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EMPIRICAL FORMULAS FOR TISSUE CORRECTION FACTORS IN COBALT TELETHERAPY

by

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Air-filled lung tissue has an absorbing capacity which is considerably lower than that of the other soft tissues of the thorax. Consequently, any change in the radiation-scattering conditions will greatly affect the dose distribution. The dose in the lung and behind it increases. This is important for the treatment planning, when such influence to the greatest extent possible must be taken into account.

Dose distributions are usually determined in a tissue equivalent medium, generally water. The change in distribution within and behind an inhomogeneity is observed and given due consideration in the treatment planning by means of tissue correction factors. The dose in the inhomogeneous region is arrived at by multiplication of the dose obtained in a homogeneous medium with the correction factor.

Tissue correction factors may be determined in several ways. One way is to compare the incident and exit doses determined for a patient with measurements performed with a tissue equivalent phantom (PFALZNER 1958, JOHNS 1964). Measurements effected in a tissue equivalent phantom (BURLIN 1957, DAHL and VIKTERLÖF 1960, SUNDBOM 1965) or in the oesophagus (VOUTILAINEN & VÄHÄTALO 1966) are also used. A tissue equivalent phantom has been employed in this study.

The aim of this work was to study the influence of pulmonary tissue upon the central axis depth dose curve with a view to finding a simple mathematical

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expression for it; this expression is required for treatment planning with the use of computers.

Measurement method. The measurements were made with the Gammatron 1 cobalt 60 unit at the Radiotherapy Clinic; the unit is equipped with block diaphragms.

A Simplex Universal Dosimeter was employed for determination of the doses. The radiation was detected with a normal ionization chamber made by the same manufacturer. The chamber was encased in perspex to achieve electron equilibrium.

Measurements were effected in a water phantom, measuring 42 cm × 36 cm × 52 cm with perspex walls. Cork material of density 0.27 g/cm^3 was utilized as pulmonary tissue equivalent material. Flat pieces of the cork material, 0.3 to 0.6 cm thick, were placed in a thin-walled perspex holder, and a lung phantom was thus obtained. The phantom could be changed in position for measurement of the tissue effect at different locations. The ionization chamber was situated in one of the pieces of cork. By re-arrangement of the pieces, the position of the chamber could be changed for measurements at different depths in the cork material. Four thicknesses of the lung phantom were used: 3.1, 6.3, 9.4 and 12.5 cm; the SSD (source-to-skin distance) was 50 cm.

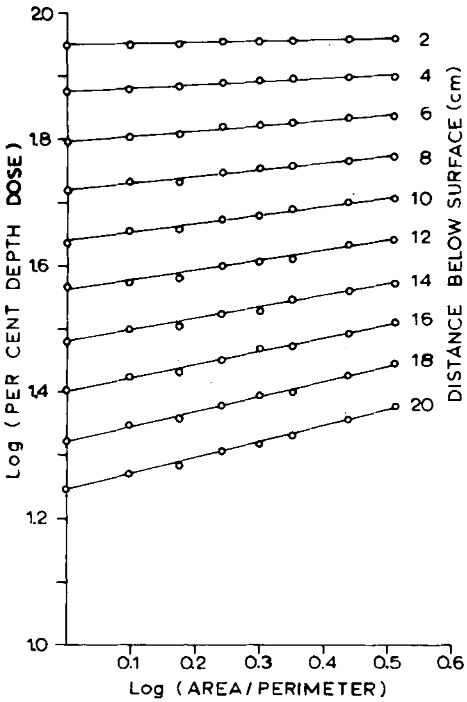
Results of measurements

The maximum dose in cobalt teletherapy is obtained at 0.5 cm below the surface; this is assigned as the 100 % dose. All other doses are compared with the maximum dose and are termed per cent depth doses.

The central axis depth dose curve. Straight lines are obtained when the logarithms of the per cent depth doses are plotted as functions of the depth below the surface (JONES et coll. 1956, PFALZNER 1960). STERLING et coll. (1964) have shown the possibility of expressing the per cent depth doses at the central axis as a function of the area per perimeter of the field. According to their findings, the following formula is valid:

$$\log C_i = h_i + m_i \log (A/P) \qquad (1)$$

where C_i is the per cent depth dose on the central axis of the field at a distance D_i (cm) from the surface
A/P is the ratio of the field area (cm^2) over field perimeter (cm)
h_i and m_i are the intercept and slope constants, respectively.



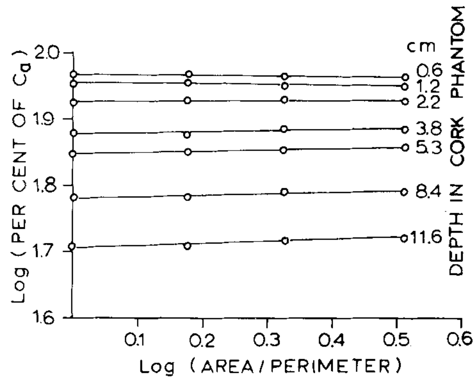


Fig. 1 (left). Change in the central axis depth dose as a function of log (area/perimeter) of the field at 50 cm SSD.

Fig. 2 (above). Change in the central axis depth dose within the pulmonary tissue-equivalent cork phantom. C_a denotes the dose in water at the entrance boundary between water and cork.

Use has been made of formula (1) in study of the central axis depth dose curve. Fig. 1 illustrates the results of measurements and the straight lines determined by the method of least squares. It is apparent that close agreement exists between the experimental points and the straight lines. These provide a basis for determination of the constants h_i and m_i: $h_i = -0.039\ D_i + 2.033$ and $m_i = 0.013\ D_i + 0.006$.

Finally, the value of C_i, the per cent depth dose on the central axis at a distance D_i (cm) below the surface, is derived from the formula:

$$C_i = \text{antilog}[-0.039\ D_i + (0.013\ D_i + 0.006)\log(A/P) + 2.033] \qquad (2)$$

This formula describes very well the central axis depth dose curve, as is evident from Figs 4 and 5. An additional check of formula (1) was made by measuring the dose at different depths below the surface and a constant value of (A/P) but by introducing variation in the length of sides of the field. The results were found to lie within 1 %.

Measurements within the inhomogeneity. The measurements in lung equivalent tissue were made with the cork phantom described. It was found that the depth

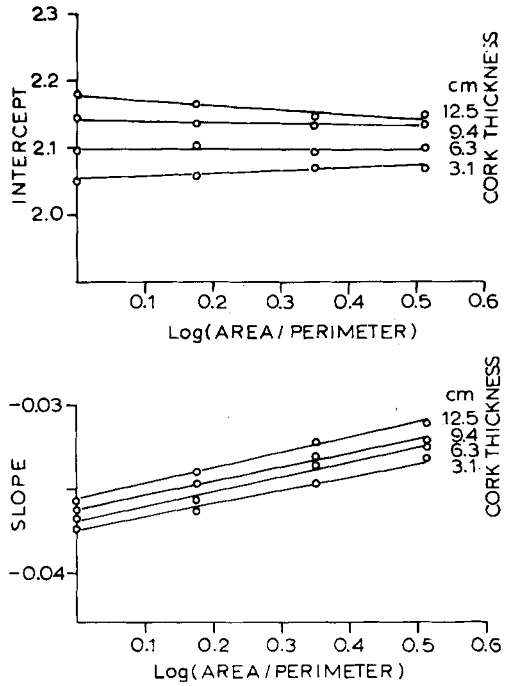


Fig. 3. Intercepts and slopes of the straight lines adapted to the experimental values measured behind the cork phantom. Some of the results are given in figs 4 and 5.

dose curve within the lung can approximately be described by one formula. If the logarithm of the measured doses, as a percentage of the depth dose value in the normal tissue at the boundary of the pulmonary tissue, is plotted as a function of $\log(A/P)$, straight lines result. The experimental values, together with the straight lines, are presented in Fig. 2. If the slopes and the intercepts of the lines are plotted as functions of the depth in the pulmonary tissue, approximately straight lines are obtained. The per cent depth dose in the pulmonary tissue may be expressed by the formula

$$C_l = (k_l/100)\ C_a \qquad (3)$$

where

C_a is the normal tissue per cent depth dose at the entrance boundary between the normal tissue and the pulmonary tissue. It can be calculated by formula (2)

$k_l = \text{antilog}[-0.024\ D_l + (0.004\ D_l - 0.008)\log(A/P) + 1.980]$

D_l is the depth in the pulmonary tissue measured in cm.

Figs 4 and 5 indicate the closeness of fit between the experimental points and the lines obtained by means of formula (3). The depth doses re-

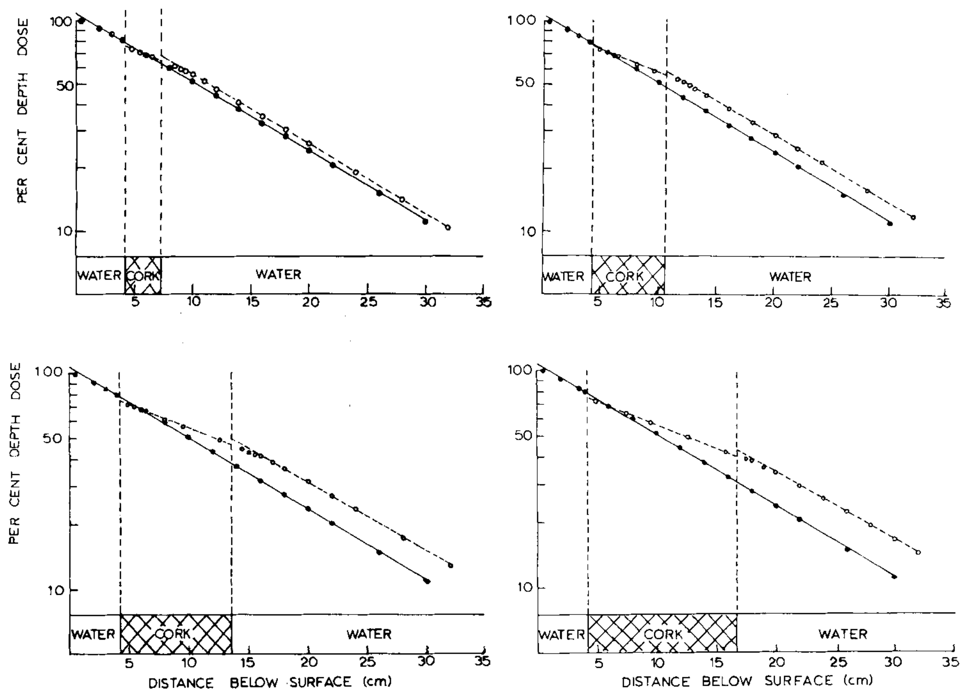


Fig. 4. Experimental results of measurements with SSD = 50 cm, field 13 cm × 13 cm, and different thicknesses of the cork phantom (ϱ = 0.27 g/cm^3)
● measurements in water
○ measurements within and behind the cork phantom
—— calculated by formula (2)
- - - calculated by formula (3) and (4)

mained constant for constant values of (A/P), even within the cork phantom. The deviations in measurement lay within 1 %.

Measurements behind the inhomogeneity. Finally, measurement was made of the depth doses beyond the pulmonary tissue, in the water behind the cork material.

Some of the derived experimental values are reproduced in Figs 4 and 5. First, by application of the method of least squares, straight lines were adapted to the experimental points, taken as the logarithms of the per cent depth doses. The intercepts and slopes obtained for these lines are given in Fig. 3 as functions of log (A/P). Plotting the intercepts and slopes as functions of the cork thickness will permit the adaptation of straight lines to the points concerned. Thus, formulas are obtained for the calculation of these para-

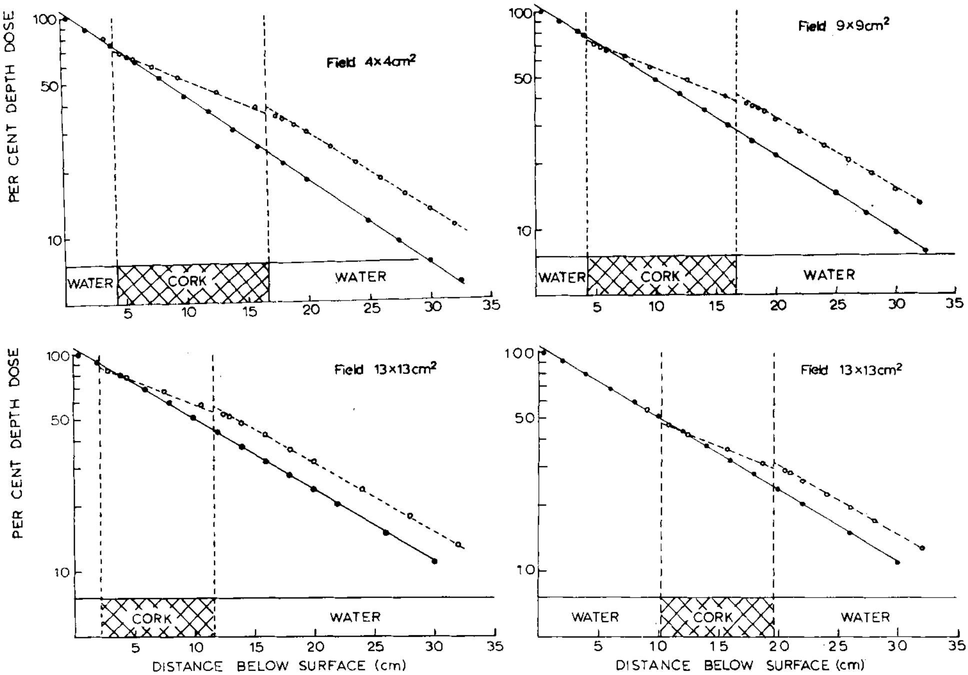


Fig. 5. Results similar to those in fig. 4 for SSD = 50 cm and fields 4 cm × 4 cm, 9 cm × 9 cm, and field 13 cm × 13 cm and the cork phantom at two different depths below the surface.
● measurements in water
○ measurements within and behind the cork phantom
—— calculated by formula (2)
- - - calculated by formulas (3) and (4)

meters for different cork thicknesses. In all, the per cent depth doses behind the pulmonary tissue can be determined with the help of the following formula:

$$C_i = \text{antilog}\{[(0.0001\, d_l + 0.0081)\log(A/P) + 0.0002\, d_l - 0.0382]D_i + (-0.0103\, d_l + 0.0703)\log(A/P) + 0.0132\, d_l + 2.0151\} \quad (4)$$

where C_i is the per cent depth dose at the central axis at a depth D_i (cm) below the skin

d_l (cm) is the thickness of the pulmonary tissue.

The other parameters have been defined earlier. The calculated results are compared with the experiments in Figs 4 and 5. The depth dose was measured behind the cork material, keeping the ratio (A/P) constant and varying the field sides. The results obtained were within 1 %.

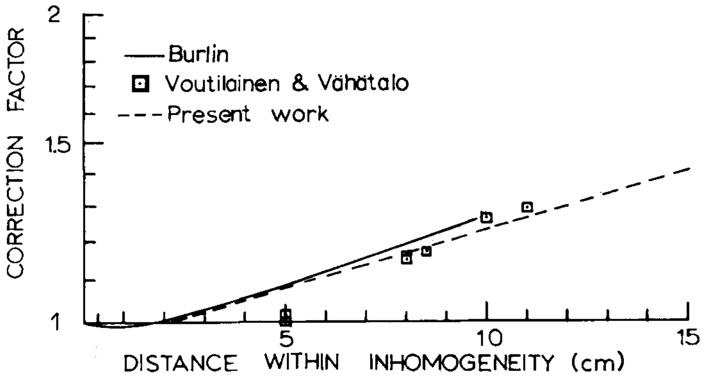


Fig. 6. Experimental results of Burlin (1957) (SSD 50—70 cm, field 10.7 cm × 10.7 cm, phantom density $\varrho = 0.38$ g/cm³. Voutilainen & Vähätalo (1966) (SSD 60 cm, field 64—150 cm², measurements in an oesophagus), and the present study (SSD 50 cm, field 10 cm × 10 cm, $\varrho = 0.27$ g/cm³).

Discussion

It has been demonstrated that the per cent depth dose at the central axis of the beam can be calculated by means of three formulas, if the effect of pulmonary tissue is to be taken into account. The first formula (2) is valid in the front of the lung, the second (3) within it, and the third (4) behind it. Fig. 4 presents the values calculated in comparison with those derived by experiment for different thicknesses of the lung phantom. Fig. 5 contains a few examples of measurements with different field sizes and different positions of the cork phantom. The agreement between the experimental points and the lines calculated theoretically is seen to be rather close. Of course, the values calculated are not valid in the close vicinity of the tissue boundaries.

Interest is attached to a comparison of these results with the correction factors published earlier. A comparison is made in Fig. 6 which reveals that the SSD does not greatly affect the factors, as has previously been pointed out by Burlin (1957). The correction factor curves published by Burlin lie slightly above the curve now presented, while the factors reported by Voutilainen & Vähätalo (1966) are slightly smaller than the present ones. Details of measurements are given in Fig. 6.

Burlin demonstrated that the correction factors reach a constant value about 6 cm behind the inhomogeneity induced by the pulmonary tissue equivalent material. Reference to Figs 4 and 5 will show that the present results disclose no constant value. The factors increase slowly, even to a depth of about 15 cm, although the increase is so insignificant that the observation made by Burlin is more or less valid.

Acknowledgement

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SUMMARY

A study was performed with the aim of finding simple mathematical expressions for the per cent depth doses when pulmonary tissues are included. Three formulas are presented that fulfil the requirements for application in treatment planning using computers.

ZUSAMMENFASSUNG

Einfache mathematische Formeln um die prozentualen Tiefendosen zu bestimmen, wenn die Bestrahlung auch Lungengewebe inkludiert, wurden studiert. Als Resultat werden drei Formeln presentiert und diese genügen um einen Bestrahlungsplan mit Hilfe einer Datenverarbeitungsmaschine aufzustellen.

RÉSUMÉ

Les auteurs ont cherché une expression mathématique simple du pourcentage de dose en profondeur quand le volume irradié comprend du tissue pulmonaire. Les résultats obtenus sont présentés sous forme de trois plans de traitement pour ordinateur.

REFERENCES

Burlin T. E.: The evaluation of the dose to the thorax in rotational cobalt 60 therapy. Brit. J. Radiol. 30 (1957), 543.

Dahl O. and Vikterlöf K. J.: Attainment and value of precision in deep radiotherapy. Acta radiol. (1960) Suppl. No. 189.

Johns H. E.: The physics of radiology. Second edition. Charles C. Thomas, Springfield, Illinois 1964.

Jones D. E. A., Gregory C. and Birchall I.: Dosage distribution in rotational cobalt 60 therapy. Brit. J. Radiol. 29 (1956), 196.

Pfalzner P. M.: Transit-dose measurements in cobalt-60 rotation therapy dosimetry. Radiology 70 (1958), 503.

— A general formula for axial depth dose derived from an empirical power law for tumour-air ratios. Radiology 75 (1960), 438.

Sundbom L.: Dose planning for irradiation of thorax with ^{60}Co in fixed-beam teletherapy. Acta radiol. Ther. Phys. Biol. 3 (1965), 342.

Sterling T. D., Perry H. and Katz L.: Automation of radiation treatment planning. IV. Derivation of a mathematical expression for the per cent depth dose surface of cobalt 60 beams and visualisation of multiple field dose distributions. Brit. J. Radiol. 37 (1964), 544.

Voutilainen A. and Vähätalo S.: Experimental determination of the pulmonary tissue factor in cobalt 60 teletherapy. Amer. J. Roentgenol. 97 (1966), 939.