Measurement of fine structures in roentgenograms
III. Studies on root canals of teeth

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A study of the projection of root canals of natural teeth on dental roentgenograms was carried out as a sequel to an earlier phantom study. The material consisted of extracted teeth and teeth *in situ* in jaw preparations. The same radiation source and focus-film distance were used throughout, but the exposure times and tube voltages were varied. The roentgenographic images of the root canals were analysed densitometrically and compared with measurements of the actual object dimensions. The root were sectioned at the level studied and their cross sections were traced and measured with the aid of a profile projector.

There was good agreement between the true breadth of the canal and that projected on the film. The maximum contrast in the image of the canal and the densitometrically measured difference in substance, expressed in metal equivalents, were proportional to the depth of the canal in the direction of radiation. The breadth of the canal in the plane of the film was the same regardless of whether the tube voltage was 50, 60 or 90 kV. On the other hand, the tube voltage affected the photographic density differences between the canal and the dentine walls. Changing the voltage from 50 to 60 kV did not affect the results, but there was a highly significant difference between 90 and 50 or 60 kV. The clinical significance of tube voltage and exposure time is discussed.

Key-words: Densitometry, x-ray; radiography; endodontics

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The roentgenographic reproduction of fine canals drilled in dentine bodies simulating the roots of teeth and the effects of various parameters of exposure on the image obtained have been described in a previous publication (*Hedin*, 1974). The true diameter of the drilled canal was compared with the image, analysed in a densitometer, both in the plane of the film and in the direction of radiation. The breadth of the canal as measured on the film always exceeded the true breadth; the thicker the dentine body, the greater the discrepancy. This magnification could be explained in terms of the nature of the dentine profile and the so-called edge spread function. The photographic density clearly affected the difference in blackening between the canal and the dentine walls. Varying the tube voltage (50, 60 or 90 kV) did not have nearly as great an effect.

The aim of the present work was to extend the preceding experiments to more natural material. As before, emphasis was

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made on the effects of various parameters of exposure on the projection of a root canal on dental film, partly with respect to the apparent breadth of the canal and partly to the degree of blackening obtained in relation to the surrounding dentine.

MATERIAL AND METHOD

1. Extracted teeth

Thirty extracted teeth, preserved in bactericidal solution, were selected. Preliminary roentgenography showed that the root canals differed in breadth and were free from denticles or diffuse calcifications. The material included teeth from both the upper and the lower jaw. The teeth were numbered and shallow notches

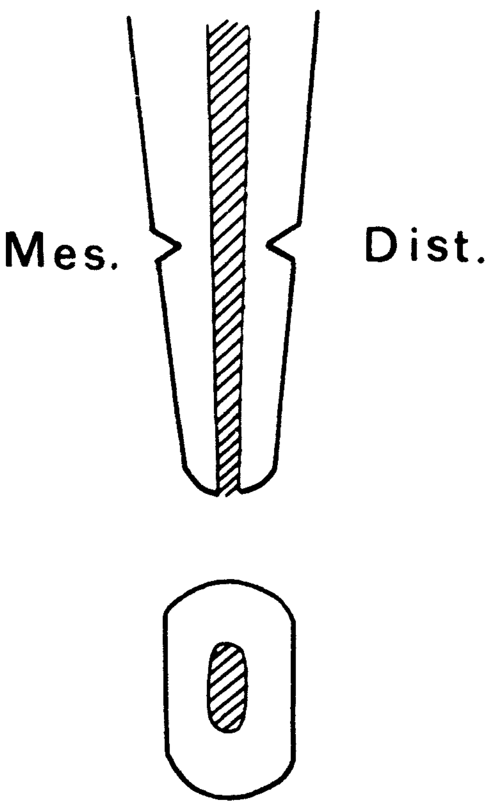

Fig. 1. The orientation points (notches) on tooth. Above: buccal view of a root; below: cross section of a root at the level of measurement.

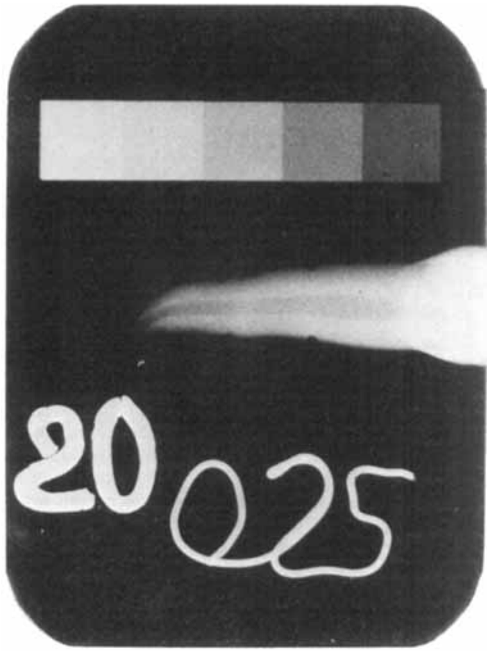

Fig. 2. Roentgenogram of an extracted tooth with orientation notches mesially and distally. Beside it are the images of the penetrometer and of lead numerals indicating the tooth number and the exposure time.

were cut at different levels mesially and distally in the roots for purposes of orientation. On some roots, notches were created at several levels to represent different root thicknesses and canal dimensions (Figs. 1 & 2). A total of 35 different levels were marked on these extracted teeth.

Roentgenography was carried out with the same source of radiation and the same film holder as previously described (*Hedin, Lundberg & Wing*, 1974). The focus-film distance was 345 mm. Total filtration: 2 mm Al. The tube voltage was 50, 60 or 90 kV. According to the manufacturer, the focus size was 0.6 × 0.6 mm for 50 and 60 kV and 1.8 × 1.8 mm for 90 kV. A tooth was fixed as close to the film as possible with wax, oriented so that the direction of radiation was buccal-lingual. The tooth under study was fixed in exactly the same way for all exposures. An aluminium step-wedge in which the steps were 0.5 or 1.5 mm was placed directly on the film (Kodak Ultra Speed dental film) and exposed together with the object. The film holder was mounted in front of a 2 mm thick lead plate. The number of the tooth and the exposure time were projected on every film with lead numerals (Fig. 2).

By means of primary roentgenography, the subjectively »optimal» exposure was determined for each tooth, and, in addition to the »optimal» film, an under-exposure and an overexposure were made at the same tube voltage. The under-exposure was usually made at half and the overexposure at twice the exposure time for the »optimal» film. All films were immediately developed in an automatic developer (Procomat Junior, Elema-Schönander).

When the films were dry, they were examined in the densitometer. The apparatus used had been described elsewhere (*Hedin et al.*, 1974). The light beam of the densitometer was passed across the image of a root at the level of the drilled notches and readings were taken at intervals of 0.1 mm as the film was advanced. The breadth of the root canal as measured densitometrically and the maximal difference in densitometer voltage recorded between the center of the root canal and the dentine walls were noted. The difference in densitometrically measured substance, expressed in mm Al, was calculated according to a method described elsewhere (*Hedin et al.*, 1974).

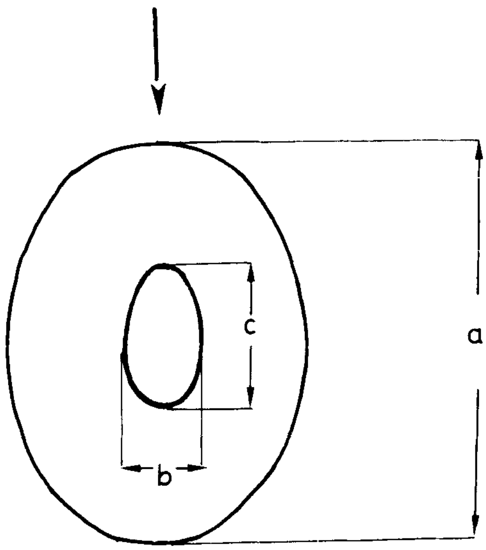

Fig. 3. The projected image of a dentine section as it appears in the profile projector. The direction of radiation is indicated by an arrow (above). a = root thickness, b = canal breadth, c = canal depth.

Calculation of the real extents of canal and root

At the level in the root at which the measurements had been carried out, part of the root could be removed with a diamond wheel and the resulting surface could be carefully polished. The surface, oriented at a right angle to the canal and in the direction of radiation, was pressed against a piece of ordinary transparent tape so that a clear image of the dentine was impressed in the glue of the tape. The tape was then mounted flat on a microscope slide which was placed on the object stage of a profile projector (Record 72, Werth). The profile projector permitted a parallel beam of light to pass the object stage and projected a sharp enlarged (20 ×) image on a viewing box on which a two-dimensional scale was superimposed. The object stage was moveable and was equipped with a micrometer screw permitting readings down to 0.01 mm. The image of the plane of dentine, impressed on the tape, was traced on the viewing box (Fig. 3) and both the breadth of the canal and the thickness of the rooth in the direction of

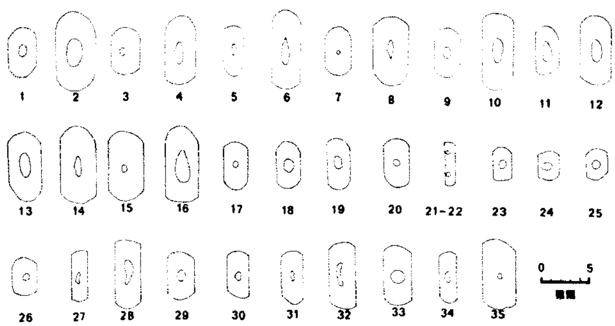

Fig. 4. Cross sections of tooth roots at the levels of densitometric analysis. Objects 1—35. The mesial and distal surfaces have been ground flat removing the orientation notches.

radiation could be determined with great precision, as demonstrated by the results of repeated measurements of an object (Table I).

The cross sections of the extracted teeth in this study at the levels of densitometric analysis are shown in Figure 4.

Table I. *Precision of the measurement of canal depth using the »tape method» and a profile projector. Results of 20 measurements on one section*

	$\bar{x}$ (mm)	$S.D._k$ (mm)
Canal breadth measured at right angle to direction of radiation	1.72	0.03
Canal depth in direction of radiation	2.72	0.02
Root breadth in direction of radiation	7.96	0.02

II. Jaws from section material

With the aid of so-called full mouth status, 31 teeth were selected from a section material; for technical reasons, only teeth from the lower jaw were included. The teeth were *in situ* in the alveoli and the jaws had been preserved in formalin.

To ensure that roentgenography would be carried out with a standardized technique, a film holder (Precision, Precision X-ray Company, USA) that simultaneously directed the radiation was used (Fig. 5). If the long cone of the roentgen tube was attached to the plane anterior part of the film holder, the focus-film distance was the same as in the experimental apparatus described above.

The jaws containing the teeth to be investigated (designated 36—66 in Tables II—III) were mounted in a stand on the table and the precision film holder was screwed fast to the stand. The object, film and roentgen apparatus now formed a rigid system in which it was possible to

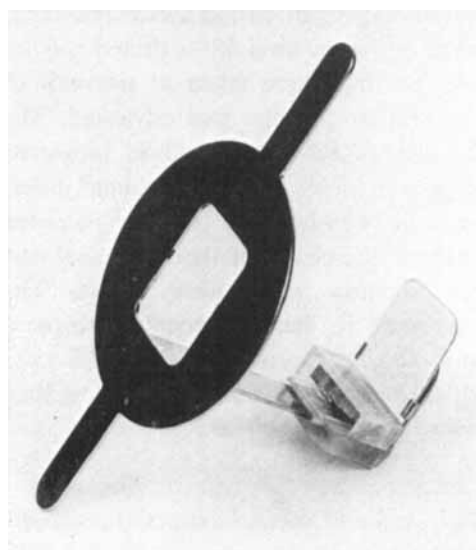

Fig. 5. The Precision film holder on which a plastic box containing the aluminium penetrometer was placed nearest the film.

change the film in the film holder without disturbing any of the adjustments. Premolars and molars came to be situated about 1.5 cm from the film and incisors and canines at a distance of about 2 cm. The aluminium penetrometer was fastened to the film holder above the occlusal surfaces of the teeth and was projected on the film at each exposure (Fig. 6). The »optimal» exposures for tube voltages 50 kV, 60 kV and 90 kV were determined empirically. In addition to the subjectively »optimal» films, overexposed and underexposed roentgenograms were made at each voltage.

On the developed roentgenograms a level was identified mesial and distal to certain roots at which the image of the root canal was sharply reproduced without superimposition. An example is seen in Figure 7. An attempt was made to select roots that differed in size and that contained canals of different breadths. As for the extracted teeth, densitometric measurements were made of the breadths of the canals (mm) and the differences in substance between the centers of the canals and the dentine walls (mm Al). For objects 36—66 the blackening of the roots on the »optimal» films was calculated in optical density units (ODU) by the method previously described (*Hedin et al.*, 1974).

For every third tooth (10 in all) the differences in blackening on the underexposed and overexposed films were also calculated in ODU. This was done for all three tube voltages. A densitometric check was made to ascertain that there was uniform film density within each of the three groups of films — light, »optimal» and dark.

All the roentgenographed teeth were extracted and the level of the root examined by densitometry was marked,

Fig. 6. Roentgen tube, film holder and jaw mounted in a rigid system. The film can be changed without disturbing these relationships.

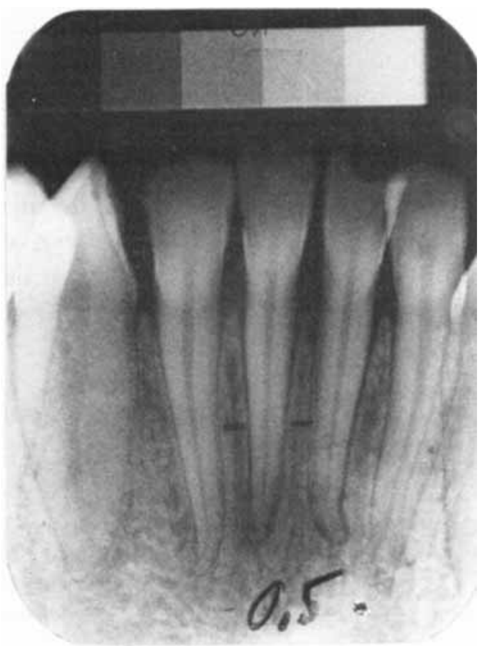

Fig. 7. Anterior part of a mandible roentgenographed using the Precision film holder and aluminium penetrometer. The film is marked at the level where blackening in the image of the dentine and root canal is to be measured. The exposure time is indicated at the bottom.

taking into consideration the geometrical enlargement of the tooth on the film. The section concerned was cut out of the root in the manner described above and the cross section of the canal was traced and its depth and breadth measured with the aid of the profile projector.

To control the accuracy with which it was possible to locate the plane marked on the extracted teeth, a study of methodological error was performed. Ten teeth *in situ* in the jaws were roentgenographed using the film holder described above, except that the latter was now attached to the occlusal surfaces of the teeth with cold polymerized acrylate so that it could be removed and replaced in exactly the same position on the jaw. Films were exposed and developed and a level of measurement was marked on the image of the root as described above. The teeth were then extracted and mesial and distal notches corresponding to the indicated levels were made. The teeth were returned to their alveoli and roentgenography was repeated. On all films the densitometric breadth of the root canal and the difference in substance between the canal and the dentine walls were measured at the level of the marking on the film or the notches on the root and the results were compared.

RESULTS

The densitometric measurements of canal breadth are compared with the true breadths in Table II. There were no major differences in the quotient between true and measured breadth for the voltages 50, 60 or 90 kV. Neither did the photographic density appear to have any significance for the results. Approximately equal numbers of light, »optimal» and dark films gave the highest value for canal breadth. For the primarily extracted teeth there was a strong correlation between true and measured canal breadth: for 50 kV = 0.93***, for 60 kV = 0.93*** and for 90 kV = 0.96***. There was a greater spread of the correlation for the teeth that were examined *in situ* in the alveoli. For some of these the measured canal breadth was considerably in excess of the true breadth. However, even for these teeth there was a strongly positive correlation between the two values: 0.81***, 0.73*** and 0.62*** for 50, 60 and 90 kV respectively. Figure 8 shows a graphic representation of the relation between true and measured canal breadth for »optimally» exposed films and a tube voltage of 60 kV. Each point is indicated by a tooth number referring to the respective cross section.

The densitometric measurements of substance in mm Al, denoting the relief of the canal against the dentine walls, were calculated for all objects. The quotients between the true depths of the canals in the direction of radiation and the measured differences in substance for the three tube

Table II. *Relation between canal breadth at a right angle to the direction of radiation in 35 sections from 30 extracted teeth and 31 sections from teeth in situ (mm) as measured by the »tape method» (x) and by densitometry on the radiographic image (y)*

Tube voltage		50 kV			60 kV			90 kV		
Photographic density		light	»optimal»	dark	light	»optimal»	dark	light	»optimal»	dark
$\frac{\Sigma x/y}{n}$	No. 1—35	0.70	0.69	0.69	0.69	0.69	0.67	0.69	0.70	0.69
	No. 36—66	0.54	0.52	0.52	0.54	0.54	0.52	0.52	0.52	0.54

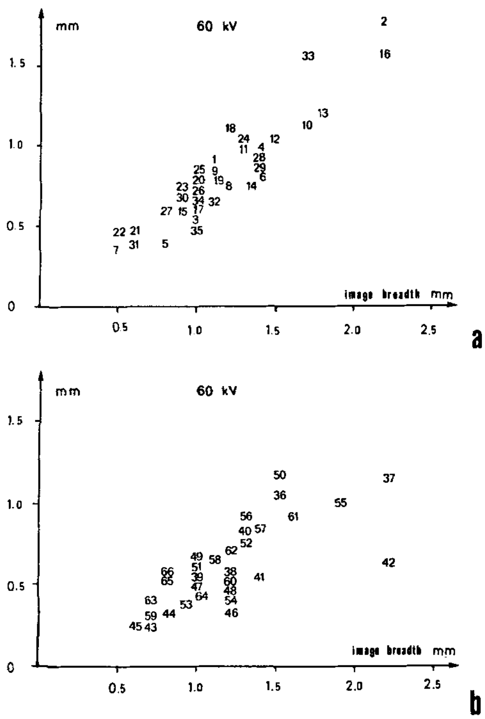

Fig. 8. The relation between the canal breadths in the extracted teeth (a) and the teeth *in situ* (b) as measured by densitometry on the radiographic image (abscissa) and by the »tape method» (ordinate). Each observation is indicated by the corresponding tooth number. Tube voltage 60 kV.

voltages and different degrees of blackening are shown in Table III. As the table shows, there was a difference between the results for extracted teeth and those for teeth *in situ*. The effects of different tube voltages were not consistent, in that 90 kV gave lower values for the extracted teeth but somewhat higher values for the teeth *in situ*. However, the differences were not large. No trend in the results corresponding to the degrees of blackening of the films could be discerned.

The relation between the measured differences in substance (mm Al; »optimally» exposed films) and canal depths (mm) is shown graphically in Figure 9. The observations are marked with tooth numbers to facilitate comparison with the cross sections (Figs. 4 & 10). There was a strong correlation between the calculated difference in substance of a root canal and the depth of the canal in the direction of radiation: 0.89***, 0.95*** and 0.98*** for 50, 60 and 90 kV respectively (»optimally» exposed films). There was a lower but still significant positive correlation for the teeth that were exposed *in situ:* 0.46**, 0.42* and 0.56*** for 50, 60 and 90 kV respectively (»optimally» exposed films).

Expressing the maximum contrast in the image of the root canals for all the »optimal» examples 36—66 in ODU, the means at 50, 60 and 90 kV were 0.65, 0.60 and 0.49 respectively. If a comparison is made between the values obtained at 50 and 90 kV or at 60 and 90 kV, there is a highly significant difference (***). There was no significant difference between those at 50 and 60 kV. The correlation between the true canal depth (in mm) and the measured difference in blackening (in

Table III. *Relation between the root depth in 35 sections from 30 extracted teeth and 31 sections from teeth in situ as measured by the »tape method»* (x) *and by densitometry on the radiographic image* (y), *the latter expressed in mm Al*

Tube voltage		50 kV			60 kV			90 kV		
Photographic density		light	»optimal»	dark	light	»optimal»	dark	light	»optimal»	dark
$\Sigma x/y$	No. 1—35	1.89	1.84	1.87	1.89	1.85	1.82	1.84	1.77	1.60
n	No. 36—66	2.15	2.06	2.03	2.15	2.17	2.24	2.28	2.24	2.21

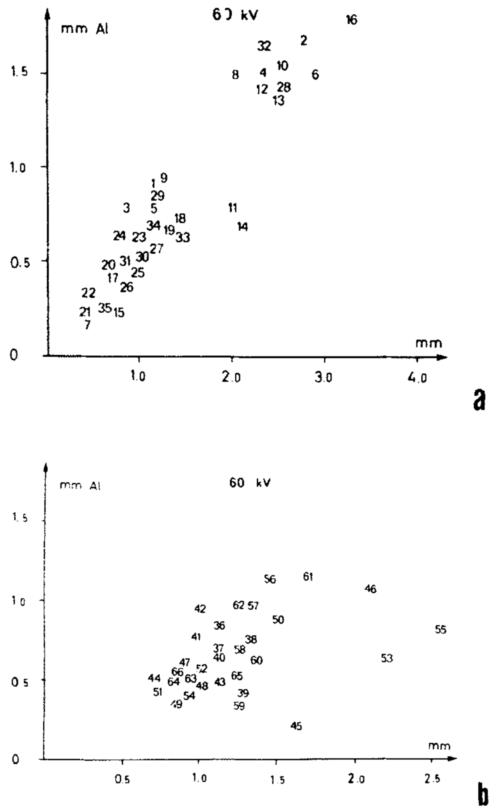

Fig. 9. The relation between densitometrically measured differences in substance in mm Al (ordinate) and as measured by the »tape method» in mm (abscissa) in the direction of radiation for the extracted teeth (a) and the teeth *in situ* (b). Each observation is indicated by the corresponding tooth number. Tube voltage 60 kV.

ODU) was 0.35*, 0.43* and 0.45* for tube voltage 50, 60 and 90 kV respectively. This relation for the teeth exposed *in situ* at a tube voltage of 60 kV is shown in Figure 10 where the cross sections of examples 36—66 are also shown.

The measurements of maximum contrast in the images of root canals on films of different average photographic density for 10 teeth *in situ* are summarized in Table IV. There was a striking difference between the light and dark films. At all three voltages there was a highly significant difference in blackening between the »optimal» and the underexposed or overexposed films. It appears from the table that halving or doubling the exposure time had a greater effect on the results than did changing the tube voltage in the range used in this study. At all three voltages the light films gave approximately 35—50 % lower values and the dark films 50—90 % higher ones.

The precision between the measurements on teeth *in situ* and with the guidance of notches in the roots is shown in Table V. There was good agreement, indicating that the image measured with the profile projector was an accurate representation of the section under study.

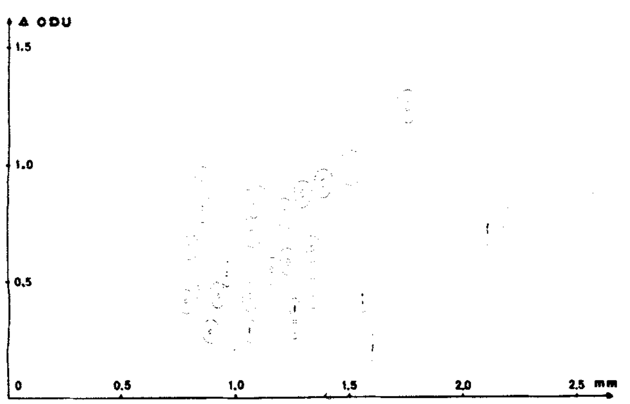

Fig. 10. The relation between measured differences in photographic density in ODU in the images of the root canals(ordinate) and the canal depths as measured by the »tape method» in mm (abscissa) for the teeth *in situ*. Each observation is indicated by the cross-section of the root at the level examined.

Table IV. *Maximum contrast in the images of the root canals of 10 teeth in situ (ODU) and the relation between the root depth as measured by the »tape method»* (mm) *and the radiographic contrast* (ODU)

Tube voltage	50 kV			60 kV			90 kV		
Photographic density	light	»optimal»	dark	light	»optimal»	dark	light	»optimal»	dark
$\bar{x}$ (ODU)	0.29	0.55	0.93	0.28	0.52	0.98	0.25	0.39	0.59
mm/ODU	4.84	2.52	1.35	5.13	2.79	1.32	5.52	3.18	2.15

Table V. *The agreement of the densitometric measurements of canal breadth and depth before and after marking the measured area with notches in the roots. n = 10*

	Range	Mean value of the difference ($\bar{x}_d$)	Standard error of the difference (S.E.M.)	t
Canal breadth (mm)	0.9 —1.7	—0.02	0.13	0.48 NS
Difference in substance (mm Al)	0.46—2.34	—0.01	0.11	0.40 NS

DISCUSSION

The natural material used in this study differed from the material used in a previous experimental study in that the roots and root canals varied in form and dimensions and the bone surrounding the teeth roentgenographed *in situ* varied both in thickness and mineral content. Because of these differences it was not possible to use the same exposure time for all objects.

The underexposed and overexposed films were fairly light and dark respectively, but the object was still visible when the film was examined in the viewing box. The exposure times for teeth *in situ* were approximately the same as those used clinically for the same roentgen apparatus and the same focus-film distance.

In spite of a relatively long focus-object distance, the roentgen rays in the beam of radiation used in this investigation were not parallel to one another. The effect of the use of diverging rays is an enlargement in the image. This geometric error was calculated in order to determine the expected size of the projected umbra and penumbra of the canal. For the extracted teeth the average expected enlargement for the canals was at the most 0.04 mm using the small focus and 0.08 mm with the large focus. The canals of the teeth which were roentgenographed *in situ* (no. 36—66) had an average expected enlargement of 0.07 mm and 0.15 mm for the small and the large focus respectively.

It is therefore clear that there was a certain amount of geometric enlargement with the radiation source used. The diameter read densitometrically was further increased by at least 0.1 mm on each side due to a systematic error of the equipment used. However, these sources of enlargement fail to account for the high values read for a number of teeth, especially of those exposed in their alveoli. It may be that individual bony ridges produced a false roentgen relief, and the effects of radiation diffused from the jaw must also be considered. It is also possible that the tooth in question may have been rotated in the jaw and thus was not exposed with the beam in the direction shown in Figure 3. These factors may explain why the quotient between »true» and densitometrically determined breadth differed for extracted teeth, where this source of error could be eliminated, and teeth *in situ*.

In the study on dentine test bodies (*Hedin*, 1974) canals of the same diameter gave higher measured values if the root was thick. There seems to be a similar trend in the natural material, at least among the primarily extracted teeth. However, direct comparisons cannot be made as readily as in the phantom study, since the depth of the canal in the direction of radiation must now also be taken into account.

As in the phantom study, the measured canal breadth was largely independent of the exposure time. This is in contrast to the impression obtained from visual observations. *Degering* (1964) for example, reported that the pulp space appears larger on overexposed films. In the phantom study on dentine test bodies, variations in the tube voltage did not appear to affect the result, and the same was true in the study on natural teeth.

The relation between the »true» difference in substance (in mm) and that read densitometrically (in mm Al) differed for the extracted teeth and the teeth *in situ* in the jaw. One reason for the difference in results is that the direction of radiation did not coincide with the maximal depth of the root canal in the buccal-lingual direction for the teeth *in situ*. It is also possible that the radiolucency of the pulp differed in the two types of material, since the jaw preparations had been preserved in a different way from the extracted teeth. Tube voltage and the photographic density were, as expected, of little significance.

As in the phantom study, the exposure time, *i.e.* the film density, was important in determining the relief of the root canal against its surroundings. This is related to the slope on the characteristic film curve. Overexposed films give a greater contrast but cannot be used in practical work since such an image can only be seen if viewed in front of a very strong light source. Furthermore, considerations of radiation hygiene preclude overexposure.

In Sweden up to the 1960's, dental roentgen equipment usually operated at 60 kV and 10 mA, but more recently, with the development of equipment to be mounted beside the dental unit, the technical properties have often been changed to 40—50 kV and 7—8 mA. In this study a decrease in tube voltage from 60 to 50 kV had virtually no effect on film quality. However, for 50 kV the »optimal» exposure time for the focus-film distance used was several seconds, even for rapid film, which means there is a high risk of blurring due to movement. If a long cone is to be used, which is desirable from the viewpoints of both projection and radiation hygiene, problems may arise from the use of voltage as low as 45—50 kV. The exposure time at 90 kV was considerably shorter, but the results obtained were clearly poorer.

This study shows that there is good correspondence between the true breadth of a root canal and that measured on the roentgenographic image. The degree of blackening of the canal in relation to its walls suggests the depth of the root in the direction of radiation. The greatest dimension of the root canal in the buccal-lingual direction may be difficult to reproduce because of anatomical variations. The relation between the degree of blackening of the canal and its actual extent, even in the third dimension, *i.e.* the buccal-lingual, is of importance for endodontic diagnostic work and has not previously been demonstrated.

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