicts fracture force plotted against cross-sectional area of the amalgapins after fracture. Pearson's correlation coefficient demonstrated a high degree of correlation (0.773) between fracture force and cross-sectional area, with reliability at the 0.05 level.

Table 2. Transverse Strength of Amalgapin-Retained Restorations and Cross-Sectional Area Measurements

Group	Bur size/number of amalgapins	Force to fracture (Mean ± SD kg)*	Total amalgapin surface area after fracture (Mean ± SD mm)
1	2/1	76 ± 6	1.37 ± 0.11
2	2/2	105 ± 6	2.61 ± 0.29
3	2/3	122 ± 9	4.46 ± 0.49
4	2/4	183 ± 9	4.55 ± 0.56
5	4/3	145 ± 8	6.01 ± 0.66

*Values rounded to the nearest whole number

N = 10 per group

Each group is significantly different from the other ($P < 0.01$, ANOVA and Scheffé's test).

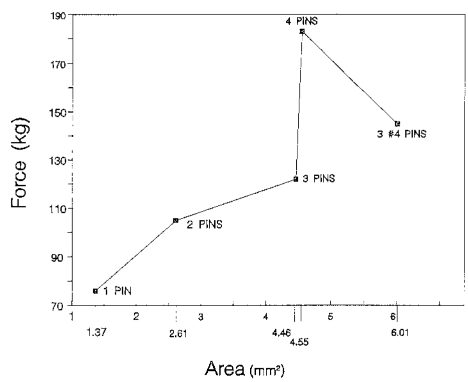

FIG 7. *Force of fracture vs cross-sectional area*

DISCUSSION

The fracture forces obtained in our study were within or above the physiologic range of masticatory forces reported by Helkimo and Ingervall (1978). Although the transverse load was directed at 45° to the occlusal surface to simulate occlusal forces, the masticatory environment is far more dynamic. It is assumed that all samples tested are likely to resist normal occlusal forces. This assumption is supported by Garman and others (1983) and Barney, Croll and Castaldi (1984) in studies examining the clinical success of pinless retention.

The correlation between the cumulative increase in cross-sectional area and fracture force is demonstrated in Figure 7. A critical surface area beyond which fracture force does not increase may exist, but was not identified. The decrease in fracture strength seen in group 5, the three #4 round-bur amalgapin group, suggests that cross-sectional area alone is not the determinant of fracture force. The fracture strength per cross-sectional area of this group was 145.4 kg/6.01 ± 0.66 mm^2 or 24.2 kg/mm^2. When compared to the four #2 round amalgapin group at 183.3 kg/4.55 ± 0.56 mm^2 or 40.3 kg/mm^2, it can be seen that there was a dramatic decrease in fracture strength even though surface area increased. These results support similar findings reported by Seng and others (1980) and suggest that the number of amalgapins is a more important determinant of fracture strength than cross-sectional area. However, there may be other explanations for these data.

An interesting pattern evolves when viewing the multiple-pin data on force to fracture per unit area. A three-pin configuration with force applied in the direction of the drawings in Table 1, regardless of pin size, is significantly weaker per unit area than a two- or four-pin configuration (see Table 1). Our pilot study data established that two pins configured as in Group 2 were stronger than when the pins were placed on the side opposite the applied force. The third pin in Groups 3 and 5 may be acting as a fulcrum or center of rotation in this system and cause the pins closest to applied force to fracture in tension. Without that pin no fulcrum is established, and a true shear force is being tested. Vectorial analysis of the load configuration from an applied load (L) results in two loads, one compressive and one in shear (Fig 8). Both resultant loads (L/2) have equal magnitude in this 45° system. Simple beam theory static analysis using a distribution load shows that groups 2 and 4 have equal stress over their pins. Groups 3 and 5 have the same distributed load, but the effective fulcrum areas differ by a factor of 2. The result is twice the stress on the side with the single pin. This predicts the results which show that the failure stress measured almost exactly one-half that of groups 2 and 4. This is a rather simplistic analysis of a complex problem, but the data support is good. Group 1 may have experienced stress due to the torsional load from rotation of the pin. Torsional shear stresses are generally higher than planar shear stress. Based on this model, there may be strong clinical implications for the geometric placement of amalgapins and possibly other pins as well. This area warrants further investigation.

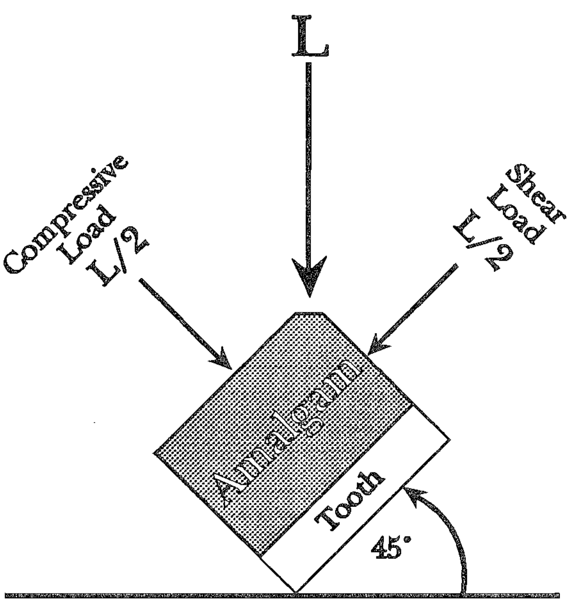

FIG 8. *Load distribution for test jig*

Despite all efforts to standardize the depth, diameter, and parallelism of amalgapin channel preparation with the use of a mounted jig, variations in cross-sectional area occurred, even within amalgapins of the same group (Table 1). Amalgapin diameters were measurably larger than the specified diameter of the burs used in their preparation. This observation has been described by Sturdevant (1985) as "runout" and is attributed to eccentricity of the chuck relative to the handpiece. It was also noted that the burs themselves varied in diameter within the same lot number. When observing the raw data retrospectively for cross-sectional area, it was obvious when a new and smaller-diameter bur was put into service. A series of smaller surface areas were recorded until the bur was replaced. By design, each group was prepared with a single bur. These variations help explain the lack of linearity in surface area increase between the three- and four-amalgapin groups.

CONCLUSION

As with all laboratory studies, the results of this study and the application of these data to a clinical situation should be interpreted carefully. Although the force was applied at a 45° angle to simulate a clinical situation as closely as possible, the forces encountered during mastication are cyclical in nature and much more dynamic. Furthermore, this study examined only one type of pinless amalgam retention, the amalgapin. Still, there are valuable lessons to be learned from these data. Within the limits of this study:

1. The transverse strength of an amalgapin-retained amalgam restoration is increased by increasing the number and cross-sectional area of the amalgapins;
2. More numerous, smaller amalgapins have greater retentive strength than fewer large amalgapins, even though they have less total surface area; and
3. The geometric configuration of the amalgapin placement and its relation to the direction of applied force may be significant. Further research is needed to clarify this observation.

Birtcil and Venton (1976) describe other pinless retentive forms such as slots, boxes, parallel walls, and grooves that when properly used in conjunction with amalgapins can augment the retention of the amalgapin-retained restoration. Determining the interrelationship of these pinless amalgam retentive forms, the geometric configuration, and how they can be combined to produce maximum retention of amalgam restorations is an area that invites further investigation.

ACKNOWLEDGMENT

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The opinions or assertions contained in this article are the private ones of the writers and are not to be construed as official or as reflecting the views of the Department of the Navy, Department of Defense, or the U S Government.

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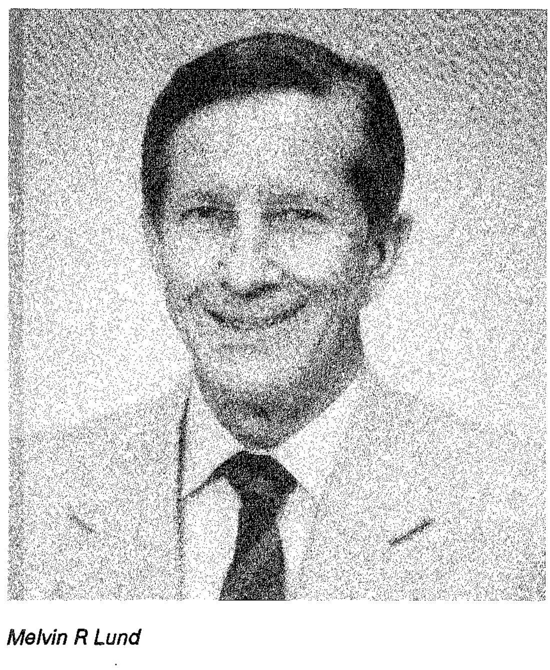
Award of Excellence

Occasionally one has the unique opportunity on behalf of the Operative Academy to praise and honor a fellow teacher such as Dr Melvin Lund. And this is a special privilege to me, as Mel is someone whose life and family have been closely interwoven with mine for several decades.

Mel was born 17 October 1922, near Siren, Wisconsin. His grade school years took place in a one-room school. His family later moved to the state of Washington and he finished high school at Auburn Academy near Seattle, then went on to take pre-dental training at Walla Walla College in southeastern Washington. Mel ended up in dental school at the University of Oregon, was graduated with OKU in 1946, and spent two years with the Army Dental Corps in Korea. Before he went to Korea, he and Marg got married; Marg stayed in Portland while he was overseas.

After five years of private practice in Camas, Washington, he chose dental education as a career. He sold out his practice and went to the University of Michigan for graduate education and an MS degree in operative dentistry. From there he moved to California, where he became one of the founding fathers of Loma Linda University School of Dentistry. As chairman of the Department of Restorative Dentistry, he watched the school grow to maturity. Under his leadership, Loma Linda quickly became prominent in the field of operative dentistry.

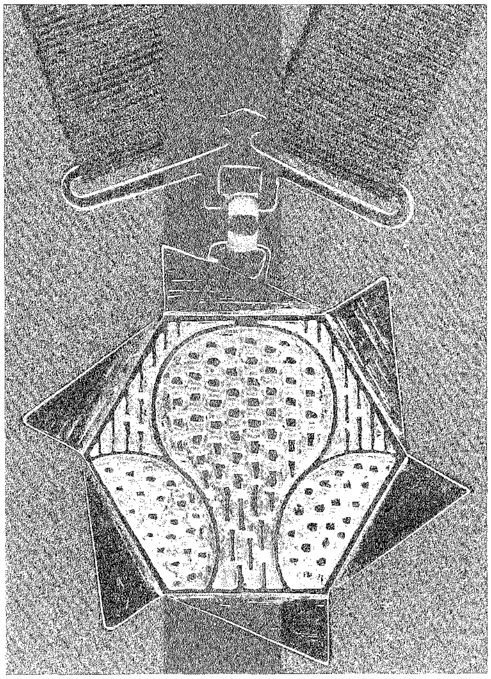


Melvin R Lund

In 1971 he and his family moved to Indiana, where he was invited to chair the Operative Department and graduate program. He has remained there for 20 years, though he has stepped down now from administrative responsibilities. Eventually he and Marg will probably retire to their country home 15 miles north of Indianapolis. They have three children: son Mark, who followed in his father's footsteps, practicing prosthodontics in Indianapolis; daughter Chris, who lives in Indianapolis; and daughter Kelley, who lives in Merced, California. Mel and Marg have nine grandchildren.

He has membership in some 15 scientific organizations, which include our beloved Academy of Operative Dentistry and our sister organization, the American Academy of Gold Foil Operators, which he has served as president. Mel also belongs to the American College of Dentists, and the American Academy of Restorative Dentistry. As most of us know, he is one of the founders of the American Board of Operative Dentistry. Furthermore, he has been an active member of the Lions Club for over 40 years.

Mel has authored or contributed to 11 textbooks and has written a multitude of scientific articles. He has given lectures and continuing education courses in Germany, Venezuela, Brazil, Mexico, Canada, China, Iceland, Spain, and Switzerland.



Award of Excellence medallion

So much for the glowing frills of his career. The things that make Pug such a great American are his humanitarian approach to life and his charisma as a teacher. He has the unique ability to inspire students and make them proud of their profession. His popularity as a teacher made itself known from the very beginning; he was always in demand as a class advisor. At Loma Linda University, he was made an honorary member of the class of 1961, having served as their class advisor for all four years. It is only natural that, in his 37 years of teaching, he has touched many lives.

Mel, we salute you, and this Award of Excellence you are receiving is not only for your leadership but for your tremendous service to operative dentistry as a teacher and humanitarian. Congratulations and best wishes from all of us!

LLOYD BAUM

DEPARTMENTS

Press Digest

Prevention of bacterial endocarditis. Recommendations by the American Heart Association. Dajani, A S, *Taubert, K A and 10 others (1990) *Journal of the American Medical Association* 264 2919-2922.

(American Heart Association, Office of Scientific Affairs, 7320 Greenville Ave, Dallas, TX 75231)

This article updates the 1984 recommendations for prophylactic coverage for bacterial endocarditis or endarteritis. The new recommendations incorporate new data and altered regimens. Perioperative administration remains the treatment of choice. Conditions which are more often associated with endocarditis are reviewed, as are the procedures likely to cause it. The American Heart Association recommends using chlorhexidine to reduce bacterial loads before invasive dental procedures. The standard regimen has changed to 3.0 g Amoxicillin one hour before a dental procedure, then 1.5 grams six hours after the initial dose. Alternative regimens are listed. This is a must-read for the practicing dentist.

Sensitivity of restored Class V abrasion/erosion lesions. *Powell, L V, Gordon, G E, Johnson, G H (1990) *Journal of the American Dental Association* 121 694-696.

(*University of Washington, School of Dentistry, Department of Restorative Dentistry SM-56, Seattle, WA 98195)

This was a study using three different treatments, with each patient receiving every treatment. The treatments were 1) Ketac-fil, 2) Scotchbond 2 + Silux, and 3) Vitrabond + Scotchbond 2 + Silux. Patients were rated at one week and six months for their perception of discomfort to air, mechanical stimulation, and hot (60 °C) and cold (5 °C) water. Glass-ionomer-lined composite restorations (group 3) significantly reduced sensitivity to air and hot and cold water, while a percentage of groups 1 and 2 were associated with increased sensitivity to air and cold water at six months.

Dental materials: 1989 literature review. R van Noort, editor (1990) *Journal of Dentistry* 18 327-352.

(University of Sheffield, School of Clinical Dentistry, Sheffield, England)

This is a comprehensive review of the published dental literature by 12 European academics. Materials reviewed are sealants, composites, glass ionomers, dentin bonding, amalgam, endodontic and impression materials, models and dies, casting alloys, ceramics, dentures, and implants. Complete bibliographic citations for referenced articles are presented.

Caries in the preschool child: aetiology. Davenport, E S (1990) *Journal of Dentistry* 18 300-303.

(The London Hospital Medical College, Department of Child Dental Health,Turner Street, London E1 1AD, United Kingdom)

This is a concise review of the carious process from the perspectives of patient factors, microflora, diet, other predisposing factors. The article references 34 pertinent articles. It is only one of nine articles on caries in this issue of *Journal of Dentistry*.

Letter

RESISTANCE TO FRACTURE: A Statistical Comment

Jagadish and Yogesh (Vol 15, pp 42-47) compared the fracture resistance of cavities prepared with silver amalgam, posterior composite, and glass cermet with intact teeth and teeth with prepared, unrestored cavities. They state emphatically in their summary, discussion, and conclusions that silver amalgam preparations are weaker than intact teeth. In their discussion, for example, they assert that the "clinician who uses silver amalgam should always be aware of the fact that whenever the cavity is cut and restored with silver amalgam, the tooth is no stronger than the intact tooth, rather it will be weaker..." (p 45).

While Jagadish and Yogesh do support conservative cavity design in the case of amalgam restorations, their repeated assertion that amalgam-restored teeth are weaker than intact teeth is actually unsupported by their experimental data. Their analysis of variance is relatively straightforward and not affected by unequal sample sizes for each treatment level. In addition, using both the procedures of Hartley (1940, 1950) and Cochran (1941), the assumption of homogeneous variances in each group is accepted. However, multiple comparisons using a conceptual unit of error rate of the collection of *k*-1 tests indicates that some of the differences assumed by Jagadish and Yogesh are not significant. Using Dunnett's (1955) multiple comparison test, the difference *d'* that a comparison must exceed to be significant at the .05 level is, in this study, 32.68. The comparison of silver amalgam and intact teeth is not reliable, according to this method. The ranking of fracture resistance for posterior composite, glass cermet, and silver amalgam does stand under this set of multiple comparisons.

Dunnett's multiple comparison procedure is less conservative than the more frequently used post-hoc Scheffé method when the treatments are compared to a control mean as in this study and could be recommended in future studies comparing various preparations with intact teeth (Kirk, 1968, pp 95-97). However, inclusion of prepared, unrestored teeth as a condition creates further conceptual and statistical problems. The prepared, unrestored condition cannot be intended as a true comparison condition. However, its inclusion increases the overall power of the *F* test in the analysis of variance and pairwise comparisons of means by spuriously increasing the sample size and degrees of freedom from error. This, of course, places even the rank ordering of posterior composite, glass cermet, and silver amalgam in question as a reliable interpretation of the study in question here.

We hope that future investigations of the effects of masticatory stresses on teeth can incorporate these statistical considerations.

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RESPONSE

The comments made in the note are well accepted and appreciated. The suggestions contained therein will be incorporated in similar future studies.

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