Clinical science: The influence of modification of cavity design on distribution of stresses in a restored molar

Document Version:
Publisher's PDF, also known as Version of Record (includes final page, issue and volume numbers)

Please check the document version of this publication:

• A submitted manuscript is the version of the article upon submission and before peer-review. There can be important differences between the submitted version and the official published version of record. People interested in the research are advised to contact the author for the final version of the publication, or visit the DOI to the publisher's website.
• The final author version and the galley proof are versions of the publication after peer review.
• The final published version features the final layout of the paper including the volume, issue and page numbers.

Link to publication

CLINICAL SCIENCE

The Influence of Modification of Cavity Design on Distribution of Stresses in a Restored Molar

J.H.P. de VREE, M.C.R.B. PETERS*, and A.J.M. PLASSCHAERT

Department of Cariology and Endodontology, University of Nijmegen, The Netherlands

In this study, two different cavity designs were compared from a mechanical point of view: (a) an axisymmetric model of a conventional class 1 cavity preparation and restoration; and (b) an axisymmetric model of a modified cavity design. The modified design was characterized by a cavo-surface angle (c.s.a.) of approximately 90° and a stepped cavity wall. Using a mathematical model, stresses were calculated by finite element analysis to compare the force distribution. It is concluded that the clinical superiority of the modified cavity design, with respect to the marginal breakdown of the amalgam restoration, can be supported by stress calculations.

Introduction.

Conventional preparations for amalgam often exhibit a cavo-surface angle (c.s.a.) of more than 90°. General agreement has been established that obtuse c.s.a., resulting in acute amalgam margin angles, are not desirable. Although careful manipulation of the amalgam carving could improve the margin angle, a cavity design alteration to decrease the c.s.a. is indicated. Recently, clinical studies have shown that a 90° c.s.a. exerts a positive influence on amalgam behavior. A cavity design with a c.s.a. of approximately 90° was introduced by Advokaat et al. (1979). Clinical results after three years (Akerboom et al., 1981) indicated a significant decrease in marginal breakdown when such a c.s.a. was applied. Morris and Heuer (1980) studied a cavity design with a reduced c.s.a. by creating a core in the enamel wall. It was concluded that the effects of different consistency and carving characteristics of the used alloys could be virtually eliminated with the modified margin.

To date, no investigations are known which have studied the influence of an alternative cavity design on the overall force distribution throughout the restored tooth. In the present study, a recently introduced model (Peters and Poort, 1983) was used to analyze the influence of cavity design on the mechanical behavior of a restored lower molar. In an idealized axisymmetric model, conventional and modified cavity preparations have been studied under two loading conditions, utilizing the finite element technique. Displacements and three-dimensional states of stress were examined and plotted throughout the model.

Materials and methods.

The method used is based on the mathematical modeling as described by Peters (1981). The characteristics of the modeling were as follows:

(1) An axisymmetric model of a human mandibular molar was constructed with contours and dimensions of the different areas (dentin, enamel, and pulp chamber), using average values as reported by Kraus et al. (1969). The base of the model was assumed to be fixed.

(2) The interface between the restoration and the surrounding biological materials had the possibility of movement, leading to gap formation.

(3) Local equilibrium and kinematic and dynamic boundary conditions resulted in a set of differential equations in the displacement field.

This set was solved by the numerical approximative method Finite Element Analysis (F.E.A.). This method has been validated in comparison with photoelastic stress analysis by Farah et al. (1973) and de Vree et al. (1983).

(4) All materials in the models were supposed to be linear, elastic, homogeneous, and isotropic continua.

(5) The relevant material properties (Young's modulus of elasticity and Poisson's ratio) were taken from the literature as gathered and evaluated by Peters (1981).

The conventional model (A) and the modified model (B) are represented in Fig. 1. To provide a fair comparison, a conventional cavity design with a c.s.a. of 90° was also analyzed (A'). Concerning the modified cavity design, the degree of tolerance of the c.s.a. was studied by analysis of a modified model with a c.s.a. of 85° (B') and 95° (B'').

The values for the Young's modulus assigned to the various structures were: (a) dentin, 1.3×10^4 N.mm^{-2}; (b) enamel, 5×10^4 N.mm^{-2}; and (c) amalgam, 2×10^4 N.mm^{-2}. Poisson's ratio was assumed to be 0.3 for all structures. The pulp was modeled as a void.

Two different load situations were considered (see Fig. 2):

X_1: Three equally large forces were applied on the restoration perpendicular to the outer contour; the total force was 500 N.

X_2: Three equally large forces were applied on the enamel perpendicular to the outer contour; the total force was also 500 N.

The models were divided into ring elements with triangular cross-sections (see Fig. 2). The displacement field within
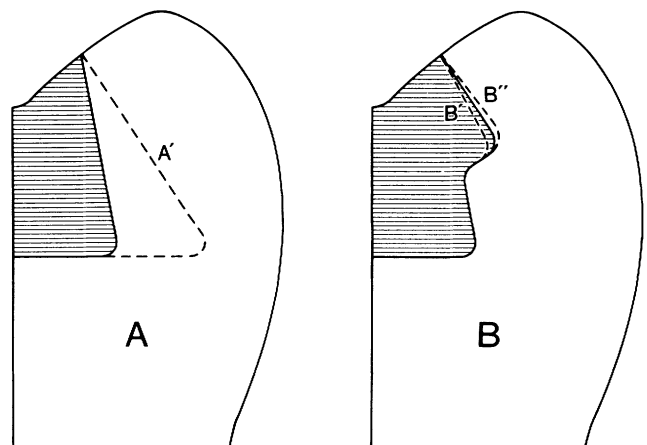

Fig. 1 – Conventional cavity designs (A and A') and modified cavity designs (B, B', and B'').

load x₁ load x₂

conventional model **(A)**

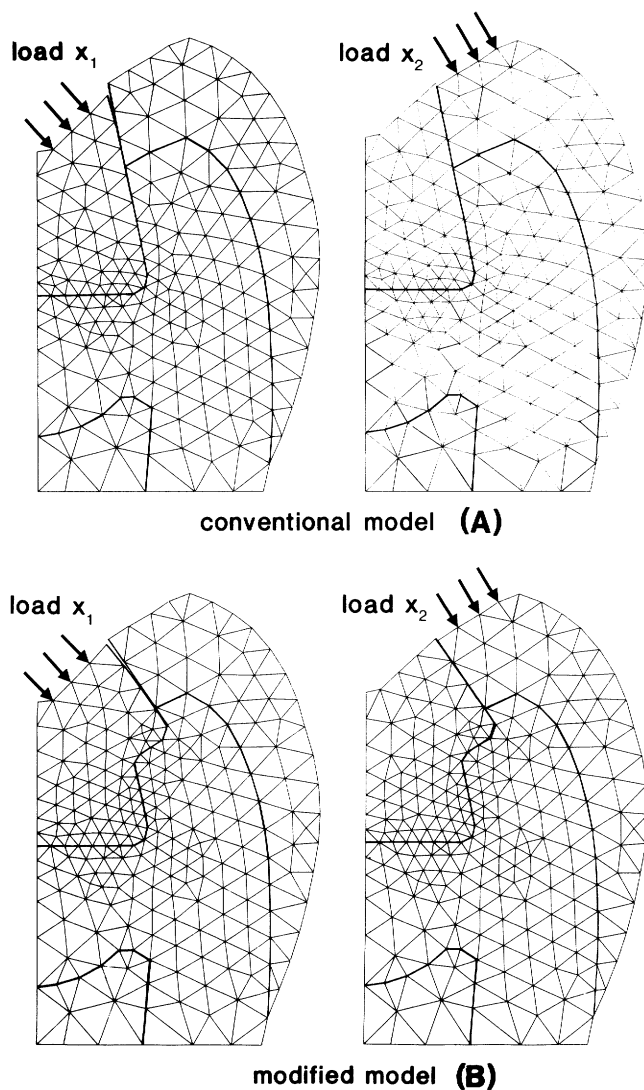load x₁ load x₂

modified model **(B)**

Fig. 2 – The deformed element meshes (enlargement 20x) of the axisymmetric models with indication of the loads X_1 and X_2 consisting of three equally large ringforces with a total force of 500 N.

each element was a linear function of the coordinates. The F.E.A. program Femsys* was used for the calculations.

For each node of the mesh, displacements were calculated, resulting in four stress components per node: the radial stress (sigr), the tangential stress (sigt), the axial stress (sigz), and the shear stress (taurz).

Subsequently, the principal stresses and their directions were derived from these stresses for both models and both load situations.

Finally, the so-called Maxwell Huber-Hencky-von Mises equivalent stresses were calculated. The equivalent stress, indicated in the Figs. as "sigeq", is widely accepted in mechanical engineering as a value for the seriousness of the state of stress caused by the combined stress components.

Results.

In order to interpret the large amount of data resulting from F.E.A. analysis, many plot figures are produced. Only

---

*Femsys is a F.E.A. program from the Eindhoven University of Technology, The Netherlands. This program runs on a Burroughs B7700ᴿ computer.

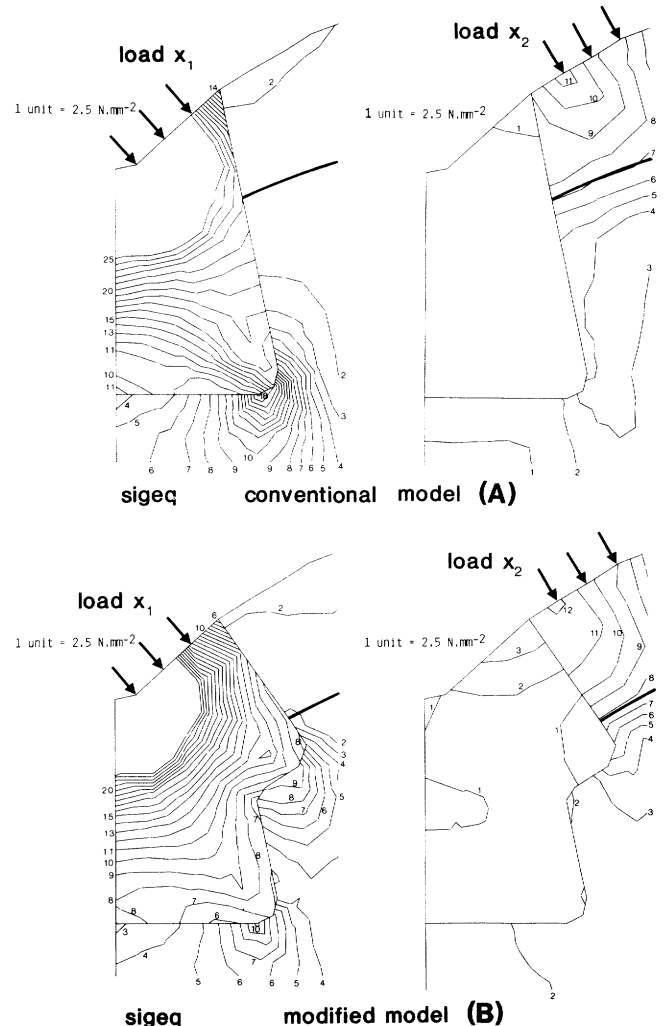sigeq conventional model **(A)**

sigeq modified model **(B)**

Fig. 3 – Levels of equivalent stress (sigeq) in the vicinity of the restoration in the conventional model (A) and the modified model (B). With loading condition X_1, the larger values in the neighborhood of the points of application of the loads are suppressed.

---

the most relevant ones are shown. In Fig. 2, plots are reproduced for both models and both load situations which represent strongly enlarged (20x) displacement fields (indicated by the displaced nodal points). In these plots, the formation of gaps can also be seen. Plots are produced showing lines connecting points with equal stress values for each of the four stress components, as well as for the equivalent stress values. In the plots with load X_1, the stresses in the immediate neighborhood of the loading site are suppressed. In Fig. 3, the equivalent stresses in the vicinity of the restorations are shown for both models and both loading conditions. In Fig. 4, the levels of equivalent stress are shown at load situation X_1 for the conventional model with a c.s.a. of 90° (model A').

Diagrams are drawn showing the distribution of stresses along specific lines. In Fig. 5, the diagrams of the distribution of stresses along a dotted line in the dentin (line PQ) near the bottom of the restoration are shown for loading condition X_1 and for both models. In Figs. 6 and 7, the diagrams of the distribution of stresses for loading condition X_1 along the indicated lines AB and CD, respectively, are reproduced. Evaluation of the three-dimensional stress situation in the modified models B, B', and B'' (c.s.a. of 90°, 85°, and 95°, respectively) for both loading conditions resulted in identical values and distribution of stresses.
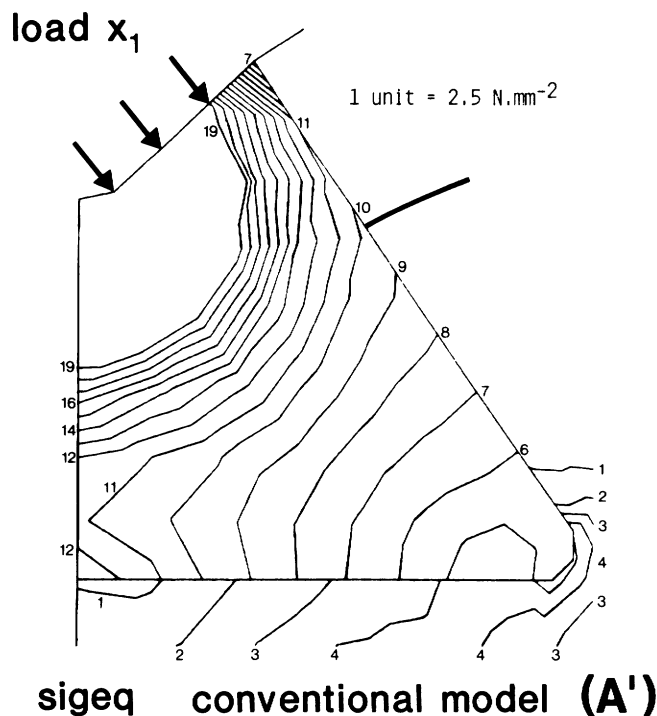
sigeq   conventional model (A')

Fig. 4 — Levels of equivalent stress (sigeq) in the vicinity of the restoration in the conventional design A' with loading condition X_1. The larger values in the neighborhood of thè points of application of the loads are suppressed.

Fig. 5 — Comparison of the stress components sigz, taurz, sigt, sigr, and sigeq along the line PQ for both models with loading condition X_1.

Discussion.

From the results in Fig. 3, it can be concluded that, under loading condition X_1, all stress components in the vicinity of the interface between restoration and surrounding biological materials are lower in the modified model as compared with those in the conventional model. Differences in stress values at the interface are up to a factor of two, in the amalgam as well as in the dentin. The enamel in this case is practically without stress, due to the occurrence of a gap between the restoration and the enamel, as shown in Fig. 2.

When taking into account the results of Fig. 4, one can draw the conclusion that the lower stress values in the vicinity of the amalgam margin are caused by the c.s.a. of $90°$. However, a cavity design as modeled in A' cannot be prepared in reality, because of the extreme loss of tissue near the axial floor and the undermining of the cusp. Therefore, the modified cavity design B would be a solution to this problem.

Considering the equivalent stresses in Figs. 5, 6, and 7, it was shown that high peak stresses in the vicinity of the inner line angles are caused mainly by the high axial stresses (sigz) and fairly high shear stresses (taurz) in this area. As shown in Fig. 3, loading condition X_2 results in only slight differences in equivalent stresses along the edges of the two types of restorations. The conventional model exhibits the lower stress values.

The principle of superposition permits the conclusion that, with any combination of loads X_1 and X_2, the modified model has lower stress concentrations along the edges of the restoration than does the conventional model. This is as true for the amalgam margin as for the dentin near the internal line angles.

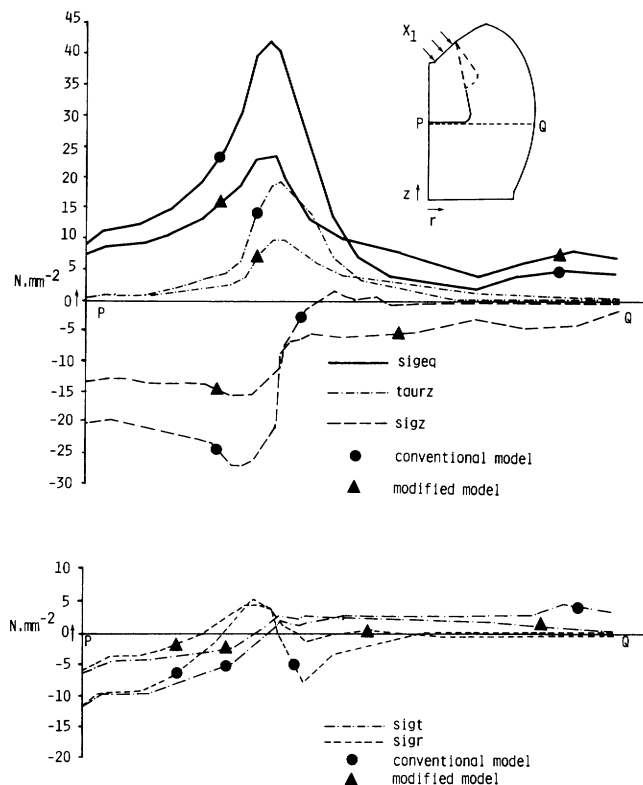Analysis of the models B, B', and B'' lead to the conclu-

sion that the $90°$ c.s.a. of the modified cavity design has a degree of tolerance of $\pm 5°$.

However, axisymmetric models do not exist in reality. The described modifications in cavity design can only be partially realized because of the various directions of the enamel rods at the occlusal surface.

The results of this study, nevertheless, give rise to the assumption that a c.s.a. of $90°$, and cavity walls which are built up in a step-wise manner, will result in a lower concentration of stresses and thereby in a decrease of the likelihood of marginal breakdown of amalgam restorations. It seems plausible that this assumption is true for a real three-dimensional model as well. In the near future, this hypothesis will be tested in a three-dimensional model of a premolar.

Conclusions.

The theoretical results obtained support the clinical experimental research as published by Akerboom *et al.* (1981) and Morris and Heuer (1980).

In comparison with a conventional cavity design, the modified design for a class I amalgam restoration results in lower stress values and less stress concentrations.

By preparing a c.s.a. of $90°$ $(\pm 5°)$, there is a decrease in the likelihood of marginal breakdown of amalgam restorations.

Fig. 6 – The stress components sigz, taurz, sigr, sigt, and sigeq along the line AB in the conventional model with loading condition X_1.
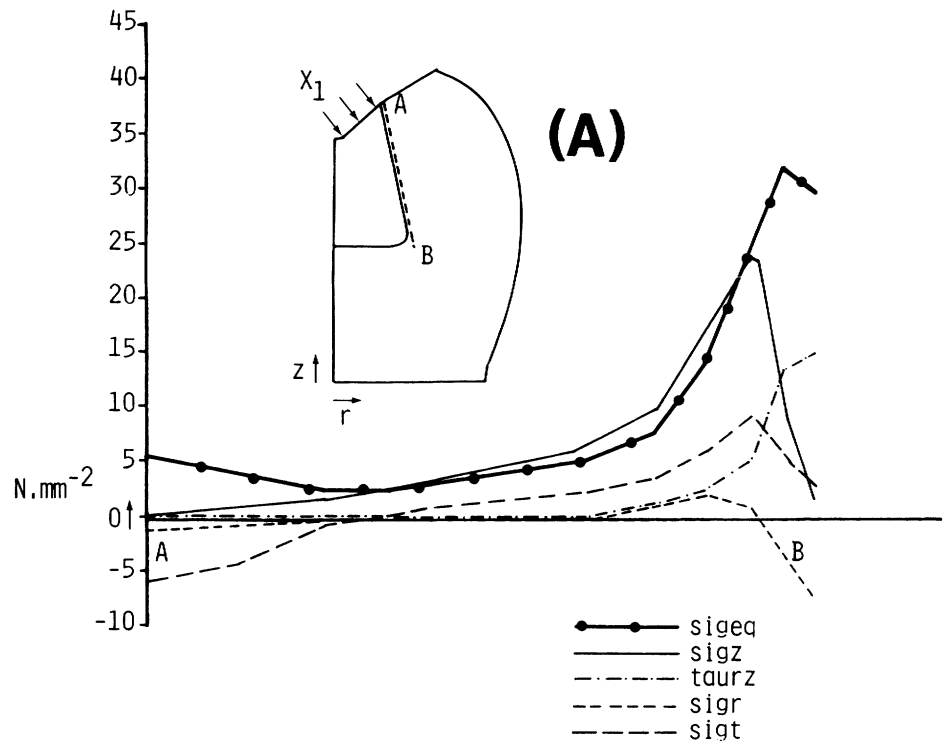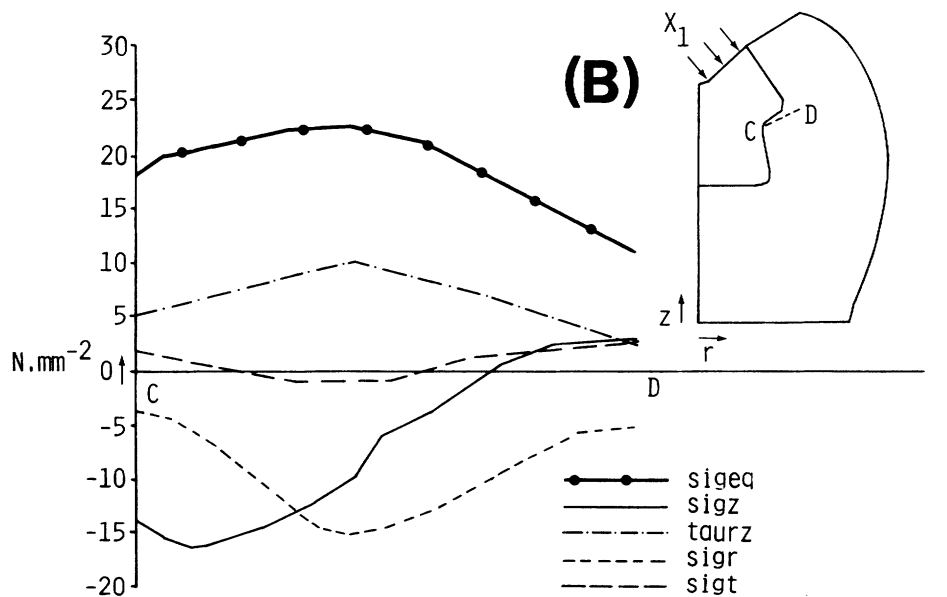

Fig. 7 – The stress components sigz, taurz, sigr, sigt, and sigeq along the line CD in the modified model with loading condition X_1.

REFERENCES

ADVOKAAT, J.G.A.; AKERBOOM, H.B.M.; van AMERONGEN, W.E.; BORGMEYER, P.J.; and van REENEN, G.J. (1979): The Influence of the Preparation on the Durability of the Amalgam Restoration, *J Dent Res* 58A:199.

AKERBOOM, H.B.M.; BORGMEYER, P.J.; ADVOKAAT, J.G.A.; and van REENEN, G.J. (1981): The Influence of the Preparation on the Marginal Breakdown of Amalgam Restorations. Results after 3 Years, *J Dent Res* 60A:520.

de VREE, J.H.P.; PETERS, M.C.R.B.; and PLASSCHAERT, A.J.M. (1983): A Comparison of Photoelastic and Finite Element Stress Analysis in Restored Tooth Structures, *J Oral Rehabil* 10:505-517.

FARAH, J.W.; CRAIG, R.G.; and SIKARSKIE, D.L. (1973): Photo-

elastic and Finite Element Stress Analysis of a Restored Axisymmetric First Molar, *J Biomechanics* 6:511-520.

KRAUS, B.S.; JORDAN, R.E.; and ABRAMS, L. (1969): **Dental Anatomy and Occlusion**, 7th ed. Baltimore: Williams and Wilkins Co., pp. 74-115.

MORRIS, C.F. and HEUER, G.A. (1980): Comparison of Amalgam Margin Angles in Conventional and Modified Cavity Preparations, *J Dent Res* 59A:380.

PETERS, M.C.R.B. (1981): Biomechanics of Cavity Preparation and Restoration of Human Teeth; Modeling and Analysis with the Finite Element Method. Ph.D. Dissertation, University of Nijmegen, The Netherlands, p. 304.

PETERS, M.C.R.B. and POORT, H.W. (1983): Biomechanical Stress Analysis of the Amalgam-Tooth Interface, *J Dent Res* 62:358-362.