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SIGNIFICANCE OF FOCUS SIZE IN IRRADIATION THERAPY

by

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It is customary in roentgen tube manufacture to reduce the size of the penumbra by means of a small focus. This applies particularly to tubes used in roentgen diagnosis, whereas the requirements in this respect are less stringent in roentgen therapy; a small focus is however always considered an advantage as long as it does not excessively restrict the loading of the anode.

Radiation sources of large area dimensions have also been employed; these have mainly been made of radioactive material. Examples are certain teleradium units (BENNER 1937), radium-containing plate applicators and moulages and solutions of radioisotopes. Roentgen sources of large area have been designed for specific purposes: for deep therapy by WITTE, ZIMMER & KESSLER (1939), BARTOW et coll. (1949), and by COLOMBO & LENZI (1951); for roentgen television by MOON (1948) and KLAMI (1963), for technical applications by HOFMANN & DIETRICH (1965) and for superficial radiotherapy by KLAMI (1965). The reason why these sources have not been developed is mainly that their practical significance has not been fully realized; thus there has been no economic incentive to those who would have the resources to investigate and manufacture them.

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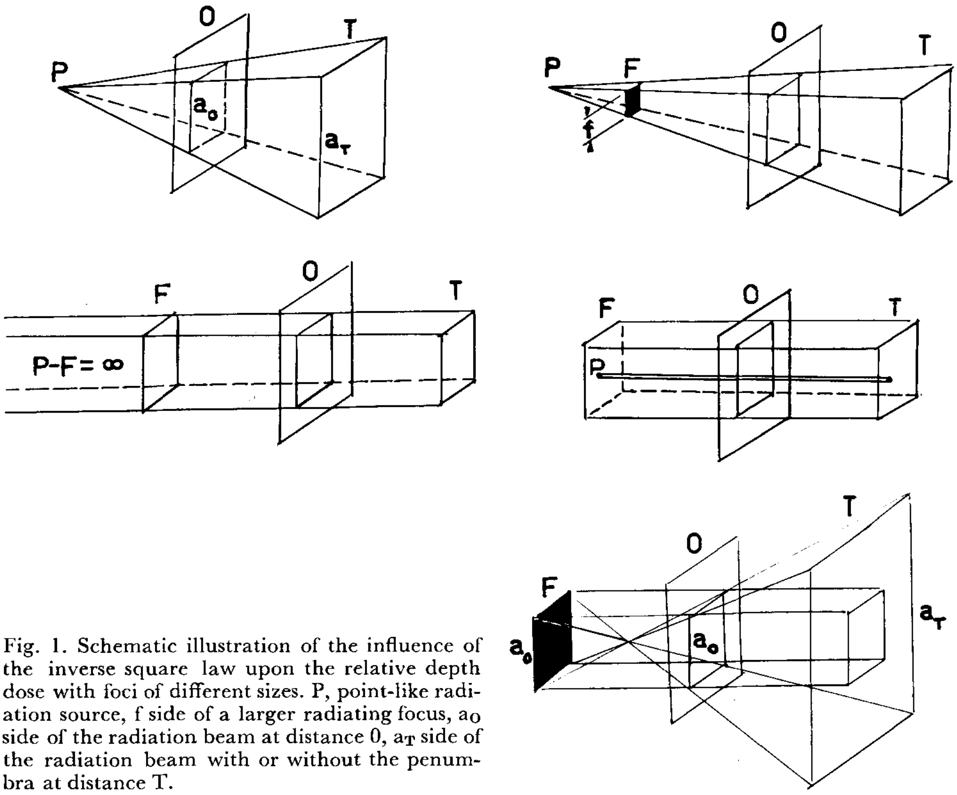

Fig. 1. Schematic illustration of the influence of the inverse square law upon the relative depth dose with foci of different sizes. P, point-like radiation source, f side of a larger radiating focus, a_O side of the radiation beam at distance 0, a_T side of the radiation beam with or without the penumbra at distance T.

The significance of the size of a plane anode in radiotherapy will be considered in this communication. The influence of size when concave and convex anode surfaces are used will be discussed in another publication.

The ratio of the radiation doses within and on the surface of an irradiated object, the so-called per cent depth dose, is determined not only by the absorbed and scattered radiation within the material of which the object is composed, but also to a large extent by the focus-object distance. When the radiation intensity is measured or calculated, no true point-sized radiating focus exists in practice, nor even a point-sized measuring instrument. A theoretical 'point' concept is however used in the following to illustrate the dependence of radiation intensity on the focus-object distance, on the size of the focus and on other associated factors. Absorption and secondary radiation are disregarded.

The inverse square law is well known (see Fig. 1, upper left): the radiation emerging from a point-like focus *P* diminishes with the distance from *PO* to *PT* because it spreads over a square surface the side of which has increased proportionally to the distance so that the area has increased in proportion to the square of the distance.

If the side of an irradiated square on the surface of an object O is denoted by a_O, and that of a square area within the object by a_T, and the corresponding radiation intensities by I_O and I_T, we have

$$\frac{I_T}{I_O}=\frac{a_O^2}{a_T^2}=\frac{PO^2}{PT^2} \tag{1}$$

from which follows that

$$I_T=I_O\frac{PO^2}{PT^2}$$

If under otherwise similar conditions, the area of the radiation surface F is large (Fig. 1, upper right) it may be theoretically replaced by a point-like focus P located farther from the object. If we denote by f the length of the side of the focus F, we may write

$$\frac{PO}{PO-FO}=\frac{a}{f} \text{ or } PO=\frac{a}{a-f}\cdot FO$$

Hence

$$I_T=I_O\left(\frac{\frac{a}{a-f}\cdot FO}{\frac{a}{a-f}FO+OT}\right)^2$$

or

$$I_T=I_O\left(\frac{a\cdot FO}{a\cdot FO+(a-f)\cdot OT}\right)^2 \tag{2}$$

The change in radiation intensity with increasing distance has decreased as a result of the increase in the size of the focus. When f equals a, I_T is equal to I_O. This may also be stated as follows.

If the area of the focus is increased until it becomes equal to the area of the object (surface O in Fig. 1, middle-left), this implies a shift of the assumed point P to infinity ($PF=\infty$), and hence the ratio of the distances PO and PT is unity.

Hence

$$\frac{PO^2}{PT^2}=1 \text{ and } I_T=I_O.$$

The difference in distance would then be of no significance. This is however only speculative. It could be the case in practice if we could delimit the cone of radiation emerging from every point P of the focus F so much that its peak

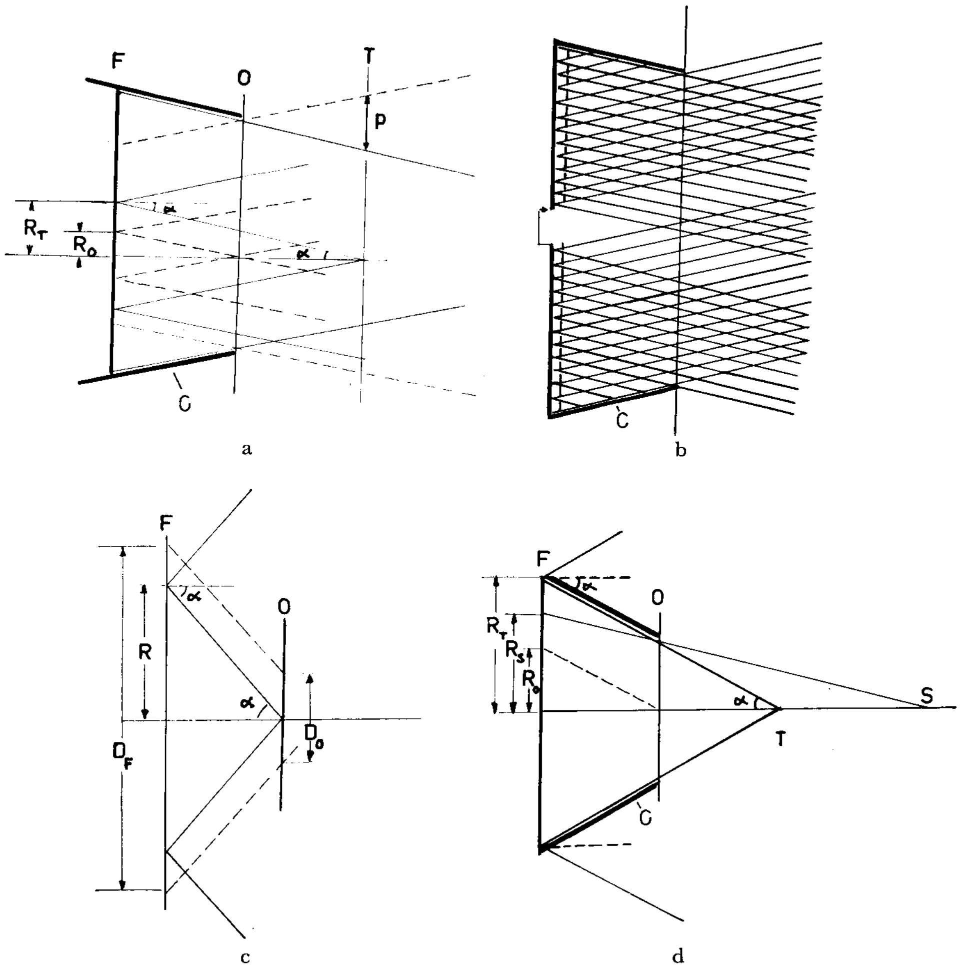

Fig. 2. Collimated radiation beams from a roentgen source of large area.

angle would be zero (Fig. 1, middle right), i.e. if we could arrange so that the radiation emerging from the whole focal surface *F* were parallel, its divergence according to the inverse square law would not occur.

If, as the other extreme (Fig. 1, lower right) the radiation cone is not limited at all (peak angle 180°), a field equal in area to the focus will be formed at distance *T* and this field will be non-homogenous, with a slightly greater intensity of radiation at the centre than elsewhere in the field. This irradiated field is composed of the points struck by radiation from all points of the focus. Radiation from only some of the points of the focus impinges on an area, the penumbra, outside this field. The intensity of the radiation in the penumbra diminishes as the distance from the centre increases and the source points from which radiation enters the penumbra decrease in number. If we denote by a_T the length of the side of the penumbra area, we get

$$\frac{a_T}{a_O}=\frac{\frac{FO}{2}+OT}{\frac{FO}{2}}$$

and

$$a_T{}^2=\left(a_O+2\frac{OT}{FO}\cdot a_O\right)^2 \qquad (3)$$

The total area exposed to the radiation thus increases with depth and with decreasing distance from the focus to the irradiated field. Especially in contact therapy (*FO* small) the size of the penumbra and the resulting excessive volume dose already preclude the use of a large focus area without separate collimation of the conical radiation beams.

If, as in Fig. 2, a and b, the conical beam emerging from each point of the anode is collimated so it becomes relatively limited, and a truncated cone *C* with a peak angle equal to the peak angles of the separate conical beams is used to limit the anode area and irradiated field, the following advantages are obtained.

1. The irradiation of the object surface becomes more uniform than in the conditions outlined above. This is particularly so the greater the number of conical beams that fall on a point on the object surface, i. e. the greater the number of foci per unit area of the anode, the larger the peak angles of the conical beams, and the larger the focus-object distance. The last condition is not stringent if the first two conditions are fulfilled. Fig. 2 c indicates that the anode surface area must be larger than the irradiated area of the object. If we denote by D_F the diameter of the former, by D_O the diameter of the latter, by α half the peak angle of the conical beam and by *R* the radius of the anode surface area irradiating a single point on the object surface, then

$$\frac{R}{FO}=\text{tang } \alpha;\ R=FO\cdot\text{tang } \alpha$$

and

$$D_F=2\ FO\cdot\text{tang } \alpha+D_O \qquad (4)$$

In practice this limits the magnitude of the peak angle.

2. The penumbra can be reduced to moderate size. It is demonstrated in Fig. 2a that when the 'peak angle' of the penumbra is $2a$ and p is its width at depth OT, then

$$p = 2 \cdot OT \cdot \text{tang } a \tag{5}$$

Also, the reduction of the penumbra requires a suppression of the peak angle.

3. From the collimation of the conical beams it follows (Fig. 2a) that radiation falls on a point on the surface of the object O from a smaller area of the anode surface F (from an area of diameter R_O) than on a point at a greater distance T from the object surface (from an area of diameter R_T). The ratio of the circular areas

$$\frac{\pi R_T^2}{\pi R_O^2}$$

may be called the geometric factor GF; the intensity of the radiation increases with distance in proportion to this ratio

$$\frac{R_O}{FO} = \text{tang } a \text{ and } \frac{R_T}{FT} = \text{tang } a$$

and hence

$$\frac{R_O}{FO} = \frac{R_T}{FT} \text{ and } \frac{R_T}{R_O} = \frac{FT}{FO}$$

regardless of the magnitude of the angle a, and

$$GF = \frac{\pi R_T^2}{\pi R_O^2} = \left(\frac{FT}{FO}\right)^2$$

Superposition of the conical beams thus leads to a geometric increase in the radiation intensity which is proportional to the square of the ratio of FT to FO. On the other hand, eq. (1), divergence of the conical beams produces a converse change in the radiation intensity according to the inverse square law. This decrease in intensity is also proportional to the square of the ratio of these same distances.

These two changes in intensity thus cancel each other, the distances lose their significance, and the intensity diminishes as in parallel radiation only owing to absorption and secondary scattering radiation.

This conclusion is valid up to a certain distance, which depends on the magnitude of the anode area and the peak angle a (Fig. 2d). The following equation gives the relationship between the desired geometric maximum depth OT, the focus-object distance FO, the radius R of the anode and the peak angle of the collimated conical beams

$$\frac{R_T}{FO+OT}=\text{tang } a \tag{7}$$

As indicated in Fig. 2d, the geometric factor decreases in value again with increasing depth S ($>T$) because the radius of the anode area that irradiates point S decreases to the value R_S, whereas the radius of the anode area that irradiates a point of the object surface remains constant (R_O). Thus

$$\frac{R_S}{R_T-R_O}=\frac{FS}{OS} \text{ and } GF_S=\left(\frac{R_S}{R_O}\right)^2=\left[\frac{(R_T-R_O)\cdot FS}{OS\cdot R_O}\right]^2$$

When $R_O=FO\cdot\text{tang } a$ is substituted

$$GF_S=\frac{(R_T-FO\cdot\text{tang } a)\,(FO+OS)}{OS\cdot FO\cdot\text{tang } a} \tag{8}$$

4. The difficulties associated with the juxtaposition of the two treatment fields are well known: either an untreated zone between the fields remains or an excessive dose falls on a zone where the fields are superimposed (Henschke 1943, and others). These disadvantages can be largely eliminated by using the arrangement of several overlapping irradiated fields, as shown in Fig. 2b.

Discussion

As the focus-object distance does not influence the relative depth dose when numerous collimated radiation beams are employed, it would of course be advantageous to increase the intensity by decreasing the distance. As noted in par. 1, p. 277, however, the irradiation of a surface is more uniform the greater the focus-object distance. This must not therefore be shortened too much. It should however be noted that uniform irradiation of the surface of an object is not of prime importance. On the contrary, a method, the so-called sieve treatment, which involves the uneven irradiation of the object surface, has long been employed. In sieve therapy the skin may be exposed to a dose of even 20 000 R instead of the customary 3 000 R, provided unexposed areas are left on the skin to facilitate recovery from radiation damage. It would hence be desirable, when 'large anode' or 'multifocus' tubes are constructed, to find a solution that would make it possible to bring an anode fitted with beam collimators in contact with the object surface and in this way to apply short distance roentgen treatment with a sieve. This presupposes that the electrons strike the anode from behind, and the produced radiation passes through the anode, and further that the anode be earthed, very thin and effectively cooled. The possibility of constructing a roentgen source of this type, and the advantages attainable by making the anode slightly convex or concave, will be discussed in a forthcoming publication.

When calculations are made to determine the usefulness of a large anode it should be remembered that many factors make it necessary to check the results by means of measurements in phantoms. The average thickness of matter penetrated by the radiation is slightly greater than the perpendicular distance from the surface to the depth in question. The outline of every radiation beam is also rendered indistinct by a focus of large area; even collimators made of heavy metal transmit some radiation and secondary radiation is produced at their edges, especially when high energy radiation is employed. These factors are under investigation.

It would be interesting to know whether the geometric factors discussed are of value with very high energy photon sources, such as the betatron and the linear accelerator. The radiation beams of these are narrow ($\sim 10^\circ$) and no collimator would be required when targets of large area are irradiated by moving the electron beam. When irradiation takes place with an energy source such as radium or cobalt 60, collimation would hardly be possible in practice owing to the thickness that would be required for the wall of the collimator.

SUMMARY

The possibilities of using radiation sources with anodes of large area in radiation therapy are explored. It is concluded that the focus-object distance can be greatly reduced without influencing the per cent depth dose if the radiation is divided into a number of collimated beams.

ZUSAMMENFASSUNG

Die Anwendbarkeit in der Strahlentherapie von Strahlenquellen mit grossen Anodenoberflächen wird erörtert und es wird festgestellt dass ohne Einwirkung auf die relative Tiefendosis, der Fokus-Hautabstand stark reduziert werden kann, wenn die Bestrahlung in mehreren Strahlenbündeln verteilt wird.

RÉSUMÉ

L'auteur a étudié la possibilité d'utiliser des sources de radiation ayant des anodes de grande surface en radiothérapie. Il conclut qu'on peut réduire beaucoup la distance foyer-objet sans influer sur le pourcentage des doses en profondeur à condition que le rayonnement soit divisé en plusieurs faisceaux collimatés.

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