Newer Studies of Radiation Exposure in Cephalometric Roentgenography Utilizing the Rando Head Phantom

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INTRODUCTION

The purpose of this investigation was to determine an accurate assessment of the amount of radiation absorption following certain radiographic exposures during a cephalometric roentgenographic examination.

This report on radiation exposures and attendant hazards[2] may be considered a further investigation to the author's earlier reports[6,7,8] on this subject. Previous studies required the use of orthodontic patients, and results therefore were somewhat limited because of any possible excessive radiation hazards to patients by repeated x-ray exposures. O'Shaughnessy and Mitchell[13] used cadavers in their study of patient radiation dose levels of various internal organs. Newer scientific procedures and methods make it now possible to obtain information without subjecting patients to *any* radiation hazards.

It is well to heed the caution of the National Council on Radiation Protection (NCRP).[11] In its report No. 39 of 1971, an advisory statement was made on the use of radiation in research on human subjects. "There are certain features that are significant for all human experimentation and deserve mention. Any study which involves human subjects must be performed under conditions which assure (1) the propriety and usefulness of the work, (2) the provision of adequate safeguards for the individuals concerned, and (3) the enlightened consent of the subject. In any research, the prospect of positive benefits is obviously associated with uncertainty. No individual, including the physician, is ethically or legally justified in undertaking human experimentation unless he has reasonable expectations that the prospects of gain will exceed the prospects of hazard or risk. . ."

We can now measure the amount of radiation exposure within various parts of the head. Is it a heavy dosage or very minimal? We want to know this for our own information so that we may govern ourselves accordingly. The results and data obtained from this investigation should answer these questions.

During the last few years there has been developed a plastic-like material which has a radio-absorptive-equivalency of human tissues. This has opened a new avenue for this investigation which could not have been carried on before.

THE PHANTOM PATIENT

The Alderson Research Laboratories have succeeded in molding this accurately human-radio-equivalent material around a natural human skeleton.[1] They refer to this resultant human form as the "Phantom Patient" which was developed in conjunction with leading educators in the field of radiologic technology. It meets the need for a lifelike patient which has unlimited availability for radiographs of any part of the body, which can be radiographed repeatedly without fear of overexposure to humans.

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By molding this plastic-like material of human-radio-absorptive-equivalency into the dried skeletal parts of the body, each anatomical part of the body has taken the desired form. In this study of radiation exposures to the orthodontic patient the head of the Phantom Patient was utilized. We shall call it the Head Phantom.

Dosimetry

The Phantom Patient[4,9] was constructed primarily for treatment planning in radiation therapy. By inserting thermoluminescent dosimeters (TLD's), sensitive pellet-shaped substances made of lithium fluoride, into various areas of the phantom the x-ray exposures to the regions inside the head can be determined.

Radio luminescence of lithium salts was known as early as 1903, shortly after the discovery of x-rays by Roentgen in 1895. Later on, other investigators made reports on their studies in radio luminescence of various lithium salts. In 1953 Dr. Farington Daniels and his co-workers at the University of Wisconsin began their studies in thermoluminescent lithium fluoride. About 1960 under the direction of Dr. Daniels, Dr. Cameron finally developed a dosimeter that, when exposed to x-ray radiation, could be read by a suitable instrument. Further refinements produced crystal solids of dosimeters (TLD) which are in use today. The pellets used in this investigation were rectangular crystalline solids measuring 1 mm x 1 mm x 6 mm.

The Head Phantom (Rando)

The human skull in the Head Phantom used in this investigation is of a person about sixteen years of age (Figs. 1 and 2). It was impregnated with a tough medium-hard inelastic isocyanate rubber matched to human soft tissues as to radio-absorptive-equivalency. Such matching assures full radiographic accuracy over the entire x-ray energy spectrum. The air spaces were considered a significant factor in light of the molding process. The oral cavity and oronasal pharynges were duplicated by special techniques which excluded plastic from these regions during molding. Sinus air spaces or other bone cavities are determined by the actual skull.

Fig. 1

The head obtained was sectioned transversely into nine segments, five of which contained dosimeters. These transverse sections afforded the oppor-

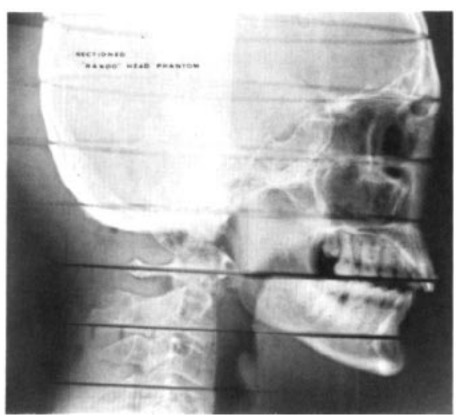

Fig. 2

tunity of recording selective internal exposure readings within certain discrete areas of the head. Winkler,[19] in his study of radiation doses in dental radiography, utilized the Alderson Rando Head Phantom and thermoluminescent dosimeters.

The exposure dosages within the several sections were measured. Other readings were made about the head and around the vicinity of the head. These exposure dosages were measured in roentgens and subsequently corrected into readings of milliroentgens (mR) for exposures at 90 kVp-15 mA for 15/60 seconds, 18/60 seconds and 21/60 seconds.

Radiation Exposure and Radiation Absorption

Radiation exposure is measured in emanated radiation energy of roentgens (r) or milliroentgens (mR).

Absorbed radiation dosages are designated as rads (radiation-absorbed-dose) and rems (rad-equivalent-man). Rads are units of absorbed dose. One roentgen of exposure will usually produce one rad of absorbed radiation in soft tissue. Rems are units of absorbed dose embodying the biological effectiveness of the x-ray radiation exposure on particular types of living tissue. One rad is equivalent to one rem in soft tissue and is the accepted dose of measurement of radiation exposure to a part.

The human population is subjected to many forms of radiation, *natural and man-made*.[9] It is estimated that every year each person receives a body dose, on the average, of 200 to 250 mRems. Most of it, about 50 to 75 mRems, is from medical and dental sources. All of the other man-made exposures consist of about 25 mRems. This average estimate of 200 to 250 mRems per year per person should not be applied *critically* for each person. It is reasonable to assume that one person may have received considerably more radiation than the estimated average, and another less.

The National Committee on Radiation Protection (NCRP) has suggested maximum permissible doses for radiation workers and other x-ray operators. These people are subjected to scattered or stray radiation hazards. Orthodontists who operate x-ray machines in their practices may be subjected to scattered radiation hazards. However, the term "permissible dose" should be qualified. It is that dose which is permissible in *addition* to the total radiation exposure from natural and man-made sources to which the general population is exposed.

Very little is known as to the maximum permissible dose in radiographing patients for diagnostic purposes.[10,11,12] Various parts of the body are more resistent to x-ray radiation and others less. However, it is generally accepted that one may use whatever amount of radiation exposure which may be necessary in diagnosis and treatment. There is much evidence that in acute exposure, up to 25 rems (25,000 mRems) to the *whole body*, there is no observable effect; doses above 300 rems (300,000 mRems) to the whole body may cause some deaths. Also, certain parts of the body may be safely exposed to maximum radiation dose of up to 6,000 rems in treatment of cancer with only reversible short-term reactions and moderate late atrophic changes. However, as little as 20 rems of exposure to the thyroid region of infants has been related to later incidence of thyroid cancer. Actually, radiation hazard is of more concern to the operator, who is subjected to frequent intervals of radiation exposure, remembering that the effects of these exposures are *cumulative*. It is important, therefore, that everyone who uses the x-ray machine, a source of radiation hazard, should incorporate into his technique all means and devices known which will attenuate this hazard. One should always be governed by the discipline that the *total* radiation exposure to one's patient should be the *least* amount necessary to produce a satisfactory diagnostic roentgenographic examination.

Method and Instrumentation

A General Electric 100 dental x-ray unit in conjunction with the Wehmer cephalostat was utilized in this study.

In this orthodontic cephalometric set-up the filtration factor was equivalent to about 3.0 to 3.5 millimeters of aluminum. Attached to the x-ray head was a collimating device restricting the primary beam to 13" x 13" at 60 inches.

The previously described "Rando" Head Phantom was repeatedly exposed to radiographic radiation. Dosimeters (TLD) were inserted into certain predetermined areas within five head sections. All nine head sections were assembled to complete the head phantom and neck which was placed into the cephalostat four feet from the floor in the precise position required in cephalometric roentgenography. Other dosimeters were attached to the *surface* at various points on the head phantom. In addition, dosimeters were attached to the 8x10 film cassette facing the head phantom. The films used were Kodak Blue Brand. The cassettes were equipped with Patterson Par Speed screens.

The total x-ray exposure was 175 mAs (15 milliamperes for 11.7 seconds) at 90 kVp. Also, radiation scatter readings were made with the Nuclear Chicago Model 2510 Ionization Chamber Survey meter. The dosimeters were read out on an Eberline Model T L R - Thermoluminescent dosimeter reader. Locations were recorded of all attached dosimeters before the head was disassembled. The head was then disassembled and the dosimeters, which had been placed within each section, were read individually and recorded. The readings were corrected for exposures at 15 mA-90 kVp for 21/60 (5.25 mAs) seconds, 18/60 (4.50 mAs) seconds and 15/60 (3.75 mAs) seconds, because it was considered that these exposures may well be within the range of producing good diagnostic roentgenograms.

Head Phantom Exposure Data

Twenty-two exposures readings were obtained from the five sections of the head phantom. In addition, readings were made of the dosimeters attached to the film cassette. As indicated on the sectional views, all individual dosimeter readings were corrected.

It was noted that the readings ranged from a maximum of 9.00 mR to a minimum of 0.45 mR. The 9.00 mR reading was recorded from a dosimeter attached to the surface of the right side of the head phantom which was in the direct path of the primary x-ray beam. As these x-rays entered the head phantom at that point, their penetration was impeded and attenuated as they passed through the head to reach the film. When the primary beam reached the exit point on the left side of the head, the dosimeter registered 0.45 mR. However, when the x-ray beam reached the film plane, its roentgen exposure value was reduced to 0.39 mR. This phenomenon obeys the law in physics: the x-ray beam varies in its intensity *inversely* with the square of the distance from the focal spot of x-ray tube.[5]

Section 3

Dosimeter readings were taken at sella, superior borders of the right and left orbits, and pupillary centers of right and left eyeballs (Fig. 3).

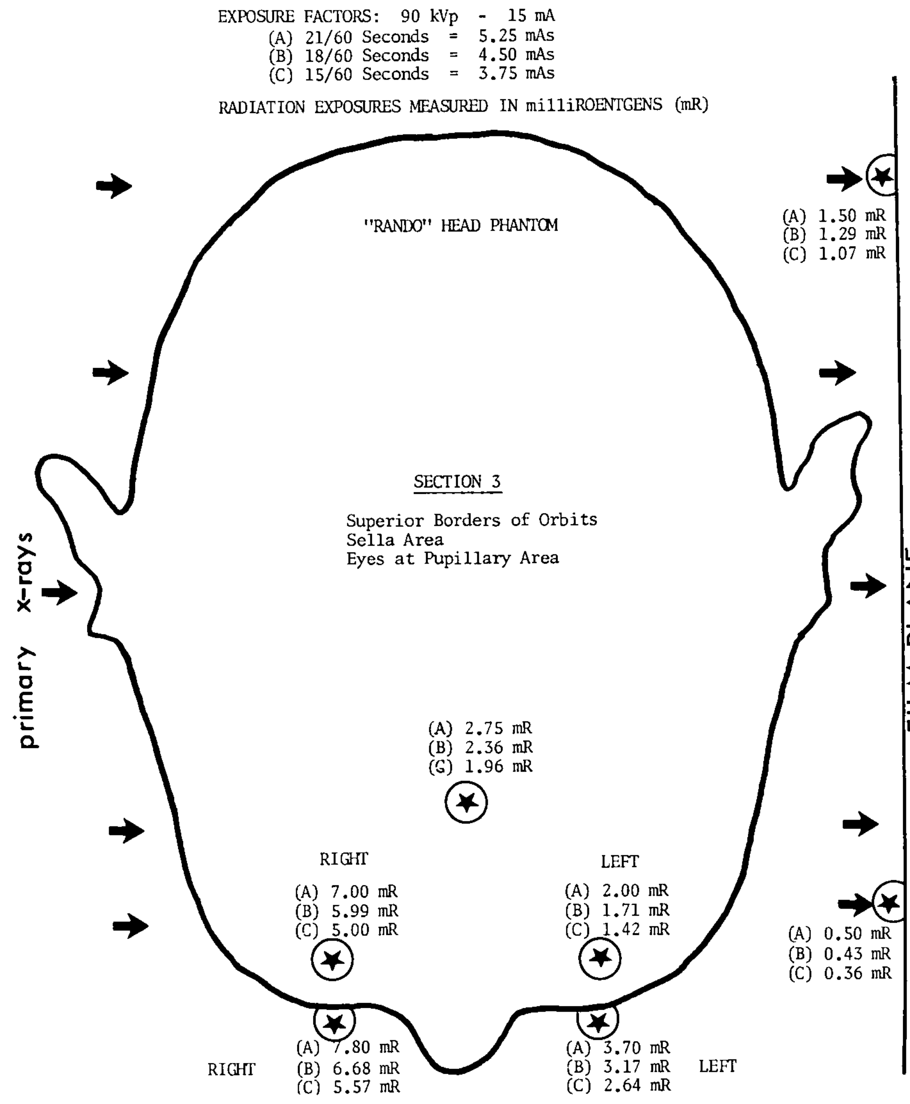

Fig. 3

Note that the exposure dosages in the sella area were considerably less than at the superior border of the right orbit but slightly more than at the left orbit. The right and left eyeball surface readings registered more than the others and again, the dosimeter at the right eyeball gave a much higher reading than the left.

The dosimeters placed on the surfaces of the posterior and anterior borders of the cassette containing the film registered very small radiation exposures. The x-ray beam passing through the superior posterior part of the brain case measured greater exposure in that area than the x-rays passing through the denser structure at the same level.

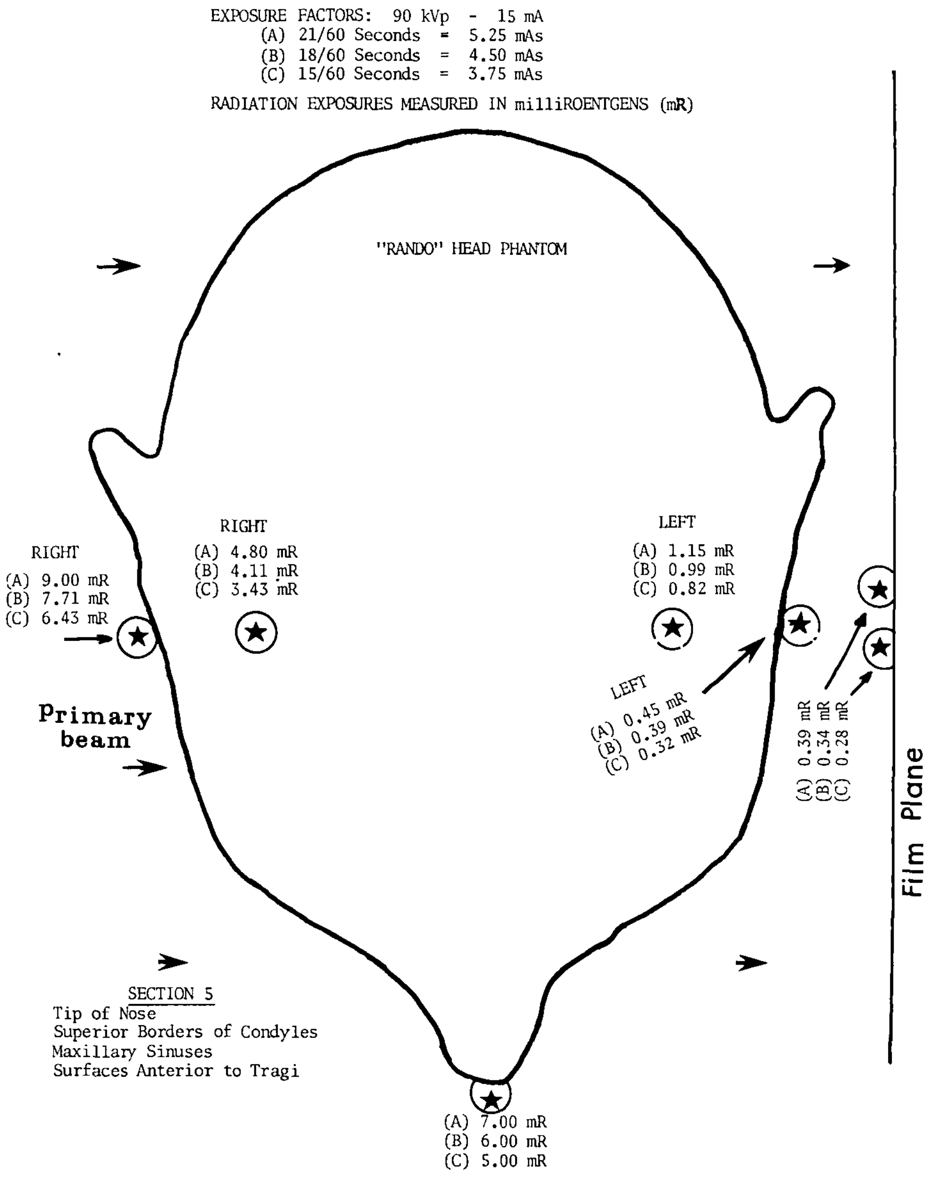

Fig. 4

Section 5

This section (Fig. 4) represents the middle and thickest portion of the head phantom at the level of porion. The central rays of the primary beam enter the head at the nearest point. Dosimeters were placed on surfaces immediately anterior to the tragi on the right and left sides. The surface of this section receives the greatest exposure dose of any section because of its short, straight-line proximity to the source.

At the entry area (right side) the exposure dosage is eighteen times greater than at exit area (left side). In the same plane the dosimeter reading at the film cassette is slightly less than at

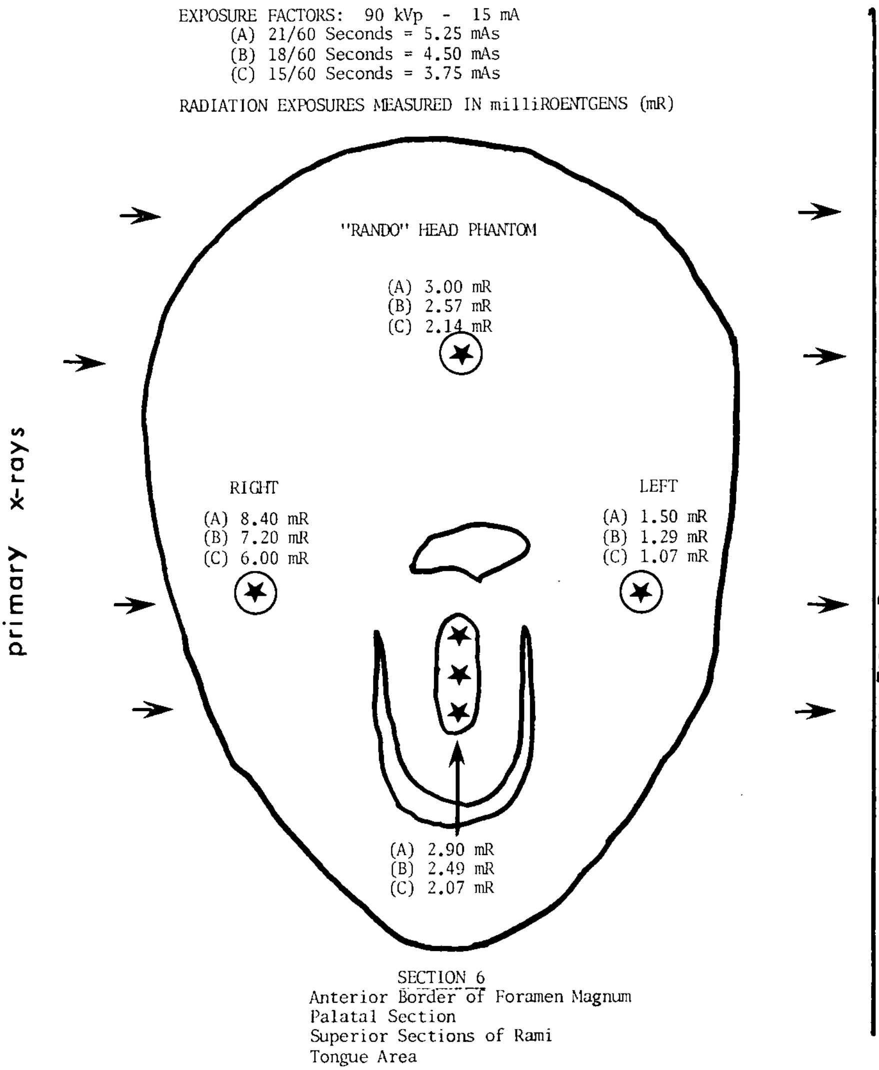

Fig. 5

the exit area. Again, in the same line of exposure the *right* condyle receives a much greater dosimeter reading than the *left* condyle. The tip of the nose, which is at an angle and farther from the x-ray source, received a smaller exposure dose than at the entry area on the right side.

Section 6

This segment is much smaller and less dense than Section 5. Dosimeters were placed at the anterior border of the foramen magnum, right and left superior sections of the rami and tongue area (Fig. 5). In the tongue area the rays were diminished in their intensity by the mandible. Again, note that the superior section of the *right* ramus received about six times more exposure dosage than the *left*.

Section 7

This segment is smaller than Section

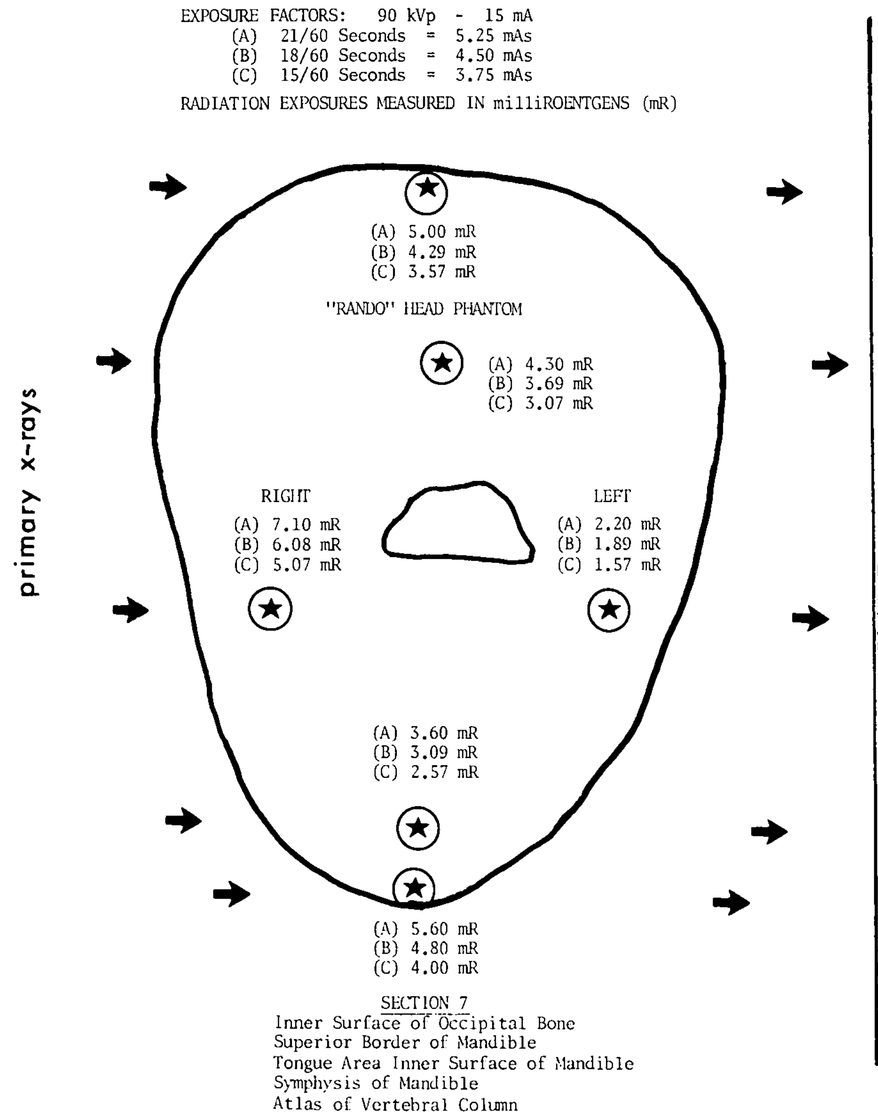

Fig. 6

6 and contains the dosimeter readings of the following (from posterior to anterior): inner surface of occipital bone, atlas of vertebral column, superior border of mandible (right and left), tongue area, symphysis of the mandible (Fig. 6).

Section 8

Figure 7 shows the smallest of all sections and is in the neck area. The posterior reading is of a vertebral segment. The anterior readings are of the right and left areas of the thyroid and submaxillary tongue areas.

Please note the primary beam exposure reading. The x-rays at the anterior portion of the film plane were not impeded by any solid matter, hence the much larger reading than at the posterior part of film plane which re-

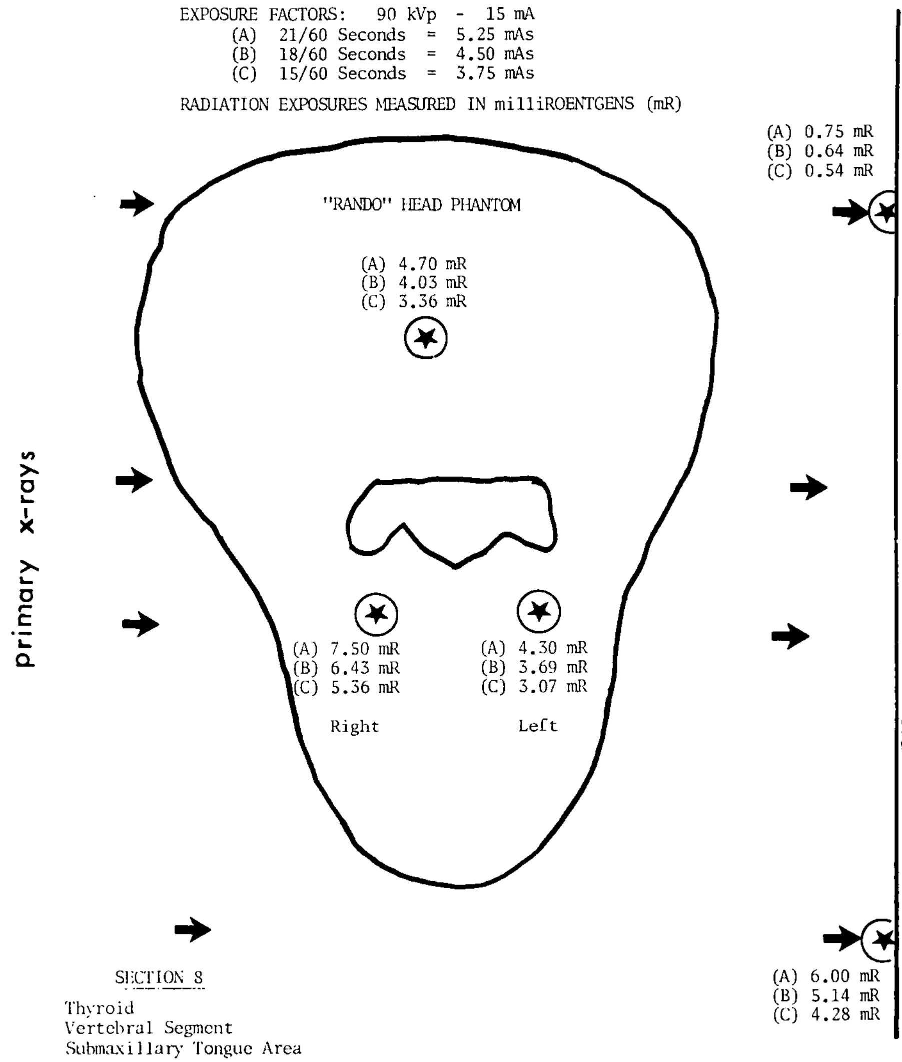

Fig. 7

ceived its reading after the rays had passed through Section 8.

Densitometer Film Registration

Film density is measured for the amount of visible light which can show through a film layer.[17] The logarithmic scale of 1, 2, 3 was the measurement used in representing density of the various areas. These readings represent 10, 1 and 0.1 per cent the amount of visible light transmitted.

We know that milliampere seconds determine the blackness of the film, and the kilovoltage determines the contrast between varying shades of blackness. If the development of films to be analyzed were processed under proper and accepted procedure for complete development and fixing, then a comparison can be made as to density of various areas of these films. Under these conditions and with the same cephalometric equipment used in the phantom study, roentgenograms were made of three patients all within the twelve year age group prior to orthodontic treatment. All three roentgenograms represented well-balanced films of good diagnostic quality. The densitometer film registrations of the backgrounds of the three films indicated practically identical full development and fixing. The other registrations of the various anatomical areas showed very slight variations, too small for the human eye to differentiate. Consequently, one can agree that all three films are clinically equal in diagnostic value. Yet, each patient was subjected to a different radiation exposure.

Patient A was exposed for 21/60 second, 15 mA - 90 kVp (5.25 mAs); patient B was exposed for 18/60 second, 15 mA - 90 kVp (4.50 mAs); and patient C was exposed for 15/60 second, 15 mA - 90 kVp (3.75 mAs). Patient B received 4.50 mAs which is 14.28% less radiation exposure than Patient A, and Patient C received 3.75 mAs which is 28.55% less radiation exposure than Patient A.

The obvious conclusion to the above should be, of course, that *total* exposure to one's patient should be the *least* amount necessary to produce a satisfactory diagnostic roentgenographic examination.

Scattered Radiation Hazards to Operator

Scattered radiation measurements were made at various areas in the operating room during the radiographing of the sectionalized head phantom using exposures of 90 kVp, 21/60 second and 15 mA (5.25 mAs).

Scattered radiation was recorded at four positions indicated in Figure 8 as solid black dots numbered 1, 2, 4 and 5. At position 1, which is at a 45 degree angle and 10 feet from the phantom head, the scatter reading was 0.004 mR. At position 2, a distance of 6 feet and at a right angle to the cephalostat, the scatter reading was 0.006 mR. At position 4 located in the laboratory separated by a 4 inch plaster wall from the x-ray room and with the straight-line distance behind the x-ray head measuring 3 feet, the scatter reading was 0.002 mR. At position 5, which was at a 45 degree angle and 6 feet from head phantom, the scatter reading was 0.008 mR.

One can be assured that all the above readings are well within the maximum permissible doses for radiation workers and other x-ray operators as suggested by the National Committee on Radiation Protection. If the operator follows accepted radiation safety precautions as described in the NCRP report No. 33, and stays at least six feet from the patient and tube head, operator exposure will be well below acceptable levels as outlined in NCRP report No. 39.

Scattered Radiation Hazard to Patient

As to the hazard of scattered radiation to the patient during a cephalometric roentgenographic examination, the primary concern was to determine the amount of radiation scatter in the area of the gonads.[14]

A dosimeter was placed immediately below the head phantom in the cephalostat about two feet above the floor. It was estimated that this would be in the area of the gonads of an actual human patient. This reading was 0.10 mR. However, since body tissues protect the gonads in an individual, and would absorb much of the radiation scatter, the exposure reading at the gonads could be much less.

Since our reading in the area of the gonads was only 0.10 mR, this could be a minimal exposure. According to the NCRP the dose equivalent to the

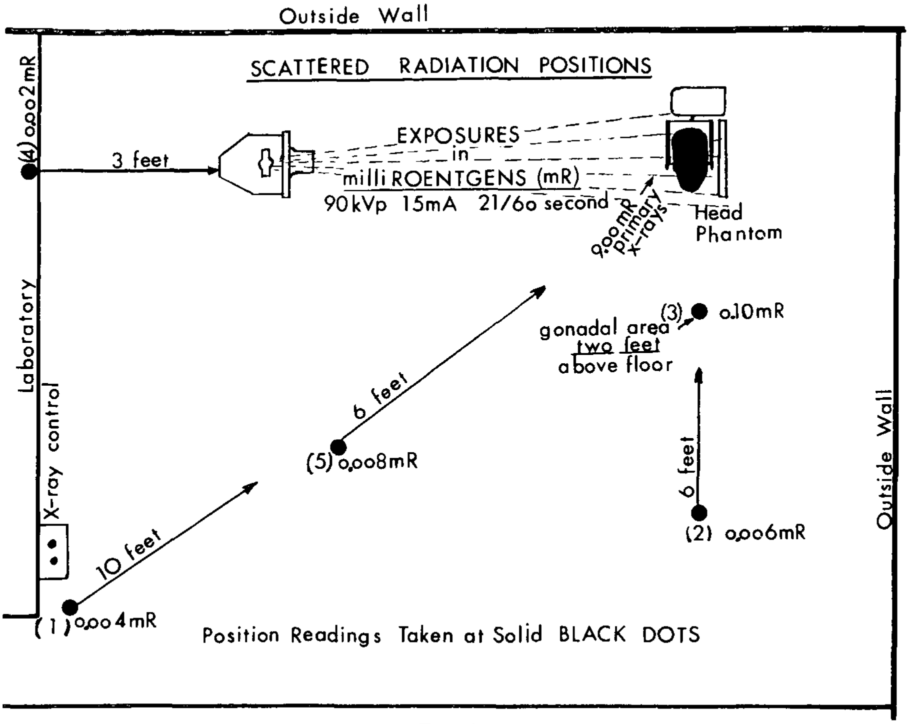

Fig. 8

gonads for the population of the United States as a whole, from all sources of radiation other than natural radiation from the healing arts, shall not exceed a yearly average of 0.17 Rem per person.

Discussion

The purpose of this study was to determine the radiation exposures to which the orthodontic patient is subjected during a roentgenographic examination, and to determine if these radiation exposures could be further reduced without affecting the diagnostic information resulting in *less* radiation exposure to the patient which is a primary goal. All exposures were made and recorded by dosimeters placed on or within the Anderson Rando Head Phantom.

It was interesting to note that maximum exposure to the right side of the head phantom, which was in the path of the primary x-ray beam, registered 9.00 mR. The exposure factors at that time were 90 kVp-15 mA-21/60 second for a total of 5.25 mAs. However, as the beam entered the head, it quickly attenuated as it passed through various structures and exited at 0.45 mR on the left side of the head on its journey to the film cassette. This means that the head absorbs about 95% of the x-rays with the right half of the head receiving the maximum exposure, and less than 5% reaching the film as shown in Figure 4 of Section 5. In a similar manner, head surface areas which are a greater distance from the focal spot of the x-ray machine receive less radiation exposure.

It was shown that all the radiation exposures can be even further reduced by using shorter exposure times such as 18/60 second and 15/60 second without clinically altering the diagnostic information on the roentgenogram.

The head, however, would still absorb 95% of the radiation, but the total radiation exposure to the patient would be materially reduced, thus less hazard to the patient.

This study also determined that the patients receiving an 18/60 second and 15/60 second exposure, respectively, had the potential of producing equally well-defined roentgenograms.

Present radiation exposures in orthodontic cephalometrics are very small compared with other types of x-ray procedures. Nevertheless, since it is an accepted fact that minimal x-ray exposure should be the goal of every x-ray operator, I believe it is incumbent upon every individual who employs the x-ray to reduce its hazards to its lowest possible degree.

Finally, I wish to emphasize that the use of the Alderson Rando Head Phantom opened new and exciting avenues for examination and investigation. It is hoped that continuing investigations and refinements in procedures and materials will ultimately result in further reduction of radiation hazards in cephalometric roentgenography.

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