A SOURCE OF ERROR IN PELVIC DOSIMETRY*

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This paper draws attention to the effect of gas filling pelvic organs of patients receiving external radiotherapy for the treatment of gynaecological cancer. Little has been written about this constantly changing source of error and its importance in the accurate planning of external beam therapy.

Earlier workers[1] have indicated that depth doses measured from standard phantoms may be greatly in error when used in the radiotherapy of the abdomen. They measured exit dose through the same thickness of similar parts of the same individual and commented that differences in exit dose of 100% occurred using 250 kv. radiation.

With regard to rotation therapy in the pelvis, it has been pointed out that water-equivalent contours should be used,[2] and that these may differ markedly from the physical contours of the pelvis due to the presence of non-water-equivalent material.

In recent years many centres have become more radical in their approach to the treatment of pelvic malignancy in women. This follows the trend set by Gilbert Fletcher[3] who has pointed out the necessity of including in the treatment field the pre-aortic nodes above and the obturator nodes below. In the majority of women this results in pelvic fields of not less than 15 cm. in length. The treated volume has therefore tended to increase. Fletcher himself quotes an incidence of severe complications of 10% at a dose of 5,500R to the pelvis in 5½ weeks. He also points out that a rapid rise in the incidence and severity of complications occurs above this dose level.

From these considerations it can be seen that in all cases a dose level at the very upper limit of tolerance is being sought and that small degrees of error will become relatively more important with regard to the production of severe and long-term complications.

INVESTIGATIONS

In this survey a number of objectives were sought. Firstly, a random series of women receiving radical pelvic irradiation had diagnostic radiographs of the pelvis taken at the time of treatment. Each patient in the series was radiographed twice weekly and films were examined for the presence of gas. Substantial quantities of gas were seen in the pelvic colon and rectum in 4 out of every 5 radiographs taken.

Size. The magnification of the films was assessed and the size of individual gas spaces measured. The mean size of the spaces was 2½ cm. and many were 4 cm. and more in diameter.

Measured effects. In the cases where gas spaces were seen a polythene rectal probe containing lithium fluoride dosimeters at intervals was inserted so that its top could be seen high in the rectosigmoid region. The patient was then treated in the normal way with the probe in position. After receiving that fraction the probe was removed and the dose was measured from the lithium fluoride dosimeters and compared with the calculated dose obtained from the treatment plan. Calculated and measured doses differed substantially in several cases (see Table I).

TABLE I. IN VIVO MEASUREMENTS OF DOSAGE BY THERMO-LUMINESCENT DOSIMETRY

Radiation type	Vagina		Rectum		Maximum planned tumour dose
	Planned	Measured	Planned	Measured	
^{60}Co	120–130	146	100–120	140	140
		150		147	
		136		135	
	130	137	90–125	130	135
		130			
	120	133	80–110	140	140
		150		123	
	120	110	80–120	90	130
Deep	90	108	60–90	93	100
X-ray	90	79	70–90	80	90
		79		63	
	90–100	98	70–100	93	100
		95		90	
	90	90	80–90	94	90
		100		88	

Looking at a typical plan, however (Fig. 1), it can be seen that the measurements were taken in an area of considerable dose gradient. It was therefore only possible to interpret very large deviations in dose. The work was carried out on patients receiving 250 kv. deep X-ray high-voltage therapy using 3·5 mm. Cu and also ^{60}Co. Because of the dose gradient problem it was decided to apply the known dimensional factors and to take some measurements in a water phantom containing an air space of similar size to that found in our patients. The phantom consisted of a perspex tank filled with water (Fig. 2), the air cavity being a perspex cylinder of inside dimensions 4·35 cm. diameter × 5·25 cm. long. Measurements of dosage were made in different positions relative to the cavity, both with and without the cavity present. A Baldwin Farmer standard dose meter was used for these measurements. Readings were taken over a range of field sizes, for both cobalt-60 and 250 kv. X-rays.

Table II tabulates the percentage increase in dose when the air cavity is present in the medium. For these readings, the ionization chamber was positioned directly behind the cavity, in contact with the cavity wall, in which position the centre of the ionization chamber is 1 cm. from the cavity inner wall. The second column of Table II gives the distance between the centre of the cavity and the front face of the perspex tank. It will be seen that for ^{60}Co the percentage increase is almost constant at 19 - 20%, irrespective of depth and field size, indicating that there is little scattered radiation. For the 250 kv. X-rays, on the other hand, the increases range from 44% for the smallest field size to 29% for the largest field. This variation is attributed to the much greater amount of scatter encountered for the 250 kv. radiation as compared with ^{60}Co. The influence of the depth of the cavity in the medium

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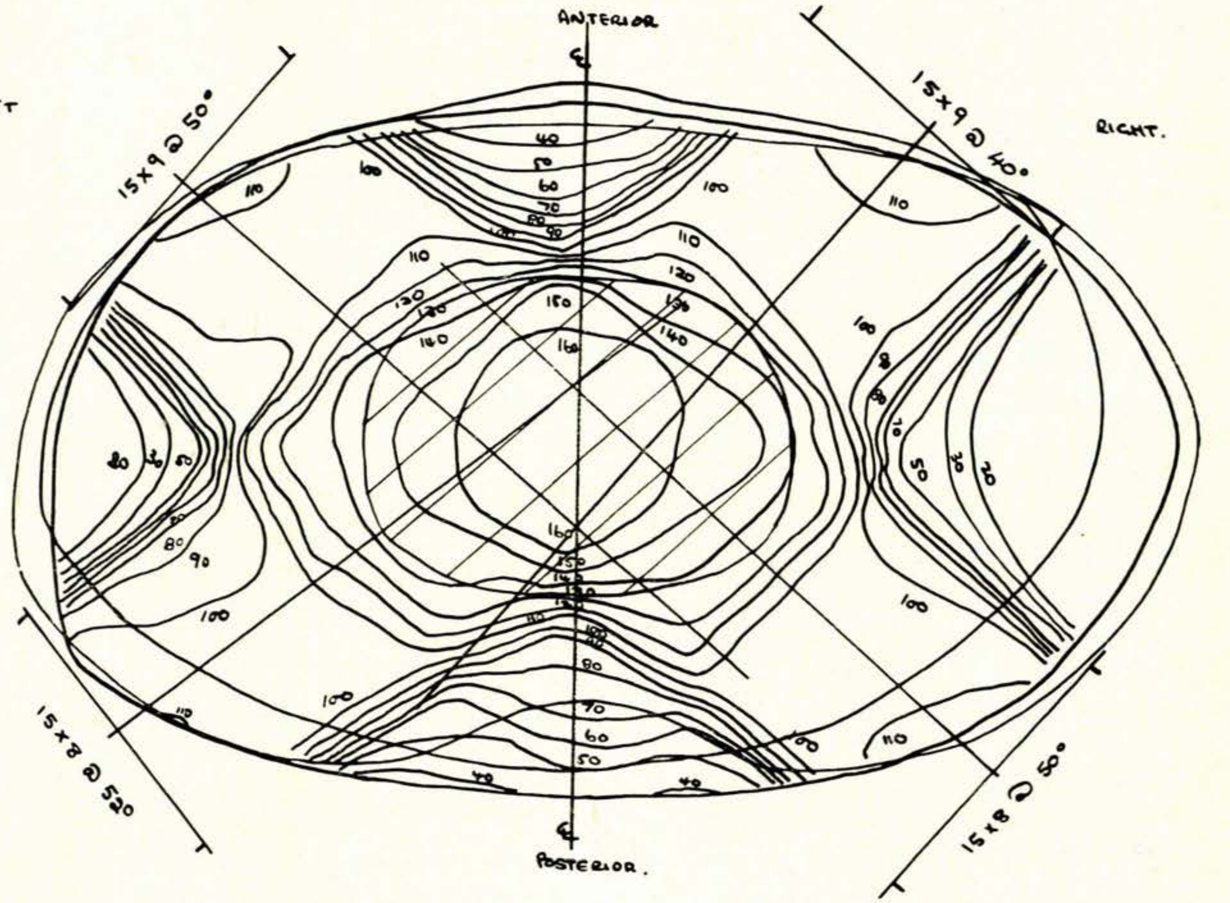

Fig. 1. A typical pelvic plan using four-field irradiation with ^{60}Co.

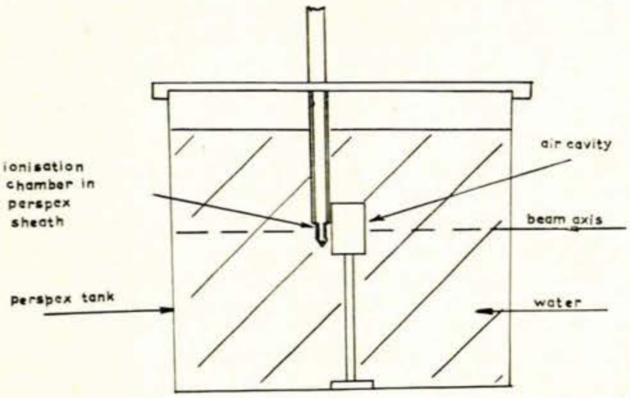

Fig. 2. Water phantom used in determining dosage variation.

is seen to be small, allowing for possible experimental error. With 250 kv. X-rays, measurements made with the chamber directly in front of the cavity showed a 2 - 4% decrease in dose due to cavity presence, which is ascribed to reduced back-scatter. Similar measurements at the side of the cavity showed a 2% decrease. Again, for 250 kv. X-rays, measurements made with the chamber at different

TABLE II. INCREASE IN DOSE CAUSED BY PRESENCE OF AIR CAVITY

Field size	*Depth of centre of cavity (cm.)*	*% increase in exposure* ^{60}*Co*	*% increase in exposure* *Deep X-ray*
5 × 15	4·4	21 ± 1	44·5 ± 1·5
	12·9	19 ± 1	44 ± 2·5
	18·9	19 ± 1	44 ± 4
7·5 × 15	4·4	18 ± 1	40 ± 1·5
	12·9	19·5 ± 1	33 ± 2
	18·9	20·5 ± 1	32 ± 3
10 × 15	4·4	19·5 ± 1	37 ± 1
	12·9	18 ± 1	32 ± 1·5
	18·9	20 ± 1	35 ± 2·5
12 × 15	4·4	19·5 ± 1	35 ± 1
	12·9	19 ± 1	32 ± 1·5
	18·9	19 ± 1	29 ± 2

distances beyond the cavity showed the percentage increase to be very little different from that immediately behind the cavity; in the discussion that follows, the percentage increase will be assumed independent of depth beyond the cavity. In the case of ^{60}Co, Burlin,[4] working with a 10-cm. thick cavity 15 × 15 cm. in cross-section, found a steep rise of dosage with distance beyond the cavity. With the very much smaller cylindrical cavity used in the present measurements, however, only a very small increase in dosage was noted, of the same order as the experimental error. It is assumed below, therefore, that the fractional increase in dosage as one proceeds beyond the cavity is constant for ^{60}Co radiation also.

EFFECTS ON ACTUAL TREATMENTS

In Fig. 3 are shown isodose curves of a 15 × 8 field, 80 cm. source-skin distance for ^{60}Co, and a 15 × 7·5 field 50 cm. focus-skin distance for the 250 kv. radiation. These are typical field sizes used for 4 field cervix treatments. The figures on the left of the central axis show the effect of a 4-cm. diameter cavity on the central axis

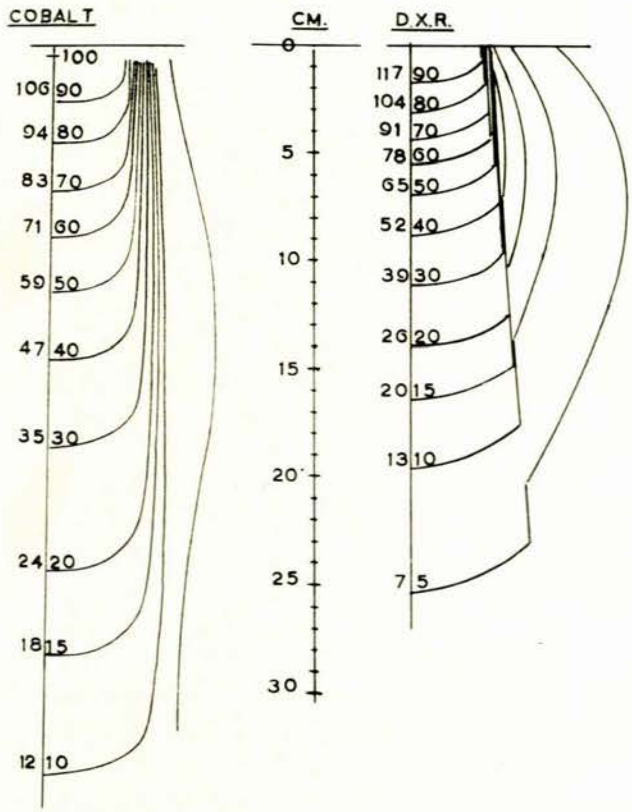

Fig. 3. Central axis depth dose variation with a 4-cm. air bubble.

per cent depth dose, based on a dose increase factor of 1·18 for ^{60}Co and 1·30 for deep X-ray therapy—these figures being scaled down from the data in Table I which are for a 4·35 cm. cavity, i.e. for

$$^{60}\text{Co}\ 1 + 0{\cdot}20 \times \frac{4}{4{\cdot}35} = 1{\cdot}18$$

$$\text{Deep X-ray therapy}\ 1 + {\cdot}33 \times \frac{4}{4{\cdot}35} = 1{\cdot}30$$

The actual effect met in practice will depend very much on the position of the cavity with respect to the skin surface and the depth of the tissues under consideration. As a working figure, however, let us consider the effect at a depth of 12 cm. Thus, 4-cm. diameter cavity with a single field firing through it will give roughly an 8% increase for either ^{60}Co or deep X-ray therapy. If the cavity is placed so that two beams are cross-firing through it, then the effect may be further enhanced. Simple geometrical considerations indicate that the cross-fire may increase the 8% figure by a maximum of a factor of 1·6, i.e. to 12%. Supposing for the moment that in some patients, large amounts of gas are present throughout the whole, or most of, the treatment period, we have to ask what will be the result of, say, a 12% increase in dosage over the specified value, arising from the presence of cavities. For the following reasons, it is considered that such a situation is potentially much more dangerous for ^{60}Co irradiation than for deep X-ray therapy. Because of the poorer depth dose obtainable with deep X-ray therapy, tumour dose can be less than skin dose by as much as 10% (typically, tumour dose will be 90 - 100%), so that even if treatment is continued to take the skin dose to the absolute limit, the treatment volume will still have, so to speak, some tolerance in hand. With ^{60}Co, however, treatment volumes are frequently planned to 130 - 140% compared with 100 - 110% on the skin, and if treatments are truly radical, then the treatment volume will be taken to the maximum possible dose.

CONCLUSION

Ideally, patients receiving radical courses of radiotherapy should be hospitalized for the duration of their treatment. Intestinal gas is produced by a combination of factors, the two most important being air swallowing and gas-forming anaerobic bacteria. Low-residue diets and a calm, ordered atmosphere probably reduce the tendency to accumulate large quantities of gas.

Certain patients are specially at risk and may develop radiation hot spots, due to dilated loops of small bowel or colon in a constant anatomical site, namely those with a previous history of abdominal surgery, peritonitis or intraperitoneal adhesions from any cause. These patients should be observed particularly carefully for symptoms related to the stage of the treatment.

We believe that it is not possible at present to calculate an air correction factor for the pelvis in view of the degree of individual variation. We have shown that measurable discrepancies of as much as 12% can occur and feel that this is a factor hitherto disregarded. Now that the very peak of tissue tolerance is being reached in nearly every case, those sources of error should be increasingly borne in mind.

SUMMARY

This paper sets out to draw attention to, and investigate, a neglected source of error in the radiotherapy of pelvic malignancy. It has long been appreciated that air spaces in the thorax are responsible for a discrepancy between actual and calculated depth doses and an air correction factor is now applied. In the pelvic regions air spaces of considerable size are often encountered and the effect of these spaces is assessed. It is concluded that the margins of error produced by these air spaces may be significant in certain groups of cases but no 'correction factor' can be applied as the variation between individuals is so great.

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