The apical level of root fillings

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The apical level of root fillings made by general practitioners, undergraduate students and an endodontist was compared. In total, 3003 root fillings were grouped morphometrically in three classes. Class A fillings were ending at a distance from the radiographic apex. Class B fillings were ending flush with the radiographic apex or with an overfilling of not more than 1 mm, while class C consisted of fillings with a moderate (1—2 mm) or marked (> 2 mm) excess. For 2187 class A fillings the distance from the apical end of the root filling to the radiographic apex was measured to the nearest 0.5 mm. The 531 class B and 285 class C root fillings were given the distance 0.0 mm. A detailed classification of root fillings with regard to their length was then developed by calculating the average distances and standard deviations. A longer apex-distance was observed for root fillings made by the general practitioners than for those made by the undergraduates and the endodontist. Class B and C fillings were infrequently observed among fillings made by general practitioners. Roots from three-rooted teeth had been filled closer to the radiographic apex by the endodontist than by undergraduates. A higher relative number of class C fillings was observed for undergraduates than for the endodontist, while the opposite observation was made for class B cases.

Key-words: Endodontics; root fillings; education, dental

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A relationship between the apical level of root fillings and the long-term result of endodontic therapy has been shown in studies carried out along two main lines. Radiographic and clinical follow-up examinations have been made (*Strindberg*, 1956; *Nicholls*, 1960; *Grahnén & Hansson*, 1961; *Seltzer, Bender & Turkenkopf*, 1963; *Engström & Lundberg*, 1965; *Ingle*, 1965; *Boysen, Giörtz-Carlsen & Ånerud*, 1972), and histological studies of the apical region and the periapical area after experimental root canal treatment have been performed, usually supplemented with a clinical and radiographic evaluation of the material (*Nygaard-Østby*, 1939, 1944; *Ketterl*, 1963, 1965; *Engström & Spångberg*, 1967; *Seltzer et al.*, 1967; *Sinai et al.*, 1967; *Seltzer et al.*, 1968; *Baume, Holz & Risk*, 1971). These investigations have shown that the root canal preparation and the subsequent level of the root filling should be different for vital and non-vital teeth, although, in both situations the aim of the operator is to reach the apical part of the root with his instruments and root filling material. In the individual case, however, the result of the treatment is influenced by the morphol-

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ogy of the root canal and, most likely, by the operator's technical skill and attitudes to endodontics.

Obviously, it would be of interest to know if the treatment result is influenced by differences in training and clinical experience. Indirectly, some information on this point can be gained by comparing earlier studies dealing with treatment results obtained by undergraduate students (*Begelmann*, 1929; *Brühlmann*, 1931; *Castagnola*, 1950; *Grahnén & Hansson*, 1961; *Engström*, 1964; *Heling & Tamsche*, 1970), by dentists with endodontics as their special field of interest (*Dimkowa*, 1927; *Lipschitz*, 1930; *Strindberg*, 1956; *Seltzer, Bender & Turkenkopf*, 1963; *Keresztesi & Kellner*, 1972), or by general practitioners (*Vollmar*, 1923; *Bugge*, 1937; *Strindberg*, 1939, *Egli*, 1963; *Brynolf*, 1967; *Sperr*, 1970; *Boysen, Giörtz-Carlsen & Ånerud*, 1972; *Bergenholtz, Malmcrona & Milthon*, 1973). However, more conclusive results would be expected by a direct comparison of endodontic treatments performed by operators with different training and clinical experience. The main purpose of the present investigation was to compare the apical level of root fillings for roots treated by general practitioners, undergraduate students, and a dentist with endodontics as his special field of interest (in the following referred to as endodontist). Such a comparison made should be of value in evaluating the undergraduate and postgraduate teaching of endodontics and might contribute to the current discussion of the aims and standard of dental treatment in general (*Moore & Stewart*, 1967; *Björn, Björn & Grkovic*, 1969, 1970; *Molven*, 1971; *Schonfeld*, 1971; *Spens & Taatz*, 1972; *Silness*, 1973).

A comparison of this type requires a detailed classification of the root fillings according to their extension in the root. As will be discussed, the classifications used hitherto are unsatisfactory in this respect. An additional aim of the present investigation was, therefore, to develop a more detailed classification of root fillings.

MATERIAL AND METHODS

Initially, records of 3118 roots treated endodontically by root filling were obtained from 681 individuals. The majority of the treatments had either been performed prior to the patients' admittance at the Department of Cariology, University of Bergen, School of Dentistry, or in this department (2685 roots, 495 patients). An additional 433 roots (186 patients) had been treated by an endodontist. At the time of treatment the present evaluation had not yet been planned.

Available radiographs and complete records from the endodontic treatment served as a basis for recording of the following clinical variables: (1) operator, (2) root treated, (3) number of roots of the treated tooth, (4) treatment form, (5) class of root filling according to the classification of *Strindberg* (1956), and (6) root canals ending at a distance from the radiographic apex. Forty-two roots with remaining part of fractured canal instrument were included in the material.

The original material was reduced by excluding teeth for which the information on the selected variables was incomplete, the radiographs were found to be unsatisfactory, as well as teeth treated in the dental school by graduate students or instructors. Roots exhibiting atypical anatomy such as malformation and bifidity were also excluded. Thus, the subsequent analysis was based on 3003 root fillings in 2581 roots.

Revisions were recorded both before

and after the second endodontic treatment. This accounts for the differences between the number of root fillings and roots. In pulpectomies made in the teaching clinic or by the endodontist the aim was to end the canal preparation and the root filling at a short distance coronally to the radiographic apex. In the treatment of pulpless teeth the aim was to fill the root canal to the radiographic apex. As root filling materials were used gutta-percha points and a paste made from Kloroperka NÖ® (*Nygaard-Østby*, 1939, 1944).

The classification and measuring of root fillings

For roots treated either by undergraduate students working under supervision of instructors or by the endodontist, the classification and measurements were based on radiographs taken immediately after completed treatment. Root fillings made by general practitioners were studied in radiographs taken prior to treatment in the dental school or by the endodontist.

The radiographs had been taken either 1) by a modified bisecting technique using a long cone, 2) by applying the bisecting rule operating a short cone, or 3) by a standard intraoral technique employing the Eggen film holder (*Carlsson & Benkow*, 1964). The first projection technique had been used for a 14-film series of intra-oral exposures taken at the Department of Oral Roentgenology. The technical standard of these radiographs had been evaluated by instructors working in that department. The great majority of exposures by the other two techniques had been made either by undergraduate students or by the endodontist. The technical standard of the exposures made by undergraduates had been evaluated by instructors in the Department of Cariology.

The classification and measuring of root fillings were performed by the author in a room specially designed for radiographic analysis. All readings were done during the first half of the day by a fixed routine which also included resting periods. The radiographs were placed over a viewing box masked to the dimension of one film and examined directly or through a magnifying glass. A circular diaphragm with adjustable light was used for analysis of smaller areas.

Root fillings were classified according to *Strindberg* (1956). The differentiation between the root-filling classes B and C, i.e. between fillings ending flush with the radiographic apex or with an overfilling of not more than 1 mm (class B) and fillings with a moderate (1—2 mm) or marked (> 2 mm) excess (class C), was made by repeated measurements of the largest dimension of the overfilling in the radiograph.

For partial root fillings (class A) the distance from the apical end of the root filling to the radiographic apex (apex-distance) was measured in radiographs which reproduced a distinct apex and a clearly visible termination of the root filling. The class A root fillings were usually measured in 2—5 radiographs, taken by one or more radiographic techniques. All measurements were performed twice with an interval of 4—5 days. The selected radiographs were marked in order to secure that the repeated measurements were made on the same radiographs.

Totally, 2187 class A root fillings were measured twice on 3349 radiographs, 1921 taken by the modified longcone technique. 763 by applying the bisecting

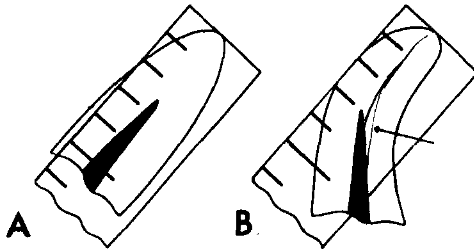


Fig. 1. The measuring of the apex-distance, i.e. the distance from the apical end of a root filling to the radiographic apex. A translucent 1 mm graded ruler was placed over the radiograph and the distance judged to the nearest 0.5 mm.

A. Normal situation, the measured distance 2.5 mm.

B. Measuring a root filling deviating from the direction taken by the apical part of the root and the root canal. The measurement is made from the position where the root filling leaves the canal (arrow). Measured distance in this case 3.5 mm.

rule operating a short cone, and 665 by the Eggen film holder.

The apex-distance was measured with a translucent ruler to the nearest 0.5 mm (Fig. 1). A deviation between two measurements of more than 1.0 mm occurred in two cases. A third and decisive measurement was made in these cases. The measurements were made in relation to the radiographic apex also for 15 roots in which the root canal could be seen to end at a distance from the radiographic apex.

For roots in which two separate root fillings were observed, the apex-distance was measured only for the most apical one. Thirty-four root fillings which in some radiographs appeared to reach the radiographic apex, in others not, were grouped as class A fillings. While the classification was determined by the radiographs exhibiting the class A situation, the subsequent calculation of the location of the apical end was also based on radiographs in which an apex-distance of zero had been recorded.

Thirty-four cases which exhibited excess filling material although the root fillings terminated short of the apex, were classified as class A fillings and measured in the usual way.

The mean apex-distance of each class A root filling was calculated as the average distance to the radiographic apex based on all measurements for that filling. Class B and C fillings were given the distance 0.0 mm. Mean distances and standard deviations for groups of root fillings were calculated both for the total number of fillings and separately for the class A fillings.

Statistical treatment of the data

Standard statistical procedures were used for calculation of the mean, standard deviation and error of the method. Student's t-test was chosen to determine systematic deviations between two sets of measurements on radiographs taken by the same projection technique. For comparisons between the different radiographic techniques, and between and within operators, a test for non-normal populations with unknown variances was used (*Hald*, 1960).

The values given in the Tables for mean distances, standard deviations and the fractiles of the standard normal curve have been adjusted by a reduction of the decimals.

RESULTS

The method error rates for measurement of the apex-distance are given in Table I. When judging the measured distance to the nearest 0.5 mm it was found that neither the analysis within radiographs taken by one of the three projection techniques, nor the comparisons between the techniques revealed any systematic deviations. Mean distances could, there-

Table I. *Method error rates within and between intraoral radiographs taken by three different projection techniques for class A root fillings*

Within techniques					
Projection	n	τ	τ %	$\bar{d}$	t
Modified Long Cone	40	0.32	7.2	—0.13	1.26
Eggen Film Holder	40	0.22	5.2	0.03	0.28
Bisecting Rule	40	0.22	6.5	0.04	0.39

Between techniques			
Projection	n	$\bar{x}$	z
Modified Long Cone	40	3.60	0.15
Eggen Film Holder	40	3.76	
Modified Long Cone	40	3.46	0.44
Bisecting Rule	40	3.61	
Eggen Film Holder	40	2.86	0.57
Bisecting Rule	40	3.04	

n = number of radiographs, τ = error of measurement,

$\tau = \sqrt{\frac{\Sigma d^2}{2n}}$ (*Dahlberg* 1948), τ % = τ in percent of mean of all measurements, d = mean difference between first and second measurement.

z = fractile in standard normal distribution.

fore, be calculated not only on the basis of measurements within projection technique, but also by combining such measurements.

A survey of the results for each group of operators is found in Fig. 2. The material is divided after differentiating by anatomical factors (Tables II, III, IV) and also according to treatment form for root fillings made by undergraduate students and the endodontist (Table V, Figs. 3, 4).

Comparison of operators

Some common findings were made for all three operator groups. As might be expected, the longest mean apex-distance among anterior teeth was recorded for maxillary cuspids (Table III). The buccal and palatal roots of the first maxillary premolars exhibited high averages in the premolar group (Table III). The greatest mean apex-distances in molars were observed for the mesio-buccal roots of maxillary molars and the mesial roots of mandibular molars (Table IV).

The root fillings in single-rooted teeth exhibited a shorter mean apex-distance than fillings from two- and three-rooted teeth ($p < 0.01$).

a. *General practitioners/undergraduate students and the endodontist*

A root filling flush with the radiographic apex or with an excess was infrequently observed among fillings made by general practitioners (7.6 %), whereas such fillings accounted for 40—50 % of the total number of root fillings made by undergraduate students or the endodontist (Fig. 2), More than 60 % of the fillings

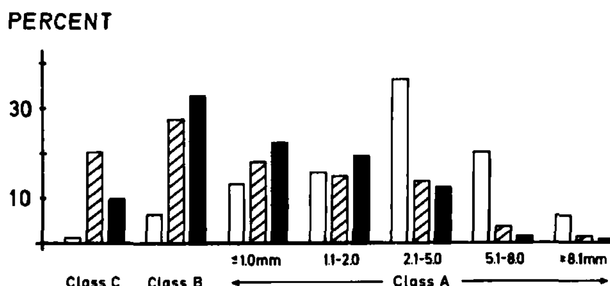


Fig. 2. Root fillings made by general practitioners (open bars), undergraduate students (lined bars) and an endodontist (continuous bars). Percentage distribution in the classes A, B & C according to *Strindberg* (1956). The root fillings in class A distributed in 5 classes according to their apex-distance. Notice that different class intervals are used.

Table II. *Mean apex-distances and standard deviations for all root fillings and for class A fillings. Distribution according to operators, number of roots and number of root fillings*

Opera-tors	Roots	All root fillings $\bar{x}$	S.D.	Class A root fillings $\bar{x}$	S.D.	No. of root fillings Total	A	%	B	%	C	%
	1	3.2	2.56	3.6	2.46	965	877	90.9	70	7.2	18	1.9
GP	2	4.6	2.74	4.8	2.60	384	365	95.1	17	4.4	2	0.5
	3	4.4	2.63	4.6	2.49	155	147	94.8	8	5.2		
	1	0.7	1.20	1.7	1.34	619	258	41.7	211	34.1	150	24.2
S	2	1.5	2.03	2.5	2.07	279	171	61.3	56	20.1	52	18.6
	3	2.3	2.53	3.2	2.44	206	146	70.9	37	18.0	23	11.1
	1	0.7	0.97	1.4	0.91	133	67	50.4	46	34.6	20	15.0
E	2	1.3	1.62	2.0	1.64	117	77	65.8	34	29.1	6	5.1
	3	1.2	1.79	2.3	1.89	145	79	54.5	52	35.9	14	9.6

Table III. *Mean apex-distances and standard deviations for all root fillings and for class A fillings. Distribution by operators and number of root fillings in classes A, B and C for anterior teeth and premolars*

Tooth	Opera-tors	All root fillings $\bar{x}$	S.D.	Class A root fillings $\bar{x}$	S.D.	No. of root fillings Total	A	%	B	%	C	%
Maxillary	GP	1.8	2.10	2.2	2.12	116	96	82.8	11	9.5	9	7.7
central	S	0.3	0.69	1.1	0.93	67	18	26.9	33	49.3	16	23.8
incisor	E	0.5	0.92	1.9	0.54	23	9	27.3	11	33.3	3	39.4
Maxillary	GP	2.0	2.19	2.4	2.19	156	131	84.0	23	14.7	2	1.3
lateral	S	0.4	0.87	1.4	1.18	72	19	26.4	37	51.4	16	22.2
incisor	E	0.2	0.48	0.9	0.65	22	5	22.7	10	45.5	7	31.8
Maxillary	GP	3.9	2.71	4.1	2.59	131	122	93.1	7	5.3	2	1.6
cuspid	S	0.7	1.04	1.5	1.05	91	41	45.1	27	29.7	23	25.2
	E	1.2	1.19	1.7	1.04	19	13	68.4	4	21.1	2	10.5
Maxillary first	GP	4.2	2.58	4.5	2.36	127	117	92.1	9	7.1	1	0.8
premolar	S	1.0	1.40	2.0	1.37	55	28	50.9	15	27.3	12	21.8
Palatal root	E	1.3	1.47	1.4	1.49	11	10	90.9	1	9.1		
Maxillary first	GP	4.3	2.57	4.5	2.44	125	119	95.2	6	4.8		
premolar	S	1.4	2.12	2.8	2.22	54	28	51.9	15	27.8	11	20.3
Buccal root	E	1.2	1.16	2.6	0.52	11	5	45.5	6	54.5		
Maxillary second	GP	3.6	2.29	3.9	2.12	158	146	92.4	11	7.0	1	0.6
premolar Single-	S	0.9	1.13	1.6	1.27	93	53	57.0	25	26.9	15	16.1
rooted with one	E	0.8	0.77	1.3	0.58	17	11	64.7	5	29.4	1	5.9
root filling												
Mandibular second	GP	3.6	2.42	3.9	2.31	137	129	94.1	8	5.8		
premolar Single-	S	1.1	1.54	2.1	1.56	85	46	54.1	19	22.4	20	23.5
rooted with one	E	1.0	1.12	1.3	1.11	14	10	71.4	3	21.4	1	7.2
root filling												

Table IV. *Mean apex-distances and standard deviations for all root fillings and for class A fillings. Distribution by operators and number of root fillings in classes A, B & C for molars*

Tooth/root	Operators	All root fillings x̄	S.D.	Class A root fillings x̄	S.D.	No. of root fillings Total	A	%	B	%	C	%
Maxillary molar Palatal root	GP	3.5	2.59	3.8	2.47	78	72	92.3	6	7.7		
	S	1.5	2.15	2.5	2.31	77	45	58.4	23	29.9	9	11.7
	E	0.9	1.56	1.9	1.86	54	24	44.4	24	44.4	6	11.2
Maxillary molar Mesio-buccal root	GP	5.9	2.50	6.0	2.36	46	45	97.8	1	2.2		
	S	3.3	2.69	3.8	2.53	66	57	86.4	6	9.1	3	4.5
	E	1.8	2.25	2.8	2.26	48	30	62.5	13	27.1	5	10.4
Maxillary molar Disto-buccal root	GP	4.4	2.34	4.6	2.24	34	33	97.1	1	2.9		
	S	2.2	2.39	3.1	2.27	68	47	69.1	10	14.7	11	16.2
	E	1.1	1.32	1.9	1.22	46	25	54.4	18	39.1	3	6.5
Mandibular molar Mesial root	GP	6.7	2.83	6.7	2.83	47	47	100.0				
	S	2.5	2.64	3.4	2.52	68	50	73.5	3	4.4	15	22.1
	E	1.8	1.95	2.4	1.90	42	31	73.8	9	31.4	2	4.8
Mandibular molar Distal root	GP	4.7	2.72	4.9	2.56	60	57	95.0	2	3.3	1	1.7
	S	1.1	1.63	1.9	1.72	72	44	61.1	15	20.8	13	18.1
	E	0.9	1.32	1.4	1.44	43	26	60.5	13	30.2	4	9.3

Table V. *Mean apex-distances and standard deviations for all root fillings and for class A fillings. Distribution by operators, treatment form, number of roots and the number of root fillings*

Treatment	Operators	Roots	All root fillings x̄	S.D.	Class A root fillings x̄	S.D.	No. of root fillings Total	A	%	B	%	C	%
Revisions*)	S	1	0.6	1.28	1.8	1.58	245	85	34.7	99	40.4	61	24.9
		2	1.5	2.35	3.1	2.55	98	47	48.0	28	28.6	23	23.4
		3	3.2	3.18	4.2	2.99	44	33	75.0	7	15.9	4	9.1
Treatment of necrotic pulps		1	0.3	0.98	1.9	1.70	142	24	16.9	63	44.4	55	38.7
		2	1.3	1.63	2.1	1.63	36	22	61.1	10	27.8	4	11.1
		3	1.3	1.47	2.2	1.27	28	16	57.1	5	17.9	7	25.0
Pulpectomies		1	1.0	1.16	1.6	1.10	228	148	64.9	48	21.1	32	14.0
		2	1.6	1.89	2.3	1.86	145	102	70.3	18	12.4	25	17.3
		3	2.2	2.38	3.1	2.26	132	95	72.0	25	18.9	12	9.1
Revisions*)	E	1	1.0	1.08	1.6	0.95	58	38	65.5	15	25.9	5	8.6
		2	1.9	2.02	2.5	1.98	34	26	76.5	7	20.6	1	2.9
		3	2.3	2.51	3.2	2.43	42	30	71.4	10	23.8	2	4.8
Treatment of necrotic pulps		1	0.4	0.81	1.2	1.03	53	17	32.1	25	47.2	11	20.7
		2	0.9	1.50	1.6	1.71	44	24	54.6	16	36.3	4	9.1
		3	0.6	0.93	1.4	0.99	42	17	40.5	20	47.6	5	11.9
Pulpectomies		1	0.7	0.69	1.2	0.43	22	12	54.5	6	27.3	4	18.2
		2	1.2	1.20	1.7	1.07	39	27	69.2	11	28.2	1	2.6
		3	1.0	1.27	1.8	1.24	61	32	52.5	22	36.1	7	11.4

*) Roots formerly subjected to pulpotomy included.

Table VI. *Comparison of mean apex-distances between operators. Significance level of differences between mean apex-distances for all root fillings (Total) and for class A fillings*

		Comparison between operators					
		GP and S		S and E		GP and E	
	Table	Total	Class A	Total	Class A	Total	Class A
The whole material		***	***	0	0	***	***
Root fillings from single-rooted teeth		***	***	0	*	***	***
Root fillings from two-rooted teeth	II	***	***	0	**	***	***
Root fillings from three-rooted teeth		***	***	***	**	***	***
Maxillary cuspid		***	***				
Maxillary second incisor	III	***					
Maxillary central incisor		***					
Maxillary second premolar, single-rooted, one root filling		***	***				
Mandibular second premolar, single-rooted, one root filling	IV	***	***				
Maxillary first premolar, palatal root		***					
Maxillary first premolar, buccal root		***					
Maxillary molar, palatal root		***	**	0		***	
Maxillary molar, mesio-buccal root		***	***	**	0	***	***
Maxillary molar, disto-buccal root	V	***	**	**		***	
Mandibular molar, mesial root		***	***	0	*	***	***
Mandibular molar, distal root		***	***	0		***	

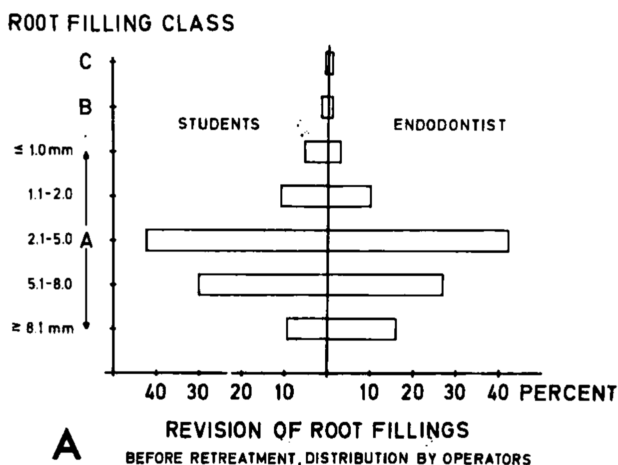
0 not significant
* $0.01 < p < 0.05$
** $0.001 < p < 0.01$
*** $p < 0.001$

made in general practice had a mean apex-distance longer than 2.0 mm. The corresponding figures for undergraduates and the endodontist were approximately 19 and 15 %, respectively (Fig. 2).

A comparison between operators showed that, provided all treatment forms were included for undergraduates and the endodontist, the root fillings made by general practitioners were located at a significantly longer distance from the radiographic apex than those performed by the other operators (Table VI). This observation was made both for the total number of root fillings and for the class A fillings alone, irrespective of anatomic grouping.

As will be discussed, comparisons between the shortest mean apex-distance observed among root fillings made by dentists in general practice and the highest averages observed for the other two operator groups, were of special interest. Such comparisons were made first with all treatments included for the latter operators and, thereafter, with specific treatment forms for the same two operator groups.

The first comparison disclosed that root fillings performed by the endodontist in mesio-buccal and mesial molar roots ended nearer the radiographic apex than root fillings from single-rooted teeth treated by general practitioners ($p < 0.01$). No differences were disclosed between the



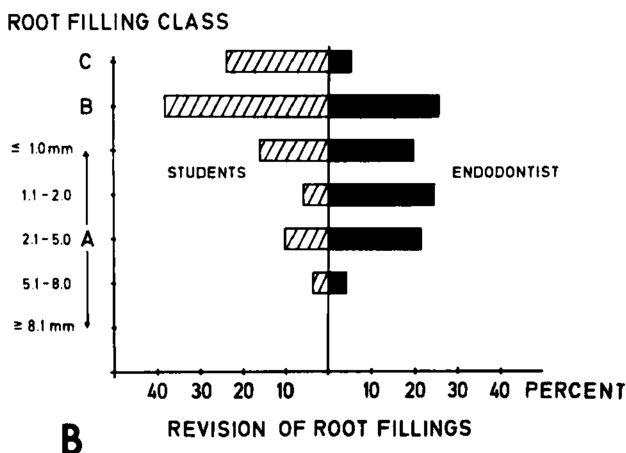


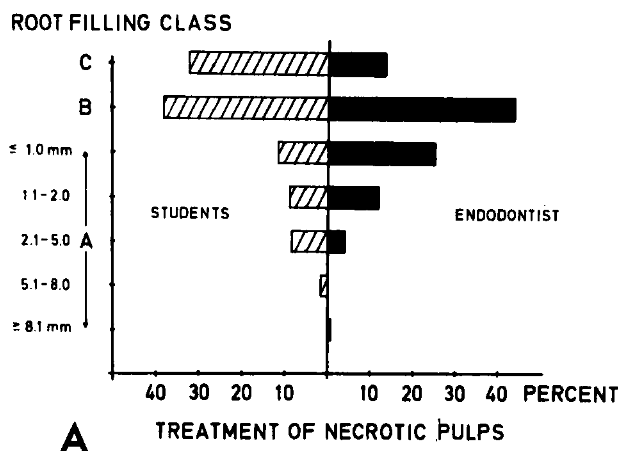
Fig. 3. A. Root fillings made by general practitioners which have been retreated by undergraduate students and an endodontist. Distribution according to apex-distance prior to retreatment. For further details see legend Fig. 2.

B. The postoperative situation for the root fillings in Fig. 3A.

same molar roots and maxillary central incisors root-filled by general practitioners.

The mean apex-distance for root fillings in single-rooted teeth treated by general practitioners was not different from the distance for mesio-buccal molar roots filled by undergraduates. However, root fillings in sertedin maxillary central incisors by general practitioners were closer to the apex than the mesio-buccal fillings just mentioned ($p < 0.01$). On the other hand, fillings in central incisors were not, on the average, located nearer the radiographic apex than root fillings inserted by undergraduates in the mesial roots of molars unless the comparison was limited to class A root fillings ($p < 0.01$).

Root fillings made by general practitioners in roots from single-, two- and three-rooted teeth for which the treatment form was unknown were compared with fillings from corresponding roots either retreated or pulpectomized by the undergraduates and the endodontist. The comparison revealed that the fillings made by the former operators had a longer apex-



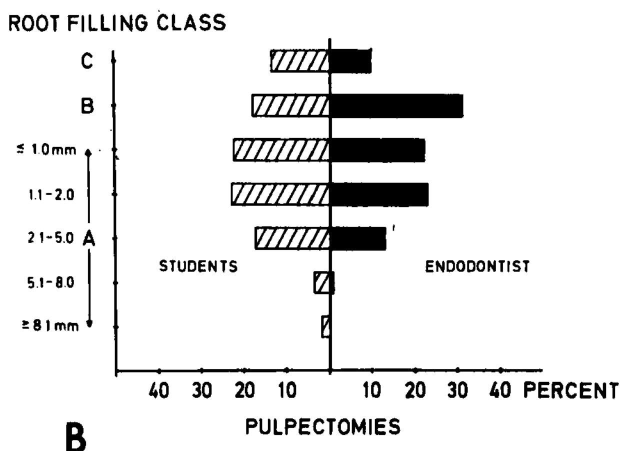


Fig. 4. The distribution of root fillings according to apex-distance. For further details see legend Fig. 2.

A. Roots subjected to treatment of primary necrosis.

B. Pulpectomies.

distance ($p < 0.01$). Moreover, retreatment in most instances resulted in a considerable lengthening of the root fillings (Fig. 3A, B).

While most of the roots subjected to retreatment had formerly been filled by gutta-percha, three root fillings consisting of other materials were encountered.

b. *Undergraduate students/endodontist*

The undergraduates had completed a higher relative number of root fillings in class C than the endodontist (Tables II, V, Figs. 4A, B). The frequency of roots filled to a distance $\leq$ 2.00 mm from the radiographic apex after pulpectomy was approximately 45 % for undergraduates and the endodontist. The frequencies in pulpectomy cases of fillings taken to the apex with or without an excess were nearly 32 % and 42 % for undergraduates and the endodontist, respectively (Fig. 4B).

Roots from three-rooted teeth had been filled closer to the radiographic apex by the endodontist than by the undergraduate students (Tables II, IV), in particular the mesio-buccal and disto-buccal maxillary molar roots (Tables IV, VI).

The class A root fillings made by the endodontist in single-, two- and three-rooted teeth ended, on the average, at a shorter distance from the radiographic apex than those made by undergraduate students (Tables II, V). The same trend was observed for all class A fillings.

Single-rooted teeth retreated by undergraduates exhibited a higher relative number of fillings in the classes B and C than observed for the endodontist (Table V). This accounts for a difference between these operator groups in the average apex-distance for the total number of refillings in single-rooted teeth ($0.05 > p > 0.01$).

DISCUSSION

The methods

The main purpose of the present investigation was to compare endodontic treatment results obtained by general practitioners, undergraduate students working under supervision and an endodontist, using the apical level of root fillings as a basis for comparison. Accordingly, the fillings had to be characterized with regard to their length.

In previous studies root fillings have been grouped in different numbers and types of classes according to their relation to the radiographic apex (*Brühlmann*, 1931; *Bugge*, 1937; *Strindberg*, 1939, 1956; *Schönbauer*, 1948; *Nicholls*, 1960; *Seltzer, Bender & Turkenkopf*, 1963; *Staub*, 1963; *Ketterl*, 1963, 1965; *Rapp*, 1965; *Engström & Lundberg*, 1965; *Engström & Spångberg*, 1967; *Brynolf*, 1967; *Heling & Tamsche*, 1970; *Sperr*, 1970; *Baume, Holz & Risk*, 1971; *Keresztesi & Kellner*, 1972; *Boysen, Giörtz-Carlsen & Ånerud*, 1972; *Bergenholz, Malmcrona & Milthon* 1973). Most often, the frequency of fillings or treated teeth has been reported for each class. In some of the studies the classifications have included an assessment of the distance from the end of a root filling to the radiographic apex (*Staub*, 1963; *Ketterl*, 1963, 1965; *Engström & Lundberg*, 1965; *Engström & Spångberg*, 1967; *Baume, Holz & Risk*, 1971; *Bergenholz, Malmcrona & Milthon*, 1973). None of the classifications used hitherto give any detailed information on the location of the apical end of root fillings in relation to the radiographic apex. Thus, it has not been possible to condense this information by giving a measure of location and a measure of dispersion. Hence, the observations are not readily amenable for further analysis, such as a direct comparison between root fillings made by different operators or from one study to another. A classification taking these aspects into account has, therefore, been adopted. Statistical parameters characterizing the apex-distance of root fillings were calculated both for the total number of root fillings and for the class A fillings.

During calculation of the mean, the fillings reaching the radiographic apex with or without an excess were all assigned the apex-distance 0.0 mm. In other words, the average location of the apical end of root fillings approached the radiographic apex as the number of fillings in the classes B and C increased. The justification of giving the classes B and C fillings a zero distance will now be discussed.

The radiographic apex is used as a plane of reference for assessment of the working length for canal preparation and the apical level of the subsequent root filling. As stressed by *Seltzer* (1971), a variety of recommendations have been made as to how far apically the root canal should be filled following pulpectomy and root canal treatment. Ideally, the zero location of a root filling should be defined as the most appropriate termination for the

filling dependent on the anatomy of the root canal and the pathologic diagnosis. Under- and overfillings should be measured relative to this location and the distribution about the ideal mean studied.

Unfortunately, not even the operator can determine the ideal level of root filling while performing the treatment. Above all, the radiographic information on the apical course of the root canal is inadequate (*Palmer, Weine & Healey*, 1971). Measurements must, therefore, be given relative to the radiographic apex, and a root filling flush with the apex will consequently be given the distance 0.0.

Overfillings were also assigned the value 0.0. In contrast to the class A fillings, they were only classified and not calculated. Such a procedure would have involved great practical problems. Excess fillings are in most instances irregular in form, thus making it impossible to set up a well-defined system for detailed measurement. The simple classification introduced by *Strindberg* (1956) is suitable and correlated with the prognosis of treatment. Accordingly, in calculating the mean and the standard deviation for the location of the apical end of root fillings, all the class B and C root fillings should be given the distance 0.0. However, in order not to mask relevant information the statistical parameters should be supplemented with the relative number of root fillings in the classes A, B and C. Likewise, additional information should be given for the class A fillings since the reasons for ending a root filling at a distance from the radiographic apex are different from those leading to a filling flush with the apex or with an excess. Ideally, the fillings in class A should comprise the group of roots which either could not (nonpenetrable) or should not (pulpectomies, eccentric location of apical foramen) be instrumented and filled to the radiographic apex while the fillings in the classes B and C should constitute the group of roots which ought to be filled to the radiographic apex.

The accuracy of measurement in clinical endodontics has apparently not been critically discussed in the literature. Lengths have, however, usually been reported with an accuracy of 1.0 or 0.5 mm (*Ingle*, 1965; *Engström & Spångberg*, 1967; *Guldener & Imobersteg*, 1972; *Weine*, 1972). The presently employed accuracy of 0.5 mm therefore corresponds to an established practice. An alternative procedure based on the magnification of radiographs and a 0.1 mm scale can hardly be applicable in clinical situations.

Radiographs had been taken by three different projection techniques. Some distortion of size and shape undoubtedly occurs in all radiography regardless of technique (*Van de Voorde & Björndal*, 1969). The three projection techniques should all give a moderate magnification of the apical part of the root, the object of the majority of the measurements performed. The fact that no systematic differences were disclosed in the analysis of the errors of the method shows that a high degree of accordance exists between the techniques for the measured part of the selected exposures.

Comparison of operators

General practitioners/undergraduate students and the endodontist. The main observation was that root fillings made by general practitioners were located significantly longer from the radiographic apex than those inserted by undergraduate students and the endodontist. This was clearly illustrated by the observation that fillings made by general practitioners in uncomplicated roots were not ending

closer to the apex than those made by the other operators in the potentially difficult molar roots.

It may be argued that this striking difference can be explained chiefly by differences in the effect of two factors which influence the composition of the material; 1) the morphology of the roots and 2) the pathologic diagnosis. These factors will now be discussed.

1) The accessibility of the apex is dependent on the morphology of the root canal and varies with the anatomy of the root. On this basis, the mesio-buccal roots of maxillary molars and the mesial root of mandibular molars should be the most difficult ones to fill close to the radiographic apex. In contrast, root fillings in single-rooted teeth, in particular maxillary central incisors, should in most instances be filled close to the apex, while the two-rooted maxillary first premolar must be considered as a tooth of intermediate difficulty. The results for all three operator groups showed a distribution of apex-distances in agreement with this hypothesis. In this respect the findings are in accordance with observations made by *Schönbauer* (1948), *Bergenholtz, Malmcrona & Milthon* (1973) and others. This shows that anatomical factors, in fact, represent a significant hindrance to adequate root filling for all three groups of operators.

Although a common pattern was observed, significant differences were disclosed for mean distances in all comparisons between general practitioners and the other two operator groups. Furthermore, the mean distances for single-rooted teeth and the maxillary central incisor filled by general practitioners were close to the distances observed for technically difficult molar roots treated by undergraduates or the endodontist. These findings show that the striking difference mentioned above can not be explained by the effect of variations in root canal anatomy.

2) With regard to the pathologic diagnosis it may be postulated that the high number of class A root fillings and the relatively long mean apex-distances observed for general practitioners are due to the sample containing: a) a high number of nonpenetrable root canals due to a considerable number of retreatments and, b) a high number of pulpectomies performed at a long distance from the radiographic apex.

a) In a number of retreatments the root canals will not be penetrable presumably because of narrowing or obliteration of the lumen by hard tissue (*Strindberg*, 1956; *Seltzer*, 1971; *Molven*, 1973). Therefore, a certain number of apex-distant root fillings must be expexted within the retreatments. The observations made for roots treated by undergraduates and the endodontist confirmed this assumption.

Comparisons were made between roots subjected to retreatment by undergraduates and the endodontist and corresponding roots filled by the general practitioners for which the type of treatment was unknown. The overall finding was significantly longer mean apex-distance for the latter roots ($p < 0.001$). In addition, it ought to be stressed that in roots formerly treated by general practitioners the new root fillings were usually advanced considerably closer to the apex during retreatment by undergraduates or the endodontist. These findings strongly indicate that even if the general practitioners had only performed retreatments, the root fillings ought to have ended nearer the radiographic apex than presently observed.

b) The aim of a pulpectomy is to place the wound surface and subsequent root filling short of the radiographic apex (*Nygaard Östby*, 1939, 1944; *Ketterl*, 1963). If the anatomy of the root canal precludes access to the most apical part of the root, the pulpectomy must, necessarily, be made at a more coronal level (*Nygaard Östby*, 1960, 1971). Such cases are chiefly encountered among molars and two-rooted premolars. In other words, they will be included among the class A fillings in roots from two- and three-rooted teeth.

Accepted principles for pulpectomy were applied both by the undergraduates and the endodontist (*Molven & Mathiesen*, 1968). The study revealed shorter distances for pulpectomies than for the corresponding retreatment groups, even for the anatomically more complicated roots. Consequently, if similar principles had been adhered to by the general practitioners, the average apex-distances for these operators should have been shorter than those observed.

In conclusion, the difference in length of root fillings made by general practitioners on one hand and undergraduate students and the endodontist on the other, can not be explained by differences in the morphology of the roots and the pathological diagnoses within the samples.

The age of the root fillings made by the students and the endodontist was known since they were studied in radiographs taken immediately after insertion. On the other hand, the age of the fillings made by the general practitioners was unknown. One may speculate if the latter root fillings initially had been located closer to the radiographic apex than observed here, and that apical disappearance (resorption) of the root filling material had taken place.

Some root filling materials are resorbable (*Nygaard-Östby*, 1944; *Castagnola*, 1950; *Seltzer*, 1971). However, the use of such materials must have been very limited in the present sample from general practice since less than 1 % of the roots subjected to retreatment had been recorded not to contain the standard filling material gutta-percha. A disappearance of gutta-percha from inside the root canal is questioned, whereas a disappearance from the periapical tissues and of the sealing paste from the apical part of the root canal may occur (*Ryn*, 1957, *Nygaard-Østby*, 1961, 1973). A vanishing of this type may have taken place in roots filled by general practitioners. Anyhow, it is not likely that such a disappearance should lead to systematically more apex-distant root fillings for these operators as compared to undergraduate students and the endodontist.

Is it reasonable to assume that the general practitioners have prepared the canals closer to the radiographic apex than they have filled the same root canals? Or do the present observations indicate a less thorough canal preparation by general practitioners than that performed in a teaching clinic or in the practice of the endodontist? No definite answers can be given to these questions. From the author's point of view, however, it seems rather unlikely that dentists adhering strictly to accepted principles for canal preparation should have accepted marked discrepancies between the levels of instrumentation and root filling. The observations might indicate, therefore, that the general practitioners have not paid the same attention to root canal preparation as was done in the teaching clinic and by the endodontist.

Moderate and marked overfillings should be avoided both in vital and pulpless teeth since they will negatively in-

fluence the prognosis (*Strindberg*, 1956; *Grahnén & Hansson*, 1961). Class C fillings were observed in approximately one per cent of the roots filled by general practitioners. The percentages were about 20 and 10, respectively, for undergraduates and the endodontist. Though some overfillings made by dentists in general practice may have disappeared, their root fillings were with regard to injurious overfillings better than those performed by the students and the endodontist.

Follow-up studies have also shown that failures after pulpectomy and treatment of pulpless roots very often are related to canal preparation and incomplete root canal fillings (*Nygaard-Östby*, 1939, 1944; *Ingle*, 1965; *Seltzer*, 1971; *Grossman*, 1972). Accordingly, underfillings should also be avoided. The present study showed that the general practitioners had filled more than 60 % of the roots to a distance of 2.0 mm or more from the radiographic apex. The corresponding numbers for the other operator groups were less than 20 %.

In summary, the comparison general practitioners versus undergraduate students working under supervision of instructors and the endodontist disclosed a more apex-distant level of root filling for the former operators than for the latter. In spite of the lack of detailed information on the treatments performed in general practice, the difference could be explained by differences in the operators' adherence to accepted principles for root canal preparation and filling and not by differences in training and clinical experience of the operator groups.

Whether this conclusion is generally valid for root fillings performed by dentists in general practice, and not only for those who have made the fillings evaluated here, cannot be answered directly by the present investigation since the sample is a selected one. On the other hand, the findings were not surprising since other studies on the standard of dental treatment have generally indicated that clinical guidelines stressed in the teaching of dentistry are not strictly applied in general practice (*Moore & Stewart*, 1967; *Björn, Björn & Grkovic*, 1969, 1970; *Molven*, 1971; *Schonfeld*, 1971; *Silness*, 1973). — The underlying reasons for this should be analysed and, possibly, corrected. For endodontics it has been suggested that the amount and quality of the endodontic training is directly related to the amount and quality of later endodontic practice (*Ingle & Teel*, 1955).

Undergraduate students/endodontist. The comparison between undergraduates and the endodontist did not reveal any marked difference such as that observed between general practitioners and the other groups. The differences which were observed must be discussed in the light of training and clinical experience and sample differences.

Both operator groups attempted to avoid marked overfilling. Nevertheless, moderate and large overfillings occurred in one fifth of the roots filled by undergraduates and in one tenth of the roots filled by the endodontist. The finding illustrates the difficulty of carrying out endodontic treatment with adequate precision. Obviously, the endodontist had mastered the filling technique better than the students.

Ideally, all root fillings in pulpectomized teeth should end at a short distance from the radiographic apex. One would expect that an endodontist made ideal fillings more often than the undergraduate students. However, in both operator groups only 45 % of the fillings made after pulpectomy ended 0—2 mm short of radiographic apex. Similar observations have been made in other teaching clinics

(*Grahnén & Hansson*, 1961; *Engström & Lundberg*, 1967). This is a challenge both to the endodontist, the undergraduate students and the instructors supervising them.

Among pulpless teeth longer apex-distances were observed for revisions than for treatment of necrotic pulps both for the undergraduates and the endodontist. This finding indicates that in cases selected for retreatment the accessibility to the most apical part of the root will, on the average, not be as readily gained as in other pulpless teeth. A main reason is, as mentioned earlier, a constriction of the lumen of the root canal due to the apposition of hard tissue after pulpotomy or partial pulpectomy. The higher frequency of nonpenetrable roots of single-rooted teeth retreated by the endodontist as compared to the undergraduates, was most likely due to a relatively higher number of such cases.

The training and clinical experience of the endodontist should be expected to be of special importance in the treatment of anatomically more complicated roots, such as commonly encountered in three-rooted teeth. The results confirmed this assumption.

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