Tumour Dose Estimation using Automated TLD Techniques

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Lithium fluoride (TLD-700) dosimeters were used to measure exit surface absorbed doses in external beam radiotherapy using an automated TLD reader. Delivered tumour absorbed doses were derived from these measurements for head and neck, pelvis and breast treatments. For the head and neck treatments (first fraction only), the mean percentage difference between prescribed and delivered tumour absorbed doses was $-0.15 \pm 3.0\%$ (± 1 SD), for the pelvic treatments $-0.83 \pm 2.8\%$ and for the breast treatments $+0.26 \pm 2.9\%$. The spread of results is approximately $\pm 3\%$ ($\pm$ 1 SD). This is comparable with the estimated uncertainty in a single TLD absorbed dose measurement in phantom ($\pm 2\%$; ± 1 SD). Thus, ICRU recommended tolerances for absorbed dose delivery of $\pm 5\%$ may not be unequivocally detectable using this method. An action level of $\pm 10\%$ is suggested, allowing investigation of possible gross errors in treatment delivery at an early stage, before the course of treatment has progressed to a point at which absorbed dose compensation is impossible.

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In vivo dosimetry has been shown to be a valuable dosimetric quality assurance tool in external beam radiotherapy (1–12). Its value lies in the estimation of clinical absorbed doses independent of the treatment machine dosimetry system. Both TLD and semiconductor diode techniques have been used, and their relative merits are well known (13–15). This paper reports a clinical trial to test the applicability of an automated TLD facility (Harshaw 6600 system) for performing exit absorbed dose measurements, from which the delivered tumour absorbed dose may be estimated using treatment planning system data (16). Exit measurements have been studied specifically to allow the possibility of a tumour absorbed dose estimate to be made at every fraction, without any perturbation of the beam between entrance surface and tumour. The value of the technique is weighed against the limits of acceptable uncertainty in radiotherapy absorbed dose delivery of $\pm 5\%$ (ICRU) (17) and according to UK requirements for reporting errors in treatment delivery (18).

The advantages claimed for TLD dosimetry for patient absorbed dose assessment include the small size of the TL dosimeters free of connecting leads and their lack of directional dependence. The disadvantages include the need for off-line (and often labour-intensive) processing and the high capital cost of TLD equipment compared with semiconductor diodes. These potential disadvantages have been addressed in this project, which has investigated the use of a TLD system with automatic chip-reading and data logging facilities, designed for and used in our Centre for measurements in diagnostic radiology and radiation protection. Thus staff time may be minimized and the cost of the system shared between radiological specialities.

The commissioning and calibration of the system has been described in a previous paper (16); only a brief description is given here. The results of this commissioning indicated an uncertainty of $\pm 2\%$ in a single TLD measurement (following appropriate calibration) under phantom irradiation conditions. In clinical practice, greater uncertainty may be expected due to patient-related factors such as the variation and estimation of the size, shape and composition and unplanned movement of the patient, during the course of treatment.

The purpose of this study is to evaluate the performance of an automated TLD system under clinical conditions. Treatment sites studied include the head and neck (with immobilization shells), pelvis (including cervix, bladder and rectum) and breast.

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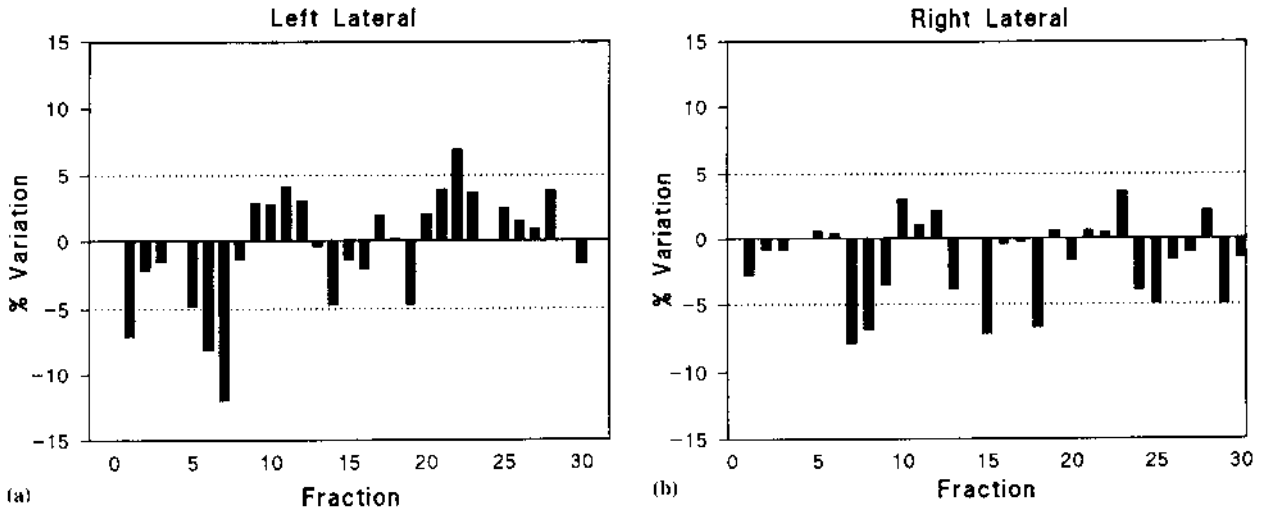

Fig. 1. Percentage difference between estimated and prescribed tumour absorbed doses for 30 fractions of a single typical patient's treatment for Ca larynx (two parallel opposed 6 MV lateral fields). (a) Left lateral field. (b) Right lateral field.

MATERIAL AND METHODS

The TLD system

The TLD system used consists of a Harshaw 6600 TLD reader, together with Harshaw XD720 dosimeters (EXTRAD), originally developed for measurements of absorbed dose to extremities. The TL elements are LiF : Mg,Ti (TLD-700) hot-pressed chips, 3×3 mm^2 in area. The dosimeter element has a thickness of 20 mg cm^{-2} and is mounted on a layer of undoped lithium fluoride for mechanical strength. The chip and substrate are inserted into a disposable pouch for use, with the layer of undoped LiF nearest to the skin. The reader has a capacity of 400 chips, which are read automatically, making it suitable for use in a large-scale study. The response of the chips is linear with absorbed dose between 0.4–1.5 Gy (16), the range of exit absorbed doses likely to be encountered in practice. After a preheat period at 130°C, data acquisition occurs at 300°C for 13.3 s, followed by a 45 s anneal at 300°C. A more detailed description of the system and its calibration has been given previously (16).

Absorbed dose calibration

A batch of dosimeters, chosen at random from the stock, was irradiated to a known absorbed dose using a linear accelerator. A reader calibration factor was derived and used to convert the TL signal to dosimetric units. The uncertainty in a single TLD measurement was estimated as $\pm 2\%$ (± 1 SD).

The relation of exit absorbed dose measurements to tumour absorbed dose

Calculation of the tumour (isocentre) absorbed dose, M_{tum}, has been described in a previous paper (16) and is estimated using the following relation:

$$M_{tum} = \frac{M_{exit,\,t,\,clin}}{R_{exit}\, k_{exit,\,tum}} \quad (1)$$

where $M_{exit,\,t,\,clin}$ is the clinical exit absorbed dose measurement. The relative exit absorbed dose (R_{exit}) is the ratio of the absorbed dose on the exit surface of a phantom of thickness t to the absorbed dose at the same depth t within a semi-infinite phantom (i.e. it is assumed there is sufficient material beyond the exit surface to provide full backscatter at the point of measurement), and $k_{exit,\,tum}$ is the ratio of exit to tumour absorbed dose from the treatment planning data.

The treatment planning systems used in this study (IGE Target 2, HELAX-TMS) take no account of the lack of scatter at exit surfaces.

Lack of full electronic equilibrium and the effect of exit surface obliquity

The dosimeters, when inserted into the disposable pouches for attachment to the patient exit surface, do not provide sufficient distal material to ensure full electronic equilibrium at megavoltage energies. Consequently, R_{exit} will be influenced by the obliquity of the exit surface (19). It has been found previously (16) that R_{exit} decreases with increasing obliquity, and corrections have been made for this effect in the clinical studies reported here.

CLINICAL STUDIES

Pilot study—head and neck (all fractions)

Eight patients receiving relatively simple parallel opposed field treatments of the larynx were chosen to form a pilot study to test the logistics of the project. Each patient was treated with an immobilization shell, which reduced the potential for patient movement and also provided reference marks used in positioning the patient. In opposed lateral treatments, these marks corresponded to the en-

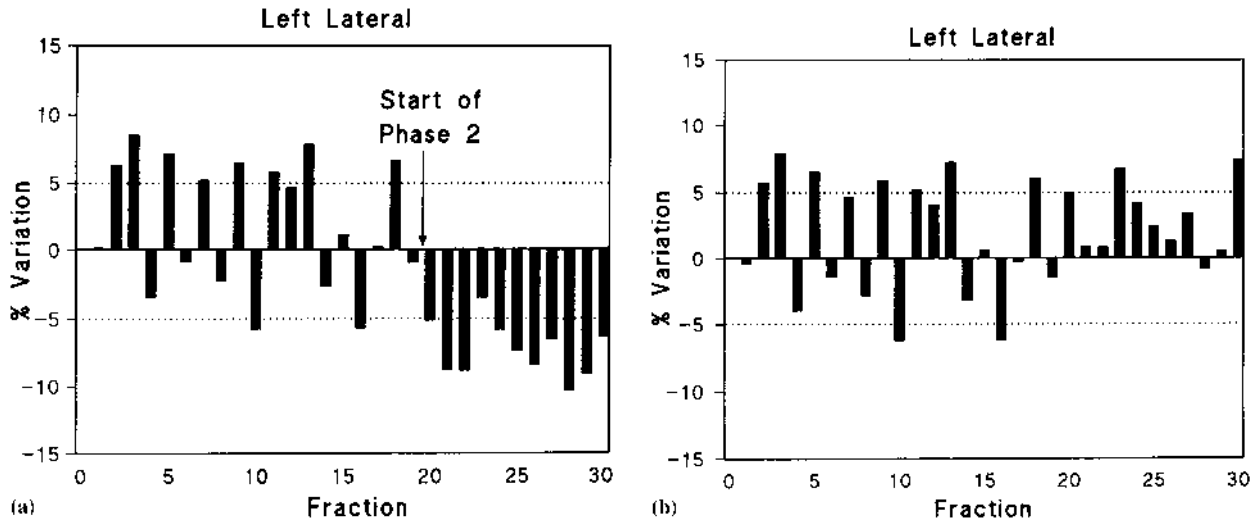

Fig. 2. Percentage difference between estimated and prescribed tumour absorbed doses for 30 fractions of a single patient's treatment for Ca larynx (two parallel opposed 6 MV lateral fields). (a) Left lateral field with no correction for exit surface obliquity, showing change in surface obliquity due to re-planning and subsequent alteration in field size and position. (b) The same left lateral field, but with correction for exit surface obliquity.

trance/exit points for each field, and therefore gave a convenient indication of the required position of the dosimeter for each measurement.

All patients were treated on a linear accelerator (Siemens Mevatron 67) operating at 6 MV. Measurements were made daily for all fractions in the course of treatment. Treatment of all patients was planned from surface contours or CT images using an IGE TARGET 2 treatment planning system.

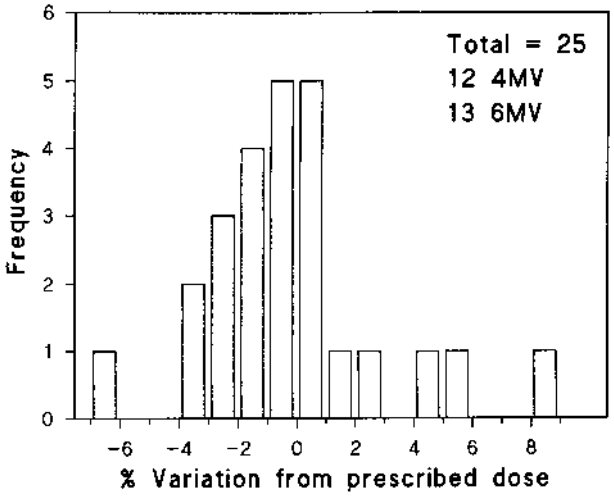

Fig. 3. Head and neck treatments. Percentage difference between estimated and prescribed tumour absorbed dose estimated from exit measurements at the first fraction for 25 patients (4 and 6 MV).

Extended study (first fraction only)

Following the pilot study, it was decided to make further exit absorbed dose measurements during the first treatment fraction only. This enabled a wider range of treatments and patients to be explored using the same resources. It also tacitly acknowledged the role of the equipment-linked record and verify systems in use on each treatment machine in assessing consistent treatment parameters. The first fraction is critical, because it is at this stage that treatment planning information, which has been transferred to the treatment machine, is used for the first time. It is highly desirable to make an independent check of the delivered tumour absorbed dose at this point in the treatment process. Agreement with the prescribed tumour absorbed dose would provide an assurance that the machine settings were correct at the onset of treatment. If an absorbed dose discrepancy were found, the verification reference file would be checked, and mistakes identified and corrected before subsequent fractions were delivered.

Head and neck

Twenty-five head and neck patients were included in the study in order to compare results with those from the all-fractions study. A wider range of treatments was included, with anterior and posterior fields being measured where possible. These were carried out at 6 MV on a Siemens Mevatron 67 and an IGE Saturne 43 linear accelerator, and at 4 MV on a Philips SL75/5 and a Siemens Mevatron 6300 linear accelerator.

Pelvis

Patients receiving pelvic irradiation presented new problems in that some of the exit points were made inaccessible

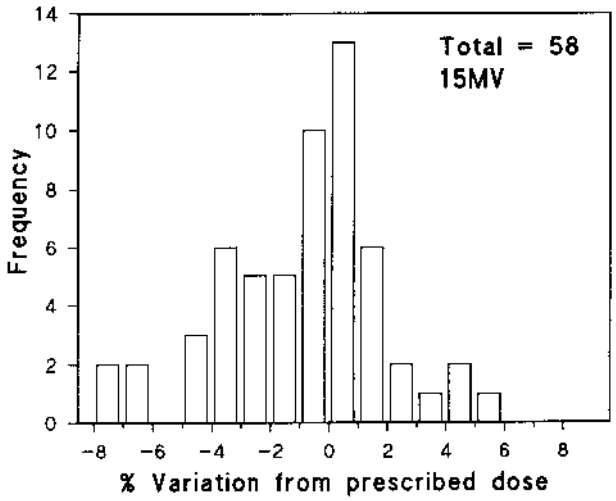

Fig. 4. Pelvic treatments. Percentage variation from prescribed tumour absorbed dose estimated from exit measurements at the first fraction for 58 patients (15 MV).

by the treatment couch. This was especially true where oblique anterior and posterior fields were encountered. For these treatments, two out of the three exit points were measured as usual and the calculations were altered accordingly. For pelvic treatments in which opposed lateral fields were not used, the exit point was not marked on the patient. In these cases the dosimeters were positioned on the patient using the laser backpointer on the treatment machine. The backpointer is checked as part of the daily QA programme, and has a tolerance of ± 3 mm. Fifty-eight patients were studied.

Breast

Measurements on 14 breast treatments were also included in the study, to examine the most extreme cases of field obliquity. These were carried out at 4 MV, on a Philips SL75/5 and a Siemens Mevatron 6300, and at 6 MV on an IGE Saturne 43.

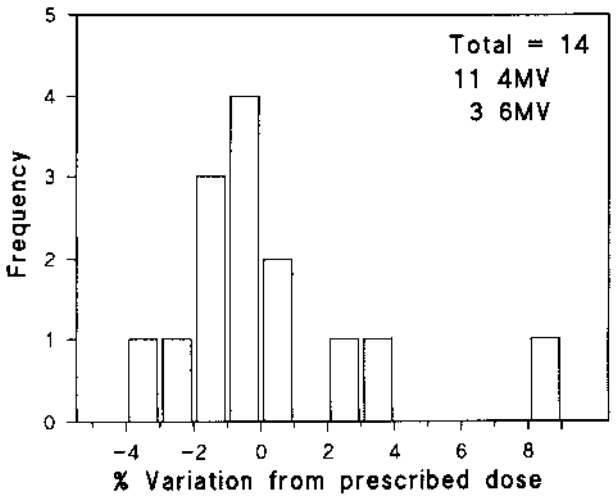

Fig. 5. Breast treatments. Percentage difference between estimated and prescribed tumour absorbed dose estimated from exit measurements at the first fraction for 14 patients (4 and 6 MV).

RESULTS

Head and neck (all fractions)

Typical results for one patient are shown in Fig. 1a and Fig. 1b. When corrected for exit surface obliquity, the estimated tumour absorbed doses lie around zero variation from the prescribed tumour absorbed dose. The majority of points lie within $\pm 5\%$ of the mean.

An interesting observation was made in this respect for one patient, whose plan was modified at fraction 20. The second phase of treatment involved a reduced field size and central axis shift. The variation from the prescribed absorbed dose when no obliquity correction is made is shown in Fig. 2a. The apparent change in delivered dose may clearly be seen. In fact, this is due to a change in exit surface obliquity. When this change is allowed for, the corrected delivered tumour absorbed doses are as in Fig. 2b.

Head and neck (first fraction only)

Fig. 3 shows the percentage variation of the estimated delivered absorbed dose from the prescribed absorbed dose for a total of 25 patients treated at 4 and 6 MV (mean $= -0.15 \pm 3.0\%$ (± 1 SD)).

Pelvis

Fig. 4 shows the percentage variation of the estimated delivered absorbed dose from the prescribed absorbed dose for a total of 58 patients treated at 15 MV (mean $= -0.83 \pm 2.8\%$ (± 1 SD)).

Breast

Fig. 5 shows the percentage variation of the estimated delivered absorbed dose from the prescribed absorbed dose for a total of 14 patients treated at 4 and 6 MV (mean $= 0.26 \pm 2.9\%$ (± 1 SD)).

It was found that, for all tumour sites, anomalously low exit absorbed doses were derived by using the point absorbed dose cursor of the planning system. This is thought to be due to the algorithm, which interpolates between nearest neighbour values on the absorbed dose matrix. Close to the exit surface, matrix points lying outside the body contour are assigned an absorbed dose value of zero. A more reliable value of the ratio of exit absorbed dose to the absorbed dose at the isocentre, $k_{exit,\,tum}$, was derived using Tissue-Maximum Ratios (16).

In all the above studies, the estimated absorbed dose refers to the total tumour absorbed dose per fraction calculated from all fields delivered in that fraction.

DISCUSSION

A technique has been developed which enables estimates of delivered tumour absorbed dose to be made, using automated TLD facilities.

Three treatment groups have been studied: head and neck, pelvis, and breast. These have included a wide range of body cross-sections and treatment plans and have covered the energy range 4–15 MV. The programme has been found to be logistically acceptable for the measurement of exit absorbed doses at the first, critical fraction.

For head and neck treatments, the spread of results ($\pm 3\%$) compares well with similar studies using semiconductor diodes. Leunens et al. (3) found a $\pm 2.9\%$ (± 1 SD) spread in estimated midline absorbed doses from entrance and exit measurements. Similar work (1) showed a $\pm 4.3\%$ spread in the ratio of target to prescribed absorbed dose along the beam axis for 11 head and neck treatments.

For pelvic treatments, Heukelom et al. (6) found standard deviations of $\pm 3.1\%$ and $\pm 2.2\%$ in exit absorbed dose measurements using semiconductor diodes, for wedged and unwedged fields, respectively. The spread of $\pm 2.8\%$ in the distribution of estimated to prescribed absorbed dose in this work refers to the tumour absorbed dose per fraction (i.e. derived from the sum of contributions from all fields), and so may be expected to be less than that for single fields.

The mean values for each treatment group are all within 1% of the expected value, but the spread of results is approximately $\pm 3\%$ (± 1 SD). This is comparable to the estimated uncertainty in a single TLD absorbed dose measurement ($\pm 2\%$; ± 1 SD). Other workers using TLD systems (5) have also seen this uncertainty; it suggests that the ICRU recommended tolerances for absorbed dose delivery of $\pm 5\%$ (17) may not be unequivocally detectable using this method. This is supported by the work of Leunens et al. (1), who have also stressed the difficulty of compliance with these tolerances in a study of 11 head and neck treatments using semiconductor diode dosimeters, where 7/11 patients received absorbed doses $> \pm 5\%$, due to irregular body contours and tissue densities. Based on these results, 95% of the measured data would lie within $\pm 6\%$ of the prescribed value (± 2 SD). For a routine dosimetry service based on this technique, an action level of $\pm 10\%$ is suggested. This would allow the identification and reporting of any absorbed doses 'much greater than intended', in accordance with the UK Health and Safety Executive requirements (18). These state that an error of $+20\%$ for a single fraction, or $+10\%$ over the whole course of treatment, should be reported. A similar limit of acceptability has been suggested by Kron et al. (5), who used TLD techniques, and Lee et al. (9), who set $\pm 7\%$ action levels in a study using semiconductor diodes.

Use of a $\pm 10\%$ tolerance level would also fulfil one of the aims of the investigation: that gross errors in treatment delivery should be identified before the course of treatment has progressed to a point at which absorbed dose compensation is impossible. Based on exit measurements, the technique could also be used, if required, at every treatment fraction without perturbation of the tumour absorbed dose by entrance surface-mounted dosimeters. An automated TLD facility of this kind, particularly when shared with other dosimetry programmes (e.g. in diagnostic radiology), reduces the effective cost of the service, often quoted as a disadvantage of TLD facilities dedicated to radiotherapy dosimetry. Under the conditions described, this system thus appears to be a viable alternative to the use of semiconductor diode dosimeters for tumour absorbed dose estimation.

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REFERENCES

1. Leunens G, Verstraete J, Dutreix A, et al. Assessment of absorbed dose inhomogeneity at target level by in vivo dosimetry: can recommended 5% accuracy in the absorbed dose delivered to the target volume be fulfilled in daily practice? Radiother Oncol 1987; 8: 237–52.
2. Leunens G, Van Dam J, Dutreix A, et al. Quality assurance in radiotherapy by in vivo dosimetry. 1. Entrance dose measurements, a reliable procedure. Radiother Oncol 1990; 17: 141–51.
3. Leunens G, Van Dam J, Dutreix A, et al. Quality assurance in radiotherapy by in vivo dosimetry. 2. Determination of the target absorbed dose. Radiother Oncol 1990; 19: 73–87.
4. Rikner G, Grusell E. Patient dose measurements in photon fields by means of silicon semiconductor detectors. Med Phys 1987; 14: 870–3.
5. Kron T, Schneider M, Murray A, et al. Clinical thermoluminescence dosimetry: how do expectations and results compare? Radiother Oncol 1993; 26: 151–61.
6. Heukelom S, Lanson JH, Mijnheer BJ. In vivo dosimetry during pelvic treatment. Radiother Oncol 1992; 25: 111–20.
7. Heukelom S, Lanson JH, Mijnheer BJ. Comparison of entrance and exit dose measurements using ionization chambers and silicon diodes. Phys Med Biol 1991; 36: 47–59.
8. Leunens G, Verstraete J, Van den Bogaert W, et al. In vivo dosimetry for tangential breast irradiation: role of equipment in the accuracy of dose delivery. Radiother Oncol 1991; 22: 285–9.
9. Lee PC, Sawicka JM, Glasgow GP. Patient dosimetry Quality Assurance program with a commercial diode system. Int J Radiat Oncol Biol Phys 1994; 29: 1175–82.
10. Nilsson B, Ruden B-I, Sorcini B. Characteristics of silicon diodes as patient dosimeters in external beam radiation therapy. Radiother Oncol 1988; 11: 279–88.
11. Essers M, Lanson JH, Mijnheer BJ. In vivo dosimetry during conformal therapy of prostatic cancer. Radiother Oncol 1993; 29: 271–9.

12. Hamers HP, Johansson K-A, Venselaar JLM, et al. Entrance and exit TL dosimetry in the conservative treatment of breast cancer: a pilot study for the EORTC Radiotherapy Co-operative Group. Radiother Oncol 1991; 22: 280–4.
13. Aukett RJ. A comparison of semiconductor and thermoluminescent dosimeters for in vivo dosimetry. Br J Radiol 1991; 64: 947–52.
14. Garavaglia G, Johansson K-A, Leunans G, et al. The role of in vivo dosimetry. Radiother Oncol 1993; 29: 281–2.
15. Sanchez-Doblado F, Terron JA, Sanchez-Nieto B, et al. Verification of an online in vivo semiconductor dosimetry system for TBI with two TLD procedures. Radiother Oncol 1995; 34: 73–7.
16. Ferguson HM, Lambert GD, Harrison RM. An automated TLD system for tumour dose estimation from exit dose measurements in external beam radiotherapy. Int J Radiat Oncol Biol Phys 1997; 38: 899–905.
17. International Commission on Radiation Units and Measurements. Determination of absorbed dose in a patient irradiated by beams of X or gamma rays in radiotherapy procedures. Report 24. Washington: ICRU, 1976.
18. Health and Safety Executive. Fitness of equipment used for medical exposure to ionising radiation. Guidance note PM77, 1992.
19. Lambert GD, Liversage WE, Hirst AM, et al. Exit dose studies in megavoltage photon therapy. Br J Radiol 1983; 56: 329–34.