American Academy of Oral Roentgenology

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A STUDY OF SOME PROPERTIES OF TWENTY-THREE DIFFERENT DENTAL X-RAY FILMS

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INTRODUCTION

Many different types of intraoral x-ray film are available. The type of film which best satisfies certain requirements can be found only by making a comparison between the films. A large number of criteria for this comparison can be used (for instance, sensitivity, color, contrast, keeping quality, etc.). Some of these criteria are used to compare twenty-three different types of x-ray film. Further information of importance for the selection of an x-ray film is also collected (for instance, expiration date, directions for use, identification mark). Some of the comparisons were made on a subjective basis.

MATERIALS AND METHODS

Table I shows the types of film which were compared. Some of the criteria make use of the density of the film. The density is a measure for the blackening of the film. In a densitometer a light beam is directed on the film, and the amount of incident and transmitted light is measured. In this investigation the measurements were made in accordance with an international standard.[1]

An essential requirement for a good comparison is a standardized developing process. This means that a fresh developing solution of the right composition must be used and that the temperature must be constant. This also holds for the developing time and for film agitation in the developing solution. Some objections to this procedure can be raised. Optimum image formation may be produced by using different compositions of developing solution and different developing times for different films.

Adequate comparison of the various films dictated the need for standardization; only one solution and one developing time were used in this investigation. The solution used was Kodak D-19b, and the temperature of the solution was al-

TABLE I

FILM NO.	MANUFACTURER	TYPE	CODE	EMULSION NO.	EXPIRATION DATE
1	Adox	Dozahn Extra-Fast	—	53 G 105-2	—
2	Adox	Dozahn Extra-Fast Blue-Base	—	153/506/1	May, 1960
3	Adox	Super	—	64 F 135-1	—
4	Agfa	Normal	25 D	7110/241	—
5	Ceaverken	Dent-X Normal	—	070735	December, 1960
6	Ceaverken	Dent-X Rapid	—	080762	December, 1959
7	Du Pont	Single-coated	S-1	551265-1	December, 1959
8	Du Pont	Double-coated	D2	550-415-12	September, 1960
9	Du Pont	Lightning-Fast	DC-2	555-300 2B	September, 1960
10	Ferrania	D 5	D 5	01331-48	May, 1960
11	Gevaert	Dentus Rapid	—	2450133	September, 1960
12	Gevaert	Dentus Super Rapid	—	2452151	September, 1960
13	Herzog	—	—	6660	—
14	Herzog	Blau Basis	—	6627	—
15	Ilford	5 P	5 P	4xF656A	—
16	Kodak	Radia-Tized	DF-1	03112015534	October, 1960
17	Kodak	Ultra-Speed	DF-57	02256037454	August, 1960
18	Kodak	Super-Speed	DF-45	213052972892	September, 1960
19	Minimax	Intermediate	BD	—	—
20	Minimax	Extra Fast	EFD	—	—
21	Rinn	Regular	DC	—	October, 1960
22	Rinn	Medium Fast	MF	—	October, 1960
23	Rinn	Extra Fast	EF	—	July, 1960

ways 20° ± 0.1° C. (The American Standards Association[2] requires a temperature of 20° ± 0.5° C.)

The developing time was 4.5 minutes. From the standpoint of protection against radiation, it is sometimes recommended[6] that the exposure time be reduced; to compensate for this, the developing time is extended. The contrast and fog of the film will probably be increased by this procedure. To collect additional information on this subject, the fog and base density and the contrast of the film were also measured using a developing time of nine minutes in contrast to the 4.5 minutes.

The movement of film and solution with respect to one another was brought about by pumping the solution in the developing tank through a pipe from the bottom to the surface; at the same time, the film was mechanically moved up and down. The different criteria will now be discussed.

Sensitivity.—Film sensitivity is a measure of the exposure time that a film needs to produce a good image. A *low* sensitivity corresponds with a long exposure (or a ***high*** dose). For this reason, the sensitivity is usually indicated by the reciprocal of the exposure. For the sake of convenience, the sensitivity will be considered proportional to the exposure time in this investigation.

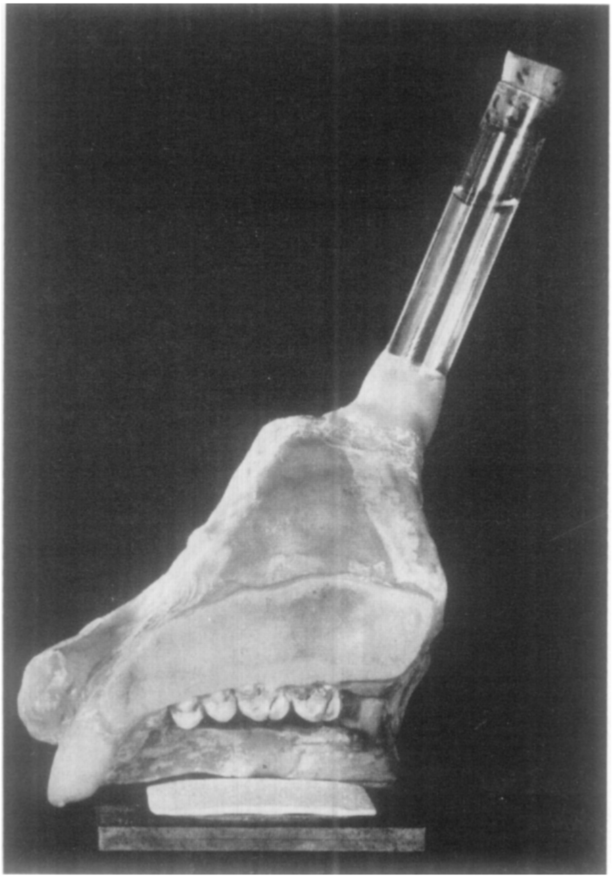
A large number of factors determine the exposure time. Therefore, the sensitivity is a relative value. For instance, the relative sensitivity can be determined by measuring the dose of radiation that a film needs to produce a certain density. This is used in the American Standard Method.[3] It is possible, however, that films which have the same sensitivity according to this method but a different contrast, will produce images that are (with the same exposure) not identical when judged on a subjective basis. The fog and the color of the film base may in the same way reduce the value of the sensitivity index when measured by an objective method. It can also be expected that different observers will have different opinions. Finally, the relative sensitivity can be affected by the quality of radiation used. For all these reasons, the relative sensitivity was determined by a subjective method. Concurrently, information was collected on the spread between the opinions of different observers and the effect of the quality of the radiation.

Exposures were made of a phantom of the upper jaw. This phantom consisted of half an upper jaw covered and penetrated with agar-agar to simulate the soft tissues. The agar-agar was covered with a thin layer of self-polymerizing acrylic, to prevent drying (Fig. 1). A series of nine exposures of this phantom was made with Kodak Radia-Tized Film. Each exposure was 1.09 times as long (a 9 per cent increase) as the preceding one. This series is called the "Standard Series." The exposures are numbered 1 to 9 and are symbolized in the calculations by "y". Irregularities of the timer and the influence of changes in line voltage were detected by measuring the dose in r units produced by the x-ray tube during each exposure. If no changes in line voltage take place and the timer is correct, the log r dose of each exposure will be proportional to the number of the film. Deviations larger than 1 per cent were corrected by adapting new numbers to the films in question, proportional to the log dose measured (numbering with one decimal).

The question now is: What is the exposure time that each type of film needs to produce a picture which is identical to No. 5 (y_0) of the standard series as far as film blackening is concerned? To determine this exposure time, five films of each type were given different exposures. (The phantom was used throughout.) Each exposure was 1.2 times as long (a 20 per cent increase) as the preceding one. Care was taken to produce at least one picture which was lighter and one which was darker than the example (y_0). Five exposures were needed, since the sensitivity of the film was not exactly known. When each exposure was made, the dose in r units (indicated by "x") in the useful beam was measured. (The position of the measuring instrument and the phantom were kept constant.) From each series of five exposures, two successive films were selected; one was lighter and the other darker than the example y_0. The choice being difficult, a third film from the series of five was selected. An observer was asked to compare each of these films, which were in random order, with the standard series and to indicate the one with which the unknown film compared best as far as density was concerned.

The following information could be collected about each type of film: Exposure with dose x_1 corresponds with No. y_1 of the standard series, and exposure with dose x_2 corresponds with No. y_2 of the standard series. By interpolation, the dose x_0 which the film with unknown speed needs in order to produce a picture identical to the example y_0 can be found.

$$x_0 = x_1 + \frac{y_0 - y_1}{y_2 - y_1}(x_2 - x_1).$$



A.

B.

Fig. 1.—Phantom used for making roentgenograms and an example of the result.

Thirteen observers (eleven dentists, one x-ray technician, and one photographer) compared the films with the standard series. This made the results more valuable, and the spread between the opinions could be calculated. (See appendix 1.)

Fog and Base Density.—The density of a developed unexposed film is the sum of the density of the film base and the fog in the emulsion. For this reason, the term *fog and base density* is used for the values measured.

A high value for fog and base density results in a lack of clear or light areas on the film (such areas would represent images of dense structures) and a decrease of contrast. The fog and base density of films developed for 4.5 and 9 minutes was determined.

Contrast.—The slope of the density-log exposure curve determines inherent film contrast. The contrast desirable for the image depends upon the diagnostic information that has to be collected from the film. In addition to inherent film contrast, there are also other factors (for example, kilovoltage) which influence the contrast as observed in roentgenograms. The slope of the density curve can be determined according to an American Standard.[6] As the requirements for this method were not fulfilled and the curve was not available over a wide range of log exposure values, the tangent to the curve at a density of 1.5 above fog and base was used as the contrast gradient or slope.

The density-log exposure curve was determined by exposing the film covered with an aluminum step-wedge (0-2-4-6-8-10-12-14 mm. aluminum). The exposure time was used in accordance with the findings described with respect to sensitivity. The developing time was 4.5 minutes for one film and 9 minutes for another.

Each film showed a series of eight different densities. In a separate experiment the transmission of each step of the step-wedge was measured with a dosimeter. The combination of the eight densities and eigth dose measurements makes it possible to plot densities against the logarithm of the amount of radiation transmitted by the step-wedge. (Only the ratios between the amounts of radiation transmitted by the step-wedge are of significance for the contrast determination.) The contrast was determined as already described: Contrast $\frac{d\ \text{density}}{d\ \log\ \text{dose}}$ at a density of 1.5, i.e., the slope of the tangent to the curve at a density of 1.5 above fog and base.

Graininess.—Heavy graininess of the film will hinder the observation of small details. If small details are of importance, a film with hardly any graininess is to be preferred. The graininess was determined on a subjective basis. The thirteen observers were asked to arrange the twenty-three x_1 films in order of graininess from 1 to 23. (A film having the lowest graininess would be No. 1.) Later on, the observers were asked to arrange the twenty-three x_2 films. Each type of film was ranked twenty-six times. The average ranking was used as a measure for graininess.

Color of Film.—The color of the film influences the general impression of the film. The degree to which interpretation is influenced by film color was not investigated. The color of the film was determined by three persons. They were permitted to choose between neutral, blue, and brown. Opinion is influenced by (1) the color of the light from the lightbox used, (2) the color of the light in the room, and (3) films of a different color which lie adjacent to the film being investigated. The color of the x_1 and x_2 films, in random order, was determined by three persons. Differences in opinion were eliminated by a joint discussion. For the reasons already mentioned, the result of this experiment has to be looked upon as a very rough estimate of the color of the film.

Packaging of the Film.—The packaging of the film must protect the film against moisture and light. Unsatisfactory protection against moisture can originate from inadequate packaging systems or from moisture absorption through the packaging material. Water leakage or absorption (if the film is not immediately unwrapped) results in a wet film and adhesion of the film to the contents of the packet. For this reason, films which have a waterproof packing are to be preferred.

Protection against moisture was determined in two ways:

1. The films were exposed to an excess of radiation and put, without unpacking, into the developing solution for 4.5 minutes. After a short rinse, they were unpacked in the fixing solution. The developing solution which leaked through the package and made contact with the film created a black area on the film. The absence or presence of blackening was used as a measure of leakage. A second film was tested in the same way after it had been bent in two directions around a cylinder with a radius of 2 cm.

2. The developing solution differs chemically from saliva and is alkaline. The pH of saliva also varies between individuals. For this reason, the absorption of water was also determined by measuring the increase in weight of the packed film after it was immersed in water for thirty seconds and dried between the folds of a towel. The process was repeated with another film after it had been bent in two directions as already described.

Identification Mark.—Most films have an identification mark to distinguish the rear and front sides of the films from each other. Mounting of the film is facilitated by the identification mark.

Thickness of the Film.—The thickness of the film varies with the type of film. Great differences can be found. Film thickness was measured with a micrometer.

Number of Coatings.—Dental x-ray film, like photographic film, originally was manufactured with an emulsion on only one side of the base material. Later, film sensitivity was increased and the contrast was doubled by coating the film on both sides with a sensitive emulsion.

Expiration Date.—When a film is stored for a long time, the fog density increases. For this reason, the films which are used should not be too old. It is of utmost importance that the manufacturer indicate the date after which the film is to be considered obsolete.

Directions for Use.—Most manufacturers mention how long the film has to be exposed. The exposure time is influenced by a large number of technical

TABLE II

Film numbers (arranged in order from maximum to minimum sensitivity)	Relative sensitivity and standard deviation: Hard radiation 70 kv. 5 mm. Al.			Soft radiation 45 kv. 1 mm. Al.			Average relative sensitivity (rounded off to two digits)	Average ranking for graininess	Fog and base density after development for		Contrast after development for	
	x_0	s_{x_0}	$\frac{100 S_{x_0}}{x_0}$	x_0	s_{x_0}	$\frac{100 S_{x_0}}{x_0}$	$\bar{x}_0$		4.5 minutes	9 minutes	4.5 minutes	9 minutes
12	1.19	0.06	4.7	1.15	0.02	1.5	1.2	20.0	0.17	0.20	1.9	2.0
3	2.20	0.03	1.5	1.98	0.06	3.0	2.1	18.4	0.12	0.25	2.0	2.2
9	2.93	0.14	4.9	2.89	0.13	4.5	2.9	15.7	0.15	0.20	2.1	2.1
17	3.29	0.04	1.2	3.11	0.08	2.5	3.2	12.4	0.17	0.18	2.4	2.4
15	3.64	0.04	1.2	3.58	0.05	0.8	3.6	11.8	0.18	0.22	2.7	3.0
1	4.38	0.21	4.8	3.75	0.08	2.2	4.1	20.9	0.06	0.18	1.9	2.0
4	4.08	0.07	1.7	4.13	0.29	7.1	4.1	16.9	0.13	0.23	2.0	2.0
14	4.59	0.09	2.0	3.81	0.05	1.4	4.2	19.4	0.13	0.17	2.1	2.1
6	4.40	0.08	1.9	4.03	0.05	1.2	4.2	12.3	0.17	0.23	2.4	2.4
13	4.62	0.16	3.5	3.87	0.16	4.2	4.2	21.2	0.05	0.06	2.2	2.5
10	4.53	0.20	4.4	4.57	0.19	4.3	4.6	18.4	0.22	0.33	1.3	1.3
18	5.27	0.19	3.5	4.46	0.32	7.2	4.9	14.4	0.20	0.27	1.5	1.6
11	5.64	0.08	1.4	5.82	0.09	1.5	5.7	7.9	0.16	0.17	2.5	2.6
20	5.76	0.26	4.5	5.94	0.11	1.9	5.8	7.7	0.13	0.16	2.3	2.5
23	5.94	0.10	1.6	5.88	0.11	1.8	5.9	7.8	0.15	0.18	2.4	2.4
2	7.32	0.08	1.1	5.56	0.08	1.4	5.9	18.1	0.14	0.19	2.1	2.4
5	7.36	0.12	1.7	7.06	0.10	1.4	7.2	9.2	0.17	0.19	2.3	2.4
16	17.0	0.4	2.2	17.3	0.3	1.8	17.	6.0	0.17	0.18	2.1	2.1
22	17.5	0.3	1.6	17.0	0.4	2.1	17.	4.9	0.13	0.13	2.2	2.5
8	19.2	0.5	2.8	19.5	0.5	2.4	19.	3.2	0.14	0.16	2.4	2.5
19	31.8	1.0	3.1	32.7	1.1	3.3	32.	2.5	0.13	0.13	2.4	2.5
21	33.4	0.5	1.6	32.4	0.5	1.5	33.	3.4	0.13	0.13	2.4	2.5
7	34.0	1.9	5.6	39.6	0.9	2.4	37.	3.7	0.12	0.13	2.0	2.0
	$x_0 = 10$			$x_0 = 10$								

factors (for instance, kilovoltage, milliamperage, filtration, focus-film distance, etc.). Although the indicated exposure time is very often accompanied by some information on these technical factors, the question remains as to whether this information is adequate. For this reason, a comparison is made between the exposure time indicated in the directions for use and the findings in this investigation.

RESULTS AND CONCLUSIONS*[4]

Sensitivity.—Table II gives the relative sensitivity and its standard deviation (caused by differences between the thirteen observers) of the films examined. The standard deviation, in per cent, is shown in columns 4 and 7.

The differences between these standard deviations are significant (Bartlett's test, Appendix 2). This means that the spread in the opinion of the observers is different for different films.

The sensitivity was estimated with radiation produced at 45 KVP with 1 mm. aluminum total filtration (0.75 mm. Al first HVL; 1.15 mm. Al second HVL) as well as at 70 KVP with 5 mm. Al total filtration (3.2 mm. Al first HVL; 4.0 mm. Al second HVL). The films to be investigated and the standard series used were always made with the same quality of radiation. This means that two standard series were used. The significance of the differences in relative sensitivity between the films (separate for the hard and the soft radiation) was calculated by using Student's t test (Appendix 3). The films for which the differences in sensitivity are not significant for both types of radiation are

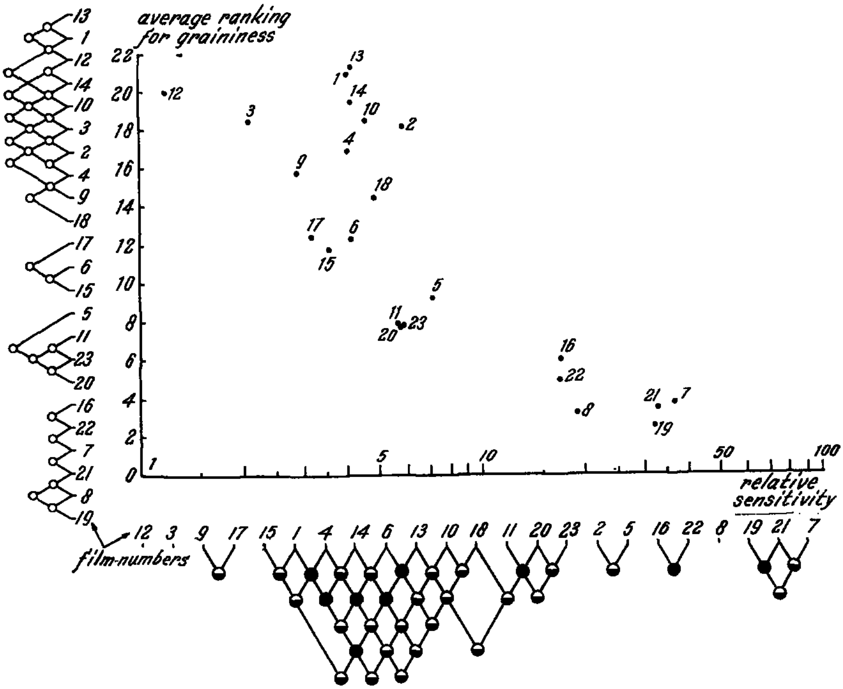


Fig. 2.—Relation between graininess and relative sensitivity. (For further explanation, see text.)

*All statistical calculations are made by using a 5 per cent level of significance.

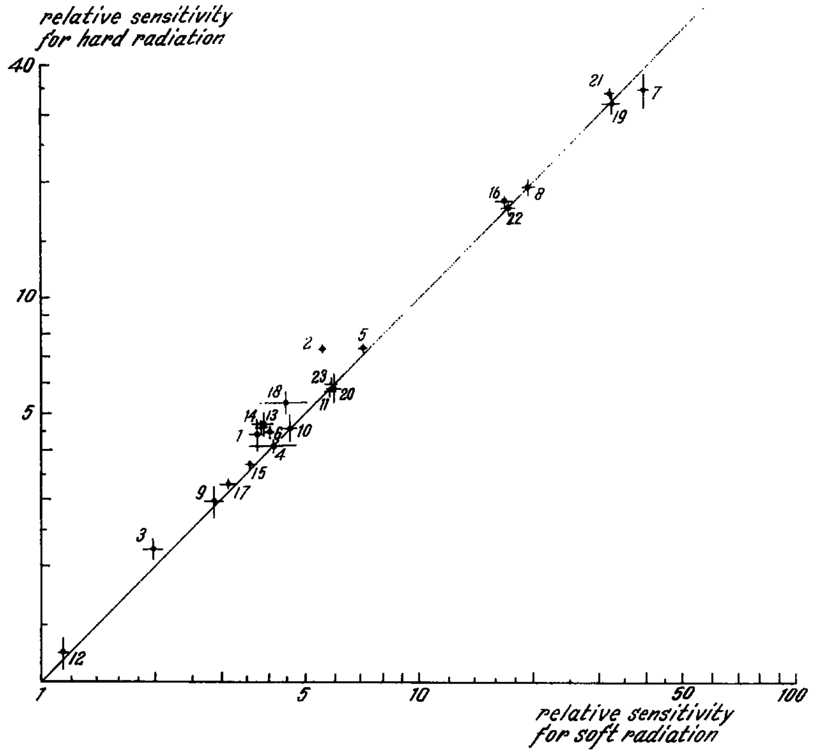


Fig. 3.—Relation between relative sensitivity for hard and soft radiation. The horizontal and vertical lines indicate a distance of two times the standard deviation to both sides.

indicated in Fig. 2 (horizontal axis) by a full-shaded circle on the intersection of the reference lines. Half-shaded circles are used on the intersection of reference lines which connect films for which one type of radiation showed a significant difference and the other did not.

A comparison between the relative sensitivities found with the hard radiation and with the soft radiation is made in Fig. 3. The relative sensitivities shown in Table II were used; they are calculated in such a way that the average relative sensitivity for both types of radiation is 10.

It could not be determined whether the films behave differently for different radiation, because of the significant difference between the standard deviations. If there is any effect, it will be a slight one; this can be seen in Fig. 3. For practical purposes, column 8 of Table II gives the average relative sensitivity rounded off to two digits. It can be noted that the film with the lowest sensitivity requires an exposure time thirty-one times as long as that required by the most sensitive film. Four groups of film can be distinguished when separations are made on the basis of a relative sensitivity increase of more than 50 per cent.

Fog and Base Density.—The fog and base density is given in Table II. Fig. 4 shows the relationship between fog and base density and relative sensitivity. It can be seen that no relationship exists between these two properties. A film with a high sensitivity can have a low fog and base density. Films with a short

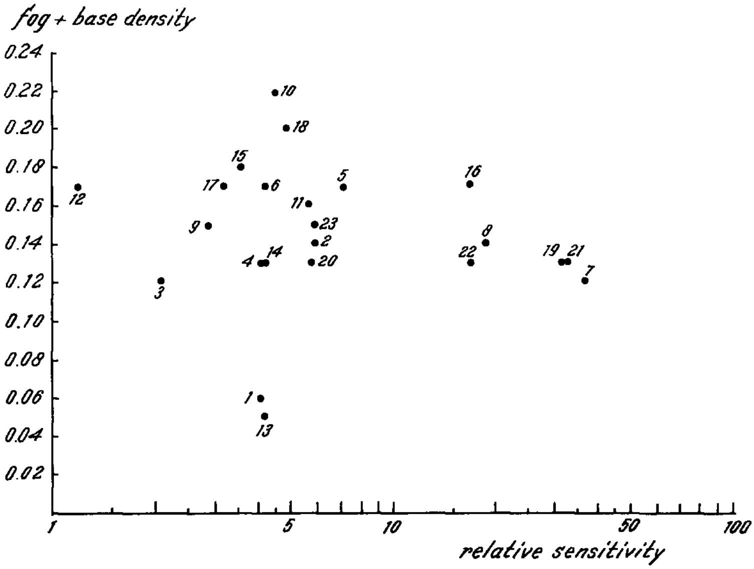


Fig. 4.—Relation between base and fog density and relative sensitivity.

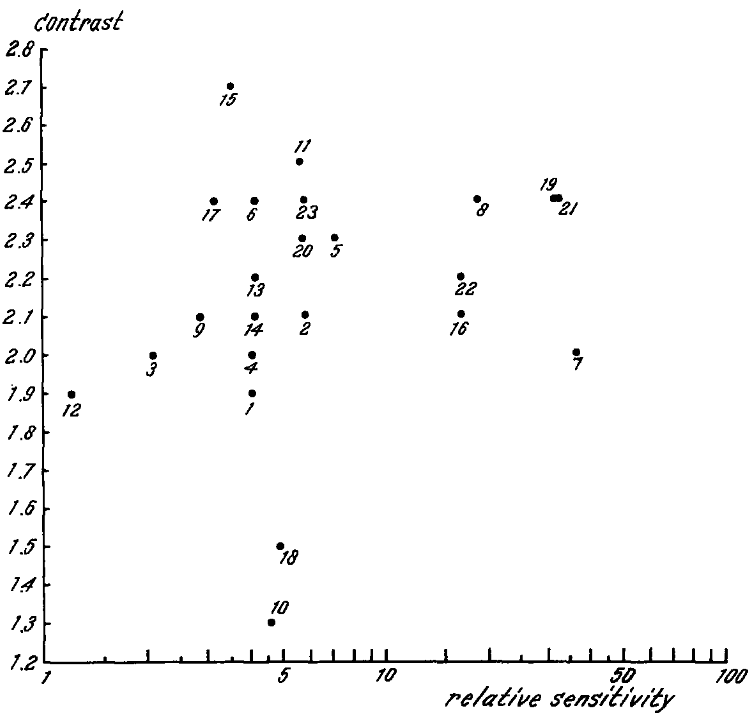


Fig. 5.—Relation between contrast and relative sensitivity.

exposure time and a low fog and base density can be found in the lower left-hand corner of the figure (films 1 and 13). An increase in development time can affect the fog and base value (Table II). Some films show no increase at all;

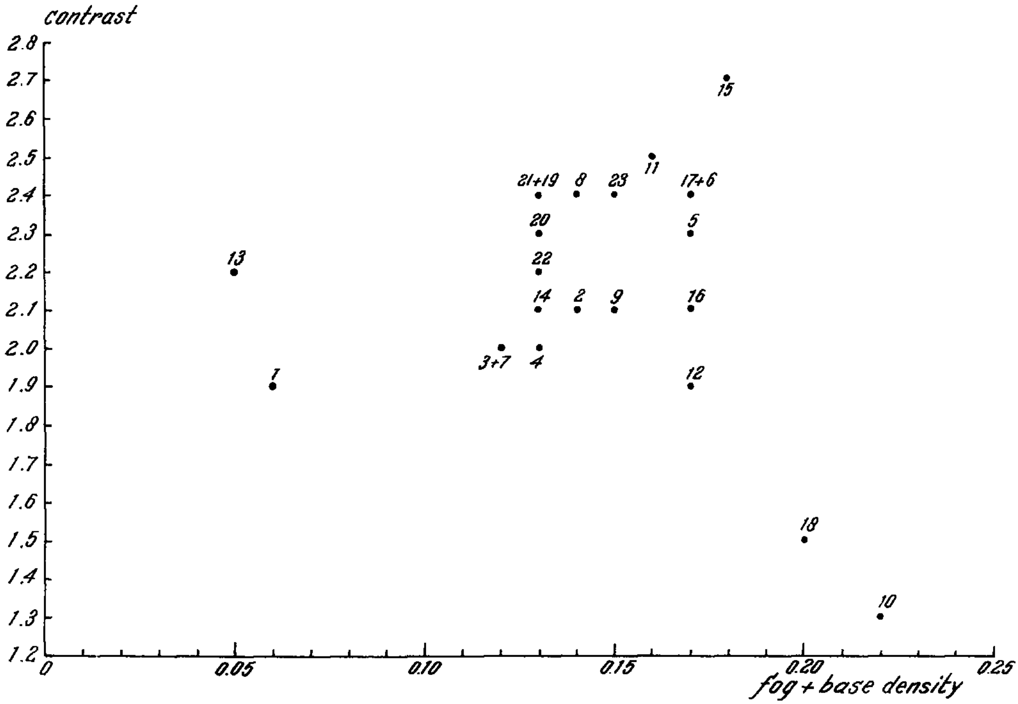


Fig. 6.—Relation between contrast and base and fog density.

others show a serious increase. This effect seems to be independent of the initial density found at a development time of 4.5 minutes. (Compare films 1 and 13.)

*Contrast.**—The contrast was measured after 4.5 and 9 minutes' development time and is represented in Table II. The maximum and minimum contrasts after development for 4.5 minutes are 2.7 and 1.3, respectively. When the contrast is plotted against the relative sensitivity (Fig. 5), it is evident that no relationship exists between these two factors. Thus, a film with a high sensitivity can have a low contrast. When the contrast is plotted against the fog and base density, as shown in Fig. 6, the conclusion can be drawn that these factors have no relationship.

Graininess.—The average ranking for graininess is shown in Table II. In Fig. 2 (vertical axis) circles are placed at the intersection of reference lines which connect those films for which the differences in the rankings for graininess were not significant (sign test). In this figure the relationship between relative sensitivity and graininess is shown. It is clear that these two properties are correlated. A higher film speed means more graininess; however, there are great differences in graininess between films with the same sensitivity. When selecting films, one can find the best ones on the lower border of the cloud of scattered points.

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*Contrast (tangent to density curve) = $\frac{\text{d density}}{\text{d log dose}}$ at a density 1.5 above fog and base.

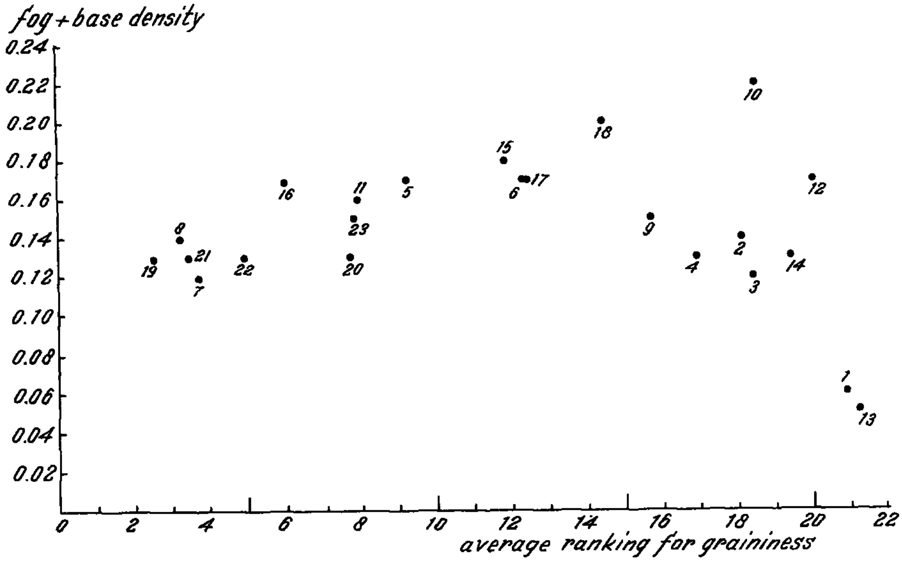

Fig.—7.—Relation between graininess and base and fog density.

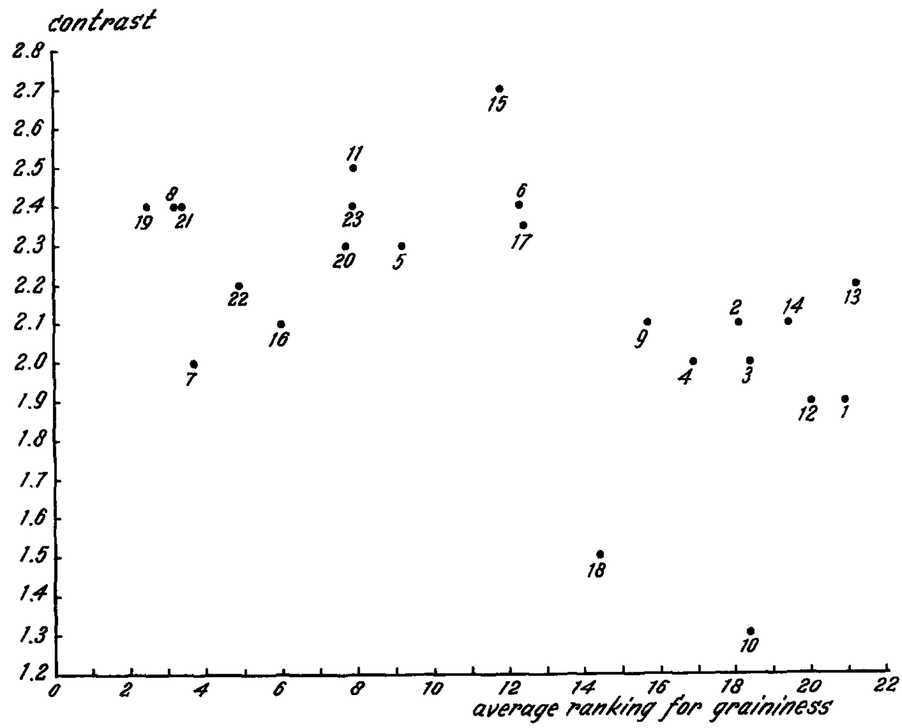

Fig. 8.—Relation between graininess and contrast.

Fig. 7 shows the relationship between graininess and fog, and in Fig. 8 graininess is plotted against contrast. Fog plus base density, as well as contrast, seems to be independent of graininess. The films located nearest to the

TABLE III

FILM NUMBER (ARRANGED IN ORDER FROM MAXIMUM TO MINIMUM SENSITIVITY)	COLOR OF FILM	LEAKAGE IN DEVELOPING SOLUTION*		WATER ABSORPTION†		PACKING MATERIAL‡	IDENTIFICATION MARK§	THICKNESS OF FILM (MM.)	NUMBER OF COATINGS (SINGLE OR DOUBLE EMULSION)
		WITHOUT BENDING	AFTER BENDING	WITHOUT BENDING	AFTER BENDING				
1	Brown	L	L	S	A	-	-	0.16	2
2	Neutral	L	L	S	A	-	-	0.16	2
3	Brown	L	L	S	A	-	-	0.16	2
4	Brown	-	L	A	A		O	0.14	2
5	Neutral	L	L	H	H	-	-	0.17	2
6	Neutral	L	L	H	H	-	-	0.17	2
7	Blue	L	L	S[1]	S - A[1]	-	-	0.16	1
8	Blue	L	L	S[1]	S - A[1]	-	-	0.16	2
9	Neutral	L	L	S[1]	S - A[1]	-	-	0.24	2
10	Neutral	-	-	S	S	M	O	0.23	2
11	Neutral	L	L	H	H	-	O	0.17	2
12	Neutral	L	L	H	H	-	O	0.17	2
13	Brown	L	L	A	A	Pl	-	0.16	2
14	Neutral	L	L	A	A	Pl	-	0.16	2
15	Neutral-brown	L	L	S	S	-	-	0.15	2
16	Neutral	-	-	S	S	-	-	0.16	2
17	Neutral	-	-	S	S	-	-	0.18	2
18	Neutral	L	L	Other size of film		-	-	0.24	2
19	Neutral	L	L	A	A	-	-	0.19	2
20	Neutral	L	L	A	A	-	-	0.19	2
21	Neutral	L	L	A	A	-	-	0.18	2
22	Neutral	L	L	A	A	-	-	0.19	2
23	Neutral	L	L	A	A	-	-	0.20	2

*L = Leakage; - = no leakage.
†S = Small amount (< 0.05 gram), A = average amount (0.05 to 0.20 gram), H = large amount (> 0.20 gram). [1]Indicates that large differences were found between the films.
‡M = Metal; Pl = plastic; - = paper.
§O = Opening; - = raised dot.

lower left-hand corner of the cloud in Fig. 7 are the best as far as fog and base density and graininess are concerned.

Color of the Film.—The results of color judging are shown in Table III. Some observers are in favor of the blue-base films. In a small experiment observers in favor of the blue films were asked to select the best film from a set of three. The first of this series was a blue-base film, the second was a neutral one, and the third was a duplicate of the neutral film covered with two layers of the base material of the blue-base film. The image in the three films was identical. In all cases the third film was selected, although this one had a higher score for graininess. The preference appeared to be based only on the color of the base material.

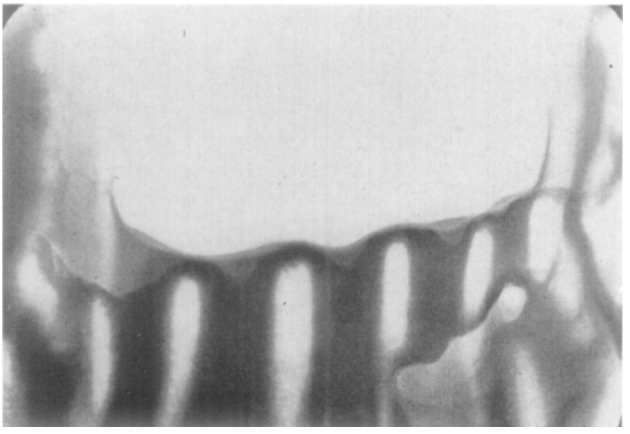

Fig. 9.—Example of result of test procedure for leakage.

Packing.—Packing-material information is given in Table III. Findings concerning leakage of developing solution through the packing material appear also in Table III. Fig. 9 shows what kind of pictures were obtained. The water absorption is also represented in Table III. It is clear that some films give an excellent protection against moisture, whereas other films are very poor in this respect.

Identification Mark.—Information on this subject is found in Table III. Most films have a raised dot, which is an efficient type of identification mark. Some films have a small hole at one corner. By turning the film, so that the hole is located in a specific corner and the length of the film is horizontal, one can distinguish the front and rear surfaces. This procedure is more complicated and takes more time than identification by means of a raised dot.

Thickness of the Film.—The thicknesses of the various films (in millimeters) are shown in Table III.

Number of Coatings.—Information as to whether the film is single- or double-coated can be found in Table III. There is only one single-coated film.

Expiration Date.—Table I gives the expiration dates of the films used in this investigation. (The exposures were made in August, 1959.) Some manufacturers do not give an expiration date.

TABLE IV

1 FILM NUMBERS (ARRANGED IN ORDER FROM MAXIMUM TO MINIMUM SENSITIVITY)	2 EXPOSURE TIME ACCORDING TO MANUFACTURER			
	MAXIMUM		MINIMUM	
	AREA	TIME (SECONDS)	AREA	TIME (SECONDS)
12	–		–	–
3	Max. molar	0.3 – 0.4	Mand. incisor	0.1 – 0.2
9	Max. molar	1¼	Mand. incisor	1
17	Max. molar	1½	Mand. incisor	0.2
15		–	–	–
1	Max. molar	0.5 – 0.7	Mand. incisor	0.3 – 0.4
4	–	0.9		0.4
14	Max. molar	0.6 – 0.8	Mand. incisor	0.4 – 0.5
6	Max. molar	1	Mand. incisor	½
13	Max. molar	0.6 – 0.8	Mand. incisor	0.4 – 0.5
10	Max. molar	1 – 1½	Mand. incisor	½ – ¾
18	Occl. film		–	–
11	–			
20	Max. molar	1	Mand. incisor	½
23	Max. molar	1	Mand. incisor	0.75
2	Max. molar	0.5 – 0.7	Mand. incisor	0.3 – 0.4
5	Max. molar	4½	Mand. incisor	2
16	Max. molar	2¼	Mand. incisor	1
22	Max. molar	2	Mand. incisor	1
8	Max. molar	2¼	Mand. incisor	1
19	Max. molar	4	Mand. incisor	2
21	Max. molar	4	Mand. incisor	2
7	Max. molar	5	Mand. incisor	2¼

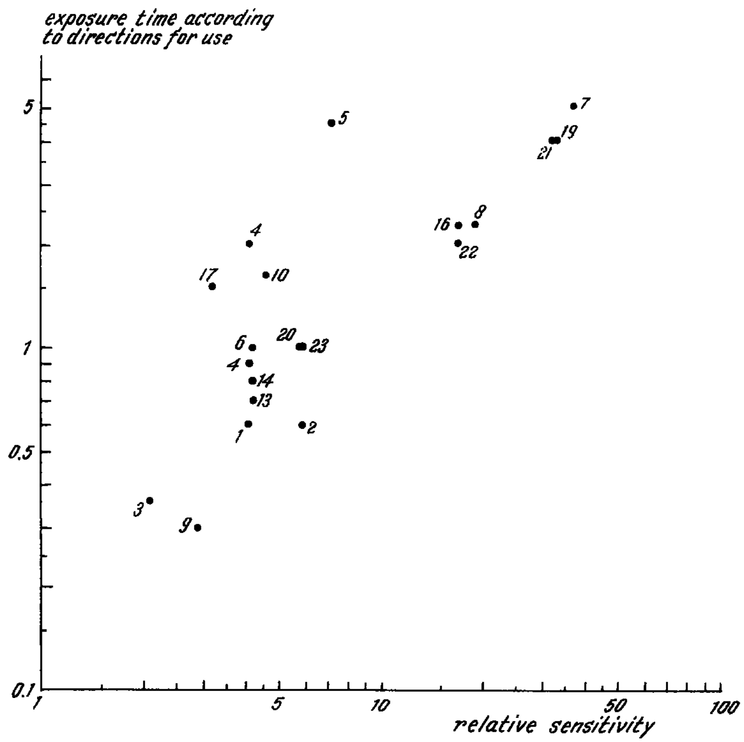

Fig. 10.—Relation between exposure time according to manufacturer and relative sensitivity.

TABLE IV—CONT'D

3 TECHNICAL DATA	4 STANDARDIZED EXPOSURE TIME	5 RELATIVE SENSITIVITY: REPEATED FROM TABLE II	RICHARDS[6] JANUARY, 1957	WUEHRMANN[7] 1959	BJÄRNGARD AND HOLLENDER[8] 1960
—	—	1.2			
10 Ma.	0.35	2.1			3.1
10 Ma. 65 kv. 40 cm.	0.3	2.9	3.1	3.5	3.4
10 Ma. 65 kv. 8"	1.5	3.2	3.1	4.0	3.4
—	—	3.6			4.6
10 Ma.	0.6	4.1			
10Ma. 65 kv. 12 – 15 cm.	2.0	4.1			
10 Ma.	0.7	4.2			
10 Ma. 65 kv. 20 cm.	1	4.2			4.7
10 Ma.	0.7	4.2			
—	1.25	4.6			
—	—	4.9		5.4	
—	—	5.7			5.2
10 Ma. 65 kv. 8"	1	5.8		7.0	
10 Ma. 65 kv. 8"	1	5.9	6.5	6.3	
10 Ma.	0.6	5.9			
10 Ma. 65 kv. 20 cm.	4.5	7.2			
10 Ma. 65 kv. 8"	2.25	17.	19.	17.	15.
10 Ma. 65 kv. 8"	2	17.			
10 Ma. 65 kv. 8"	2.25	19.	19.	21.	18.
10 Ma. 65 kv. 8"	4	32.		25.	
10 Ma. 65 kv. 8"	4	33.	29.	31.	
10 Ma. 65 kv. 8"	5	37.	38.	40.	

Directions for Use.—In Table IV, column 2 gives the maximum and minimum exposure times specified by the manufacturers. Column 3 gives the technical data as mentioned in the directions for use. The exposure times for the upper molar area were recalculated for the same technical conditions as far as necessary and possible. The results of this procedure are shown in column 4. Column 5 includes the relative sensitivity found in this investigation. Fig. 10 shows the relationship of this information. The graph illustrates that films with the same speed may require different exposure times according to the directions for use. This difference can be explained by the inadequate information on technical data. The exposure time is affected, for instance, by the amount of filtration.

DISCUSSION

In a United States Federal specification,[5] five classes of speed are designated. The maximum and minimum exposures in this specification are 0.55 and 0.04 roentgens (a ratio of 14). The ratio in exposure between the films of maximum and minimum sensitivity as found in this investigation is 31. Since this latitude is much larger than the latitude in the United States Federal specification (a ratio of 14), all dental x-ray films cannot be classified in the United States system.

Paffenbarger and associates[5] state that fog and contrast increase when the speed increases. When fog and base, instead of fog alone, are measured, it is found that the sensitivity and the fog and base density are independent factors. In this investigation the sensitivity and the contrast do not show a relationship either.

A comparison between speed indices published by other investigators and the results of this investigation are shown in Table IV. The largest difference between the findings is 50 per cent. For a better comparison, the findings of the other three investigators were recalculated to produce the same average speed. Since this investigation was carried out, the speeds of films Nos. 5, 6, and 15 have been changed.

SUMMARY

On a subjective basis, the speed of twenty-three different types of film was estimated. The fastest film available is thirty-one times as fast as the slowest film. The fog and base density, the contrast, and the graininess of the films were also estimated. These factors are independent of each other. Only the sensitivity and graininess show a correlation. Information was also collected with respect to the color of the film, the protection against moisture by packaging, the identification mark, the thickness of the film, the number of emulsion surfaces, the expiration date, and the exposure time according to the manufacturer's directions for use. Differences in protection against moisture through packaging, lack of information regarding expiration dates, and unsatisfactory information on technical data in connection with the exposure time were found.

APPENDIX 1

Instead of the y_1 and y_2 values, the average opinion of the observers $\bar{y}_1$ and $\bar{y}_2$ was used for the interpolation. The film with dose x_1 corresponds now with the average opinion $\bar{y}_1$, and x_2 with $\bar{y}_2$.

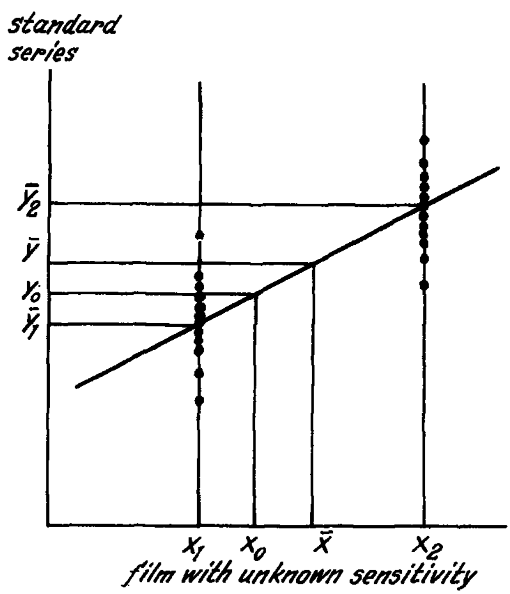

Fig. 11.—The relation between the r dose received by the two films of unknown sensitivity (x_1 and x_2) and the standard series (y).

In those cases in which three films were selected, the averages of those two succeeding films which had a $\bar{y}_1$ and $\bar{y}_2$ higher and lower than y_0 were used.

The interpolation was carried out with these averages $\bar{y}_1$ and $\bar{y}_2$. This procedure can also be looked upon as a part of a regression problem (Fig. 11).

$$y = \bar{y} + b\ (x - \bar{x})$$

$$\text{where } b = \frac{\bar{y}_2 - \bar{y}_1}{x_2 - x_1}$$

$$\bar{y} = \frac{\bar{y}_1 + \bar{y}_2}{2} = \frac{\Sigma\ y_1}{26}$$

$$\bar{x} = \frac{x_1 + x_2}{2} = \frac{\Sigma\ x_i}{2}$$

$$\text{so}: y_0 = \bar{y} + b(x_0 - \bar{x})$$

$$\text{or}: x_0 = \bar{x} + \frac{1}{b}\ (y_0 - \bar{y}$$

The variance of x_0 ($S^2_{x_0}$) can now be estimated:

$$x = \bar{x} + \frac{1}{b}\ (y - \bar{y})$$

$$S^2_x = \frac{1}{b^2} S^2_y \quad \text{(The variance in b can be neglected.)}$$

$$S^2_x = \frac{1}{b^2}\left\{S^2_{\bar{y}} + S^2_b\ (x - \bar{x})^2\right\}$$

$$\text{where } S^2_{\bar{y}} = \frac{S^2_y}{26} \text{ and } S^2_b = \frac{S^2_y}{\Sigma\ (x_1 - \bar{x})^2}$$

$S^2_{x_0}$ is found by substituting x_0 for x:

$$S^2_{x_0} = \frac{1}{b^2}\left\{S^2_{\bar{y}} + S^2_b\ (x_0 - \bar{x})\right\}$$

APPENDIX 2

The differences between the $\frac{100 s_{x_0}}{x_0}$ values are significant for both hard and soft radiation when Bartlett's test is applied ($P \ll 0.001$). Bartlett's test can be applied to these values since $\frac{100 s_{x_0}}{x_0}$ is nearly proportional to log $\frac{x_0 + s_{x_0}}{x_0}$.

(See discussion of sensitivity in "Materials and Methods.") The standard deviation of the relative sensitivity (based on the average of the observations, with 24 degrees of freedom) varies between 0.8 and 7.2 per cent. The standard deviation of the observations varies also between 1.008[5] and 1.072.[5] or between 4 and 42 per cent.

APPENDIX 3

The significance of differences between the relative sensitivities were calculated by using Student's t test. In some instances the difference between the standard deviations (Fisher's F test) made it necessary to use Welch's approximation for the number of degrees of freedom for the t test.

REFERENCES

1. International Organization for Standardization: I.S.O. Recommendation R 5, Diffuse Transmission Density (Photography), ed. 1, October, 1955. (This standard is identical with American Standards Association: American Standard for Diffuse Transmission Density Z 38.2.5, 1946, approved March 5, 1946, New York, 1946.)
2. American Standards Association: American Standard Temperature for Photographic Processing Solution, pH 4.5, 1953, approved Dec. 8, 1953, New York, 1953.
3. American Standards Association: American Standard Method for the Sensitometry of Medical X-ray Films, pH 2.9, 1956, approved Jan. 27, 1956, New York, 1956.
4. Dixon, W. J., and Massey, F. J.: Introduction to Statistical Analysis, ed. 2, New York, 1957, McGraw-Hill Book Company, Inc.
5. Paffenbarger, G. C., Forziati, A. F., and Kumpula, M. P.: A Discussion of Federal Specifications GG-Y-620 and L-F-310 for Dental X-ray Apparatus and Dental X-ray Film, J. Am. Dent. A. 59: 472-477, 1959.
6. Richards, A. G.: Roentgen Ray Radiation and the Dental Patient, J. Am. Dent. A. 54: 476-487, 1957.
7. Wuehrmann, A. H.: Relative Film Speeds of Commonly Used Intraoral Film, Oral Surg., Oral Med. & Oral Path. 12: 1091-1094, 1959.
8. Bjärngard, B., and Hollender, L.: Radiation Doses in Oral Radiography. III. A Limited Survey of Dental X-ray Units, Odontol. Rev. 11: 193-206, 1960.