Radiographic Phenomena In Cephalometric Roentgenography

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Historical

In discussing radiographical phenomena one should have some historical information as to the impact Roentgen's discovery made upon the world at the time. Roentgen, himself, described his discovery in the now famous paper *A New Kind of Rays* which was published on December 28, 1895. When Roentgen published his paper, he did not, of course, realize that Goodspeed, at the University of Pennsylvania, had accidentally made an x-ray photograph about six years earlier. Goodspeed had discarded these photographs as freaks and let it go at that, but when Roentgen gave his discovery to the world, Goodspeed re-examined his plates, and in one of his lectures at the University of Pennsylvania on February 22, 1896, had this to say:

"We can claim no merit for the discovery, for no discovery was made. All we ask is that you remember, gentlemen, that six years, day for day, the first picture in the world by cathodic rays was taken in the physical laboratory of the University of Pennsylvania."

As the use of x-rays became more world wide, Roentgen became greatly disturbed by reports reaching him of peculiar skin reactions in persons using the x-ray machines. He could not believe that these reactions were due to x-ray. It was, however, Sir Joseph Lister who convinced Roentgen of the dangerous radiation hazards. When Lister addressed the British Association for the Advancement of Science in September 1896, he said in speaking of x-rays:

"There is another way in which the roentgen rays connect themselves with physiology and may possibly influence medicine. It is found that if the skin is long exposed to their action it becomes very much irritated, affected with a sort of sunburn. This suggests the idea that the transmission of the rays through the human body may be not altogether a matter of indifference to internal organs, but may by long continued action produce, according to the condition of the part concerned, injurious irritation or salutary stimulation."

Lister's prophetic words were evidenced by the disastrous experiences of the early investigators, some of whom died from the effects of x-ray radiation. A contemporary of Roentgen, our own Thomas Edison, thought that Conrad Roentgen should profit financially by his discovery, but Roentgen refused to exploit it. Many honors came to Roentgen. He received the first Nobel prize in physics in 1901 and donated the money to the University of Wurzberg to be used in the interests of science.

The final chapter has not been written as to the future role x-ray will play in science and history, for as recent as this year a large x-ray corporation has reported a new process called xeroradiography which produces an image on a dry plate. By this process selenium coated aluminum plates are given an electrostatic charge prior to the x-ray

Presented at the reunion meeting of the Graduate Department of Orthodontia, University of Illinois, March 1956, Chicago, Illinois.

exposure. The exposure time is about 8 times as long as for x-ray film. After exposure, the plates are dusted with a fine chemical dust which clings to the charged surface like iron filings to a magnet. X-rays reaching the plate tend to dissipate the electrostatic charge depending on the density of the subject x-rayed. The more dense the tissue, the less dissipation of the electrostatic charge. Hence, the fine detail of definition between hard and soft structures. Like sound tape, these plates can be erased and used repeatedly. However, as yet, these plates are too slow and limited in their use. In their present form of development they certainly cannot be used in cephalometric roentgenography for they cannot be traced in the conventional manner. These plates can, however, be photographed very easily.

The X-Ray Machine

The x-ray machine, in itself, is quite an intricate mechanism. It is not imperative that one must understand the construction of all the parts of this marvelous machine in order to produce a good roentgenogram. However, the productive part, the x-ray tube, should be described to appreciate fully the remarkable powers of this device. It is the source of radiation, producing the roentgen rays or x-rays.

Any good x-ray machine calibrated and capable of delivering up to 30 milliamperes and 90 kilovolts, with a focal spot measurement not exceeding three millimeters square, is quite ample and desirable. Most dental x-ray machines are equipped with tubes which cannot meet such requirements.

The X-Ray Tube

The modern x-ray machine is usually equipped with a Coolidge hot cathode tube enclosed in a shockproof case. This kind of x-ray tube (Fig. 1) was developed by Dr. W. D. Coolidge in 1912 and consists of a lead glass bulb from which most of the air has been pumped out to create a pressure of about 0.00001 millimeter of mercury—almost a complete vacuum. Within this tube are two metallic electrodes, the cathode and anode, opposing each other from the opposite ends of the tube and separated by a few millimeters. The face of the anode toward the cathode is at an angle of 15° to 22°. Within the face of the cathode is embedded a tungsten filament in a focusing cup. The small filament of tungsten wire in the cathode end of the tube is heated to incandescence to about 3240°F. At this temperature, there is a spontaneous emission of electrons. With a further increase in temperature, more electrons are emitted. Then, as a high voltage current is passed through this filament, these electrons are hurled against the tungsten spot (focal spot) of the anode to complete the circuit. This stream of electrons, called the cathode rays, bombards this target at tremendous speeds. The speed at which these electrons travel depends on the kilovoltage. The greater the kilovoltage, the higher the speed. As these electrons (from the cathode) hit the tungsten anode, some of the electrons (less than 2 per cent) collide with the other electrons or atom nuclei of the anode, and the result of this collision produces the roentgen rays in various wave lengths. The rest of the electron stream passes into the tungsten target between the atoms and produces tremendous heat.

The very short waves are the most penetrating and, therefore, are the useful or primary rays. The long waves, called the Grenz rays or soft rays, are of little value in roentgenography and have no great penetrating power. They are, however, a disturbing factor in roentgenography and also present a radiation hazard. Fortunately, the x-ray tubes constructed today filter out most of these soft rays. Additional attachments such as aluminum filter disks in the x-ray head can further eliminate these undesirable rays from the useful field.

Roentgen rays or x-rays have the same speed of light, and, like ultraviolet rays and electric waves, are invisible and travel in a straight line. Unlike light rays, however, they cannot be refracted, focused, or reflected by mirrors. X-rays exhibit the remarkable phenomenon of passing through bodies of various densities. When stopped or slowed down in their passage through dense or very large bodies, the x-rays are absorbed by these bodies. This absorption sets up another phenomenon, secondary radiation. This is another disturbing factor with which to cope. Further explanation of this phenomenon will be discussed later.

The amount of electric current passing through a machine or conductor can be measured. The unit of measure is an ampere. The x-ray machine is so calibrated that it measures these units in milliamperes or 0.001 ampere. Milliamperage, during radiation, affects and determines the density of an image on a film, that is, the blackness. The higher the milliamperage, the greater will be the density. Milliamperes multiplied by seconds of time are called milliampere-seconds, the basis of comparison for radiation.

The pressure or electromotive force which drives an electric current through a conductor or wire is measured in units called volts. Because of the tremendous amount of electromotive force necessary to push the electrons across the gap between the cathode and anode of an x-ray tube, the units employed in roentgenography are kilovolts or 1,000 volts. Kilovolts control the resulting contrast of x-ray films. This contrast is necessary in defining the various densities of a body as they appear on a film. Hence, in penetrating very hard tissues, a high kilovoltage would be required.

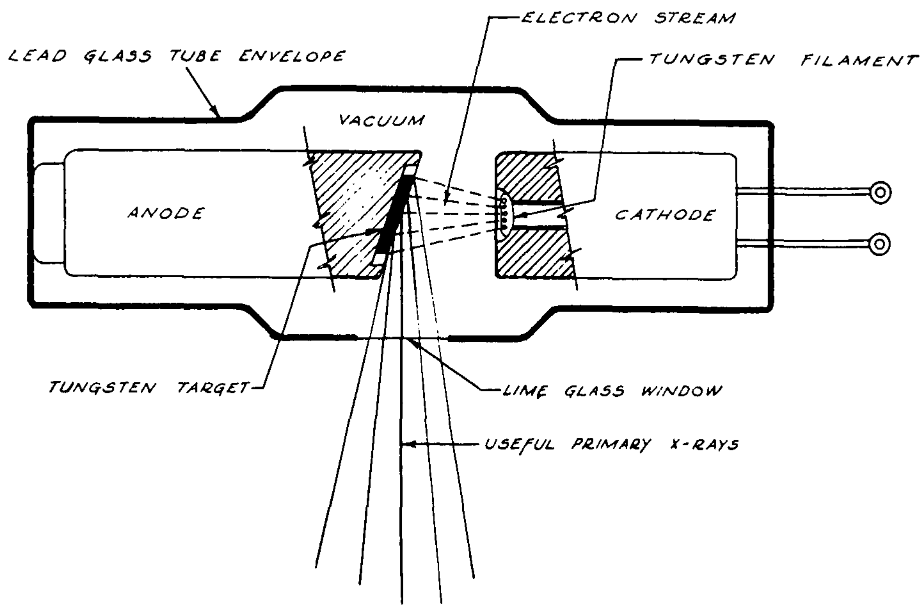

Fig. 1 X-ray tube.

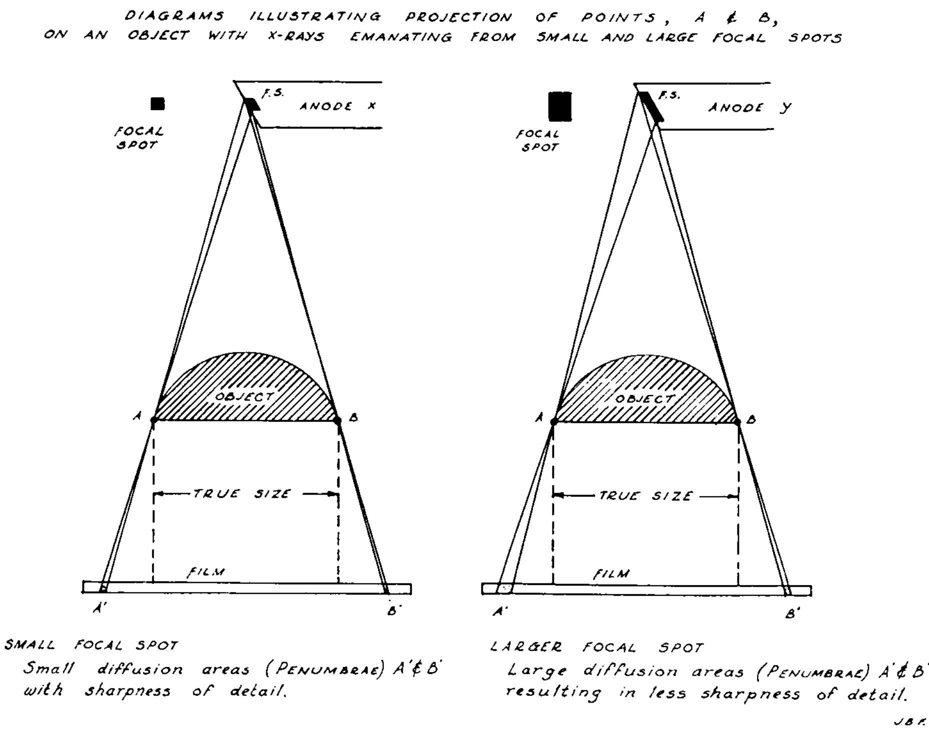

Fig. 2 Diagrams illustrating projection of points A and B on an object with rays emanating from large and small focal spots.

The Focal Spot

The "actual focal spot" area (the area of the tungsten target, bombarded by electrons) is slightly larger than the filament of the cathode because the face of the target is at an angle (15 degrees to 22 degrees) to the long axis of the tube (Fig. 1). This inclination determines the "effective focal spot" of the tube for the rays emanating through the window. The "effective focal spot" size (Fig. 2) is a determining factor in detail sharpness in radiographic projection, the smaller the focal spot, the more detail sharpness and less diffusion. Dental x-ray tubes have effective focal spot measurements of 1.3 to 1.8 millimeters square, hence, the sharpness of detail in dental roentgenograms. However, the dental x-ray machine is one of limited power. To subject the dental x-ray tube to a high current intensity would burn out the focal spot of that tube.

As has been stated before, x-rays emanate from the focal spot of the anode stream through the lime glass window of the x-ray tube. An x-ray emanating from the exact center of the focal spot has been termed the "central ray." This is merely a hypothetical suggestion. There are many rays emanating from the center of the focal spot. However, x-rays given off in that area are usually very short and, therefore, the most penetrating, and cause the least distortion of the image on the roentgenogram.

Focal Film and Object Film Distance

The focal-film distance is measured from the center of the focal spot (tar-

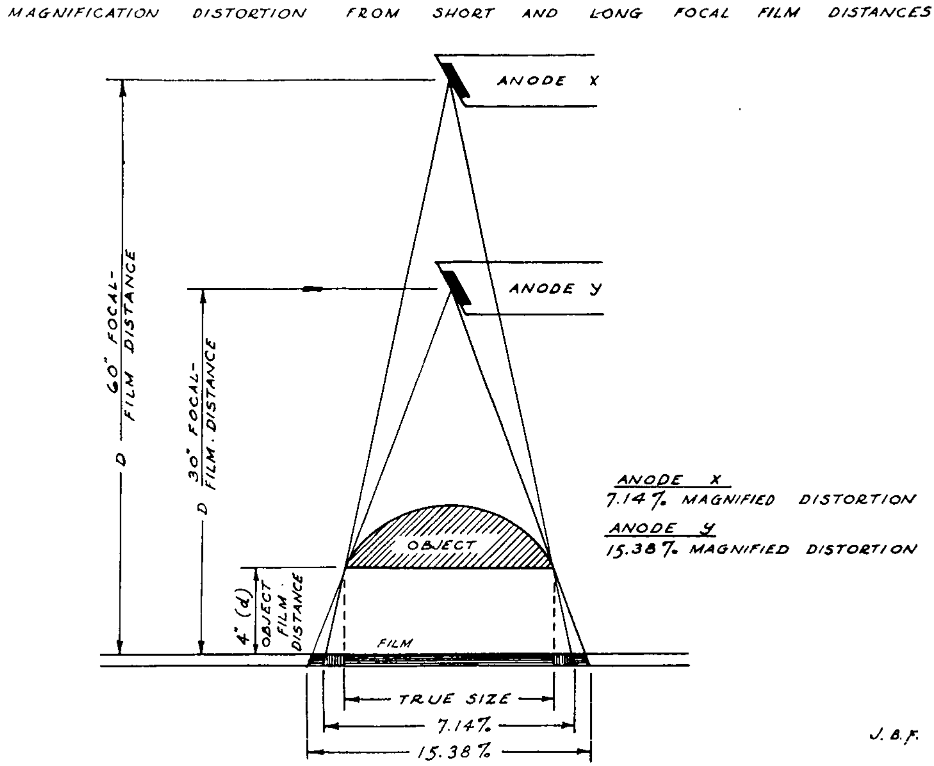

Fig. 3 Magnification distortion from short and long focal film distances.

get) on the anode to the film in the cassette. In roentgenographic cephalometry, the focal-film distance is of utmost importance; besides improving the detail sharpness of the roentgenogram, the long focal-film distance helps decrease the magnification distortion. The standardized distance from the focal spot to the midsaggital plane of the cephalostat is usually fixed at sixty inches. Therefore, the focal-film distance is this fixed distance plus the object-film distance, which is the distance from the mid-saggital plane to the film, which is two to three inches longer. Of course, it is not possible to get a true rendition of an image of an object on a film without some magnification because the body being radiographed cannot be contained in the same plane of the film. However, the greater the focal-film distance the less distorted is the magnification of the true image of the object (Fig. 3).

In the matter of focal-film distance and object-film distance, it is shown diagrammatically in Figure 4 that we have two x-ray tubes of equal potential and of equal sized focal spots and a constant focal-film distance. X-rays emanating from the focal spot through points A and B create areas of diffusion (penumbra) A^1 and B^1. The greater the object-film distance becomes the greater the areas of diffusion and magnification distortion, and also the less detail sharpness or definition. In addition, it should be observed that the rays emanating from the "heel" portion of the anode produce a smaller area of diffusion, hence better definition. Therefore, in setting up the x-ray tube for

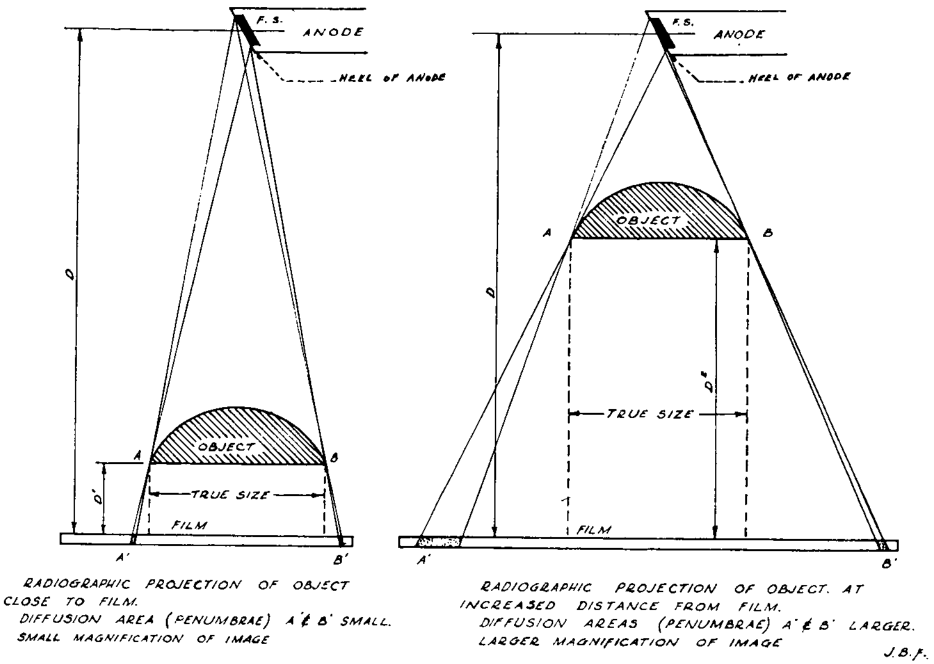

Fig. 4 Different projections due to different object-film distances.

cephalometric roentgenography, it is advisable that the heel end of the anode is toward the facial portion of the head. In this manner, the x-rays emanating from that portion of the tube produce the least amount of diffusion on the film and give a better definition of facial skeletal landmarks.

Secondary Radiation

A disturbing factor in x-ray radiation is that of secondary radiation. As is known, the primary x-rays emanating from the x-ray tube have the unique property of passing through a body to cast an image on a film, but some of these rays are absorbed by the body and surrounding area. This phenomenon of absorption sets up foci of "miniature x-ray tubes" within the body radiographed and the surrounding area reached by x-rays, which in turn send out rays of various wave lengths in different directions. These are called secondary rays. Some of these rays are directed toward the film and produce a fogging, thereby obscuring, in effect, the detail sharpness of the image. It is understandable that the greater the total mass and area of the body under radiation, the greater the factor of secondary radiation. This is an important consideration in cephalometric radiography when one considers the size and mass of the human head. By reducing the beam of primary x-rays, and limiting these rays to the anatomical part desired, the "fogging" effects of secondary radiation can be reduced to a minimum. Devices such as cones, cylinders, diaphragms, aluminum filters, and grids help limit the effects of secondary radiation by limiting the area of primary radiation. In roentgenographic cephalometry, the area for radiation can be limited to a circular area ten inches in diameter. It is not necessary to radiograph that portion of the cranium above the sella tur-

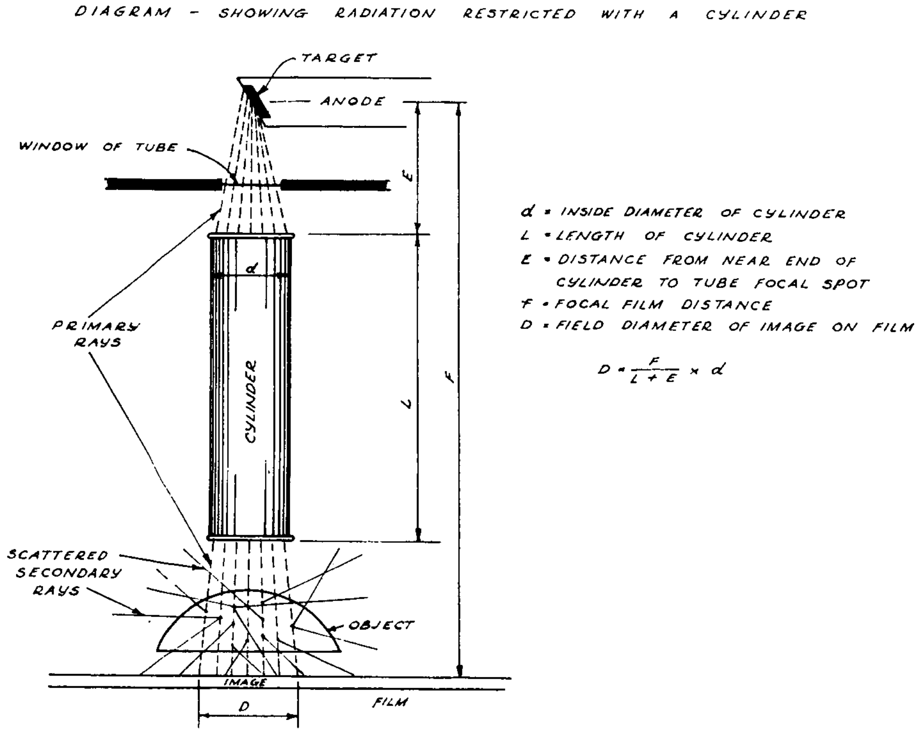

Fig. 5 Diagram showing radiation restricted with use of a cylinder.

cica and nasion and below the chin point. Using the ear point (porion) as the center of a circle, a radius of five inches will cover an area of the head sufficient to include all points for measurement. This can be accomplished with the use of a limiting device such as a cylinder (Fig. 5). As indicated in Table 1, the length and diameter of the cylinder to cover an area of ten inches has been computed on the basis that the film is approximately five inches from the mid-saggital plane. That means the focal-film distance is sixty-five inches.

MEASUREMENT IN INCHES

Inside Diameter of Cylinder	*Distance of Near End of Cylinder to Focal Spot*					
	1.5	2.0	2.5	3.0	3.5	
2	11.5	11.0	10.5	10.0	9.5	*Length of Cylinder at FocalFilm Distance of 65 inches for 10 inch Diameter of Film Image*
2.5	14.75	14.25	13.75	13.25	12.75	
3.0	18.0	17.5	17.0	16.5	16.0	
3.5	21.25	20.75	20.25	19.75	19.25	

Table I

X-RAY HOLDERS OR CASSETTES

Because of the great focal-film distance which is necessary in cephalometric roentgenography, the exposure time would be too long and impracticable if one were to use ordinary non-screen film. In order to decrease this exposure time very materially, one must use screen x-ray films which are placed in cassettes with intensifying screens. Each cassette holder, composed of Bakelite and metal cover, contains two intensifying screens. The Bakelite cover, facing the x-ray tube, is transparent to x-rays. Also, the screen facing the tube is thinner than the rear one to allow for better penetration and less absorption. The intensifying screens are composed of cardboard, coated usually with fluorescent crystals of calcium tungstate or a similar chemical. The film is placed between the two screens. The film used, as stated before, *must* be a screen film which is sensitive to the fluorescence of the screen. The fluorescent glow of the intensifying screens is produced by the x-rays in their action on the coating of calcium tungstate. The fluorescent action of the screens speeds the action of the x-rays on the screen-sensitive film. Actually, the fluorescent glow of the screens has a greater effect on the screen-sensitive film than the primary x-ray beam. It has been shown, experimentally, that only two per cent of the primary radiation affects the screen film when using intensifying screens. That means that more than ninety-eight per cent of the effect of radiation on a film is produced by the fluorescence of the screens. However, detail sharpness or definition is impaired by the use of intensifying screens. This, of course, cannot be avoided entirely. Bucky diaphragms can be used to aid in detailed sharpness. However, that means more radiation exposure. Obviously, if an extremely sensitive non-screen film could be developed, intensifying screens in cassettes would not be necessary. This offers another field of investigation.

RADIATION HAZARDS

The subject of radiation hazards to both patient and operator has been reported in a previous paper. However, certain salient points should again be emphasized, especially in regard to the position of the operator.

Those of us who work with x-ray equipment should be aware of the dangers of scattered or stray radiation. In addition, one should always be cognizant of the radiation hazards from primary rays to our patients. It is well to have some practical understanding of the energy or radiation which is emitted from the x-ray tube. X-ray radiation is a form of energy which is obviously very useful but could also be very dangerous to those who are ignorant of its cumulative lethal potentialities.

We are all cognizant of the dangers of x-ray burns from primary or direct radiation. This type of burn proved disastrous and fatal to some early investigators. As a result of their sad experiences we have learned to be careful and stay out of the path of the rays when operating x-ray equipment. However, we are not too informed regarding the risks involved from the effects of scattered or stray radiation. It should be remembered that the effects of x-ray radiation (primary or otherwise) on human tissue is *cumulative* and *irreversible.*

The radiation output of an x-ray tube is measured in roentgen units. Handbook 41 issued by the United States Department of Commerce, National Bureau of Standards defines a roentgen unit. It makes no difference whether the x-ray radiation is primary, secondary, or scattered for they are all measured in roentgen units. It is merely a question of intensity per unit of time. Therefore, the National Bureau of Standards defines the maximum total dose to which any part of the body of a person shall be permitted to be exposed continuously or intermittently in a given time as 300 mille roentgens per week.

High Kilovoltage Technic

The technic of cephalometric roentgenography is very well standardized. The usual exposure for lateral roentgenograms followed by many operators is 20 milliamperes for 2½ seconds at 60 kilovolts. This is a total of 50 milliampere seconds of radiation. In seeking for a technic which will better define the soft structures without materially affecting the hard tissue definition, we have modified the above technic with a higher kilovoltage and lesser milliamperage. Two millimeters (aluminum disks) of filtration have been added to the x-ray head which further screens out the undesirable long wave x-rays or Grenz rays without affecting the quality of the resulting roentgenogram. In addition, we have reduced the radiation hazard to the patient as well as to ourselves. Instrument readings made by the General Electric X-ray Corporation prove this point. All lateral cephalometric roentgenograms produced in our office have been the result of *one* standardized technic for all patients regardless of age or size of head. The exposure time is 4/10 second at 20 milliamperes and 90 kilovolts. Our position, during this exposure, is about four or five feet to the left of the patient obliquely facing the x-ray machine. Of course, the x-rays are limited to the head of the patient because we use a sixteen inch by three inch diameter cylinder as a limiting device. This position was determined from readings made by the General Electric Corporation. It was found that the safest position for the operator was not behind the x-ray head but to the side of the patient.[2]

Conclusion

There is still much to be desired in roentgenographic cephalometry. There is no question that x-ray machines capable of delivering much higher kilovoltages, such as those with rotating anodes, would further improve the technic. However, these machines are very costly. It is our belief that the development of non-screen films, similar to dental films, which are extremely sensitive to the radiation required in cephalometric roentgenography should be the next step.

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