Replacement reasons and service time of class-II amalgam restorations in relation to cavity design

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Jokstad A, Mjör IA. Replacement reasons and service time of class-II amalgam restorations in relation to cavity design. Acta Odontol Scand 1991;49:109–126. Oslo. ISSN 0001-6357.

Four hundred and sixty-eight class-II amalgam restorations were placed in 210 patients. The restorations had been inserted by seven Scandinavian dentists in their clinics, among their regularly attending patients. Impressions of the teeth with cavity preparations had been made, and epoxy casts fabricated. The designs and qualities of the cavities were assessed in accordance with an evaluation system for class-II cavities designed for use on models. The restorations were observed yearly and scored in accordance with the USPHS criteria. In case of replacement the reason was recorded, and the service time calculated. The restorations were observed throughout a period varying from 8 to 10 years. At the end of the observation period, 212 restorations had been lost owing to dropout patients, 68 restorations had been replaced, and 188 restorations remained functional. The commonest criteria for replacement were secondary caries ($n = 30$) and restoration bulk fractures ($n = 24$). Using univariate statistics and multivariate discriminant analyses, the time of service and the reasons for replacement were correlated with different clinical variables, including different indices for the dimensions and qualities of the cavity preparation. Several features of the cavity design could be associated with the service time of the restoration or with the reason for replacement, or both. Secondary caries was primarily associated with cavity design features gingivally on the proximal surface ($p < 0.001$). At the patient level the rate of secondary caries correlated with the total number of restorations placed during the observation period, irrespective of the quality of the cavosurface margins or the size of the cavity. Restoration bulk fractures could be related to cavities with narrow and deep occlusal parts, or deep proximal parts ($p < 0.001$). The discriminant functions predicted correctly between 70% and 93% of the actually failed restorations in the failure groups. The good prediction performance indicates that a linear discriminant analysis that includes aspects of the prepared cavity may be applied to predict the reasons for failure of restorations. ☐ *Cavity preparation; clinical study; discriminant analysis; operative dentistry; restoration survival*

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The optimal design of class-II cavities for amalgam restorations is constantly changing, as reflected by the variation in teaching concepts in dental schools (1). The changes incorporated into 'modern' cavity designs are primarily based on extrapolations from in vitro studies and less on results from clinical investigations (2, 3).

There are many reports from biophysical stress analyses of restored teeth, in which different aspects of the cavity designs have been associated with mechanical failures of the restoration or of the prepared tooth (4). Specific features of the cavity designs have also been related to restoration discrepancies in short-term longitudinal (5–9) or in cross-sectional (10–13) studies. Other investigators have associated specific features of the cavity design with adverse effects on the hard or soft tissues in cross-sectional studies (14–17) or in longitudinal studies (18–20). However, few of the alleged benefits of 'modern' cavity designs have been documented in long-term clinical trials, by correlating aspects of the cavity design to the prevalence and reasons for replacements or to the service time of the restorations (21).

The rate of restoration replacements vary among dentists (22), and treatment decisions depend on the operator's diagnostic abilities

(23), the treatment philosophy (24), and other reasons (25). On the other hand, dentists prepare cavities for restorations with variable morphologies, qualities, and dimensions (26, 27). It is therefore possible that the cavity preparation may also have influenced the clinical behavior of the restorations. It can be assumed that if such a relationship exists, an association between the service time, or the cause of replacement of the restoration, and the cavity design will appear after clinical service.

The first aim of the present study was to test the hypothesis that the service time and/or the replacement reasons for class-II amalgam restorations were associated with features of the cavity design. However, it has been shown that restoration failures have a multifactorial etiology. Therefore, it was considered necessary to relate the clinical performance to groups of predictor variables instead of measuring the association to each individual predictor variable. Consequently, the second aim of the study was to construct a model of predictor variables presumed to influence the clinical prognoses of the restorations.

Materials and methods

Seven general practitioners in Scandinavia placed 468 Mo, DO, and MOD restorations in 210 patients in their clinics between December 1979 and January 1983. The dentist worked in private practice, in public health practice, or in the school dental service. Each operator placed between 1 and 12 restorations in the teeth of a random selection of their regularly attending patients. The age of the patients varied from 8 years to 71 years at the time of insertion of the restorations. No criteria were given to the dentists for the selection of patients or for instructions on preparation techniques. The need for restorations could be due to primary caries or to replacement of failed restorations. The cavities are therefore considered to reflect the clinical situation in everyday dental practice.

A conventional amalgam alloy (Revalloy, SS White Ltd., U.K.) and four non-gamma-2 precapsulated alloys (Amalcap Non-gamma-2, Vivadent, Germany; Dispersalloy, Johnson & Johnson, USA; Indiloy Shofu Dental Corp., Japan; Tytin, SS White Ltd.) were randomly assigned to the teeth to be restored.

The descriptions of the dimensions and average qualities of the prepared cavities have been published (26, 27). The operators were instructed to take an impression (Xantopren blue and Optosil, Bayer, Leverkusen, Germany) of the tooth immediately before the insertion of the amalgam. Epoxy plastic casts (Durcupan, Fluka AG, Buchs, Switzerland) were made of the impressions. The casts were examined in a stereomicroscope (Spencer American Optical) at ×10 magnification, and the various features of the prepared cavities were measured or classified by using two-, three-, or four-point scales (28).

The patients have been recalled each year for examination of their dental status. Impressions were made of the specific restoration or restorations that were included in the present trial (Xantopren blue and Optosil, Bayer) at each recall during the first 5 years after the placement. The restorations placed by three of the operators were in addition photographed. The restorations have also been rated annually in accordance with the criteria of the USPHS index (29). If the restoration needed replacement, recordings were made of the date, the reason for replacement, and the location of the defect in the restoration. In case of bulk fractures the last photographs and impressions made before the fracture were examined for typical wear facets or deep sulci on the occlusal surface.

The patients were also grouped in accordance with the extent of restorative treatment received during the observation period, estimated by the incidence of restorations placed because of primary or secondary caries during the trial period. Zero to 0.5 new restorations per year was taken to indicate little treatment experience, medium treatment experience was defined as 0.5–2 restorations per year, and >2 is referred to as high treatment experience. This variable combined two factors, caries activity of the patient and treatment philosophy and skill of the dentist, which are two important prognostic variables that were difficult to assess separately. An attempt to reduce the effect of the possible different treatment philosophies among the participating dentists was done by instructing the dentists to score the restorations using the USPHS criteria (29) and to retrieve the failed restorations for further metallographic examinations (30). Further details of the materials and methods have been described previously (26, 27, 31, 32).

Statistics

The hypothesis that the reason for replacement was independent of the cavity design was assessed by using chi-square statistics applied on the cumulative prevalence of the different reasons for replacement and coded levels of the explanatory clinical variables. The second hypothesis, that the service time of the restorations was independent of the cavity design, was measured by Mann–Whitney tests for the explanatory variables with ordinal scales and Kruskal–Wallis tests for the explanatory variables with interval scales. The independence between the explanatory variables was assessed by computing the correlation matrix with all the cavity design variables included. The definitions and the description of the cavity design variables are presented in Table 1; the definitions of the other explanatory clinical variables have been described in another article (32). Further descriptions of the definitions of the cavity designs have been reported (26, 27).

The third hypothesis, that the clinical behavior could be related to groups of predictor variables rather than individual variables, was assessed by using linear discriminant analyses. The discriminant functions and the sensitivity and specificity of these functions were calculated with all explanatory variables included or only with cavity design variables included. The sensitivity of the model was measured as the probability that a failed restoration had been predicted to fail, while the specificity was measured as the probability that a restoration still in service had been predicted to survive the observation period. The percentage of correct classification predicted by each discriminant function was assessed by comparing it with the actual fate of the restorations during the 8- to 10-year observation period. The discriminant analyses were based on calculations of Wilks's lambda (U-test) for the restorations replaced because of caries, restoration bulk fractures, or tooth fractures and for the restorations remaining in function after the 8- to 10-year observation period. Initially, both forced entry and stepwise variable selection entry based on minimized overall Wilks's lambda were applied. Preliminary analyses showed that both algorithmsproduced nearly the same results. The stepwise variable selection entry was therefore chosen. The analyses were applied on three variants of the definition of the response variable, yielding a total of six discriminant analyses. The equalities of the group covariance matrices were calculated with Box's M test, and differences between the groups were shown by using a multivariate F statistic. The relative importance of the explanatory variables for the response variable was estimated by the size of their coefficient and correlation values in the discriminant function and for the prevalence of inclusion in the different discriminant functions.

Results

By May 1990 the observation period varied between 8 and 10 years for the different restorations. In this period 68 restorations had been replaced in 53 patients. Of these, 16 patients with 21 restorations dropped out of the study, after the restorations had been replaced. In addition, another 86 patients with 212 restorations dropped out of the study. The dropout of patients was mainly due to adolescents who discontinued the public school dental services because of their age. Twenty patients were dismissed from the trial owing to replacement of their restorations ($n = 25$ restorations). The remaining 22 of the 68 failed restorations had been replaced in 17 patients who remained in the study. In addition, 71 patients with 188 restorations continued throughout the study.

Table 1. List of cavity design variables and indication of statistical techniques used

1. Distance between buccal and lingual cusps measured in millimeters
2. Distance of the circumference of the proximal surface
3. Occlusal buccolingual mean width of the cavity
4. Occlusal buccolingual maximum width of the cavity
5. Occlusal buccolingual width over the axial wall
6. Occlusal buccolingual width at the dovetail (only MO and DO restorations)
   Discriminant analyses:
   Alt.1. Measured in millimeters, 3→8 mm
   Alt.2. Measured in proportion of cusp distance. Range, 0→99
   Chi-square and ANOVA:
   Proportion of inter-cusp distance: (0–33 = 1) (34–49 = 2) (50–66 = 3) (67–99 = 4)
7. Proximal buccolingual width at the isthmus
8. Proximal buccolingual width at the gingival margin
9. Proximal buccolingual width, average
   Discriminant analyses:
   Alt.1. Measured in millimeters. Range, 8→15 mm
   Alt.2. Measured in proportion of cusp distance. Range, 0→99
   Chi-square and ANOVA:
   Proportion of proximal circumference (0–33 = 1) (34–49 = 2) (50–66 = 3) (67–99 = 4)
10. Minimum distance from marginal ridge to the gingival margin
11. Maximum distance from marginal ridge to the gingival margin
12. Mean distance from marginal ridge to the gingival margin
    Discriminant analyses:
    Measured in millimeters. Range, 0–7 mm.
    Chi-square and ANOVA:
    Coded: (0–2 mm = 1) (3–4 mm = 2) (5–7 mm = 3)
13. Distance from the central groove of the occlusal surface to the pulpal wall
14. Same as above but over the pulpoaxial angle
15. Distance from the axial wall to the proximal surface
    Discriminant analyses:
    Measured in millimeters. Range, 0–5 mm
    Chi-square and ANOVA:
    Coded: (0–1.5 mm = 1) (2–2.5 mm = 2) (3–5 mm = 3)
16. Volume of the cavity
    Calculated from: (((depth_o+depth_i)/2) * ((cusp+i_cusp+d_cusp)/3)) + (((i_circ * g_circ)/2) * depth_p*ging)
    Discriminant analyses:
    Measured in square millimeters. Range, 11–317
    Chi-square and ANOVA:
    Coded: (11–100 = 1) (101–200 = 2) (>200 = 3)
17. Location of the cavosurface margin on the cusp incline
    Chi-square and ANOVA
    Code: R = follow fissures, S = some cusp incline removed, M = cusp removed < 2/3, T = cusp removed > 2/3, V = cusp fracture imminent
    Discriminant analyses:
    Coded: (R,S,M = 1) (T,V = 0)
18. Parts of enamel remaining <1 mm next to previous restorations
    Discriminant analyses, chi-square and ANOVA:
    Code 0: Slices < 1 mm remain, 1: Slices > 1 mm or not present

Sixty-two restorations had been replaced because of secondary caries or because of tooth or restoration bulk fractures, whereas three restorations were lost owing to marginal degradation and three because they were included in larger restorations. All secondary caries had developed on the proximal surfaces ($n = 30$). The restoration bulk fractures occurred either along the buccoproximal margin ($n = 4$) or occlusally across the isthmus ($n = 20$). In four teeth typical wear facets on the occlusal surface was seen on the last photograph or on the impression made before the bulk fracture.

Table 1. *Cont.*

19. Deep fissures extending from the cavosurface angle
    Chi-square and ANOVA
    Code ++ = fissures removed or not present, BO = buccal fissure present,
    LO = lingual fissure present, PO = proximal fissure present
    Discriminant analyses:
    Coded: (++ = 1) (BO,LO,PO = 0)
20. Distance from the proximal surface to the medial wall of dovetail
    Discriminant analyses, chi-square and ANOVA
    Code 1 = distinctive dovetail, 0 = no dovetail
21. Morphology of the gingival floor
    Chi-square and ANOVA
    Code A = distinctive lock, F = flat, T = undermined enamel or chamfer
    Discriminant analyses:
    Coded: (A = 1) (F = 2) (T = 0)
22. Bevel of the axiopulpal line angle
    Chi-square and ANOVA:
    Code A = bevel smooth, T = no beveling
    Discriminant analyses:
    Coded: (A = 1) (T = 0)
23. Location of acute internal line angles
    Chi-square and ANOVA:
    Code: AA = smooth, PF = pulpofacial, PA = pulpoproximal,
    PL = pulpolingual, GL = gingivolingual, GF = gingivofacial
    Discriminant analyses:
    Coded: (AA = 1) (PF,PA,PL,GL,GF = 0)
24. Acuteness of external gingivoproximal line angle
    Discriminant analyses, chi-square and ANOVA:
    Coded: 0 = 45–60, 1 = 45–60/90, 2 = 60–70, 3 = 60–70/90, 4 = 70–80,
    5 = 70–80/80–90, 6 = 70–80/90, 7 = 80–90, 8 = 90/90, 9 = 90
25. Areas with cavosurface angles < 90°
    Chi-square and ANOVA:
    ++ = no areas, OB = occlusal buccal, OP = occlusal proximal, OL = occlusal
    lingual, PB = proximal buccal, GP = gingivoproximal, PL = proximal lingual
    Discriminant analyses:
    Coded: (++ = 1) (OB,OP,OL = 1) (PB,PL,GP = 0)
26. Areas with changing cavosurface angles (facets)
    Chi-square and ANOVA:
    R = walls smooth and well defined, S = ragged in isolated areas, M = ragged
    over larger areas, T = poor definition, V = cavity form and walls impossible to differentiate
    Discriminant analyses:
    Coded: (R,S,M = 1) (T,V = 0)

7\. Degree of occlusal discernible walls

28\. Same as above but for the proximal part of the cavity
    Tooth inspected directly occlusally for converging, or diverging walls
    Chi-square and ANOVA:
    A = retention conspicuous, T = retention absent in one or more areas,
    V = retention absent or result in gross loss of tissue
    Discriminant analyses:
    Coded: (A = 1) (T,V = 0)

There were no restorations with deeply carved sulci on the occlusal surface in the bulk fracture group. Eight restorations were replaced owing to fracture of the tooth. The cumulative number of failed restorations over time is shown in Fig. 1.

The 212 restorations lost because patients dropped out of the study showed, as a group, different mean values for some of the cavity design variables compared with the other restorations. This possibly introduced a bias in the measurements of the association between the explanatory clinical variables and the clinical behavior of the restorations.

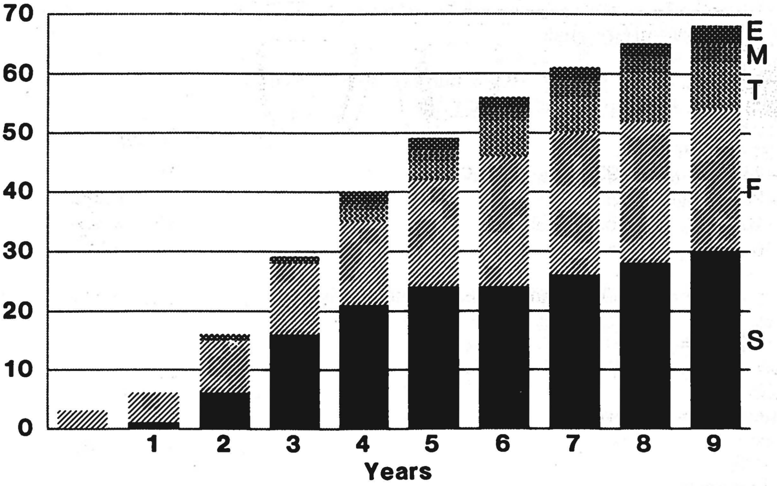
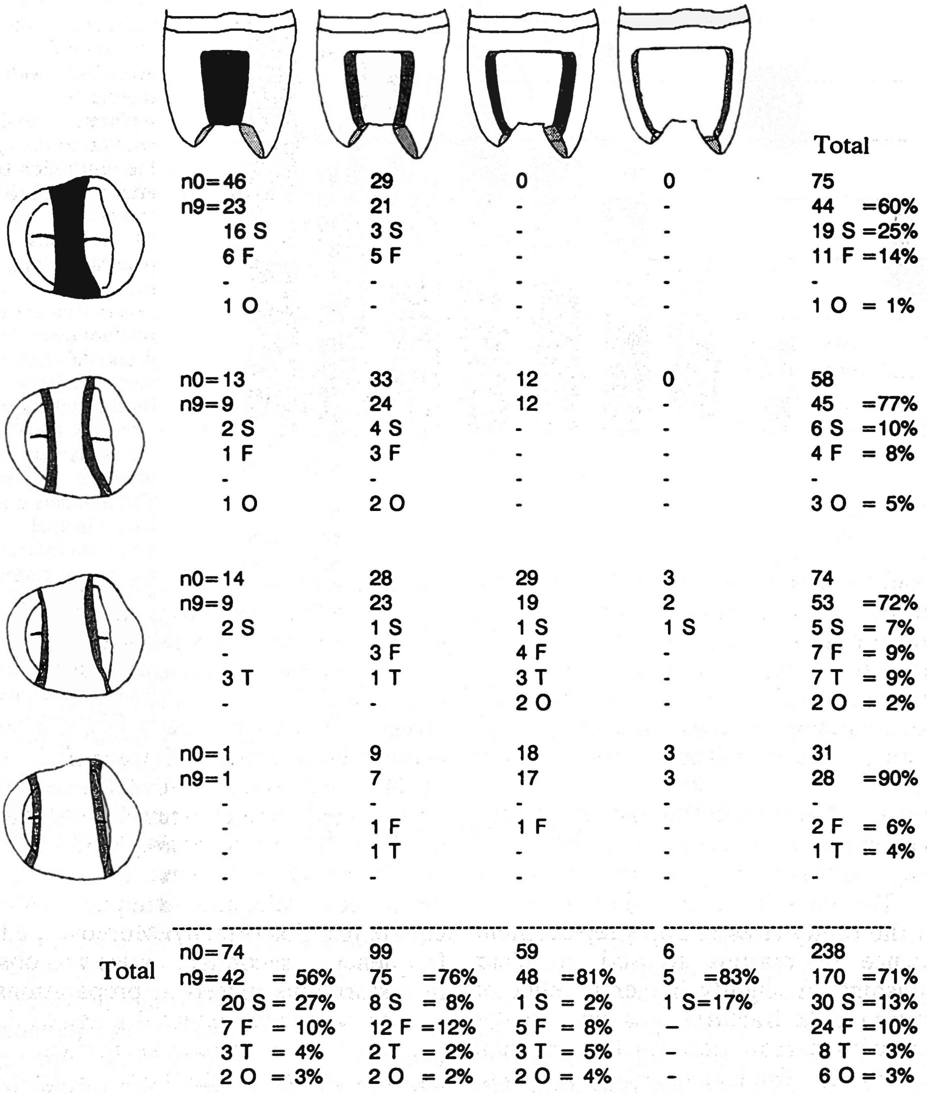


Fig. 1. Cumulative number of replaced restorations in accordance with the reasons for replacement and in relation to the age of the restoration ($n = 68$ after 9 years). S = secondary caries ($n = 30$ after 9 years), F = restoration bulk fracture ($n = 24$ after 9 years), T = tooth fracture ($n = 8$ after 9 years), M = restoration margin fracture ($n = 3$ after 9 years), E = extended into larger restoration ($n = 3$ after 9 years).

To avoid the potential bias, only the cavity preparations of the restorations that survived the entire observation period ($n = 188$), in addition to the replaced restorations ($n = 68$), were included in the statistical analyses. Eighteen models were of inferior quality, preventing all statistics from being computed.

Cross-tabulations between the reasons for replacement and different quantitative cavity design variables are presented in Figs. 2 and 3. The data from the tabulations between the cavity sizes and the replacement prevalence or reasons showed no clear relationships. A slightly higher number of restoration bulk fractures was seen in the cavities with narrow occlusal buccolingual widths (Fig. 2). The incidence was also high in the cavities with deep proximal parts (Fig. 3) and low in the cavities with shallow occlusal parts. Secondary caries prevailed in the cavities with restricted external occlusal outline or proximal outline (Fig. 2). All tooth fractures ($n = 8$) occurred in teeth with cavities with occlusal buccolingual widths greater than half of the intercuspal distance (Fig. 2). With regard to the cervicoaxial location of the gingival margin on the proximal surface, no association could be found with the prevalence or any specific reason for replacement.

Only a few of the qualitative aspects of the cavities could be associated with the replacement reasons and prevalence. The presence of undermined enamel could be related to secondary caries, depending on the location of the undermined enamel. Thus, while 13 of 55, or 24%, caries were observed in the group with undermined enamel along the axial walls on the proximal surface, only 2 of 48 = 4% were seen in the group with undermined enamel along the gingival margin (Fig. 4). The secondary caries incidence was lower when the cavosurface angle was evaluated as adequate, compared with inadequate margins (Fig. 4). Moreover, a higher frequency of secondary caries was observed in restorations placed in preparations with one or two acute external gingivoaxial line angles on the proximal surfaces. Deep figures connected with the cavosurface angle occlusally ($n = 11$) and enamel slices of less than 1 mm remaining between the restoration and other restorations or fissures did not influence the clinical behavior of the restoration. The internal features of the cavity preparations, such as rounding of the occlusal internal line angles, beveling of the axiopulpal line angle, and placement of proximal locks, could not be associated with any specific reason for replacement or with longer service time of the restorations. The occlusal retention—that is, the convergence or divergence of the cavity walls—could not be associated with the prevalence or reasons

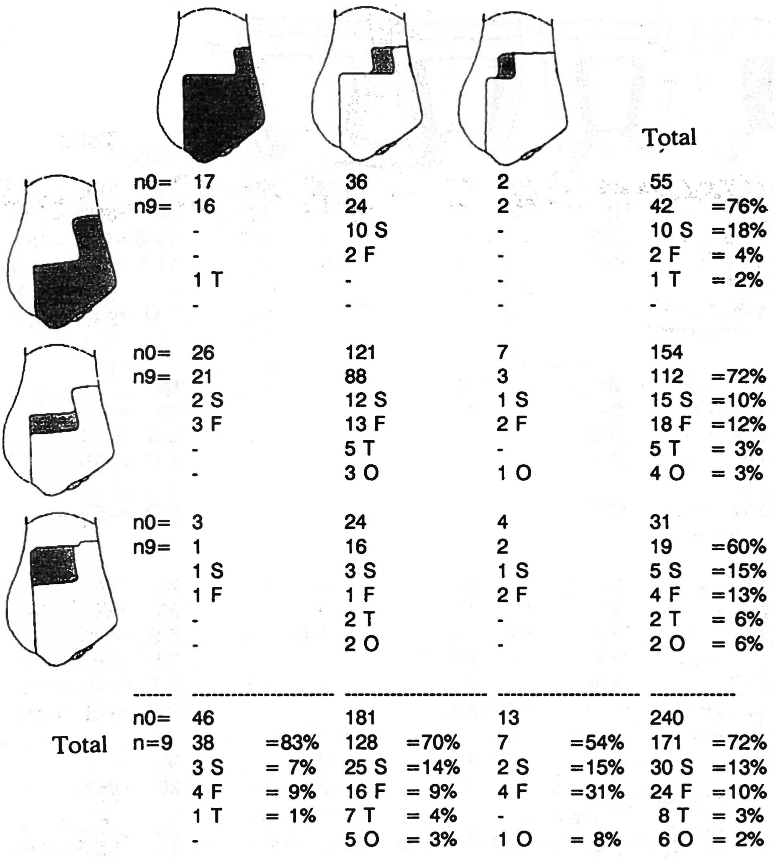


					Total
	n0=46	29	0	0	75
	n9=23	21	-	-	44 =60%
	16 S	3 S	-	-	19 S =25%
	6 F	5 F	-	-	11 F =14%
	-	-	-	-	-
	1 O	-	-	-	1 O = 1%
	n0=13	33	12	0	58
	n9=9	24	12	-	45 =77%
	2 S	4 S	-	-	6 S =10%
	1 F	3 F	-	-	4 F = 8%
	-	-	-	-	-
	1 O	2 O	-	-	3 O = 5%
	n0=14	28	29	3	74
	n9=9	23	19	2	53 =72%
	2 S	1 S	1 S	1 S	5 S = 7%
	-	3 F	4 F	-	7 F = 9%
	3 T	1 T	3 T	-	7 T = 9%
	-	-	2 O	-	2 O = 2%
	n0=1	9	18	3	31
	n9=1	7	17	3	28 =90%
	-	-	-	-	-
	-	1 F	1 F	-	2 F = 6%
	-	1 T	-	-	1 T = 4%
	-	-	-	-	-
	n0=74	99	59	6	238
Total	n9=42 = 56%	75 =76%	48 =81%	5 =83%	170 =71%
	20 S = 27%	8 S = 8%	1 S = 2%	1 S=17%	30 S =13%
	7 F = 10%	12 F =12%	5 F = 8%	–	24 F =10%
	3 T = 4%	2 T = 2%	3 T = 5%	-	8 T = 3%
	2 O = 3%	2 O = 2%	2 O = 4%	-	6 O = 3%

Fig. 2. Cross-tabulation of the prevalence and reasons for replacement of 238 class-II amalgam restorations, categorized by the buccolingual occlusal (vertical diagrams) and proximal (horizontal diagrams) cavity width. The dark areas indicate the limits between the different categories. The numbers and letters in each subgroup indicate the number of restorations at base line (n0), the number in service at the end of the observation period (n9), and the number of replacements because of secondary caries (S), restoration bulk fracture (F), tooth fracture (T), or other reasons (O).

for replacements, whereas convergence of the proximal cavity walls showed a slightly higher prevalence of secondary caries compared with the diverging or parallel walls (Fig. 5).

Several variables of the cavity design could be associated with both the service time and reason for replacement (Table 2). Significant differences between the subgroups were observed for the quantitative variables: the cavity volume, the occlusal and proximal buccolingual widths, and the axiogingival



								Total	
	n0=	17		36		2		55	
	n9=	16		24		2		42	=76%
		-		10 S		-		10 S	=18%
		-		2 F		-		2 F	= 4%
		1 T		-		-		1 T	= 2%
		-		-		-		-	
	n0=	26		121		7		154	
	n9=	21		88		3		112	=72%
		2 S		12 S		1 S		15 S	=10%
		3 F		13 F		2 F		18 F	=12%
		-		5 T		-		5 T	= 3%
		-		3 O		1 O		4 O	= 3%
	n0=	3		24		4		31	
	n9=	1		16		2		19	=60%
		1 S		3 S		1 S		5 S	=15%
		1 F		1 F		2 F		4 F	=13%
		-		2 T		-		2 T	= 6%
		-		2 O		-		2 O	= 6%
	n0=	46		181		13		240	
Total	n=9	38	=83%	128	=70%	7	=54%	171	=72%
		3 S	= 7%	25 S	=14%	2 S	=15%	30 S	=13%
		4 F	= 9%	16 F	= 9%	4 F	=31%	24 F	=10%
		1 T	= 1%	7 T	= 4%	-		8 T	= 3%
		-		5 O	= 3%	1 O	= 8%	6 O	= 2%

Fig. 3. Cross-tabulation of the prevalence and reasons for replacement of 240 class-II amalgam restorations, categorized by the occlusal depth (vertical diagrams), and proximal depth (horizontal diagrams). The dark areas indicate the limits between the different categories. The numbers and letters in each subgroup indicate the number of restorations at base line (n0), the number in service at the end of the observation period (n9), and the number of replacements because of secondary caries (S), restoration bulk fracture (F), tooth fracture (T), or other reasons (O).

location of the margin on the proximal surface. Significant qualitative variables were the quality and the location on the cusp incline of the cavosurface margin and the acuteness of the external gingivoaxial line angle ($p < 0.05$). The mean surface time was also influenced by the degree of occlusal and proximal convergence of the cavity walls, whereas the occlusal cavity depth could be related to the reasons for replacements ($p < 0.05$). However, the cross-correlation between the cavity design variables showed that the explanatory variables were strongly interrelated (Table 3). Conclusive statements about the univariate relationships are thus precluded.

Before the first discriminant analysis the group means of the different restoration groups were examined and analyzed for any differences (Table 4). In general, the one-way analysis of the group means identified the same cavity design variables that were identified by the two other univariate statistics. In the first analysis the replaced restorations were pooled into one group, whereas the remaining restorations formed the second group. The explanatory clinical variables exerting the strongest influence on the calculations of the discrimination scores were the patient's age and treatment experience, the operator, and various indices for the dimension of the cavities and of the cavosurface angle ($p < 0.001$). The association with explanatory variables not related to the dimensions and qualities of the cavity preparations have been described in another article (32). When only the cavity design variables were included in the functions, the explanatory variables with the greatest influence on the calculation of the dis-

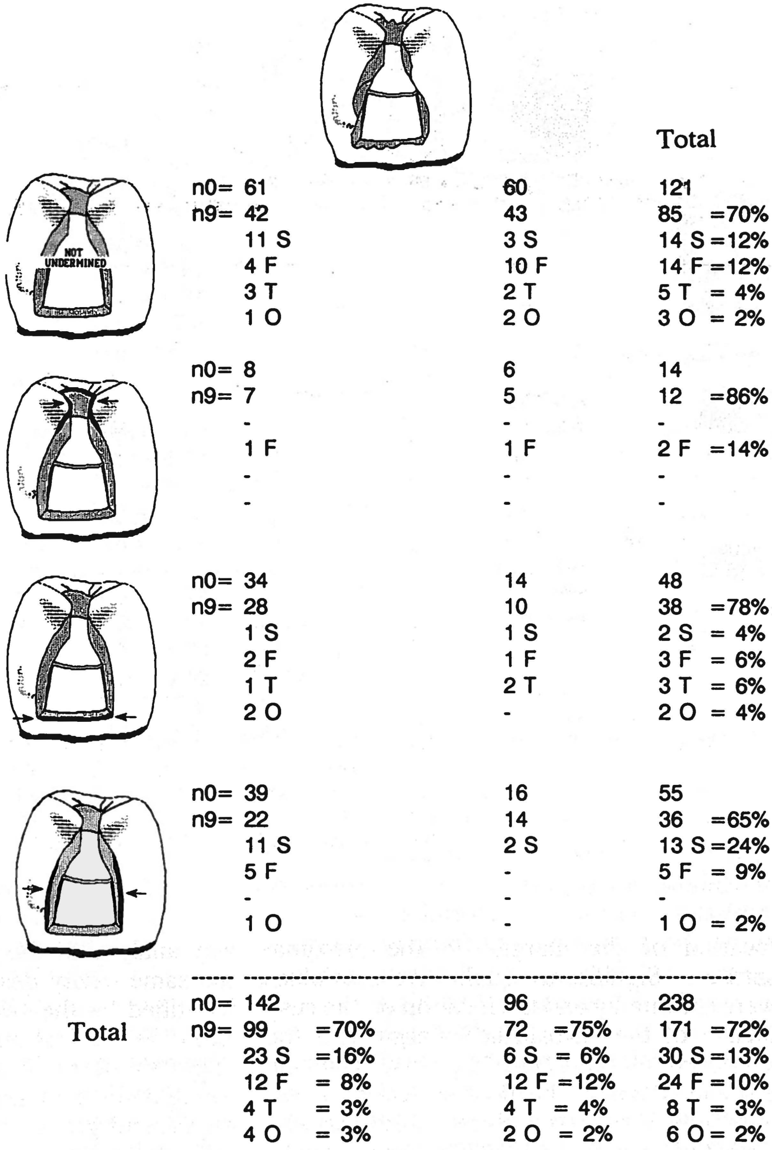
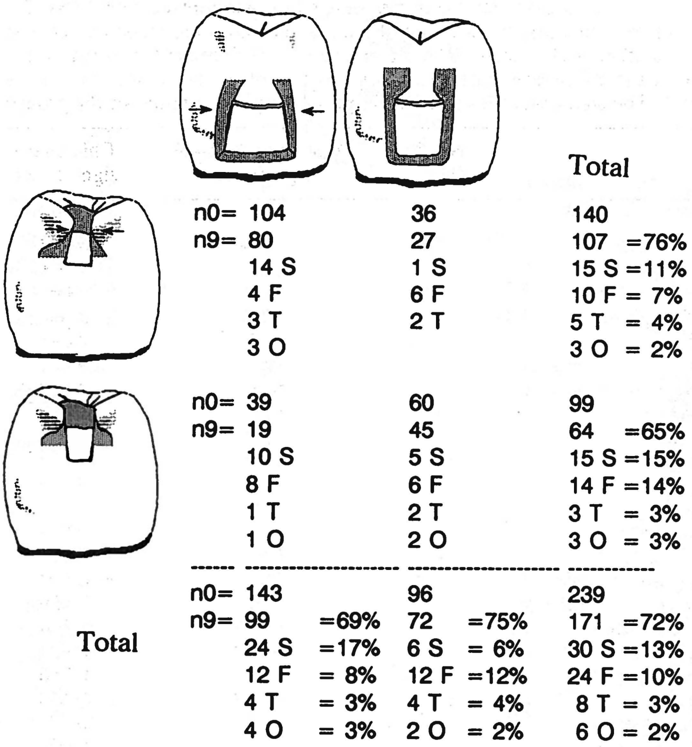


Fig. 4. Cross-tabulation of the prevalence and reasons for replacement of 238 class-II amalgam restorations, categorized by the presence or location of undermined enamel (vertical diagrams) and by an adequate or poor quality of the cavosurface angle (horizontal diagrams). The location of the undermined enamel is marked with arrows, and the quality of the cavosurface angle is dichotomized in accordance with the figure in the first row. Poor quality of the cavosuface margin is in the left column (n = 142), acceptable cavosurface margins in the right column (n = 96). The numbers and letters in each subgroup indicate the number of restorations at base line (n0), the number in service at the end of the observation period (n9), and the number of replacements because of secondary caries (S), restoration bulk fracture (F), tooth fracture (T), or other reasons (O).

				Total
	n0=	61	60	121
	n9=	42	43	85 =70%
		11 S	3 S	14 S =12%
		4 F	10 F	14 F =12%
		3 T	2 T	5 T = 4%
		1 O	2 O	3 O = 2%
	n0=	8	6	14
	n9=	7	5	12 =86%
		-	-	-
		1 F	1 F	2 F =14%
		-	-	-
		-	-	-
	n0=	34	14	48
	n9=	28	10	38 =78%
		1 S	1 S	2 S = 4%
		2 F	1 F	3 F = 6%
		1 T	2 T	3 T = 6%
		2 O	-	2 O = 4%
	n0=	39	16	55
	n9=	22	14	36 =65%
		11 S	2 S	13 S =24%
		5 F	-	5 F = 9%
		-	-	-
		1 O	-	1 O = 2%
	n0=	142	96	238
Total	n9=	99 =70%	72 =75%	171 =72%
		23 S =16%	6 S = 6%	30 S =13%
		12 F = 8%	12 F =12%	24 F =10%
		4 T = 3%	4 T = 4%	8 T = 3%
		4 O = 3%	2 O = 2%	6 O = 2%

criminant scores were the occlusal depth at the isthmus, the quality of the cavosurface angle, proximal buccolingual width and depth, presence and location of undermined enamel, acuteness of external gingivoaxial line angles, and the degree of convergence of the cavity walls ($p < 0.001$).

When the failure group was defined as the 30 restorations replaced because of secondary caries, the discriminant function included the operator, the patient's age and treatment experience, and the proximal buccolingual width gingivally as important explanatory variables ($p < 0.001$). Only three explanatory variables were included in the discriminant function when only the cavity design variables were available for inclusion. All three explanatory variables were related to the gingival part of the proximal surface (Table 5).



				Total
	n0=	104	36	140
	n9=	80	27	107 =76%
		14 S	1 S	15 S =11%
		4 F	6 F	10 F = 7%
		3 T	2 T	5 T = 4%
		3 O		3 O = 2%
	n0=	39	60	99
	n9=	19	45	64 =65%
		10 S	5 S	15 S =15%
		8 F	6 F	14 F =14%
		1 T	2 T	3 T = 3%
		1 O	2 O	3 O = 3%
	n0=	143	96	239
	n9=	99 =69%	72 =75%	171 =72%
Total		24 S =17%	6 S = 6%	30 S =13%
		12 F = 8%	12 F =12%	24 F =10%
		4 T = 3%	4 T = 4%	8 T = 3%
		4 O = 3%	2 O = 2%	6 O = 2%

Fig. 5. Cross-tabulation of the prevalence and reasons for replacement of 239 class-II amalgam restorations, categorized by the convergence or divergence of the cavity walls occlusally (vertical diagrams), and proximally (horizontal diagrams). Only the relevant part of the cavity is shown, and convergence is marked with arrows. The numbers and letters in each subgroup indicate the number of restorations at base line (n0), the number in service at the end of the observation period (n9), and the number of replacements because of secondary caries (S), restoration bulk fracture (F), tooth fracture (T), or other reasons (O).

In the last discriminant analysis, in which the failure group consisted of 24 restorations replaced because of restoration bulk fractures, the discriminant function included the patient age, the proximal and occlusal depth, the occlusal buccolingual width at the isthmus, and the degree of convergence of the cavity walls in both the proximal and occlusal parts as the most important ($p < 0.001$). The function also included the operator and type of amalgam alloy, as described in the conjoint report (32). When only the cavity design variables were available for inclusion, the discriminant function included the same explanatory variables and also the cervico-axial location of the margin on the proximal surface.

Different explanatory variables were included in the discriminant analyses depending on how the grouping variables were coded. The ranking of the stage of inclusion in the discriminating function was also dependent on whether the analysis included all the explanatory clinical variables or only the cavity design variables (Table 5). In general, the eigenvalues of the functions decreased markedly when only the cavity design variables were included in the discriminant function. However, in all six analyses, significant differences at the $p < 0.001$ level were observed between the two groups (Table 5).

The predictive values of the discriminant functions—that is, the sensitivity and specificity in the different discriminant analyses—are presented in Table 6.

Discussion

Statistical considerations

An assessment of which features of a prepared cavity predict the prognosis of a restoration presents methodologic problems in selecting the optimal study design and statistical technique. It is not possible to

Table 2. Explanatory variables associated with the service time and replacement reason for class-II amalgam restorations. The service time of the restorations is the response variable in the Wilcoxon/Kruskal–Wallis tests. The prevalence of replacement reasons is the response variable in the chi-square statistics. Categorization of the explanatory variables is shown in Table 1. The significance levels indicate probability of equalities of the groups

	No. in Table 1	Wilcoxon/Kruskal significance	Chi-square significance
Occlusal part			
Buccling. width (mm)	(3)	0.009	0.017
Buccling. width, average	(3)	0.000	0.011
Buccling. width, maximum	(4)	0.002	0.002
Buccling. width, isthmus	(5)	0.006	0.004
Depth, average	(13)	0.925	0.096
Depth, at isthmus	(14)	0.182	0.005
Location on cusp incline	(17)	0.001	0.022
Remaining enamel slices	(18)	0.654	0.783
Remaining fissures	(19)	0.343	0.463
Box-only preparation	(20)	0.135	0.115
Convergence of walls	(27)	0.025	0.250
Proximal part			
Buccling. width, isthmus	(7)	0.021	0.009
Buccling. width, gingiva	(8)	0.009	0.006
Buccling. width, average	(9)	0.003	0.002
Buccling. width (mm)	(9)	0.034	0.026
Location gingivally, min.	(10)	0.049	0.004
Location gingivally, max.	(11)	0.207	0.004
Location gingivally, mean	(12)	0.855	0.086
Depth, average	(15)	0.092	0.668
Lock in gingival floor	(21)	0.293	0.207
Ging. axial l.a. acuteness	(24)	0.001	0.002
Convergence of walls	(28)	0.006	0.342
Occlusal and proximal part			
Volume (mm^3)	(16)	0.044	0.051
Bevel pulpoaxial line angle	(22)	0.783	0.677
Rounding, internal l.a.	(23)	0.125	0.990
Undermined enamel	(25)	0.123	0.423
Quality of cavosur. angle	(26)	0.002	0.030

se a basic statistical technique such as a complete randomization design owing to the lack of independence between the cavity design variables (33). Also clinical studies using randomized block designs or matched-pair designs are difficult to conduct without a large, and possible selective, patient base to choose from (34). Multivariate statistical techniques are therefore required to discover any cause–effect relationships between the cavity design variables and the clinical behavior of the restoration. A further problem is how to define or describe an optimal class-II cavity design. A description must consist of dichotomous variables, such as undermined enamel present/not present; discrete variables, such as quality of the cavosurface angle; and continuous variables, such as buccolingual widths. Although it is clinically unrealistic to regard the prepared cavity as many separate clinical variables instead of a unity, the calculation of an index for the morphology of the cavity may not be meaningful (35). On the other hand, owing to the statistical interaction between the explanatory variables, it is difficult to estimate quantitatively the influence of each separate feature of the prepared cavity on the clinical behavior of the restoration.

A statistical technique that may identify properties of the cavity preparation which influence the clinical behavior of the restoration is linear discriminant analysis (36). This statistic calculates discriminant scores

Table 3. Correlation between the cavity design variables, assessed by Pearson correlation coefficient. Asterisks indicate degree of correlation: * = $p < 0.01$ ** = $p < 0.001$

		3a	3b	4	5	7	8	9a	9b	10	11	12	13	14	15	16	17	18	19	20	24
Buccling. width (mm)	(3a)																				
Buccling. width, average	(3b)	**																			
Buccling. width, maximum	(4)	**	**																		
Buccling. width, isthmus	(5)	**	**	**																	
Buccling. width, isthmus	(7)	**	**	**	**																
Buccling. width, gingiva	(8)	**	**	**	**	**															
Buccling. width (mm)	(9a)	**	**	**	**	**	**														
Buccling. width, average	(9b)	**	**	**	**	**	**	**													
Location gingivally, min.	(10)	**	*	*		**	**	**	**												
Location gingivally, max.	(11)	**	*	*		**	*	**	**	**											
Location gingivally, mean	(12)	**	**	*	**	**	**	**	**	**	**										
Depth, average	(13)	**	**	**	**			*				**									
Depth, at isthmus	(14)	**	**	**	**							**	**								
Depth, average	(15)	*				*		**	*			**	*	*							
Volume (mm^3)	(16)	**	**	**	**	**	**	**	**	**	**	**	**	**	**						
Location on cusp incline	(17)	**	**	**	**	**	**	**	**	*	**	**	**	**		**					
Remaining enamel slices	(18)																*				
Remaining fissures	(19)														*		*	*			
Box-only preparation	(20)	**	*	*	*								*					**	**		
Lock in gingival floor	(21)		*	*																	
Bevel pulpoaxial line angle	(22)												*	**							
Ging. axial l.a. acuteness	(24)					*		*	*												
Undermined enamel	(25)					*			*											*	
Quality of cavosur. angle	(26)																		*	*	
Convergence of occlusal wall	(28)						*		*								*				**

from combinations of explanatory variables and relates the discriminant score to a response variable. The coefficients of the function are chosen so the values of the function differ as much as possible between the groups. Thus, the functions include the explanatory variables that maximize the between-group sum of squares relative to the within-group sum of squares (36). In dentistry, the statistical technique has been used to analyze facial pain (37), predict high-caries risk patients (38, 39), and diagnose periodontitis (40). It was therefore anticipated that by using the statistics with the specific restoration failure reasons as response variables, the explanatory variables in the discriminant function with the highest coefficients and correlations would be related to the success or failure of the restorations.

The sensitivity and specificity levels differed among the discrimination functions. The most obvious reason is that since a replacement is a terminal event, only one reason for replacement can be recorded. Another explanation is that dentists do not necessarily discover or diagnose correctly the clinical state of the restorations (23). If the last factor is present, not only will the classification rates of the discriminant functions decrease, but the calculation of the discriminant function is also confounded. The operators in the present study had been trained in assessing the restorations by the USPHS system (29), so this source of error was presumably controlled. Another factor with probable influence on the sensitivity and specificity levels was the non-continuous nature of the explanatory variables. When combinations of continuous and discrete variables are included in a discriminant function, the probability of incorrect classification increases (41, 42). A further effect could have been caused by the slightly different covariance matrices for some of the discriminant functions (Table 6).

Confounding factors related to the design of the study is the lack of a qualitative eval-

Table 4. The mean values with standard deviations of the explanatory variables in the group of restorations that remained in service (n = 188) and of the different failure groups (n = 68). The values are presented in millimeters (mm), proportion of buccolingual widths (bl), proportion of the cavity features assessed as acceptable (pro), cubic millimeters (mm^3), and in degrees. The significance was calculated by a one-way analysis of variance

	No. in Table 1	Remain in service (n = 188)	Secondary caries (n = 30)	Bulk fracture (n = 24)	Tooth fracture (n = 8)	U-test
Occlusal part						
Bucclingual width (mm)	(3)	2.6 ± 1.0	1.9 ± 0.6	2.3 ± 0.8	3.4 ± 1.0	0.000
Bucclingual width, average (bl)	(3)	0.48 ± 0.17	0.35 ± 0.12	0.43 ± 0.16	0.58 ± 0.07	0.000
Bucclingual width, maximum (bl)	(4)	0.50 ± 0.20	0.36 ± 0.13	0.48 ± 0.23	0.58 ± 0.19	0.002
Bucclingual width, isthmus (bl)	(5)	0.47 ± 0.16	0.35 ± 0.11	0.39 ± 0.11	0.58 ± 0.13	0.000
Depth, average (mm)	(13)	2.1 ± 0.6	2.0 ± 0.7	2.3 ± 0.5	2.5 ± 1	0.080
Depth, at isthmus (mm)	(14)	2.1 ± 0.5	2.0 ± 0.4	2.3 ± 0.5	2.7 ± 0.7	0.014
Location <2/3 of cusp incline (pro)	(17)	0.49 ± 0.50	0.80 ± 0.41	0.58 ± 0.50	0.13 ± 0.35	0.001
No remaining enamel slices (pro)	(18)	0.88 ± 0.32	0.80 ± 0.41	0.79 ± 0.41	0.75 ± 0.46	0.343
No remaining fissures (pro)	(19)	0.91 ± 20	0.85 ± 0.31	0.92 ± 0.25	0.93 ± 0.12	0.268
Occlusally converging walls (pro)	(27)	0.61 ± 49	0.50 ± 0.51	0.42 ± 0.50	0.63 ± 0.52	0.26
Proximal part						
Bucclingual width, isthmus (bl)	(7)	0.44 ± 0.13	0.34 ± 0.13	0.42 ± 0.12	0.47 ± 0.16	0.001
Bucclingual width, gingiva (bl)	(8)	0.42 ± 0.12	0.31 ± 0.10	0.38 ± 0.10	0.43 ± 0.15	0.000
Bucclingual width, average (bl)	(9)	0.43 ± 0.12	0.33 ± 0.11	0.40 ± 0.11	0.45 ± 0.16	0.000
Bucclingual width (mm)	(9)	5.1 ± 1.5	3.8 ± 1.2	4.7 ± 1.3	5.4 ± 2.0	0.000
Location gingivally, min. (mm)	(10)	3.2 ± 0.8	2.8 ± 0.9	2.7 ± 0.9	3.7 ± 0.8	0.096
Location gingivally, max. (mm)	(11)	4.3 ± 0.8	3.9 ± 0.9	3.9 ± 0.8	4.8 ± 1	0.104
Location gingivally, mean (mm)	(12)	3.6 ± 0.8	3.2 ± 0.7	3.3 ± 0.7	4.2 ± 0.8	0.003
Depth, average (mm)	(15)	1.6 ± 0.4	1.7 ± 0.4	1.8 ± 0.5	1.8 ± 0.4	0.082
Lock in gingival floor (pro)	(21)	0.75 ± 43	0.86 ± 0.35	0.79 ± 0.41	0.63 ± 0.52	0.459
Gingivoaxial line-angle (degr)	(24)	80 ± 17	70 ± 22	67 ± 33	81 ± 18	0.006
Occlusally converging walls (pro)	(28)	0.58 ± 50.0	0.80 ± 0.41	0.50 ± 0.51	0.50 ± 0.53	0.085
Occlusal and proximal part						
Volume (mm^3)	(16)	52 ± 36	36 ± 19	49 ± 26	76 ± 27	0.011
No box-only preparation (pro)	(20)	0.96 ± 0.19	0.85 ± 0.36	1	0.75 ± 0.50	0.055
Beveled pulpoaxial line-ang. (pro)	(22)	0.73 ± 0.44	0.64 ± 0.49	0.68 ± 0.48	0.83 ± 0.41	0.705
Rounded internal line-ang. (pro)	(23)	0.86 ± 0.35	0.87 ± 0.35	0.87 ± 0.34	0.75 ± 0.46	0.845
No undermined enamel (pro)	(25)	0.79 ± 0.41	0.55 ± 0.51	0.79 ± 0.41	1	0.013
Good quality cavosurface (pro)	(26)	0.54 ± 0.50	0.37 ± 0.49	0.33 ± 0.48	0.12 ± 0.35	0.015

uation of the proximal surfaces beyond the use of USPHS criteria and X-ray photographs at the yearly recalls. More detailed examinations for poor proximal adaptation, porosities, subgingival surface roughness, or size of overhangs were thus not carried out. Although none of these criteria were used as reasons for replacements during the trial, it was realized that these aspects could have influenced the prognosis of the restoration. However, the proximal surfaces were not examined for several reasons. The most important reason was that, since the main objective in this clinical trial was to collect clinical data that reflected the status of the dental treatment carried out in the general practices, any interference with the daily treatment carried out by the dentists was avoided. On the other hand, the clinicians involved in the present study were informed of the general guidelines for safeguarding of patients in clinical trials (43, 44). It was therefore assumed that they kept to an acceptable quality of dental care and would correct and report any discrepancies of the restoration if detected. A second reason was the lack of universally accepted and simple evaluation systems for scoring these discrepancies on the proximal surface. Finally, the cost and logistic factors must be considered, since it was believed that the potential gain of information obtained in a

Table 5. Summary of the explanatory variables included in the discriminant analyses using the stepwise method. The selection of explanatory variables were based on multivariate F-statistics. The significance levels at all steps were $p < 0.05$. The failure groups were A = replacements due to secondary caries, tooth or restoration fractures, C = replacements due to secondary caries, F = replacements due to restoration bulk fractures. Increase in value of the variables increases the risk of failure, while increase in value of the variables in bold types decreases the risk of failure

		All clinical variables included in function			Only cavity variables included in function		
Discriminant groups	No. in Table 1	A	C	F	A	C	F
Explanatory variables							
Patient treatment experience		1	1				
Patient age		**2**	**4**	**1**			
Operator		5	3	6			
Intraoral location		7					
Type of alloy				7			
Occlusal buccolingual width, isthmus	(5)			**5**			**2**
Proximal buccolingual width, isthmus	(7)				7		
Proximal buccolingual width, gingiva	(8)	**8**	**2**		**1**	**1**	
Proximal buccolingual width, mean	(9)	9	6				
Occlusal depth, mean	(13)			2			3
Occlusal depth isthmus	(14)	3			2		
Proximal cavity depth	(15)			4	6		1
Gingivoaxial line angle acuteness	(24)				5	2	
Undermined enamel	(25)	**10**	7				
Cavosurface angle quality	(26)	4			4		
Wall convergence, both parts	(27 + 28)			3	3		4
Wall convergence, proximal part	(28)	6	5			3	
Eigenvalue		0.658	0.613	0.208	0.222	0.141	0.111
Wilks's lambda		0.603	0.620	0.828	0.819	0.877	0.890
Significance		0.000	0.000	0.000	0.000	0.000	0.001

scanning electron microscope could not be justified by the use of necessary extra time and laboratory personnel.

Several cavity design variables were identified by the univariate statistics as influential on both the reasons for replacement and the

Table 6. Concordance of predicted classifications to the actual classifications using discriminant analyses, with different definitions of the failure groups. Box's M test measures the equality of the group covariance matrices

	Sensitivity	Specificity	Correctly classified	Box's M significance
Failure group = secondary caries, tooth and restoration fractures				
All variables	0.86	0.67	0.81	0.016
Cavity variables	0.69	0.73	0.70	0.010
Failure group = secondary caries				
All variables	0.93	0.86	0.92	0.014
Cavity variables	0.77	0.81	0.77	0.080
Failure group = restoration bulk fracture				
All variables	0.77	0.78	0.77	0.065
Cavity variables	0.69	0.70	0.69	0.015

surface time of the restoration. Whereas the chi-square test only gave some indication of the association between the cavity design and failure reasons, the significance levels in the non-parametric one-way analyses of variance indicated the severity of the cavity design discrepancies in terms of reduced clinical service. One variable that was identified as clinically significant by the later statistic was the proximal depth, since three restorations placed in cavities with proximal parts >2.5 mm fractured after 2, 4, and 6 months of clinical service. However, the interrelationship between the explanatory variables (Table 3) precludes further statistical inferences based on the univariate statistics.

The different discriminant analyses and the univariate statistics identified approximately similar cavity design variables of the surface time and the replacement reasons for the restorations (Tables 2, 4, and 5). Owing to the low number of failures related to marginal degradation ($n = 3$) there were no attempts to associated the explanatory variables with this failure reason. The number of tooth fractures was also low ($n = 8$), and detailed analyses were therefore difficult. However, the general impression was that tooth fractures were mainly associated with cavities with large and deep parts both occlusally and proximally (Table 4). The analyses focused primarily on the two main failure groups—that is, bulk fractures and secondary caries.

Cavity design versus failures

The restorations replaced because of secondary caries were associated with cavity design variables of the proximal part. Narrow extensions, especially at the gingiva, could be associated with increased prevalence of secondary caries. It is possible that the operator in these cases had not extended the preparation beyond the actual caries on the enamel surface. This was not possible to inspect on the epoxy casts. However, the observation draws attention to the possibility that conservation of tooth tissue proximally increases the risk of leaving sectors of demineralized enamel along the cavosurface angle. Previous authors have suggested that the incidence of secondary caries is reduced when the restoration margins are placed subgingivally (14, 15). The data from the present study do not show that the prevalence of secondary caries can be related to the cervicoaxial location of the margin. However, the lack of relationship may be influenced by the study design in the present study, since the gingival extension of the prepared cavities was not assessed clinically but relative to the occlusal marginal ridge on the epoxy casts (28). Moreover, the hypothesis that non-supported cusps increase the risks for secondary caries (45) was not supported by the data, since the incidence of secondary caries was low in the restorations with wide occlusal parts (0 of 31 observed, 13% expected) (Fig. 2). Several qualitative explanatory variables of the class-II cavities were also associated with secondary caries. These were undermined enamel and acuteness of the external axiogingival line angles on the proximal surface, the degree of convergence of the proximal buccolingual walls, and the quality of the cavosurface angle. The relationship between undermined enamel proximally and secondary caries may be due to the fracturing of margins during the placement of the amalgam matrix (46) or during the condensation of the amalgam (47). The two cavity design variables acuteness of axiogingival line angle and degree of convergence of the proximal cavity walls can be viewed as factors that influence the ability of the operators to condense optimally the amalgam in the proximal box. This observation supports the hypothesis that the high incidence of secondary caries gingivally on the proximal surfaces is primarily the result of lack of condensation of the amalgam into the proximal corners (48). The relatively poor association between the quality of the cavosurface angle and secondary caries was unexpected. It is possible that the criteria used in the present study for evaluating the quality of the cavosurface margin was too rough and that the cavosurface margins considered acceptable were, in effect, clinically unsatisfactory. The same cavity preparations had also been scored in accordance with the CMI index (49). However, since most of the cavosurface margins were considered unacceptable by the CMI index, the authors had concluded that the CMI index was too finely graded (26). The present data indicate that this conclusion was somewhat premature, and the index could indeed have been more clinically relevant than the one used in the present study. A further potential implication of this observation is that the prerequisite for the development of secondary caries may develop at a certain unknown level of the cavosurface margin quality, and further categorization of the quality beyond this level is clinically irrelevant.

The lack of association between restoration bulk fractures and internal cavity design features is in accordance with previous reports (5, 6). The 24 fractures were distributed in 22 patients, showing that the fractures were not restricted to a few patients with heavy occlusal contacts (32). The cavity design features that seem to predispose for bulk fractures are narrow buccolingual widths, markedly converging buccolingual walls, and deep occlusal and proximal parts ($p < 0.001$) (Table 5). The clinical implication of this conclusion is uncertain, since it is generally assumed that bulk is needed in class-II cavities, especially in the isthmus region (1–3). However, this assumption is primarily based on in vitro studies, and a literature search did not identify clinical studies supporting the rationale of preparing cavities for restorations with larger bulk occlusally. Although the very early failures probably were related to supracontact, the data thus show that the risk for bulk restoration fractures is not reduced by deepening of the occlusal aspects. Confounding factors on the results may have been caused by an adverse anatomic form of the antagonizing cusp (5), a potentially detrimental effect of an exaggerated reproduction of deep sulci on the occlusal surface (13), or an uncritical use of a base (50). These aspects were not evaluated in the present study, although the last impressions or photographs made before the failures were examined for wear facets or deep sulci made occlusally. The correlation between the reproduction of occlusal anatomy and cavity width has not been reported in the literature, but the carving of deep occlusal sulci is probably not influenced by the buccolingual cavity size. On the other hand, the use of a base is commonest in deep cavities. It is therefore uncertain whether the increased frequency of fractured restorations in the deep cavities observed in the present study is the result of a cavity design that produced higher tensile stress in the restoration (6, 7) or is due to weakening of the restoration support by thick layers of base materials (50).

Cavity design variables that could not be associated with the clinical behavior of the restorations were beveling of the axiopulpal line angle, presence of proximal locks rounding of the internal line angles, remaining fissures in continuation from the cavosurface angle, or slices of less than 1 mm of enamel remaining between two restorations occlusally. Although the effects of these variables may appear after many years of service, the data after 8 to 10 years' clinical service show that these design variables are clinically unimportant features of the class-II cavities for amalgam.

References

1. O'Hara JW, Clark LL. The evolution of the contemporary cavity preparation. J Am Dent Assoc 1984;108:993–7.
2. Robinson PB. The evolution of cavity shape for minimal amalgam restorations. Dent Update 1985;12:357–70.
3. Hunter AR, Hunter AJ. The class II caries lesion. II. Alternative direct cavity preparations. NZ Den J 1989;85:116–21.
4. Morin DL, Douglas WH, Cross M, DeLong R. Biophysical stress analysis of restored teeth: experimental strain measurements. Dent Mater 1988;4: 41–8.
5. Nadal R, Phillips RW, Swartz ML. Clinical investigation on the relation of mercury to the amalgam restoration. II. J Am Dent Assoc 1961;63:488–96.
6. Terkla LG, Mahler DB. Clinical evaluation of interproximal retention grooves in class II amalgam cavity design. J Prosthet Dent 1967;17:596–602.
7. Terkla LG, Mahler DB, Eysden Van J. Analysis of amalgam cavity design. J Prosthet Dent 1973;29: 204–9.
8. Berry TG, Laswell HK, Osborne JW, Gale EN. Width of isthmus and marginal failure of restorations of amalgam. Oper Dent 1981;6:55–8.
9. Osborne JW, Gale EN. Failure at the margin of amalgams as affected by cavity width, tooth position and alloys selection. J Dent Res 1981;60:681–5.

10. MacRae PD, Zacherl W, Castaldi CR. A study of defects in class II dental amalgam restorations in deciduous molars. Can Dent Assoc J 1962;28:491–502.
11. Mathewson RJ. Determination of cavo-surface angles in primary molar cavity preparations. J South Calif Dent Assoc 1972;40:1062–6.
12. Elderton RJ. An in vivo morphological study of cavity and amalgam margins on the occlusal surfaces of human teeth [Thesis]. London: University of London, 1975.
13. Elderton RJ. Cavo-surface angles, amalgam margin angles and occlusal cavity preparations. Br Dent J 1984;156:319–24.
14. Budtz-Jørgensen V. Gingival health and secondary caries adjacent to cervical restorations [Abstract 73]. IADR Program and Abstracts, 1971.
5. Hammer B. Nachkontrolle von 1–5 jährige amalgam-, komposit- und goldgussfüllungen [Thesis]. Bern: University of Bern, 1978.
16. Cavel WT, Kelsey WP, Blankenau RJ. An in vivo study of cuspal fracture. J Prosthet Dent 1985;53:38–42.
17. Eakle WS, Maxwell EH, Braly BV. Fractures of posterior teeth in adults. J Am Dent Assoc 1986;112:215–8.
18. Lang NP, Kiel RA, Anderhalden K. Clinical and microbiological effects of subgingival restorations with overhanging or clinically perfect margins. J Clin Periodontol 1983;10:563–78.
19. Markitziu A. A ten-year follow-up study of alveolar bone loss influenced by two dissimilar class II amalgam restorations. J Oral Rehabil 1987;14:23–4.
20. Meyer S. Approximalpräparation und parodontalprophylaxe. Eine klinische studie. Dtsch Zahnaerztl Z 1988;43:300–3.
21. Thomas AE. Evaluation of principles of cavity preparation design. Ala J Med Sci 1970;20:379–82.
22. Bailit HL, Chiriboga D, Grasso J, et al. A new intermediate dental outcome measure, amalgam replacement rate. Med Care 1979;17:780–6.
23. Elderton RJ, Nuttall NM. Variation among dentists in planning treatment. Br Dent J 1983;154:210–6.
24. Boyd MA. Amalgam replacements: are decisions based on fact or tradition? In: Anusavive KJ, ed. Quality evaluation of dental restorations: Criteria for placement and replacement. Chicago: Quintessence Publ Co, 1989: 73–82.
25. Report of the committee of enquiry into unnecessary dental treatment. London: Department of Health and Social Security, 1986.
26. Jokstad A, Mjör IA. The quality of routine class II cavity preparations for amalgam. Acta Odontol Scand 1989;47:53–64.
27. Jokstad A. The dimensions of everyday class-II cavity preparations for amalgam. Acta Odontol Scand 1989;47:89–99.
28. Jokstad A, Mjör IA. Cavity designs for class II amalgam restorations. A literature review and a suggested system for evaluation. Acta Odontol Scand 1987;45:257–73.
29. Cvar JF, Ryge G. Criteria for the clinical evaluation of dental restorative materials. San Francisco: US Government Printing Office, 1971; USPHS publication 790–244.
30. Johansson B, Mjör IA. Marginal degradation and corrosion of a dispersed high copper amalgam. Scand J Dent Res 1988;96:75–82.
31. Jokstad A, Mjör IA. Cavity design and marginal degradation of the occlusal part of class-II amalgam restorations. Acta Odontol Scand 1990;48:389–97.
32. Jokstad A, Mjör IA. Analyses of long-term clinical behavior of class-II amalgam restorations. Acta Odontol Scand 1991;49:47–63.
33. Carlos JP. Tricks and traps in dental clinical trials. Community Dent Oral Epidemiol 1985;13:79–81.
34. Letzel H, Van't Hof MA, Vrijhoef MM, Marshall GW Jr, Marshall SJ. A controlled clinical study of amalgam restorations: survival, failures, and causes of failure. Dent Mater 1989;5:115–21.
35. Goepferd SJ, Kerber PE. A comparison of two methods for evaluating primary class II cavity preparations. J Dent Educ 1980;44:537–42.
36. Lachenbruch PA. Discriminant analysis. New York: Hafner Press, 1975.
37. Wastell DG, Gray RJ. The numerical approach to classification: a medical application to develop a topology for facial pain. Stat Med 1987;6:137–46.
38. Abernathy JR, Graves RC, Bohannan HM, Stamm JW, Greenberg BG, Disney JA. Development and application of a prediction model for dental caries. Community Dent Oral Epidemiol 1987;15:24–8.
39. Bader JD, Graves RC, Disney JA, et al. Identifying children who will experience high caries increments. Community Dent Oral Epidemiol 1986;14:198–201.
40. Sterne JA. Application of statistical modelling to peridontal diseases as viewed by the statistician. In: Guggenheim B ed. Periodontology today. Basel: Karger, 1988:86–94.
41. Gilbert ES. On discrimination using qualitative variables. J Am Stat Assoc 1968;63:1399–1412.
42. Tatsuoka MM. Multivariate analysis. New York: John Wiley and Sons, 1971.
43. ADA, FDA, NIH. In: Wychoff HD, Weigl DG, eds. Clinical evaluation of dental materials. Bethesda; National Institutes of Health, 1980; publication no. 80–117.
44. FDI, Federation Dentaire Internationale. Recommendations for clinical research protocols for dental materials. Inter Dent J 1982;32:403–23.
45. Anusavice KJ. Criteria for selection of restorative materials: Properties versus technique sensitivity. In: Anusavice KJ, ed. Quality evaluation of dental restorations. Chicago: Quintessence Publ Co 1989.
46. Boyde A, Knight PJ. SEM studies of class II cavity margins. Matrix band application. Br Dent J 1972;133:331–7.
47. Øilo G. Adaptation of amalgams to cavity walls. J Oral Rehabil 1976;3:227–36.
48. Mjör IA. Frequency of secondary caries at various anatomical locations. Oper Dent 1985;10:88–92.
49. Tronstad L, Leidal I. Scanning electron microscopy of cavity margins finished with chisels or rotating instruments at low speed. J Dent Res 1974;53:1167–74.

50. Robbins JW. The placement of bases beneath amalgam restorations: review of literature and recommendations for use. J Am Dent Assoc 1986; 113:910–2.

Received for publication 7 February 1990