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The integral absorbed dose in conventional and panoramic complete-mouth examinations

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The complete dental arches can be examined radiographically by three techniques:

1. The conventional method, involving ten to twenty intraoral films.
2. A technique in which the source of radiation is placed inside the mouth and the film is bent in a curved plane around the patient's face (Panograph, Panoramix). The direction of the beam is opposite that of the first technique.
3. A technique known as tomography, which permits the curved plane of the dental arches to be recorded. In this technique both the source of the radiation and the film are outside the mouth and rotate around the patient's head (Orthopantomograph, Rotagraph, Panorex).

To study the deleterious effects of the radiographic examination, dose measurements are used.† The *exposure*, expressed in roentgens (r), informs one of the ionization that can be produced by the radiation in air through its interaction with air in a small volume of interest. The *absorbed dose* is the quotient of the energy imparted by the radiation to the matter in a volume element divided by the mass of the matter in that volume element. The unit of absorbed dose is ergs per gram or rad (1 rad = 100 ergs per gram).‡

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†The terminology for the different units used in this article is kept in agreement with International Commission on Radiological Units and Measurements report 10^a and 10^b, National Bureau of Standards Handbooks 84 and 85 (1962).

‡In the case of electronic equilibrium, an exposure of 1 r corresponds to an absorbed dose in air of 86.9 ergs per gram.

In radiography, harm to the patient is not ordinarily thought of as the result of the absorbed dose at a certain spot; rather, it is determined by the total amount of radiation imparted to the entire body. To compensate for this discrepancy, most investigators mention, separate from the exposure in roentgens, the field size they used. To be able to determine the total amount of energy administered to the patient, the quality of the beam is a factor which also must be incorporated. This was done by Mayneord,¹ in 1942, when he introduced the concept of *volume dose*. This is the summation of the exposure over a large number of small volume elements of the area irradiated by the primary radiation. It is expressed in roentgen liters or, when related to the irradiated mass, in gram roentgens.

Since the absorption of radiation in the different tissues of the human body, to which an exposure of 1 r is given, is different, the International Commission on Radiological Units and Measurements (I.C.R.U.) introduced the quantity known as *integral absorbed dose* (1953). It is equal to the total amount of absorbed energy in a given region of interest and can be expressed in gram rads (1 gram rad = 100 ergs).

The usefulness of these newer conceptions in dosimetry for our purpose in comparing the panoramic techniques with the conventional method is obvious. The differences in field size and entrance and exit areas of these techniques are so great that a comparison of the exposures in roentgens becomes rather meaningless.

The purpose of this investigation was to collect information on the integral absorbed dose received when the following techniques are used:

1. Conventional complete-mouth x-ray examination.
2. Panoramic examination with the Panoramix (intraoral x-ray tube).
3. Panoramic examination with the Orthopantomograph.

PROCEDURE

Integral absorbed dose determinations are made possible by assuming that the amount of primary and secondary radiation leaving the patient can quantitatively be neglected in comparison to the radiation absorbed by the human tissues. Accepting this premise, the total amount of absorbed radiation equals the energy flowing through a cross section of the x-ray beam before entering the patient. It can be shown² that the energy fluence per roentgen (F_1) is given as follows:

$$F_1 = \left(\frac{86.9}{\mu_a/\rho} \right) \text{ air} \quad (\text{erg/cm.}^2) \quad (1)^*$$

where $\frac{\mu_a}{\rho}$ is the mass energy absorption coefficient.

The total amount of energy (E_t) is found by multiplying F_1 by the area, A , of a cross section of the beam (in square centimeters) and the exposure, X (in roentgens), measured at this section. Back scatter from the patient should be excluded, and the surface of the cross section should be perpendicular to the intersecting rays throughout.

*Some investigators use 83.8 instead of 86.9. The I.C.R.U., however, in report 10^b (Handbook 35, Washington, D. C., 1962, National Bureau of Standards), gives the value as 86.9.

$$E_t = 86.9 \left(\frac{\rho}{\mu_a} \right)_{\text{air}} A X \text{ (erg)} \quad (2)$$

For nonhomogeneous dose distributions, the dose should be integrated over the surface as follows:

$$E_t = 86.9 \left(\frac{\rho}{\mu_a} \right)_{\text{air}} \int X_A \, dA \text{ (erg)} \quad (3)$$

For conversion from ergs to gram rads, it is noted that 1 gram rad equals 100 ergs. Tables² of the coefficient $\left(\frac{\rho}{\mu_a} \right)_{\text{air}}$ for monochromatic radiation show

that this factor changes rapidly with photon energies from 10 to 100 kev. (Fig. 1,A, right-hand curve). The beam from the x-ray tube, however, is not homogeneous and an exact calculation of the absorption coefficient is possible only when the spectral distribution of the beam is known. A practical approximation is possible when the quality of the beam is determined by means of the half-value layer (HVL) (the thickness of aluminum which reduces the exposure to 50 per cent of its initial value). The half-value layer of the heterogeneous beam can be used to specify an effective photon energy which is that energy of a monochromatic radiation which exhibits the same half-value layer. The half-value layer of a monochromatic beam can be calculated from attenuation coefficient tables³⁻⁶ (Fig. 1,A, left-hand curve). The direct relation between HVL and mass energy absorption coefficient of air can now be determined and is illustrated in Fig. 1,B.

In some techniques the half-value layer of the beam changes with the direction of the radiation. This nonhomogeneity of the quality with the direction can be incorporated in the calculation by integrating $\frac{\rho}{\mu_a}$ over the surface of the cross section used to determine the integral absorbed dose. This changes the formula to the following:

$$E_t = 86.9 \int \left(\frac{\rho}{\mu_a} \right)_{\text{air}} X_A \, dA \text{ (erg)} \quad (4)$$

The technical details of the measurements for the three techniques studied were as follows:

Technique 1. Conventional complete-mouth x-ray examination. The exposure and field size were measured at the same distance from the focal spot. The time for the exposure determination was equal to the total of the exposure times used for the different areas. The quality of the radiation was determined by measuring the half-value layer in millimeters of aluminum. In another technique in which the tube potential was changed for the different areas, the exposure and half-value layer were measured for each area in order to calculate the integral absorbed dose separately.

Technique 2. Examination with the source of the x-ray beam inside the mouth. The extension of the x-ray tube containing the anode is constructed so as to permit the rays to emerge in all directions except where the anode or

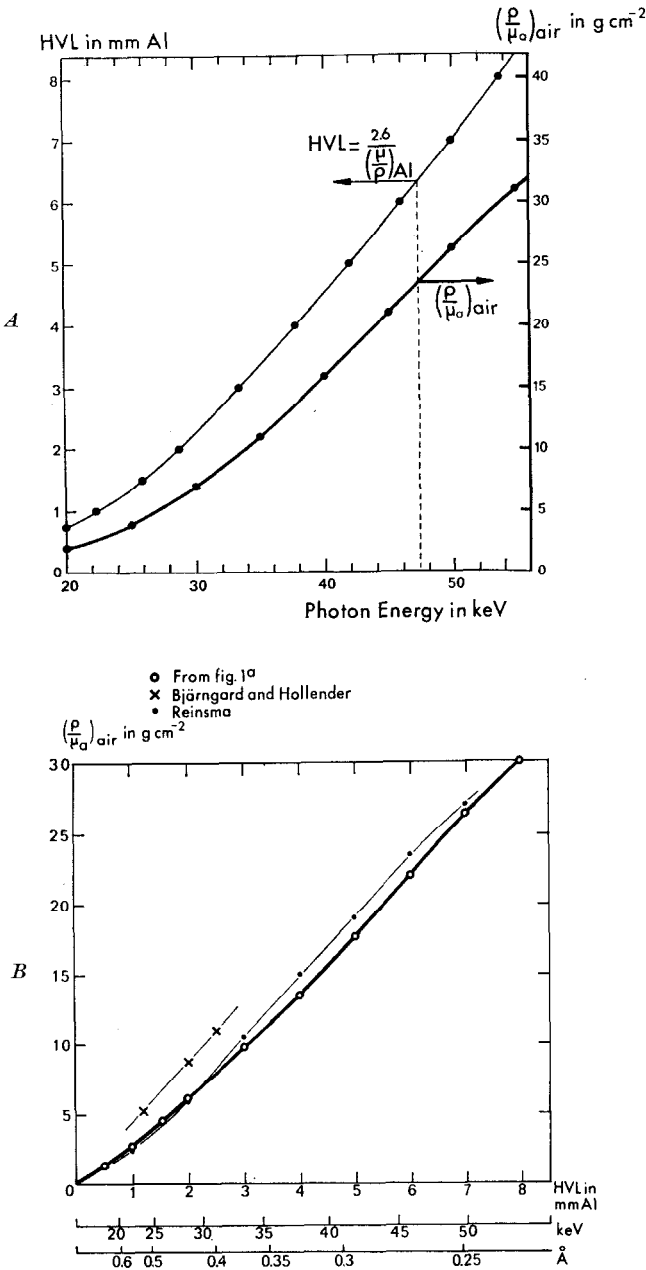


Fig. 1. A, Half-value layer (in millimeters of aluminum) and the reverse of the mass energy-absorption coefficient of air $\left(\frac{\rho}{\mu_a}\right)_{\text{air}}$ as a function of photon energy. B, Reverse of the mass energy-absorption coefficient of air $\left(\frac{\rho}{\mu_a}\right)_{\text{air}}$ plotted against the half-value layer (in millimeters of aluminum), the photon energy, and wavelength.

the wall of the tube and filter absorb most of the radiation (Fig. 2). As already stated, the surface of the cross section used for the measurements should be perpendicular to the direction of the radiation. Since the rays are generated at a small spot, this surface is a sphere. The axis of the extension of the x-ray tube is an axis of symmetry for the exposure distribution over this sphere. Its surface can therefore be divided into curved areas of spherical segments, as indicated in Fig. 3, to produce surfaces with a practical uniform exposure. The area (A) of the curved surface of each spherical segment is given by the following equation:

$$A = 2 \pi r h \quad (5)$$

where r is the radius of the sphere and h the height of the spherical segment. For each segment, the exposure and the surface should be determined. One should also take into consideration the fact that the rays going through different segments do not penetrate the same amount of glass and aluminum when leaving the x-ray unit. These differences in filtration change the quality of the radiation. In order to incorporate this effect, information on the change in HVL with the

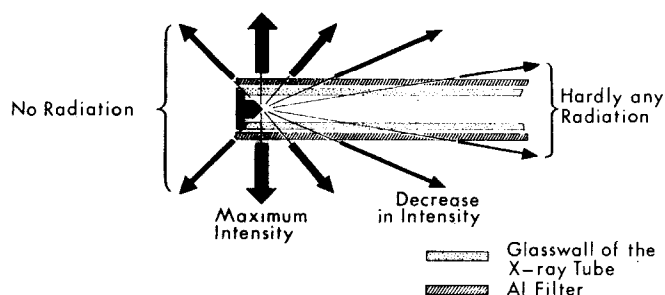


Fig. 2. Cross section of the anode carrying part of the Panoramix x-ray tube. Width of arrows indicates intensity of radiation in different directions.

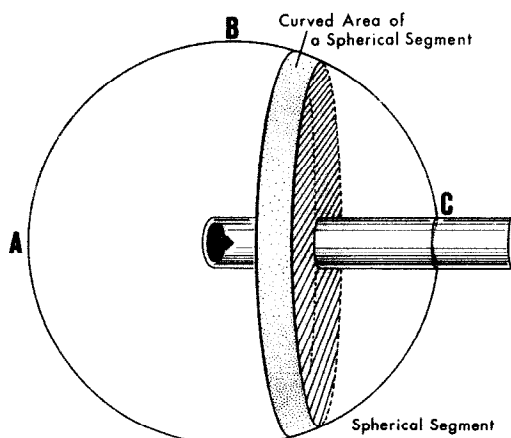


Fig. 3. Relation between spherical segment and x-ray tube.

direction of the rays is needed. To summarize, the integral absorbed dose can be calculated when the exposure, the area, and the HVL for the curved surface of each spherical segment are known.

Technique 3. Panoramic examination with the orthopantomograph. In this technique the diaphragm consists of a small slit (approximately 0.3 mm. in width). During exposure, the narrow beam revolves successively on three rotational axes. In Fig. 4 the surface *ABCD*, constructed perpendicular to the rays, was used for the field size and exposure measurements. To reach this surface, the beam passes in some directions through a perspex plate, part of the Orthopantomograph, 7 mm. in thickness. The influence of this filtration on

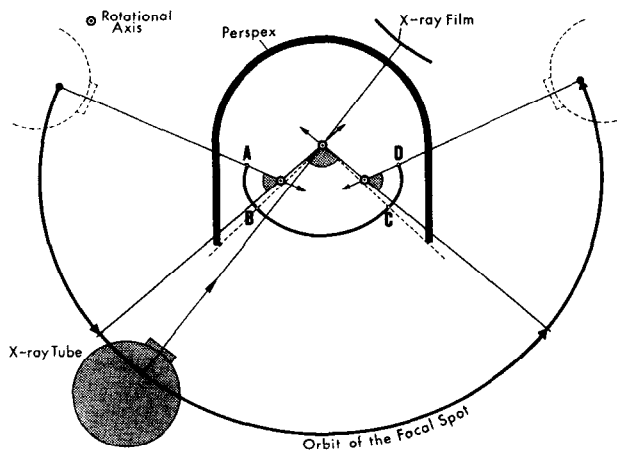


Fig. 4. Horizontal cross section through Orthopantomograph. (See text.)

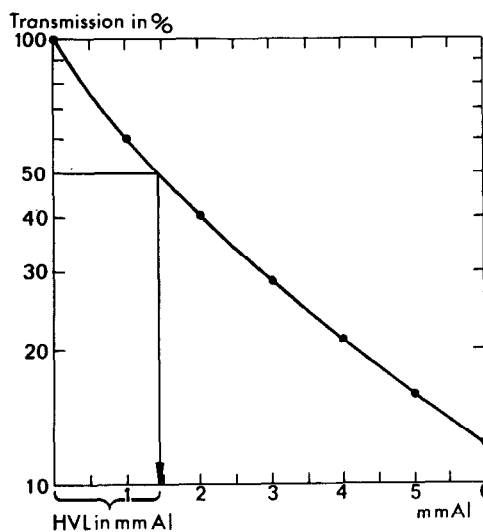


Fig. 5. Absorption curve illustrating half-value layer determination.

the quality of the beam was included in the calculation by using different half-value layers for the different areas (*AB*, *BC*, and *CD*).

All HVL determinations were carried out by plotting an absorption curve from which the thickness in millimeters of aluminum required to reduce the exposure to 50 per cent was read (Fig. 5).

To determine the exposure at the different places, a Philips universal dosimeter with thimble chambers was used. A pilot study was made of the non-uniform irradiated cross sections with the aid of an x-ray film. This film was placed and exposed at the specific curved surface, that is, according to line *ABC* in Fig. 3 and line *ABCD* in Fig. 4. The blackening of the film served as a guide for locating the areas where the exposure had to be measured with ionization chambers. The density-exposure curve of the film was recorded in a separate experiment. This curve permitted reading of the exposure at the different locations. This additional information, together with exposure measurements made with the thimble chambers, made it possible to construct a continuous curve showing the exposure-area relationship (Table I and Figs. 6 and 7). The

Table I

Technique No.	Means used to determine:	
	Area of cross section of beam	Exposure distribution at cross section
1	Roentgenogram	Ionization chamber
2	Calculated	Ionization chamber and roentgenogram
3	Roentgenogram	Ionization chamber and roentgenogram

Table II

X-ray machine—Ritter Century x-ray unit, Model E
Amperage—10 Ma.
Exposure data—

Jaw	Area			
	Central and lateral incisor (KVP)	Cuspid (KVP)	Premolar (KVP)	Molar (KVP)
Upper	65	65	70	75
Lower	60	65	65	70

Exposure time—31/20 seconds for all areas
Added filtration—None
Field diameter—6.0 cm. at 46 cm. focal spot distance
These conditions valid for:
Focal spot—skin distance—42 cm. (long-cone)
Film—Kodak Ultra-Speed
Developing solution—Kodak D 19b*
Temperature—20° C.
Developing time—4.5 minutes

*The composition of this solution is equivalent to the developing solution prescribed in *American Standard Methods for the Sensitometry of Medical X-ray Films* (P H 2, 9-1956), published by the American Standards Association.

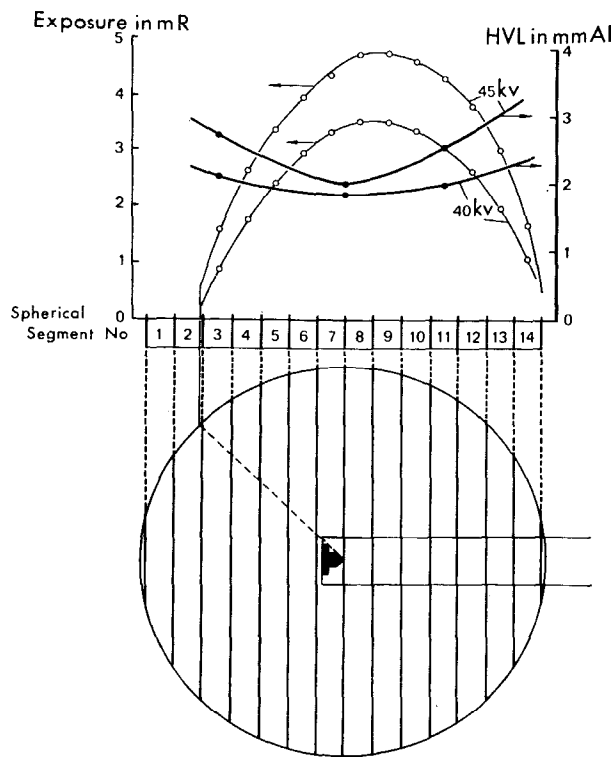


Fig. 6. Exposure and half-value layer distribution on curved area of spherical segments.

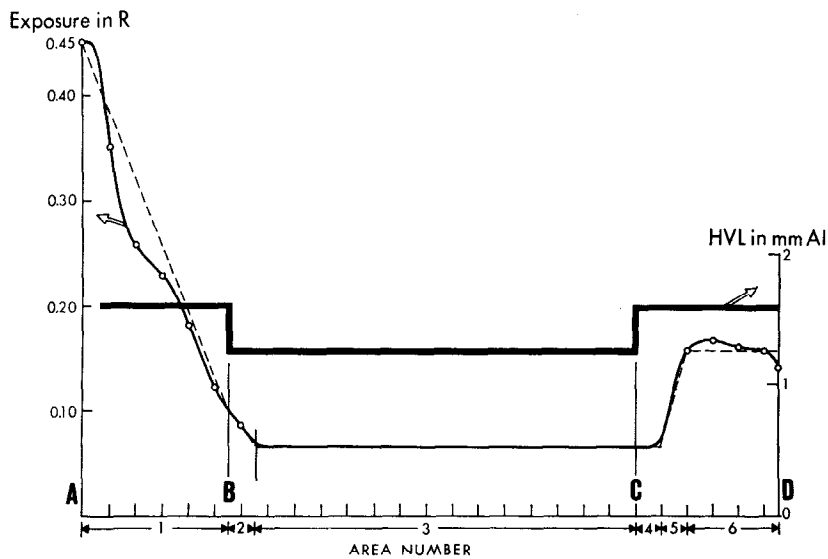


Fig. 7. Exposure and half-value layer distribution on curved surface ABCD from Fig. 4. In the final calculation, the exposure-area relationship was assumed to follow the dashed line

roentgenograms can also be used to find the field size for Techniques 1 and 3. The field size in Technique 2 was calculated by using equation 5 (Table I).

RESULTS

Conventional complete-mouth x-ray examination

The technical details of the experiment are shown in Table II.

The integral absorbed dose can be calculated with the use of equation 2:

$$E_t = 86.9 \left(\frac{\rho}{\mu_a} \right)_{\text{air}} A X \text{ (ergs)}$$

Table III

KVP	HVL (mm. Al)	$\left(\frac{\rho}{\mu_a} \right)_{\text{air}}$ (g. cm. ⁻²)	X (r)	A (cm. ²)	E _t (ergs)	
60	1.75	5.1	0.46 (2 areas)	28.3	0.58	10 ⁴
65	1.95	5.9	2.2 (8 areas)	28.3	3.19	10 ⁴
70	2.0	6.3	1.3 (4 areas)	28.3	2.01	10 ⁴
75	2.3	7.1	0.72 (2 areas)	28.3	1.25	10 ⁴
Total					7.03	10 ⁴ (700 gram rads)

Table IV

X-ray machine—Philips, Oralix Amperage—7.5 Ma. KVP—50 Exposure data—				
Jaw	Exposure time (seconds)			
	Central and lateral incisor area	Cuspid area	Premolar area	Molar area
Upper	0.65	0.5	0.65	1.15
Lower	0.35	0.5	0.5	0.65
Added filtration—None Field diameter—6 cm. at 12 cm. focal spot distance These conditions are valid for: Focal spot-skin distance—10 cm. Film—Kodak Ultra-Speed Developing solution—Kodak D 19b Temperature—20° C. Developing time—4.5 minutes				

Table V

HVL (mm. Al)	$\left(\frac{\rho}{\mu_a} \right)_{\text{air}}$ (g. cm. ⁻²)	X (r)	A (cm. ²)	E _t (ergs)	
1.45	4.1	12.9	28.3	13	10 ⁴
16 exposures					(1,300 gram rads)

The calculation with the pertinent data can be followed in Table III.

Another technique with a shorter focal skin distance and a lower KVP was also studied. The technical details of this procedure can be found in Table IV.

The integral absorbed dose was calculated by means of the information contained in Table V.

Examination with the intraoral x-ray tube

The conditions for which the integral absorbed dose was calculated are shown in Table VI.

Fig. 6 shows a cross section through the x-ray tube and a sphere with the anode as a center. The results of the measurements of the exposure and half-value layer on the surface of this sphere are also represented. The calculation of the

Table VI

X-ray machine—Koch and Sterzel, Panoramix	
Amperage—0.5 Ma.	
KVP—45 (upper jaw), 40 (lower jaw)	
Exposure time—0.06 second	
Added filtration—1.5 mm. aluminum	
These conditions are valid for:	
Intensifying screens—Dr. Goos-Elka, high-definition	
Film—Gevaert-Agfa, Structurix S	
Developing solution—Kodak D 19b	
Temperature—20° C.	
Developing time—5 minutes with intermittent N ₂ agitation	

Table VII

Spherical segment No.	Area A^* (cm.^2)	45 KVP				40 KVP			
		HVL (mm. Al)	$\left(\frac{\rho}{\mu_a}\right)_{\text{air}}$ (g. cm.^{-2})	X (r)	E_t (ergs)	HVL (mm. Al)	$\left(\frac{\rho}{\mu_a}\right)_{\text{air}}$ (g. cm.^{-2})	X (r)	E_t (ergs)
1	45.2	2.15	—	0	—	—	—	0	—
2	45.2	2.32	—	0	—	—	—	0	—
3	45.2	2.55	9.0	0.0016	56.6	2.1	6.1	0.0009	21.6
4	45.2	2.75	8.0	0.0026	81.7	2.0	6.0	0.0017	40.1
5	45.2	3.0	7.2	0.0034	96.1	1.95	5.7	0.0024	53.7
6	45.2	3.3	6.2	0.0039	95.0	1.9	5.3	0.0029	60.4
7	45.2	2.32	6.1	0.0043	103.0	1.85	5.2	0.0033	67.4
8	45.2	2.15	6.1	0.0047	112.6	1.85	5.2	0.0035	71.5
9	45.2	2.10	6.2	0.0047	114.5	1.9	5.3	0.0035	72.9
10	45.2	2.10	7.2	0.0046	130.1	1.95	5.7	0.0034	76.1
11	45.2	—	8.0	0.0043	135.1	2.0	6.0	0.0030	70.7
12	45.2	—	9.0	0.0038	134.3	2.1	6.1	0.0026	62.3
13	45.2	2.75	9.8	0.0030	115.5	2.2	6.8	0.0019	50.7
14	45.2	2.55	11.0	0.0017	73.4	2.4	7.6	0.0011	32.8
Total, upper jaw 1,247.9						Total, lower jaw 680.2			
Total for examination 1,928 ergs (19.3 gram rads)									

*See equation 5 (*r* = 7.2 cm., *h* = 1 cm.).

integral absorbed dose using the curved surfaces of the spherical segments can be followed in Table VII.

Examination with the Orthopantomograph

The investigation was carried out with the technical conditions listed in Table VIII.

Fig. 7 shows the unrolled surface of the cross section *ABCD* from Fig. 4; the radii of this surface were 4 and 10 cm. Exposure and HVL thickness at the different areas are also represented. The calculation of the energy passing through this surface is recapitulated in Table IX.

The results show that large differences exist between the amounts of energy administered to the patient with the three techniques. The difference between

Table VIII

Apparatus—Lääkintäsähkö, Orthopantomograph
X-ray machine—Siemens, Monodor
Amperage—20 Ma.
KVP—69
Slit width—0.3 mm.
Focal spot—slit distance—8 cm.
Distance focal spot—rotational axis—26 cm. and 32 cm.
Added filtration—None
Time of exposure—14 seconds
These conditions are valid for:
Focal spot—film distance—46.5 cm.
Intensifying screens—Du Pont, High-Speed
Film—Kodak, Royal Blue
Developing solution—Kodak, D 19b
Temperature—20° C.
Developing time—5 minutes with intermittent N ₂ agitation

Table IX

Area No.	HVL (mm. Al)	$\left(\frac{\rho}{\mu_a}\right)_{air}$ (g. cm. ⁻²)	\bar{X} (r)	<i>A</i> (cm. ²)	<i>E_t</i> (crgs)
1	1.6	4.5	0.45 + 0.10	5.5 × 9.2	5.44 10 ³
			2		
2	1.26	3.4	0.10 + 0.065	1.0 × 9.2	0.22 10 ³
			2		
3	1.26	3.4	0.065	14.5 × 9.2	2.56 10 ³
4	1.6	4.5	0.065	1.0 × 9.2	0.26 10 ³
5	1.6	4.5	0.065 + 0.16	1.0 × 9.2	0.40 10 ³
			2		
6	1.6	4.5	0.16	3.5 × 9.2	2.01 10 ³
				Total	10.89 10 ³
					(109 gram rads)

the two conventional techniques is relatively small (700 and 1,300 gram rads). This effect is due to the difference in quality of the radiation. The difference between the conventional procedures and Techniques 2 and 3 is relatively large. Generally, the exposure at the skin, in roentgens, is used to study the influence of the quality of the radiation on the dose that the patient receives. A comparison between the change in the exposure at the skin and the change in the integral absorbed dose can be made, using the conditions which showed the largest difference in KVP (upper molar area, 50 to 75 KVP). It is found that the decrease in exposure at the skin to 24 per cent (from 1.5 r for 50 KVP to 0.36 r for 75 KVP) is partly compensated in the integral absorbed dose calculation by an increased value for $\frac{\rho}{\mu_a}$, the integral absorbed dose being reduced to 40 per cent (0.15 kg. rads for 50 KVP to 0.062 kg. rads for 75 KVP). The reduction in the amount of radiation energy that the patient receives is therefore not as great as the skin dose suggests.

The smallest integral absorbed dose is found when the Panoramix machine is used. When an examination of the patient can be made with either the conventional technique or one of the two panoramic techniques, the Panoramix (intraoral x-ray tube) has to be preferred.

The roentgenograms obtained with the three techniques are not identical, however. Each technique has its special field of application.

DISCUSSION

Only a few publications dealing with integral absorbed dose measurements in oral radiology are available. Bjärngard and Hollender⁷ reported, for a conventional full-mouth x-ray examination, 4,700 gram rads with Kodak Radiatized films, fourteen pictures and a field size of 19.6 cm.² Corrected to the use of Kodak Ultra-Speed films ($\times 0.19$), sixteen pictures ($\times 1.14$), and a field size of 28.3 cm.² ($\times 1.44$), a figure of 1,460 gram rads is found. The slightly larger values for $\frac{\rho}{\mu_a}$ used by Bjärngard and Hollender (Fig. 1,B) may explain the variance with our results of 700 and 1,300 gram rads.

The small difference in total absorbed energy when the quality of radiation is changed was explained by showing that the reduction in skin exposure with a higher KVP was partly compensated by a larger coefficient $\frac{\rho}{\mu_a}$.

Because of the increased ratio of scattering to absorption with greater photon energies, a substantial part of the energy entering the patient with a primary beam generated with a higher KVP may leave the patient as secondary radiation. In order to make suitable calculations, it was assumed that this amount of exit secondary radiation could be neglected. Zieler⁸ made a study of the relation between the percentage of secondary radiation leaving the patient and the physical conditions of the irradiation. He showed that with a field size of 14 by 14 cm. on a phantom of extremely large dimensions, 21 per cent of the incident energy, generated at 60 kv. constant potential, is lost by secondary radiation; at 80 kv., 28 per cent is lost. Still higher energy losses are found

when the distance from the beam to the borders of the (smaller) phantom are shorter.

With the conventional technique, and especially with orthopantomography, the field size is small in comparison to the size of the object. This justifies the conclusion that the integral absorbed dose measurement overestimates the exact value probably by approximately 20 per cent.

Many technical factors influence the quantitative results obtained. An important factor is the sensitivity of the film and the use of intensifying screens. It may seem unjustifiable to compare techniques which make use of different film-screen combinations, but it should be realized that in orthopantomography the thickness of the layer portrayed is proportional to the width of the x-ray beam. The slit diaphragm at the x-ray tube, regulating the width of the beam, can be made narrower if the speed of the screen-film combination is increased. A gain in thickness of the layers visible on the film is therefore possible by the use of more sensitive films and screens. This improvement may be associated with a loss of detail. In this study a combination of factors was used, producing a maximum thickness with the available x-ray machine (a slit of 0.3 mm. and sensitive films and screens).

The Panoramix machine produces roentgenograms with an enlarged image. This enlargement, made with a focal spot size of 0.1 mm., permits the use of low-speed screens (high definition) without too much loss of detail.

As a general conclusion, Table X gives a summary of the integral absorbed dose measurements, together with some advantages and disadvantages of each technique.

SUMMARY

Conventional and panoramic complete-mouth x-ray examinations differ in so many respects that a comparison of the amount of radiation administered to the

Table X

	<i>Conventional technique</i>	<i>Panoramic examination</i>	
		<i>Panoramix</i>	<i>Orthopantomograph</i>
X-ray tube	Extraoral	Intraoral	Extraoral
Film	Intraoral	Extraoral	Extraoral
Advantages	Good detail	Relatively good detail; two exposures	One exposure; complete mandible, including temporo-mandibular joint, is shown
Disadvantages	Restricted to teeth and surrounding structures; sixteen exposures	Poor projection of upper molar area; often overlapping of teeth; two exposures	Less detail; tomo-gram of a layer of limited thickness
Integral absorbed dose (rounded off to 2 digits)	10 ⁵ ergs; 1,000 gram rads	1.9 10 ³ ergs; 19 gram rads	1.1 10 ⁴ ergs; 110 gram rads

patient cannot be made with the use of exposure measurements in roentgens. The integral absorbed dose, being the total amount of energy absorbed by the patient and expressed in gram rads or ergs, is more suitable for this purpose. This dose was determined by measuring the amount of energy passing through a cross section of the x-ray beam before entering the patient.

The integral absorbed dose for a complete-mouth examination with the conventional technique was, for two different techniques, 700 and 1,300 gram rads. It can be shown that, for the conventional technique, an increase in KVP reduces the amount of radiation which the patient receives, but not as dramatically as the skin exposure suggests. Examination by the panoramic technique with the Orthopantomograph delivers 110 gram rads to the patient, whereas 19 gram rads is administered during examination with the Panoramix. These findings constitute an argument in favor of the new techniques and emphasize the need to consider them when selecting a technique for a complete-mouth examination.

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