The dimensions of everyday class-II cavity preparations for amalgam

Asbjørn Jokstad

Department of Anatomy, School of Dentistry, University of Oslo, Oslo, and NIOM, Scandinavian Institute of Dental Materials, Haslum, Norway

Jokstad A. The dimensions of everyday class-II cavity preparations for amalgam. Acta Odontol Scand 1989;47:89–99. Oslo. ISSN 0001-6357.

Six hundred and ten epoxy plastic models, made from impressions of permanent teeth in which class-II cavity preparations for amalgam restorations had been prepared by eight Scandinavian dentists, were examined. The outlines of the cavity preparations were relatively large, with mean buccolingual extensions occlusally of 50% of the intercuspal distance and proximally of 40% of the length of the circumference of the proximal surface. There was a gradual increase in the size of the cavities towards the distal part of the dental arch, measured both in millimeters and in relation to the anatomic structures. The amount of hard tissue being removed varied among the operators and was possibly influenced by the dentist's ability to handle the cutting instruments. The large cavity preparations may be the result of using procedures for cavity preparation which are not adjusted to the tremendous cutting potential of modern dental instruments to produce stereotyped 'ideally designed' cavities. □ *Cavity measurements; operative dentistry; techniques*

Asbjørn Jokstad, Department of Anatomy, Dental Faculty, P.O. Box 1052 Blindern, University of Oslo, N-0316 Oslo 3, Norway

The operational steps of cavity preparation for amalgam restorations are to a large extent based on the guidelines suggested by Black (1) at the turn of the century. These guidelines introduced the concept of 'extension for prevention'. This concept stemmed the current clinical practice of removing minimal quantities of hard tissue (2, 3). Although Black later recommended smaller cavity preparations for patients with improved oral hygiene (4), the concept for many years formed the basis for operative techniques.

In the dental literature there are numerous modifications of Black's cavity designs (5–7). Most of the modifications were never substantiated by clinical research data but rather by other developments in dentistry: the invention of restorative materials with superior physical qualities and handling properties (8); the advancement of preventive methods and oral prophylaxis (9–11); the increased use of fluorides and better oral health in the population (12–15); the increased knowledge of the biologic effects of materials on oral tissues (16–19); the application of biomechanic principles (20, 21); the improved access to dental services (22); and the technologic changes of the equipment in the dental office (23–28).

The general guideline in the teaching of operative dentistry today is to maintain a maximum amount of tissue (29–31). It is not known to what extent the dentists in general practice have adopted the principles of conservative operative dentistry.

The aim of the present examination was primarily to assess the morphology of routine cavities prepared for amalgam restorations.

The physical properties and the chemical stability of amalgam give indications of a possible extensive function period as a restorative material in an oral environment. Clinical experience does, however, show that amalgam restorations after a relatively short time exhibit properties not predicted by the results from the standardized measurements in the laboratory. It is not clear to what extent the morphology of the cavity preparation influences the long-term prognosis of the restoration. A second aim of this study was therefore to identify dis-

Table 1. The frequency and location of 610 examined cavity preparations

Upper 383 (62.8%)									
	Molars		Premolars		Premolars		Molars		
	Dis	Mes	Dis	Mes	Mes	Dis	Mes	Dis	
	12	48	77	44	55	80	53	14	
Right	(9.8%)		(19.8%)		(22.1%)		(11.2%)		Left
308									302
(50.5%)	28	55	33	11	15	33	31	21	(49.5%)
	(13.6%)		(7.2%)		(7.8%)		(8.5%)		
Lower 227 (37.2%)									

crepancies believed to influence the prognosis of the restorations. The restorations are part of a longitudinal study of the clinical performance of amalgam.

Materials and methods

Epoxy plastic models, made from impressions of permanent teeth in which class-II cavities for amalgam restorations had been prepared by eight Scandinavian dentists, were examined. The clinical experience of the operators varied from 15 to 30 years. A total of 610 cavity preparations were examined (Table 1). The number of models returned by each operator varied from 19 to 108. The most usual locations of the cavity preparations among the operators are outlined in Table 2.

Each cavity was measured with a periodontal probe with millimeter marks (CGB, Hilming) and a flexible strip of squared millimeter paper. The measurements were made at various predetermined locations on the tooth. The occlusal buccolingual width was calculated as a fraction of the intercuspal width. The widths were measured at the axiopulpal line angle (isthmus) and at the dovetail (Fig. 1). The proximal buccolingual width was calculated as a fraction of the extent of the proximal surface. This was defined as the length of the circumference between the two utmost buccally or lingually located parts of the cusp. The buccolingual widths were measured at the axiopulpal line

Table 2. Operators and the location of the cavity preparations by surface. 15% of the preparations were MODs, which count as two cavity preparations

	Upper				Lower				
	Premolars		Molars		Premolars		Molars		
Operator	Mesial	Distal	Mesial	Distal	Mesial	Distal	Mesial	Distal	Total
1	30	33	6	1	6	11	3	2	92
2	7	8	24	—	—	2	19	2	62
3	20	31	8	11	8	18	6	5	107
4	12	22	14	6	3	11	19	16	103
5	8	31	38	2	1	4	19	5	108
6	18	22	10	6	4	12	15	13	100
7	—	5	1	—	—	2	5	6	19
8	4	5	—	—	4	6	—	—	19
	99	157	101	26	26	66	86	49	610

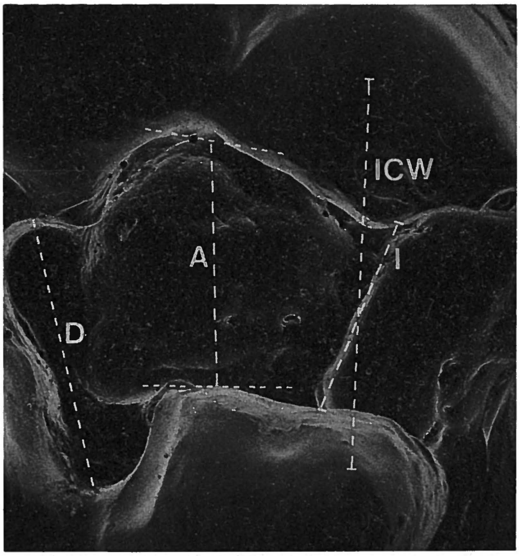

Fig. 1. Measurement of the mean occlusal buccolingual extensions of the cavity preparations. ICW = intercuspal width; I = width at the isthmus; A = width in average; D = width at the dovetail.

angles (isthmus) and at the gingival margins (Fig. 2). The proximal gingival extension was measured as the distance between the margin and the approximate location of the marginal ridge. The depth of the cavity was measured as the distance between the cavosurface margin and the pulpal floor or the axial wall.

The age of the patients varied from 8 years to 71 years, with a mean of 28 years. For operators 3, 4 and 6 the mean age of the patients varied from 36 to 40 years; for operator 1 it was 31 years; and for operators 2, 5, 7, and 8 it was 12–16 years. The operators were instructed to make an impression (Optosil/Xantopren, Bayer) of the tooth before condensing amalgam into the cavity. No instructions on preparation techniques were issued in advance; that is, no information on the presumed correct size or morphology of the cavity was presented to the operators. Although the clinicians knew that the cavity preparations were to be examined, they did not know what was to be measured and how. The cavities are therefore considered to reflect the clinical situation in everyday dental practice.

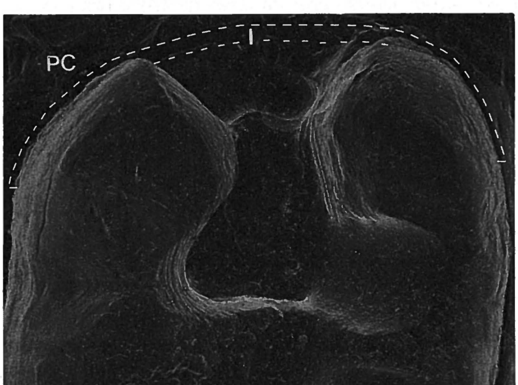

Fig. 2. Measurement of the mean proximal buccolingual extensions of the cavity preparations. PC = length of the proximal circumference; I = width at the isthmus.

The Student–Newman–Keul procedure for one-way analysis of variance (ANOVA) was used at a significance level of 0.05. The procedure determined the extent of the deviation of cavity dimensions in the different tooth categories and between the operators.

Results

Occlusal surface

The mean buccolingual width was 0.5 (SD, 0.2) of the intercuspal width, varying from 0.1 to 1.0. The width was <0.2 in 4% of the models, primarily upper premolars, and >0.8 in 13% of the models, mainly lower molars (Fig. 3). Fig. 4 illustrates the occlusal extensions in the different tooth categories. The buccolingual widths were, in general, enlarged in the lower molars (0.7) and the distal widths in the upper molars (0.6), compared with in the upper premolars (0.4) ($p < 0.05$).

The intrasurface buccolingual extension narrowed slightly towards the axiopulpal line angle in the molars. The narrowing was most obvious mesially in the lower molars (Fig. 4). The extension broadened in the premolars, especially mesially in the upper premolars.

Proximal surface

The mean gingival extension was 3.6 mm (SD, 0.8 mm) from the marginal ridge, varying from 1 to 7 mm. The gingival extension

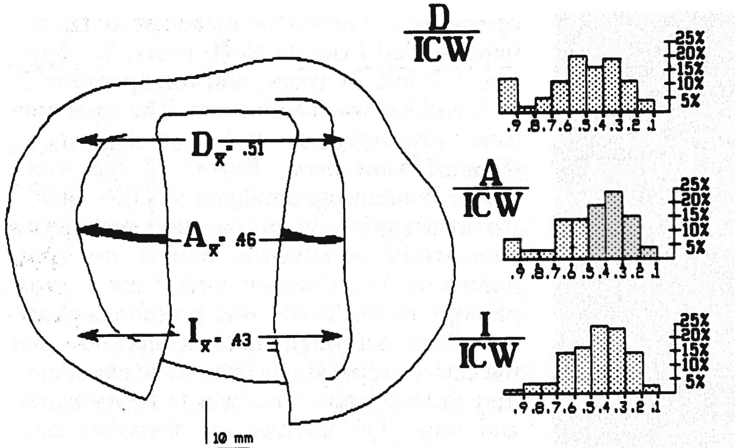

Fig. 3. The mean and prevalent occlusal buccolingual extensions of the examined cavity preparations. D/ICW = extensions at the dovetail; A/ICW = extensions on average; I/ICW = extensions at the isthmus; D_x = mean extension at the dovetail; A_x = mean extension on average; I_x = mean extension at the isthmus. All values are represented as fractions of the intercuspal width ($n = 600$) (the difference in the number of observations from $n = 610$ is due to model artifacts).

was <2 mm in 9% of the models, primarily the lower premolars, and >6 mm in 2% of the models (Fig. 5).

The gingival floor was either curved or stretched nonperpendicular to the tooth axis in 42% of the models. The gingival extension varied up to 2 mm for some preparations. The variable intrasurface gingival extensions prevailed on the distal surface of the upper premolars.

The mean buccolingual width was 0.4 (SD, 0.1) of the length of the proximal circumference, varying from 0.1 to 1.0. The width was <0.2 at the gingival margin in 5% of the models, primarily upper premolars, and >0.6 at the isthmus in 14% of the models, mainly lower molars (Fig. 5).

The intrasurface buccolingual extension narrowed towards the axiopulpal line angle; that is, the walls converged. The angle between the facial and lingual walls and the gingival floor varied on the different surfaces. The walls were more parallel on the mesial surface of the upper molars than on the proximal surfaces of the upper premolars ($p < 0.05$).

Figs. 6 and 7 illustrate the proximal extensions in the different tooth categories. The buccolingual width and the gingival extension were increased on the distal surfaces of the upper (0.5 and 4.4 mm) and lower (0.5 and 4 mm) molars compared with on the other surfaces ($p < 0.05$).

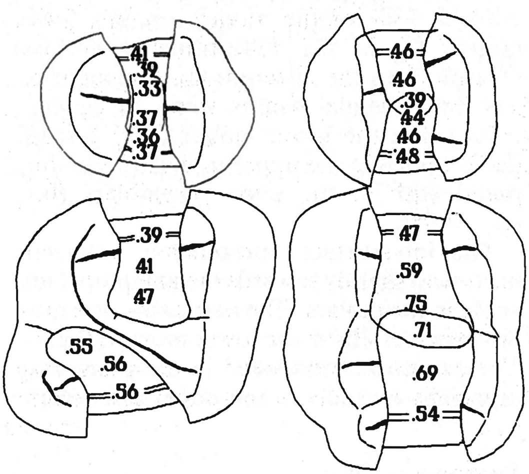

Fig. 4. The mean occlusal extension of the cavity preparations in the different tooth categories. The buccolingual extensions are represented as fractions of the intercuspal width.

Depth

The mean occlusal depth was 2.2 mm (SD, 0.6 mm) from the cavosurface margin to the pulpal floor, varying from 0.5 to 5 mm. The depth was <1 mm in 5% of the models, primarily lower premolars, and >5 mm in one model (Fig. 8).

The mean occlusal depth at the location of the axiopulpal line angle—that is, the isthmus—was 2.2 mm (SD, 0.6 mm). The intrasurface difference between the depth at

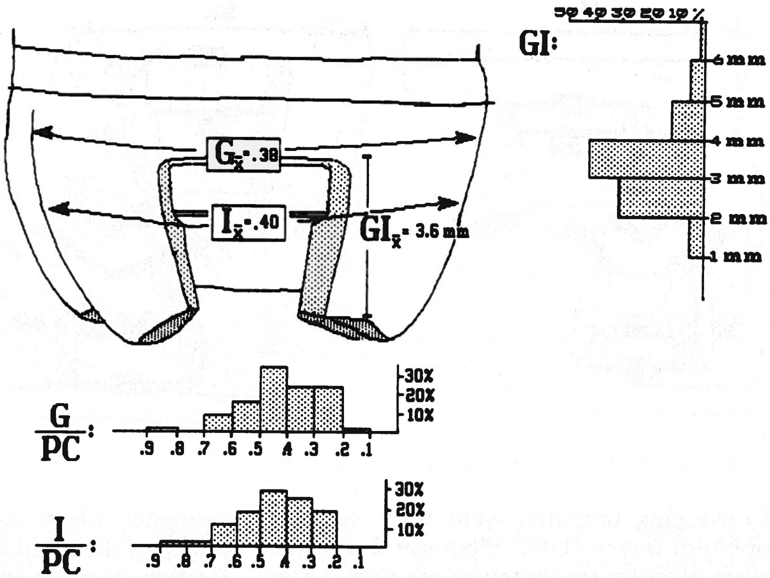

Fig. 5. The mean and prevalent proximal extensions of the examined cavity preparations. G/PC = buccolingual extensions at the gingival margin; I/PC = buccolingual extensions at the isthmus; G_x = mean extension at the gingiva; I_x = mean extension at the isthmus. All values are represented as fractions of the proximal circumference. GI = gingival extensions, and GI_x = mean gingival extension, measured from the marginal ridge to the gingival margin ($n = 605$) (the difference in the number of observations from $n = 610$ is due to model artifacts).

the isthmus and the rest of the pulpal floor varied from −3 to 1.5 mm. A shallow depth at the isthmus relative to the pulpal floor was more pronounced mesially in the upper molars than in the other surfaces ($p < 0.05$).

Fig. 9 illustrates the occlusal depths in the different tooth categories. An increased

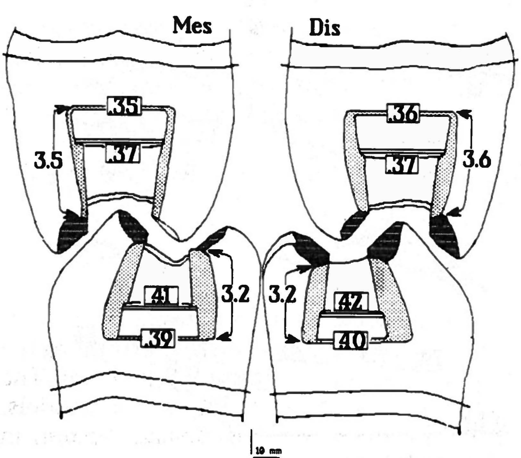

Fig. 6. The mean proximal extension of the cavities prepared in the premolars. The buccolingual extensions are represented as fractions of the proximal circumference. The gingival extension is measured from the marginal ridge to the gingival margin.

depth was observed in the upper molars (2.3 mm mesially, 2.5 mm distally) and distally in the lower molars (2.4 mm) compared with in the lower premolars (1.8 mm) ($p < 0.05$).

The mean proximal depth was 1.7 mm (SD, 0.5 mm) from the cavosurface margin to the axial wall, varying from 0.5 to 3.5 mm. The depth was <1 mm in 17% of the models, mostly premolars, and >2 mm in the premolars and >2.5 mm in the molars in 4% of the models (Fig. 8).

Fig. 9 illustrates the proximal depth in the different tooth categories. The depth was greater in the lower (1.8 mm) and upper (1.9 mm) molars than mesially in the lower (1.4 mm) and upper (1.6 mm) premolars ($p < 0.05$).

Operator variance

Significant differences from the average for certain variables was observed between the operators: operators 4 and 5 prepared large and deep cavities, and operators 6 and 8 prepared small cavities ($p < 0.05$). Broadening of the occlusal buccolingual extension towards the axiopulpal line angle was observed for operators 5 and 8 ($p < 0.05$).

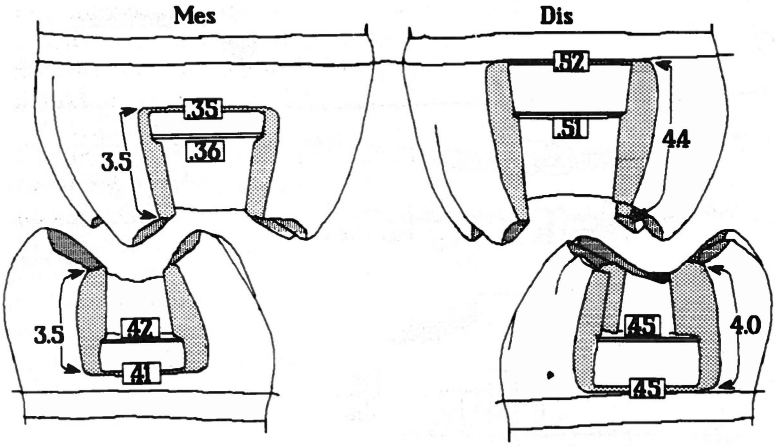

Fig. 7. The mean proximal extension of the cavities prepared in the molars. The buccolingual extensions are represented as fractions of the proximal circumference. The gingival extension is measured from the marginal ridge to the gingival margin.

Converging proximal walls were seen for operator 6 ($p < 0.05$). Operator 2 provided most of the cavity preparations with a shallow occlusal depth at the isthmus relative to the pulpal floor. Fig. 10 illustrates the outline of the mean cavity preparation of a few operators.

Discussion

Vale (32) suggested, after strength measurements on premolars, that the occlusal buccolingual width should not exceed one-fourth of the intercuspal extent. Later investigations have shown that in vitro cusp fractures are caused by a complex interaction among the load application, the occlusion, the tooth type, and the extent of the cavity preparation (33–35). The relationship between cusp fractures in vivo and occlusal and proximal widths and depths is unclear (36). It is therefore questionable to assume that the clinical prognoses of the restorations placed in these cavities are reduced because of the relatively large extensions. On the

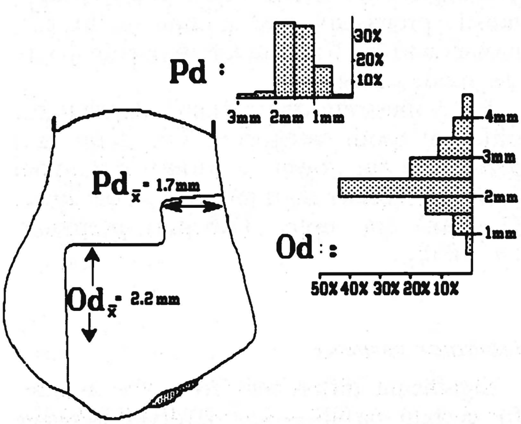

Fig. 8. The mean and prevalent depths of the examined cavity preparations. OD = occlusal depths; PD = proximal depths; OD_x = mean occlusal depth; PD_x = mean proximal depth. All depths measured from the cavosurface margin to the pulpal or axial wall ($n = 604$) (the difference in the number of observations from $n = 610$ is due to model artifacts).

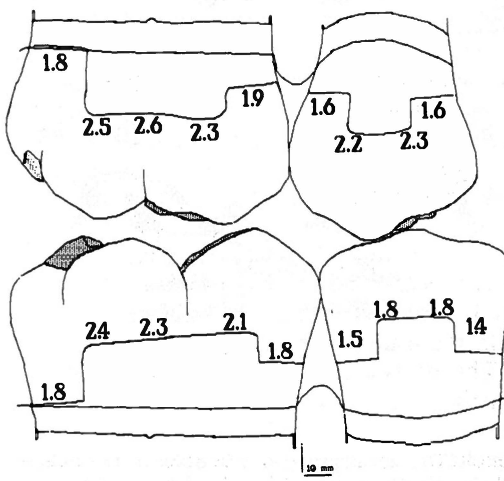

Fig. 9. The mean of the cavity preparations in the different tooth categories. The depth is measured from the cavosurface margin to the pulpal or axial wall.

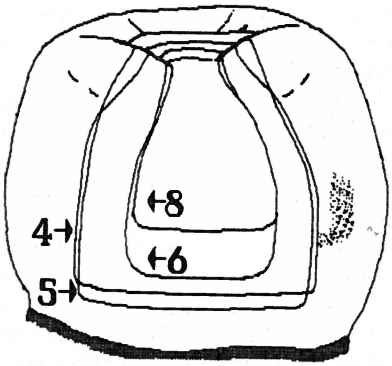

Fig. 10. The external outlines of the cavity preparations of operators 4, 5, 6, and 8.

other hand, the risk of macro- and microfractures of the restoration increases if the occlusal width is enlarged (37–39). Wide cavities render the remaining tooth structure more susceptible to strain during the cavity preparation (40), the placement of the matrix band (41–43), or the condensation of amalgam (44, 45). Stress generated in the tooth at this stage may later cause fractures of the remaining tooth (46–51).

The occlusal and proximal bulk fractures of amalgam restorations that develop after some years occur most often in the lower molars (52). This may be caused by a different cusp morphology, higher functional forces in the molars, or the lateral movements of the jaw. In the present study the mean buccolingual extension was larger in the lower molars than in the other teeth. The occlusal walls also converged more distinctly towards the isthmus. A decrease of the buccolingual extension towards the isthmus reduces the strength of the restoration at this point. It is therefore possible that the high prevalence of bulk amalgam fractures in the lower molars can be explained by the generally higher frequency of large restorations with the affiliated narrow isthmus parts.

The extent of the caries determines primarily the dimension of the prepared cavity. If the patients, as in the present study, are checked regularly, the caries is usually minimal. The proximal extensions are in these cases governed mainly by the anatomy of the proximal surface of the adjacent tooth—that is, the margins are located free from contact with the surface. The characteristic morphology of the proximal surfaces in the different tooth categories may explain the observed variation in cavity outlines. The increased buccolingual extension in the posterior teeth may be explained by the broadened contact areas (53). This is in agreement with the prevalent cavity preparations, with parallel proximal walls on the relatively flat mesial surface of the upper molars. The mean gingival extension increased in the molars. This is in harmony with a decreased axiogingival convexity but in conflict with the shorter clinical crowns throughout the arch (53).

The axiogingival convexity is more pronounced and also located more gingivally on the distal surface. On the other hand, the distal surface is usually lower (53). The identical mesial and distal extensions in the premolars are therefore expected. However, the difference between the mesial and distal extensions in the molars cannot be explained by the surface anatomy. Assuming that the extent of the carious lesions governed the extensions insignificantly, factors other than the surface anatomies influenced the amount of tissue removal.

It is not possible on models to assess the position of the margins in relation to the adjacent tooth or in relation to the anatomical root. The probability of contact between the proximal margins and the neighboring tooth can therefore only be assumed. Tentative minimum mean values are <2 mm from the marginal ridge or a buccolingual width <0.20% of the length of the proximal circumference. Ten percent of the cavity preparations in the present material include margins that are, according to these values, in contact with the adjacent tooth.

The distance between the marginal ridge and the cementoenamel junction is approximately 6 mm for premolars and molars (54). The distance from the alveolar crest to the gingival sulcus is 0.7 mm and to the dentinoenamel junction 2 mm (55). On the basis of these values, 2% of the gingival margins are placed on the anatomical root, 4% within the junctional epithelium, 19% in the sulcus, and 84% supragingivally. This differs from surveys indicating that gingival margins mostly are located subgingivally (56–59). The variation may be explained by a different mean age of the patients or a different proportion of restorations due to primary caries versus secondary caries.

Proximal secondary caries and marginal crevices develop primarily in the line point angles (60–63). The detection of these defects depends to a large extent on the use of bitewing radiographs. It is recognized that gingival defects will appear on the film at an early stage if the gingival margin is parallel to the X-ray beam. It was therefore unexpected to discover that 40% of the cavity preparations included a gingival margin with a variable extension. The restorations placed in these cavity preparations will project potential defects only at the most gingival section of the margin onto the film, owing to the radiopaque shadowing of the amalgam. The influence of a variable gingival floor on the radiographic diagnosis of secondary caries should be assessed. This would especially be pertinent for the new filling materials, since these entail new radiographic opacities and cavity preparation designs.

Depth

The enamel thickness and the cemento-enamel junction cannot be detected on plastic models. The relationship between the pulpal and axial walls and the pulp can therefore only be assumed. The mean thickness of enamel occlusally is 2–2.5 mm. The distance between the occlusal fissures and the pulp is 5 mm for premolars and molars (64).

The minimum thickness of amalgam to withstand the chewing forces has previously been set at 1 mm (65). Most textbooks recommend a depth to the dentinoenamel border, although it has also been proposed that restorations may be placed entirely in the enamel (66). The clinical minimum occlusal depth is also influenced by the occlusal and proximal buccolingual widths, the form of the antagonist, and the patient's bite force. It is therefore difficult to anticipate the prognosis of the 5% of the restorations placed in cavities prepared with an occlusal depth <1 mm.

One-third of the models displayed a variable occlusal depth. This should be avoided, according to data from in vitro studies. The clinical significance of this cavity feature remains unknown, however, except when there in addition is no dovetail, converging occlusal walls, or a sloping pulpal floor towards the isthmus.

The thickness of the enamel proximally, and the in-depth anatomy of the occlusal fissures, is identical in premolars and molars (54, 64). Moreover, the etiology and the progress, and the detection of caries, are presumably identical in the tooth categories. This contrasts with the observed increase of the cavity depth in the more distal teeth.

Operator

In the present material the morphology of the cavity preparations varied among the operators. Although some can be attributed to the different age compositions of the patient groups, certain cavity features could be recognized as characteristic for the individual operator. Variations were noted for grooves axiogingivally and/or proximally, parallel or converging proximal walls, rounded or acute internal line angles, and cavity extensions. It is possible that the numerous publications of more or less clinically successful modifications of design have made the profession reluctant to adopt new techniques in operative dentistry. It could also be observed that to various extents the operators prepared larger and more unconventionally designed cavities posteriorly. The amount of hard tissue removed is thus influenced by the dentist's ability to handle the cutting instruments. This factor can parallel the observations of variable detection capabilities and caries treatment decisions among operators (67–70).

The reason for the cavity preparations—that is, primary caries or the failure of a previous restoration—was not registered. Nor was the extent of the caries or the dimensions of any previous restorations registered. It is therefore imprecise to describe the cavity preparations as overextended. The general impression was, however, that a considerable amount of hard tissue was being removed in the posterior teeth. This contrasts with the general guideline in modern operative dentistry, which is to preserve as much tissue as possible (71, 72). Perhaps the tremendous cutting potential of modern dental instruments (73–75) has made the 'inherited' procedures for preparing cavities inappropriate.

Many of today's procedures for cavity preparation were developed at a time when dental instruments rotated relatively slowly. A reasonable cutting efficiency could therefore only be obtained by a large diameter of the bur (76). Using these large burs often resulted in an excessive removal of sound tissue (77). The observation that the extension could be reduced by initially completing the outline of the cavity before removing the caries was an important consideration in Black's textbook (78). Today, a high peripheral speed of the bur can be obtained, and the size of the burs has decreased radically. Yet dental students and dentists continue to prepare the outline form initially instead of focusing on the removal of caries (6, 72, 79).

During the preclinic courses at many dental schools the students are taught to prepare cavities with 'ideal designs' (80). The training of students to prepare ideal cavities may be valuable for educational purposes. It is possible, however, that instructors have focused too much on teaching stereotyped ideal designs, instead of teaching principles to meet certain physical requirements of the material. The training in operative dentistry may thus have created the belief that the cavity prepared with an ideal design is without exception the optimal cavity preparation.

Using Black's sequence of operative procedures with high-speed burs together with the concept of 'ideal design' will result in large cavities even after moderate caries attacks. A preferable approach would be initially to remove the carious tissue, followed by a 'locking' of the cavity and finishing of the margins (81). This method will result in tissue-conservative cavity preparations (82). The approach is furthermore logical and thus easier to apply on smaller or modified cavity preparations and for various restorative materials. Focusing on the caries and then adjusting as little as possible after it has been removed should be the goal for the future education in cavity preparation techniques.

References

1. Black GV. Probabilities. Am J Dent Sci 1875;8:241.
2. Ottolengui R. Extension for prevention. Dent Items Int 1901;23:322–33.
3. Kells CE. Three score years and nine. Chicago: Lakeside Press, 1926.
4. Black GV. Limitation of extension for prevention. Dent Summary 1904;24:173–7.
5. Sigurjons H. Extension for prevention. Historical development and current status of GV Blacks concept. Oper Dent 1983;8:57–63.
6. O'Hara JW, Clark LL. The evolution of the contemporary cavity preparation. J Am Dent Assoc 1984;108:993–7.
7. Lund MR. The development of amalgam preparations. In: The dental annual. Bristol: Wright, 1985;131–9.
8. Fischer CH. Fortschritte in der zahnerhaltung durch neue werkstoffe. Dtsch Zahnarztl Z 1971;26:228–34.
9. Parfitt JB, Herbert WE. Operative dental surgery. 6th ed. London: Edward Arnold and Co., 1948.
10. Gordon J, Morris A. A new approach to cavity preparation. Br Dent J 1950;88:302.
11. Pickard HM. Everyday procedures in dentistry. Cavity preparation for amalgam fillings. Br Dent J 1954;96:59–65.
12. Thomas AE. Evaluation of principles of cavity preparation design. Ala J Med Sci 1970;20:379–82.
13. Gilmore HW. New concepts for the amalgam restoration. London: Henry Kimpton Dental Monographs, 1964.
14. DeBoer JG. Extension for prevention. Ned T Tandheelk 1965;72:427–39.
15. Knight T. Trends in cavity design. J Dent Assoc S Afr 1966;21:247–54.
16. Mosteller JH. The relation between operative dentistry and periodontal disease. J Am Dent Assoc 1953;47:6–14.
17. Ramfjord SP. Periodontal aspects of restorative dentistry. J Oral Rehabil 1974;1:107–26.
18. Bernier JL, Knapp MJ, Boyers RC. Pros and cons on high-speed rotary instruments. Dent Progr 1960;1:47.
19. Stanley HR. Pulpal response to dental techniques and materials. Dent Clin N Am 1971;15:115–26.
20. Guard WF. A study of stress pattern variations in buccal-lingual sections of class II cavity restorations as a result of different cavity forms [Thesis]. Lincoln: University of Nebraska, 1954.
21. Gabel AB. Present-day concepts of cavity preparation. Dent Clin N Am 1957;1:3–17.
22. Judes H. Improved cavity design for amalgam restorations. Isr J Dent Med 1975;24:28–30.

23. Ingraham R, Tanner HM. The adaption of modern instruments and increased operating speeds to restorative procedures. J Am Dent Assoc 1953;47:311–23.
24. McEwen RA. High speed preparations. Dent Clin North Am 1957;1:31–42.
25. Kilpatrick HC. High speed and ultra speed in dentistry. Philadelphia: W. B. Saunders, 1959.
26. Motsch A. Rationalisierung in der konservierenden zahnheilkunde. Dtsch Zahnaerztl Z 1969;23:347–54.
27. Dreeser HP. Die drehzalabhänige präparation. Ein beitrag zur rationalisierung der präparationsarbeit. Dtsch Stomatol 1972;22:868–89.
28. Eames WB, Nale JL. A comparison of cutting efficiency of air-driven fissue burs. J Am Dent Assoc 1973;86:412–5.
29. Kinzer RL, Morris C. Instruments and instrumentation to promote conservative operative dentistry. Dent Clin N Am 1976;20:241–58.
30. Osadetez CJ. Conservative amalgam instrumentation. Ont Dent J 1977;51:18–21.
31. Welk DA, Laswell HR. Rationale for designing cavity preparations. Dent Clin N Am 1985;29:241–9.
32. Vale WA. Cavity preparation. Ir Dent Rev 1956; 2:33–41.
33. Re G, Norling BK. Fracturing molars with axial forces. J Dent Res 1981;60:805–8.
34. Re GJ, Norling BK, Draheim RN. Fracture strength of molars containing three surface amalgam restorations. J Prosthet Dent 1982;47:185–9.
35. Cavel WT, Kelsey WP, Blankenau RJ. An in vivo study of cuspal fracture. J Prosthet Dent 1985; 53:38–42.
36. Nadal R, Phillips RW, Swartz M. Clinical investigation on the relation of mercury to the amalgam restorations. II. J Am Dent Assoc 1961;51:489–96.
37. Berry TG, Laswell HR, Osborne JW, Gale EN. Width of isthmus and marginal failure of amalgam. Oper Dent 1981;6:55–8.
38. Birtcil RF Jr, Pelzner RB, Stark MM. A 30-month clinical evaluation of the influence of finishing and size of restoration on the margin performance of five amalgam alloys. J Dent Res 1981;60: 1949–56.
39. Goldberg J, Munster E, Rydinge E, Sanchez L, Lambert K. Experimental design in the clinical evaluation of amalgam restorations. J Biomed Mater Res 1980;14:777–88.
40. Bell JG, Smith MC, Pont de JJ. Cuspal fracture of MOD restored teeth. Aust Dent J 1982;27:283–7.
41. Powell GL, Nicholls JI, Rolver MP. Influence of matrix bands, dehydration and amalgam condensation on deformation of teeth. Oper Dent 1980;5:95–9.
42. Krainau R. Verformungsmessung an kavitten der klasse II unter matrizenbandeinwirkung [Thesis]. Göttingen: University of Göttingen, 1985.
43. Krainau R, Meyer G, Vogel A, Lauterborn W. Kavittsdeformation unter matrizeneinwirkung-Messungen mit hilfe granulationsoptischer methoden. Dtsch Zahnarztl Z 1987;42:102–4.
44. Bell JG. An elementary study of deformation of molar teeth during amalgam restorative procedures. Aust Dent J 1977;22:177–81.
45. Braly BV, Maxwell EH. Potential for tooth fracture in restorative dentistry. J Prosthet Dent 1981;45: 411–4.
46. Cameron DE. The cracked tooth syndrome. J Am Dent Assoc 1964;68:405–11.
47. Grimaldi JR. Measurement of lateral deformation of the tooth crown under axial compressive cuspal loading [Thesis]. Otago: University of Otago, 1971.
48. Snyder DE. The cracked tooth syndrome and fractured posterior cusps. Oral Surg 1976;41:698–704.
49. Rosen H. Cracked tooth syndrome. J Prosthet Dent 1981;47:36–43.
50. Fisher FJ. Toothache and cracked cusps. Br Dent J 1982;153:298–300.
51. Salis GF, Hood JA, Stokes AN, Lirk EE. Impact fracture of natural teeth. J Dent Res 1985;64:651.
52. Lemmens LM, Peters CR, Van 't Hof MA, Letzel H. Influence on the bulk fracture incidence of amalgam restorations: a 7-year controlled clinical trial. Dent Mater 1987;3:90–3.
53. Mannerberg F. Frilägging av präparationsgränsen. Tandlakartidningen 1973;65:26–30.
54. Wheeler RC. Dental anatomy, physiology and occlusion. 5th ed. Philadelphia: W.B. Saunders, 1974.
55. Block PL. Restorative margins and periodontal health: A new look at an old perspective. J Prosthet Dent 1987;57:683–9.
56. Björn AL, Björn H, Grkovic B. Marginal fit of restorations and its relation to periodontal bone level. Odontol Rev 1969;20:311–21.
57. Hansen BF. Marginal fit of dental restorations in a 35 year old Norwegian urban population. Dentomax Fac Radiol 1980;9:78–80.
58. Steffensen B. Præpareringsgrænsens cervikale placering. En literaturoversigt. Tandlaegebl 1983; 87:389–96.
59. Arneberg P, Silness J, Nordbø H. Marginal fit and cervical extent of class II amalgam restoration related to periodontal condition. A clinical and roentgenological study of overhang elimination. J Periodont Res 1980;15:669–77.
60. Laswell HR. A prevalence study of secondary caries occurring in a young adult male population [Thesis]. Indianapolis: University of Indiana, 1966.
61. Spens E. Vergleichende untersuchungen über die häufigkeit des auftretens der sekundären randkaries. Dtsch Stomatol 1972;22:90–100.
62. Eide R, Birkeland JM. Revisjon av fyllinger lokalisasjon av defekter. Nor Tannlegeforen Tid 1982; 92:159–62.
63. Mjör IA, Smith DC. Detailed evaluation of six class 2 amalgam restorations. Oper Dent 1985;10:17–21.
64. Fredriksen G. The measures of human teeth [Thesis]. Oslo: University of Oslo, 1970.
65. Mahler DB. An analysis of stresses in a dental amalgam restoration. J Dent Res 1958;37:516–26.
66. Fusayama T. Enamel cavity amalgam filling. Jpn J Conservative Dent 1971;13:171–5.
67. Espelid I, Tveit AB. Radiographic diagnosis of min-

eral loss in approximal enamel. Caries Res 1984; 18:141–8.
68. Nuttall NM, Elderton RJ. The nature of restorative dental treatment decisions. Br Dent J 1983;154:201–6.
69. Elderton RJ. Treatment variation in restorative dentistry. Rest Dent 1984;1:3–8.
70. Merrett MC, Elderton RJ. An in vitro study of restorative dentistry treatment decisions and dental caries. Br Dent J 1984;157:128–33.
71. Osborne JW, Hoffman R, Ferguson GW. Conservation of tooth structure. J Ala Dent Assoc 1972;56:24–6.
72. Sturdevant CM, Barton RE, Sockwell CL, Strickland WD. The art and science of operative dentistry. 2nd ed. St Louis: The C.V. Mosby Co., 1985.
73. Christensen DO. Temperature and stress profiles in teeth during cavity preparation [Thesis]. Salt Lake City: University of Utah, 1973.
74. Pearlman S. The cutting edge. Interfacial dynamics of cutting and grinding. DHEW publ (NIH) 1976; 76–670.
75. Brown WS, Christensen DO, Lloyd BA. Numerical and experimental evaluation of energy inputs, temperature gradients and thermal stresses during restorative procedures. J Am Dent Assoc 1978;96: 451–8.
76. Eichner K. Normal-, hoch und höchsttouriges bohren und schleifen von zahnartsubstanzen. Munich: Hanser Verlag, 1966.
77. Henry EE, Peyton FA. The relationship between design and cutting efficiency of dental burs. J Dent Res 1954;33:281–92.
78. Lester KS. Burs, teeth and hand instruments. Austral Dent J 1978;23:231–6.
79. Cavity preparations, Project ACORDE. Washington DC: National Audiovisual Center, 1975, 121–70.
80. Achter van D. Are Black's cavity preparations still of value? Rev Belg Med Dent 1967;22:399–410.
81. Elderton RJ. New approaches to cavity design. Br Dent J 1984;157:421–7.
82. Wolff MS. Conservative technique results in better restorations. Dent Stud 1981;60:32–6.

Received for publication 22 March 1988