THE USES OF A COBALT UNIT FOR RADIOTHERAPY

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X-rays generated at a kilovoltage of 250 have been used in the treatment of malignant disease for about 30 years. It was found that when high doses were given, damage to the skin and subcutaneous tissues was frequent. After desquamation of the skin had subsided, pigmentation followed and during the succeeding 18 months permanent and unsightly telangiectasis developed. This was often associated with a variable amount of fibrosis of the soft tissues. With conventional X-ray therapy the maximum dose fell on the skin, which therefore suffered most severely.

The absorption of X-rays in tissue increases with increase in the atomic weights of the elements composing the tissues. Thus, absorption of X-rays in bone is two and a half times higher than in soft tissues, mainly due to the high calcium content of the skeleton.

In clinical practice this had two disadvantages: firstly, in the irradiation of lesions deep to a bony structure, such as tumours of the mouth or maxillary antrum, the dose actually received by the tumour was materially less than the calculated dose, because the overlying bone acted as an absorbing shield; secondly, the very high dose received by the bone predisposed towards fracture in later years, and in the presence of infection, osteomyelitis and its complications.

The beam produced by an average 250-kV. X-ray therapy machine falls to 30 per cent. of its intensity by the time it has passed halfway through the body. It is thus very difficult to give a high dose of irradiation to deep-seated tumours, particularly where differential sensitivity between normal and malignant tissues is low.

These difficulties have been largely overcome by the use of X-ray and gamma-ray beams generated at a voltage of one million or more, so-called supervoltage irradiation therapy.

With supervoltage rays the maximum dose falls not on the skin, but at a level 0.5 cm. deep to it for a 1,000-curie ^{60}Co source. The skin is thus comparatively spared.

The absorption of supervoltage irradiation in

bone is no greater than its absorption in soft tissues. It follows that the risk of fracture and radionecrosis is greatly diminished. Moreover, the screening effect of bone is not important, which means that the dose received by tumours deep to bone is adequate.

Many supervoltage machines have a high output. We can take advantage of this by increasing the distance from radiation source to skin surface to as much as 100 cm., compared with an average of 50 cm., with a 250-kV. machine. If the inverse square law is recalled, it will be clear that the ratio between the dose received by the skin and the dose received at a depth within the body is much greater with supervoltage therapy. This ratio is known as the percentage depth dose, and it follows that deep-seated tumours can be treated with much greater facility because of the improved percentage depth dose.

There are many types of supervoltage machine. In some powerful X-ray beams are produced by the impact of high-energy electrons on metallic targets; in others use is made of a penetrating beam of gamma rays produced by certain radioactive isotopes manufactured in the atomic pile.

One of this latter class of machine is the 'Theratron,' which combines the advantages of supervoltage irradiation with rotation of the treatment head.

The 'Theratron' Cobalt 60 Unit

This machine, which was constructed by Atomic Energy of Canada Ltd., has been in clinical use at Mount Vernon Hospital since March 1954. It is intended primarily for rotation therapy.

The radioactive source is cobalt 60, which has a half-life of 5.3 years. This isotope produces a powerful gamma ray beam equivalent to an X-ray beam of 2 to 3 million volts. The source is a short cylinder of 2 cm. diameter, housed in a massive head of lead-tungsten alloy. The head is carried on a C-shaped arm, at the other end of which is a counterweight. This weight also serves as a direct radiation shield (see illustration).

The 'Theratron' 1,000-curie cobalt unit.

Two types of movement of the treatment head are possible: partial or complete rotation in the vertical plane and oscillation at right angles to it over a limited arc. Thus, whatever the position of the source, the central axis of the beam—as defined by diaphragms—passes through the same fixed point, which is the centre of rotation. Speed of rotation can be fixed at anything up to a maximum of two and a half revolutions per minute. The treatment couch has a full range of horizontal movements and vertical adjustments are hydraulically operated.

By means of these devices the centre of rotation can be made to coincide with any point within the body.

The output of the machine is about 45 röntgens per minute in air at 75 cm. from the source and treatment times vary between five and 15 minutes, depending on the depth of the lesion below the body surface. The radioactive cobalt source is approximately 1,000 curies, which is equivalent to nearly 2,000 g. of radium element.

Advantages of Rotating Supervoltage Therapy

In addition to those advantages of supervoltage treatment already mentioned, the use of partial or complete rotation of the treatment head gives the maximum possible ratio between the dose de-

livered to the tumour and the dose received by the surrounding normal tissues. During rotation the tumour is under continuous irradiation, whereas the normal tissues through which the beam is passing are constantly changing. Thus, normal tissues between skin surface and tumour receive a minimum dose and the risk of late radiation damage is therefore diminished.

The penetration of a supervoltage beam is so great that up to 25 per cent. of the beam may emerge on the other side of the patient. This high exit dose is a disadvantage; it is obviated by the use of a rotating head which 'distributes' the total dose over a larger volume of tissue and consequently over a larger exit portal.

Radiation Dose

The biological effect of irradiation depends ultimately on physical and chemical changes taking place at the molecular level within the cell, or, looked at another way, on the number of ionizations occurring per unit volume of tissue.

Because the density of ionization per unit length of track increases as the energy of the beam increases, there were strong reasons for assuming that the dose of supervoltage irradiation in röntgens would have to be increased if biological effects

comparable to those caused by 250-kV. X-rays were to be achieved. This has proved to be so.

It had been known for some time that a dose of 5,000 r. in five weeks at 250 kV. corresponded approximately to 6,500 r. from a 10-g. teleradium unit given in the same overall time. This teleradium gamma ray beam was roughly equivalent to an X-ray beam of 1.6 million volts. It was therefore thought that for beam energies in the 3 to 4 million volt range—such as the 'Theratron' beam—a dose of 7,500 r. to a small tissue volume could readily be given in about six weeks.

Most cases have been treated with doses of this order.

Tissue Reactions

When a high-energy or gamma ray quantum strikes matter, most of the resulting electrons are projected forwards. This is why the maximum dose from a supervoltage beam falls below the skin surface. The appearance of the skin during treatment is thus no guide to tissue tolerance.

After two or three weeks' treatment slight erythema of the skin may occur. Towards the end of treatment this may deepen and perhaps be accompanied by a little dry desquamation. In very few cases does moist desquamation ever develop, and then only if higher doses are given. It is never severe.

The reaction of mucous membranes is correspondingly slight. Towards the end of irradiation a fibrinous film may be seen, but it is usually not severe and only very rarely a reason for stopping treatment earlier than intended.

Systemic reactions are generally negligible. Nausea is an occasional complaint, but vomiting is rare. The patient's energy and well-being are usually maintained normally throughout treatment. A very striking feature is the infrequency of diarrhoea, even when large volumes of abdominal and pelvic viscera are treated.

It is too early to be dogmatic about late tissue damage, since the first group of patients was treated only three and a half years ago. However, if severe damage were to have been common, it would have been evident by now, whereas, in fact, radio-necrosis has not been seen.

During the months following the end of treatment progressive thickening of the subcutaneous tissues develops. This is usually not severe. In a few, dense fibrosis of the soft tissues occurs with 'leathering' of the muscles. Pigmentation of the overlying skin is slight and telangiectasis does not occur.

Selection of Cases for Treatment

In the absence of past experience selection criteria had to be evolved empirically. It was

decided that only those groups of cases which could not be effectively treated with conventional deep X-ray therapy would be considered for supervoltage irradiation, provided that the tumours were of types known to be radiosensitive in some degree.

In practice this meant that certain deep-seated tumours would be treated where an otherwise insufficient tumour dose would have been given with conventional X-rays. Carcinomas of the oesophagus, bronchus and bladder fell within this group. In addition, certain accessible tumours were treated where the violence of the mucosal reaction might have precluded the giving of a sufficient dose with 200-kV. X-rays. Carcinomas of the posterior part of the tongue, pharynx, post-nasal space and extrinsic carcinomas of the larynx and post-cricoid region fell into this category.

The low absorption of supervoltage rays in bone commended their use in bone sarcomas and in soft tissue sarcomas adjacent, or fixed, to bone.

One group of cases—chordomas—was treated to test the accepted notions of tumour sensitivity.

Tumours of the Upper Air Passages

The site of origin of these tumours has been between the posterior one-third of the tongue and the upper trachea. The primary tumours have often been locally advanced and sometimes associated with fixed metastatic glandular masses when first seen.

It has been possible to treat most of these cases with one field, using a partial rotation technique.

Tumour resolution is often noted within three weeks of starting treatment and, in favourable cases, is well marked at the end of six weeks' irradiation.

In the minority who develop a brisk mucosal reaction it has been necessary to reduce the daily dose a little or sometimes to suspend treatment for a few days. The reaction usually subsides rapidly.

Deep-seated Tumours

Carcinomas of the bronchus have to be carefully selected. Radical irradiation is only worthwhile in histologically proved squamous carcinomas, and this automatically excludes the majority of referred cases. Those treated have previously been deemed inoperable, either because of technical difficulty in removal of the tumour—for example, infiltration of the trachea—or because of the patient's poor vital capacity.

The tumour is accurately localized and irradiated to a tumour dose of about 6,500 r. in six weeks. Towards the end of treatment retrosternal discomfort and burning are almost invariable and are due to radiation-induced oesophagitis. This settles rapidly. Some degree of progressive lung fibrosis is inevitable; as it is not yet known how

disabling this will finally prove, the dose of 6,500 r. should not be much exceeded.

Most patients referred with carcinoma of the oesophagus usually have extensive lesions and when first seen are only able to swallow fluids with difficulty. The tumour is localized very accurately by barium swallow and oesophagoscopy and treated by a complete rotation technique to the same order of dose as a carcinoma of bronchus.

Within a fortnight dysphagia improves and, in many cases, the patient may be eating solid food by the time of his discharge from hospital. The tumour can often be eradicated locally and a fibrotic stricture usually follows. These strictures need cautious dilatation later.

Most cases of carcinoma of the bladder have been fairly advanced when first seen. The volume of pelvic tissue to be treated is determined by examination under anaesthesia and cystoscopy with the insertion of markers. In nearly all cases it is necessary to treat the whole bladder with a full rotation technique. Symptomatic improvement is usual.

Chordomas

These tumours arise from the remnants of the primitive notochord. They have a characteristic histological picture with many small dark nuclei in large vacuolated cells. They may be found anywhere over the site of the notochord, but are most frequent in the sacral region.

Until recently chordomas were universally regarded as radio-resistant tumours and this belief, together with their surgical inaccessibility, made the outlook particularly poor.

Over 20 chordomas have been treated with dramatic results. The tumours are clearly radio-sensitive and respond well to only moderate doses of supervoltage irradiation. Large masses filling the hollow of the sacrum have melted away and the disease has remained quiescent for observation periods of up to three years. Calcification of chordomas after irradiation is uncommon.

Sarcomas of Bone

A large group has been treated. Most sarcomas have limited radio-sensitivity and treatment policy has consisted in radical irradiation, followed by amputation in selected cases.

A tumour dose of 7,000 to 8,000 r. has been delivered in about seven weeks, often to large volumes of tissue without particular difficulty. The usual immediate result has been improvement in the patient's condition, disappearance of pain, marked regression in tumour size and recalcification of the area radiologically.

Subsequent management has depended on clinical and X-ray findings. If there is any clinical

evidence of activity three to six months after irradiation and a chest X-ray is normal, amputation is advised; if there is no clinical evidence of activity, it is reasonable to postpone amputation.

The rationale for this policy is as follows: because of early blood-borne metastases amputation in bone sarcomas has given such generally bad results that it is being increasingly abandoned. By delaying operation—and using the interval for a radical radiotherapeutic attack on the tumour—a natural selection is allowed to act and those patients who develop pulmonary metastases are spared an unnecessary amputation.

Similar considerations apply to many soft tissue sarcomas.

Results

The follow-up period is too short for any presentation of survival rates and we are still at the stage of dealing in clinical impressions.

Tumours of the upper air passages are nearly all squamous carcinomas; most are radio-sensitive and many disappear with a moderate dose of supervoltage irradiation. Many are very advanced when first seen and are suitable for palliative treatment only. In the less advanced group a number of tumours have regressed completely and have not recurred so far.

Though large numbers of carcinomas of the bronchus are referred for treatment, rigid selection has meant that only a comparatively small series has been treated. Immediate results are encouraging and many tumours can certainly be eradicated locally. This is equally true of even the advanced groups of carcinomas of the oesophagus, which have been treated radically. The problem here is not the destruction of the primary, which can usually be achieved, but that most patients die of their metastases.

Results in the irradiation of carcinoma of the bladder are difficult to assess. The radiotherapist is asked to treat a very advanced group of cases where often little more than palliation can be offered. No great developments can be expected until the effect of supervoltage irradiation can be tried on a less advanced group.

Time alone will decide the worthwhileness of the bone sarcoma experiment. It is certain that many useless amputations have been avoided and it is equally sure that the majority of cases can be helped in an important symptomatic way. Amputation specimens, obtained after radical irradiation, are now becoming available and in a number of cases no viable tumour has been found. This work is continuing.

It has been established that radiation is the treatment of choice of chordomas. This tumour is undoubtedly commoner than had been thought and

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many cases have hidden their identity under false histological labels. The importance of making the diagnosis accurately is enhanced now that an effective treatment exists.

Availability of Apparatus

A number of different models of rotating cobalt supervoltage apparatus are now available. Newton Victor Ltd., 132 Long Acre, London, W.C.2, make the 'Orbitron' with a price range of £11,000 to £14,000 and a delivery time of 12 months. Nuclear Engineering Ltd., Woolwich Road, London, S.E.7, also make rotating cobalt apparatus, the cost of which is in the region of £21,000 and

a delivery date of 10 to 12 months. The British agents for the 'Theratron' are Watson & Sons (Electro - Medical) Ltd., North Wembley, Middlesex. All prices exclude the cost of the radioactive cobalt source, which would be approximately £5,000 for a 1,000-curie source.

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