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IN VIVO DOSIMETRY WITH TLD IN CONSERVATIVE TREATMENT OF BREAST CANCER PATIENTS TREATED WITH THE EORTC PROTOCOL 22881

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Two anthropomorphic phantom breasts and six patients with breast carcinoma were irradiated according the prescriptions of the EORTC protocol 22881 on the conservative management of breast carcinoma by tumorectomy and radiotherapy. During the implantation procedure for an iridium-192 boost, three tubes were implanted, enabling the measurement with TLD rods of the dose within the breasts of the phantom and the patients during one fraction of the external x-ray therapy and during the interstitial therapy. Measured doses were compared with calculated values from a 2-D dose planning system. In general a fair agreement was found between the measured and calculated doses in points within the breast for the external beam therapy as well as for the interstitial treatment.

In 1989, a new clinical EORTC (European Organization for Research and Treatment of Cancer) trial was started: protocol 22881, 'Phase III study in the conservative management of breast carcinoma by tumorectomy and radiotherapy: assessment of the role of the booster dose of radiotherapy'. The objectives of this trial were to investigate the role of the booster dose in breast conservative treatment with respect to the effects on the local recurrence rate and on the cosmetic results. Since a large number of patients was needed for this trial, many radiotherapy centres throughout Europe were asked to participate. It is obvious that for this type of multicentre trials external reviews and good dosimetric quality assurance (q.a.) procedures are needed.

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In several quality audit projects (e.g. (1)) it has been demonstrated that the main frequency of deviations from protocols occurs in the definition of the target volume and treatment volume, whereas the accuracy of the dose calculation is often within acceptable limits. For the treatment of the female breast there can be differences in the definition of the target volumes by different radiation oncologists, even in the same clinical situation. However, it may be expected that the treatment volume is uniformly defined and treated (since it is defined not on anatomical grounds but according to the dose distribution), but that the main deviations occur in the dose distribution and dose calculation procedures. There are difficulties and uncertainties in the calculation of the absorbed dose, since the shape of the breast deviates considerably from the cubic phantom. Loss of scattering caused by large parts of the beams in free air and the different thicknesses and source to skin distances will give rise to uncertainties with a common one- or two-dimensional calculations. For the above mentioned trial, the EORTC-radiotherapy cooperative group supported a dosimetric pilot study (2). Its main purpose was to show the feasibility of a simple mailed dosimetric survey. TLD was chosen due to its suitability for mailed and in vivo q.a. procedures. Entrance and exit dose measurements were performed and an analysis

was made of the results, separately for the dosimeters positioned on the medial and lateral side of the breast, in order to find the best conditions to be used in further q.a. procedures (2).

For the study that is the subject of the present paper, the same patients were asked to cooperate in further TLD measurements of the dose inside the breast, during external beam therapy and during interstitial iridium-192 therapy. Two antropomorphic phantom breasts were also measured with the same technique. Purpose of this part of our work was to compare the results of in vivo measurements, performed during completely normal clinical procedures, with computed two-dimensional dose distributions for both irradiation modalities. Furthermore, we wanted to assess the value of phantom measurements as compared to in vivo patient measurements. In the present report the results of these internal measurements will be presented and discussed.

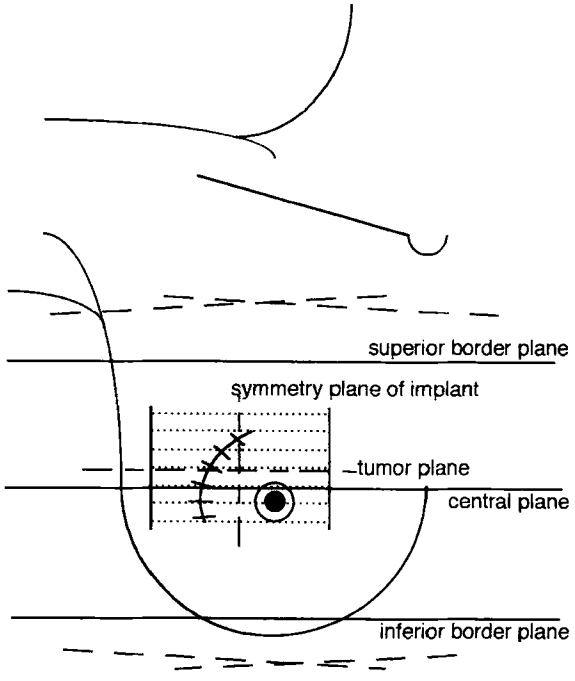


Fig. 1. Definition of the central, the tumor and the border planes, as given in the protocol. Central and tumor planes are supposed to coincide when the distance is less than 2 cm. An implantation of the needles is shown. Three tubes were implanted for TLD measurements, in the tumour plane and the border planes (tubes not shown in the figure).

Material and Methods

Rando Alderson phantom. For this study two differently sized breasts, left and right side, were prepared for measurements on a Rando Alderson antropomorphic phantom. Beeswax, with a density of 0.923 g/cm^{-3}, was used to mould the phantom's breasts.

Patients. Six patients were asked to cooperate in this study. The patients were fully informed about the procedures and cooperated voluntarily. All patients satisfied the criteria for EORTC protocol 22881. The only criterion for the selection of the patients was the suitability of the interstitial treatment technique for the boost treatment.

Standard therapy regimen. The technique of the external beam therapy has been described in more detail elsewhere (2). Only the most important aspects are presented here. Two tangential 6 MV linear accelerator beams were used with a fixed source-to-skin distance of 100 cm. For alignment in the dorsal plane of the treatment volume, the gantry of the accelerator was generally rotated over an extra 2 to 3 degrees with respect to the direction of the opposing fields. The collimator was rotated to minimize the lung volume in the fields. A wedge filter was used in both fields in order to get a dose homogeneity in the target volume of minimum 95% to maximum 110% of the prescribed dose. The dose prescription in the EORTC protocol is 50 Gy in 25 fractions of 2 Gy in 5 weeks, specified at the intersection of the central axes of the tangential fields. For computer planning purposes and using a simple lead wire technique, three contours were taken in the planes defined in the protcol: the 'central plane', containing the central axes of the two tangential beams, and the two 'border planes', 2 cm from the cranial border ('superior border plane') and 2 cm from the caudal border ('inferior border plane') of the irradiated volume. The 'tumour plane' is defined in the protocol as the plane through the centre of the primary tumour site. In all 6 patients the contour in the tumour plane was assumed to be the same as in the central plane. This is allowed in the protocol, if this plane is closer than 2 cm from the tumour plane as was the case in our patients. Fig. 1 illustrates the plane definitions. The interstitial therapy is given after a rest period of 2 to 3 weeks. Needles were loaded with 0.3 mm diameter iridium-192 wires with an active length in the range of 6 to 10 cm. Templates were used to keep the needles in a fixed position at a distance of 1.8 or 2.0 cm from each other. The choice of the number of needles and the active length of the wires was based on surgical and mammographic information regarding the position and size of the original tumour.

Modified therapy regimen. A slightly modified time schedule was used in this study:

- treatment simulation (for planning purposes)
- 24 × 2 Gy external beam therapy in 5 weeks
- 2–3 weeks' rest period
- implantation session with, on the same day,
  - treatment simulation (for contour checks)
  - 1 × 2 Gy external beam therapy
  - start of interstitial therapy

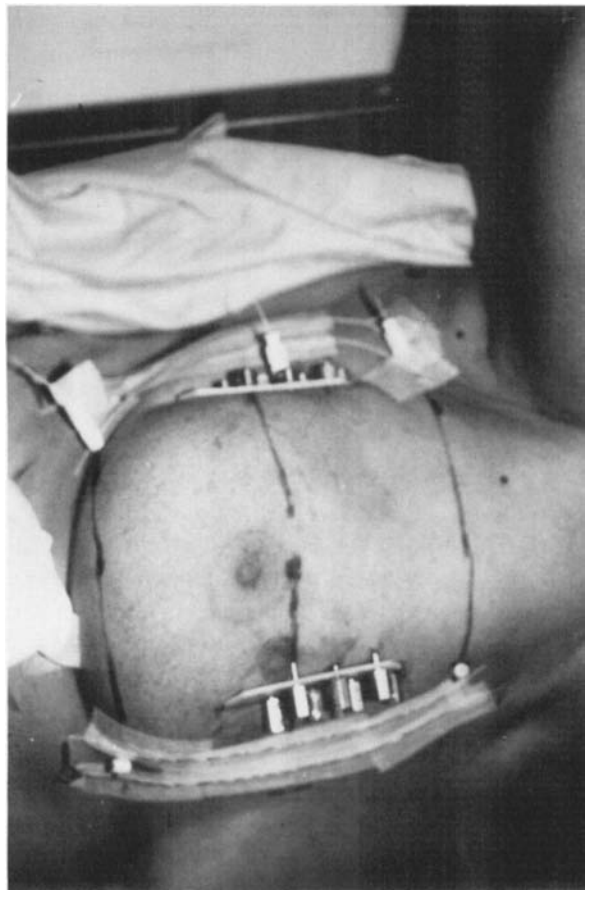


Fig. 2. A view of an implanted breast.

Our six patients received 24 fractions of 2 Gy in the first 5 weeks. After the rest period the implantation was performed. The patient's breast was implanted under full anaesthesia with 7 to 11 stainless steel needles, which were placed in a two-plane triangular pattern ('Paris system'). During this procedure three extra plastic tubes were implanted for the TLD measurements in the three planes: in the tumour plane, in the superior, and the inferior border plane. An illustration of the implanted breast of one of the patients is given in Fig. 2. In the iridium templates, used for equidistant placement of the needles, extra holes were drilled in symmetry points for exact positioning of the tube. On the same day similar contours were taken as in the first session because of the expected deformations due to the implant. X-ray pictures were taken using dummy strings with five lead markers in the tubes, in the AP and tangential direction. The dummy strings were fixed in such a way that the middle lead marker was to be positioned in the symmetry plane of the implant (Fig. 1). The remaining fraction of 2 Gy external beam treatment on the 6 MV linac was given on the same day, enabling us to perform the external beam measurements. After this the interstitial treatment was started. The treatment was fully completed at the end of the iridium treatment. The measurements did not influence the overall treatment time. Since the total dose and the overall treatment time were kept the same for the scheme used in this project as in the conventional scheme, only minimal differences were expected with respect to the radiobiological effects of the two schemes. A simple calculation based on the radiobiological models confirmed this.

TLD-technique. The LiF-7 extruded rods have a diameter of 1 mm and a length of 6 mm. The dosimeters were supplied by the laboratory of the Radiation Physics Department of the Sahlgren Hospital in Göteborg and measured according to the methods described in detail by Hansson & Johansson (3). In Göteborg 5 TL dosimeters were loaded in polyethylene plastic tubes at 1.6 cm centre-to-centre distance. The strings were then mailed to Tilburg for irradiation. When returned to Göteborg, the TLDs were read, individually calibrated and checked for reproducibility. The reproducibility of the determined dose was about 1% (1 SD) (3). The individual calibration was made in a cobalt-60 beam. In order to check the energy dependence of the irradiation geometry, the TLDs have also been irradiated in a 6 MV beam in Göteborg, of which the calibration was made in accordance with the IAEA dosimetry protocol (4). A correction for supralinearity behaviour of the LiF material was necessary, since the measured dose in the different points could vary from 1 to 15 Gy. TL readings with respect to the readings for a dose of 2 Gy were determined in the ^{60}Co beam. It was assumed that the correction for supralinearity behaviour is also valid in the 6 MV beam. The supralinearity relationship for iridium radiation was determined with the aid of a high dose rate Gammamed ^{192}Ir afterloading equipment. Low-dose rate experiments, using iridium wires in a PMMA phantom, confirmed the results. The TLDs were positioned guided by the lead markers with the middle TLD of each string in the symmetry plane of the implant (Fig. 1). The following in vivo measurements were performed for six patients. During the last external beam fraction, given after the implantation of the needles, TLD strings were placed inside the breast in all three tubes. The strings were irradiated in both fields. Subsequently, two of the implanted tubes were loaded with new strings for measurement of the dose during the interstitial treatment with iridium wires. One of these strings was placed in the tumour plane, and the other string was placed in the tube that was closest to the implant (i.e. one of the border planes, see Fig. 1). During the treatment, the strings were replaced once by a new set for reasons of measurement statistics. In this way, 4 strings were used for each patient. The breasts of the Rando Alderson phantom were 'implanted' with the same needles and tubes as in the real patients. Measurements were made in the external field irradiation, inside the

breasts as well as during the interstitial iridium treatment. The same type of TLD-strings were used as with the patients.

Computer calculations. Dose distributions were calculated using a commercial 2D dose planning system (Theraplan, AECL/Theratronics, programmes CBEAM and ISODOS (5)). The distributions were calculated twice: with the contours of the first and with the contours of the second treatment simulation including the breast deformations due to the templates. Dose values of individual points taken from the latter were used for the comparison with the TLD measurements. For the calculation of dose distributions for the phantom irradiation, a correction was applied for the different density of the phantom material. In accordance with the present procedures in the Tilburg radiotherapy department, no corrections for inhomogeneities (lung) were applied. The dose distributions were normalized to 100% in the central plane in the point where the central axes of the beams intersect, in accordance with the protocol. The dose distributions were calculated in three planes: the central plane, the superior, and the inferior border planes. An example of a central plane calculation, indicating the positions of the 5 TLDs in one string, is shown in Fig. 3. For the calculation of the dose distribution of the interstitial implant, some assumptions were made: all needles were supposed to be implanted straight and parallel. The active length of each wire is assumed to be symmetrically placed with respect to the symmetry plane of the implant, see Fig. 1. For each patient a relative dose distribution was computed in this symmetry plane. The treatment time was calculated for a dose of 20 Gy, specified on the 85% isodose line, whereas the dose distribution was normalized to 100% as the average of the dose in the 'basal dose points' in the symmetry plane of the implant, according to the rules of the Paris system (6). The air kerma rate specification of the certificate of the supplier (Amersham International Ltd) was used. The air kerma rate of the wires varied from 0.5 to 0.9 $\mu Gy \cdot h^{-1} \cdot mm^{-1}$ (4.44 – 74.0 MBq/cm). The treatment time varied from 20 to 40 h.

Results

For different radiation qualities the TLD reading per absorbed dose to water was determined relative to the reading per absorbed dose in a standard polystyren phantom, which was irradiated in a cobalt-60 beam. Results are presented in Table 1. The phantom construction, used for the repeated reproducibility and sensitivity checks, lead to a small difference in TL-response compared to the actual calibration and measurement set-up. A.o. no plastic tubes were used during these checks. This difference had to be taken into account, which was the reason why the value for cobalt-60 in Table 1 slightly deviates from 1 000. The correction for supralinearity behaviour of the LiF material was determined for cobalt-60 as well as for iridium-192 energy in the range of doses from 1 to 20 Gy. The ratio of the TL reading at a certain dose relative to the reading at

Table 1

Radiation quality dependence of the LiF thermoluminescent dosimeters, measured under 'patient equivalent conditions'

Radiation quality	Reading per absorbed dose to water for the radiation quality relative to the reading per absorbed dose in a standard polystyren phantom irradiated in a cobalt-60 gamma beam
^{192}Ir	1.070
^{60}Co	0.980
6 MV	0.965
8 MV	0.960

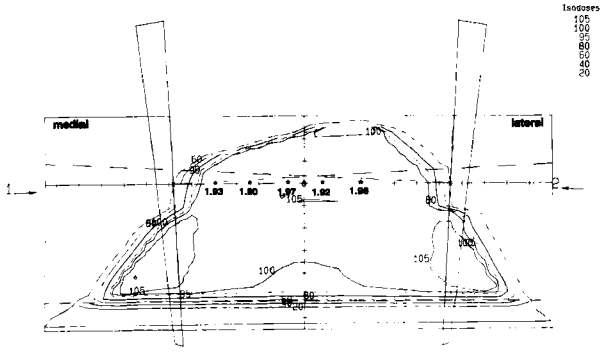


Fig. 3. The computed dose distribution in the central plane for one patient irradiated with 6 MV photon beams. The position of the TL-dosimeters and the measured dose values are indicated; 100% is equal to 2 Gy. The computation was performed with 5 mm bolus covering the entire breast.

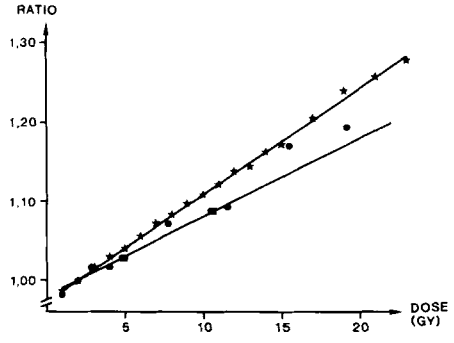


Fig. 4. The supralinearity behaviour of the LiF rods for cobalt-60 and iridium-192 energies in the range 1 - 20 Gy. The ratio denotes the TL reading for the actual dose relative to the reading for the calibration dose, 2 Gy. ★ ^{60}Co; ● ^{192}Ir high dose-rate; ■ ^{192}Ir low dose-rate.

Table 2

Breast in vivo dosimetry for the 6 MV external beams. The mean and standard deviation is given for the ratio: determined to stated dose

No. of measurements	Plane	n	$x \pm \sigma$
Two phantoms			
	Superior	10	0.96 ± 0.02
	Central	10	0.96 ± 0.01
	Inferior	10	0.97 ± 0.05
Six patients			
	Superior	30	0.99 ± 0.06
	Central	30	1.00 ± 0.06
	Inferior	30	0.98 ± 0.03

the calibration dose of 2 Gy is presented in Fig. 4. The measurements were corrected for both effects. In Fig. 3, the computed external beam dose distribution in the central plane for one of the patients is given. The positions of the dosimeters and the measured doses are indicated. In Table 2 the mean ratio of determined to stated dose is presented for the three planes separately. The results from two phantom measurements and from six patients are averaged. The mean values are some per cent below unity for the phantom measurements, but close to unity for the patient measurements. For the patient measurements, the central plane dosimeters display a mean of unity, while the ratios are slightly lower in the other planes. This can be seen more clearly in Table 3, where the results are shown for two groups of dosimeters: those in a position in the middle part of the breast (i.e. more than 3 cm distant from the skin) and those in a more peripheral position (less than 2 cm from the skin). The ratios are somewhat higher (about 3%) in the middle part of the breast than in parts in the vicinity of the skin. In Fig. 5 the computed dose distribution in the symmetry plane of the implant is shown for one of the patients. The projected position of the dosimeters in the two tubes (in the tumour plane and

Table 3

Breast in vivo dosimetry for the 6 MV external beams. The results of all dosimeters and those of two subgroups are given

No. of measurements	Position	n	$x \pm \sigma$
Two phantoms			
	All dosimeters	30	0.96 ± 0.03
	Periphery (< 2 cm)*	8	0.95 ± 0.03
	Middle part (> 3 cm)*	14	0.96 ± 0.02
Six patients			
	All dosimeters	89	0.99 ± 0.05
	Periphery (< 2 cm)*	11	0.97 ± 0.06
	Middle part (> 3 cm)*	67	1.00 ± 0.04

* Distance from the skin.

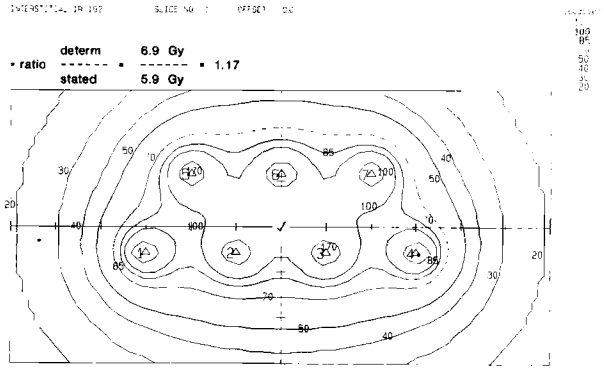


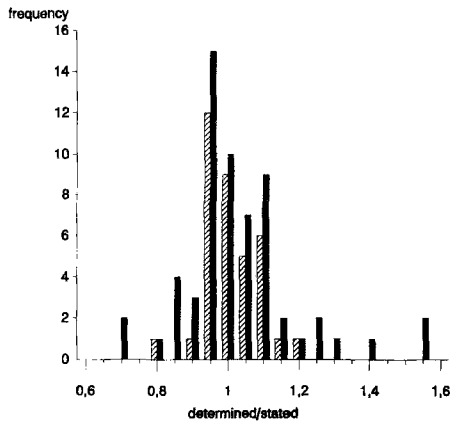
Fig. 5. The computed dose distribution in the symmetry plane of the implant for one patient. The projected position of the TL-dosimeters (the string is perpendicular to the plane) and the measured dose values are indicated (20 Gy prescribed on the 85% isodoseline).

in one of the border planes) as well as the measured doses are indicated in Fig. 5. The ratios of determined-to-computed dose for dosimeters inside the tumour plane, parallel to the wires, and in the off-axis plane are given in Fig. 6. In the tumour plane the mean measured dose is 2.5% higher than the computed dose. In the border plane this mean deviation is larger and increases to about 24%. Fig. 7 presents the results obtained in the breast phantom measurements. The results are similar to those obtained in the patients. However, the spread in the results is significantly lower in the phantom measurements as compared to the patient measurements.

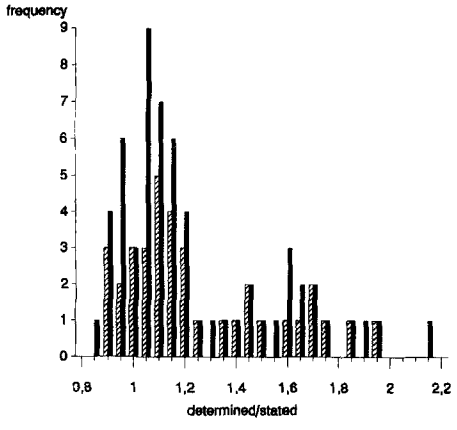
Discussion

The advantages of thermoluminescent material for in vivo dosimetry have been shown in several studies, for example by Mechakra Tahiri et al. (7) who used TLD to determine the dose to the skin of the breast during an implantation and by Marinello et al. (8) who determined the dose contribution to the axillary region from an iridium-192 implant. Furthermore, its value for mailed dosimetry programs has been discussed extensively by Hansson & Johansson (3).

Several precautions, however, have to be taken into account when using this type of dosimetry. As mentioned above, extensive reproducibility and sensitivity checks have to be performed before and after each measurement. The following method has been used to determine the energy dependence for iridium-192 radiation. The absorbed dose in water was determined in a PMMA phantom using a small ionization chamber at a distance of 2 cm from an HDR iridium source. The dose in water at that point was derived using the Bragg-Gray cavity theory, as well as the so-called photon detector principal. The ionization chamber was air kerma calibrated in a cobalt-60 and in an

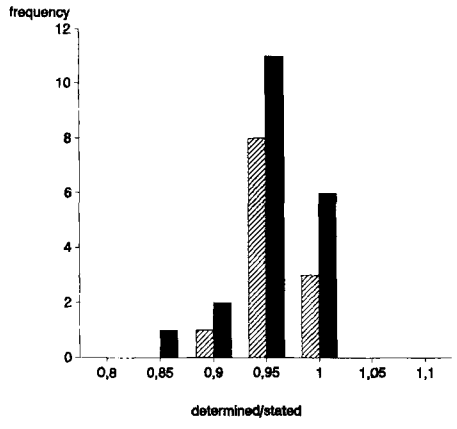


(a)



(b)

Fig. 6. The ratios of measured to computed dose for interstitial therapy obtained with six patients. a) dosimeters inside the tumor plane (n = 60, mean value = 1.025, 1 SD = 0.158), b) in the off-axis plane (n = 60, mean value = 1.241, most probable value = 1.05). In both histograms the results are presented separately for only the middle three TLDs per string (▨), and for all five TLDs per string (■).



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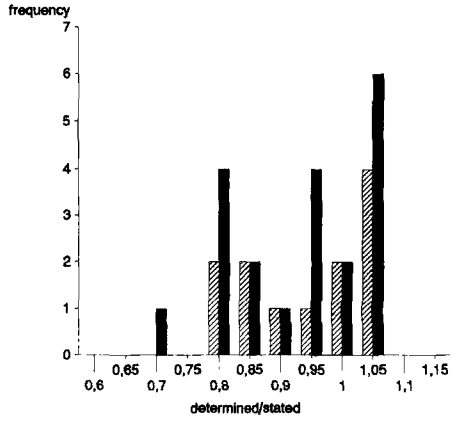

(b)

Fig. 7. Ratios of measured and computed dose for the interstitial irradiation of the Rando Alderson anatomical phantom. a) dosimeters inside the tumor plane (n = 20, mean value = 0.954, 1 SD = 0.036), b) in the border plane (n = 20, mean value = 0.931, most probable value = 1.01). Again, results are shown separately for only the middle three TLDs per string (▨), and for all five TLDs per string (■).

iridium-192 beam respectively. Considerations were taken with respect to the interaction coefficients, to the wall effect, to the displacement effect, and to the non-uniformity of the fluence over the air cavity. The dose determined with the two ionization chamber methods agreed within 2%; the mean value was used for determination of the energy dependence of the TL dosimeters. The TL dosimeter with surrounding material was then positioned at the same point. For calibration of the high energy photon beams the IAEA protocol (4) was used.

In our case, the supralinearity behaviour of the LiF-7 rods was examined by exposing them to doses in the range of 1 to 20 Gy in a cobalt-60 beam. The importance of the correction of the TL reading of the dosimeters for the different doses, relative to the TL reading for the calibration dose (2 Gy), can be read from Fig. 4. In the external beam measurements the correction for supralinearity is generally small (< 1%) due to the small variations in dose compared to the calibration dose. In the interstitial irradiations the correction for supralinearity is significant in a number of cases. For example, for 15 Gy it is about 13% compared to the calibration at 2 Gy (Fig. 4). We have found that the supralinearity behaviour of the TL dosimeters varied for different photon beam qualities. For the lower photon energy of iridium-192, a lower reading was registered in the high-dose region than for cobalt-60. No explanation regarding these different supralinearities can be given. It is assumed here that the dose dependence of the reading of the TLDs for cobalt radiation is also valid in a 6 MV photon beam.

In other EORTC dosimetric intercomparison studies, deviations between measured and stated dose values are

defined as 'acceptable' if they are smaller than or equal to $\pm 4\%$; deviations in the range $> \pm 4\%$ to $\leqslant \pm 7\%$ are called minor deviations and above $\pm 7\%$ major deviations. Using these definitions and after application of the correction factors discussed above, an acceptable level of agreement is found between the average value of the measured and computed dose obtained in the external beam irradiation (Table 2). There is a good average agreement for points located in the middle part of the breast. For points lying more peripherally (medial or lateral in the superior or inferior border plane) the values are a few per cent lower (Table 3). This can readily be expected, because of the lack of surrounding scattering tissue in these points. When we look at the values obtained with the individual patients, we observe a rather large spread in the results. For the 6 patients the average ratios of the measured and computed dose in each TLD string ranged from 0.94 to 1.08 in the superior border plane; from 0.90 to 1.05 in the central plane and from 0.95 to 1.03 in the inferior border plane. In the individual patients (6 patients $\times$ 3 planes = 18 observations) four TLD strings showed a minor deviation and two major deviations were noted.

In the calculation of the dose distribution the influence of the templates was ignored. The thickness of the PMMA templates was 2 mm, leading to a maximum dose reduction of 0.8% in the 6 MV beam. Another possible cause of deviations is the limited accuracy of the routine procedure to take the contours with a lead wire. Although the contours were checked for this occasion with cardboard moulds, errors of several millimeters have certainly been introduced, leading to an estimated error of plus/minus 2–3% in the dose calculation. Above this, positional inaccuracies during the treatment set-up contribute to the total inaccuracy of the method. Our results obtained with both Rando Alderson anatomical phantom breasts (Tables 2 and 3) are slightly lower than those obtained with the patients. An explanation could be the different scattering properties in beeswax and breast tissue. The differences are, however, not statistically significant. A smaller spread in the results is observed for the phantom measurements compared to the patient measurements. Apparently, the patient movement during set-up and irradiation leads to this larger spread. Our results are in agreement with other studies on breast irradiation with tangential fields. For example, Knöös et al. (9) have shown that measured values in a phantom breast are typically lower than calculated with a standard dose planning system. The order of magnitude of their deviations was minus 2–6% for open fields and up to minus 8% for wedged fields. Chin et al. (10) have shown that correction for lung density leads to about 4% increase of the calculated dose for a 6 MV beam in the hot spot regions in the lateral and medial sides of the calculation planes, whereas a 7% increase in dose can be noted in the lung tissue itself. These results are confirmed on our own dose planning system for a fictitious patient. However, the influence on the calculated dose in the measuring points, which are in general located about 2 cm (range 1.4–2.5 cm) from the lung inhomogeneity, is much smaller ($\leqslant 1\%$). Therefore, we expect that not taking into account lung inhomogeneities in the planning procedure has no significant influence on the results in the different measuring points. In general the Rando Alderson phantom measurements support the results obtained in the patient measurements.

We are aware of the fact that in all results with the external photon beam, small variations can occur due to the instability of the linear accelerator (Therac-6, Theratronics Int. Ltd. Canada). Stability checks are performed every morning during start-up. The mean value of three checks shows only a small variation (1 SD = 0.45% over the two months' period in which the measurements were performed), but separate measurements can show a deviation of max. $\pm 2\%$ from the mean. This will add up to the other uncertainties in this study. From the data presented here we conclude, that we have found an acceptable level of agreement between the measured dose and the dose calculated with a two-dimensional dose planning system. Nevertheless, three-dimensional planning will certainly increase the accuracy of dose calculation, especially in the off-axis planes.

Also in the interstitial part of the treatment a comparison was made between the stated and the measured dose values for all TLD positions; see Fig. 6. Only points lying inside the implant (Fig. 6a) showed usable information; for points outside the implant, i.e. in the off-axis plane, too large deviations were found and we had to conclude that the reconstruction technique to determine the distances was inadequate (Fig. 6b).

The result of the ratio of the stated and measured dose for the points lying inside the implant, i.e. in the tumour plane was 1.025 (± 0.158, 1 SD) averaged for all 60 TLD measurements. The positioning of the TLD strings within the tubes is rather critical, the distance between the first and last rod in a tube being 6.4 cm from one centre to the other, while the active lengths of the iridium wires is only 7.0 cm on the average. This means that a small error in the positioning of the string along the tube brings one of the dosimeters into a steep dose gradient. When only the results of the middle three TLDs, close to the symmetry plane of the implant in each tube, are averaged for all 6 patients, the mean ratio proved to be 1.009 (± 0.078, 1 SD). The spread in this result is much lower than for all five points per string. This is shown in Fig. 6a with the light bars; the dark bars are related to all TLDs in the strings. In general the standard deviation for the results of each patient separately is lower. The mean value of the middle TLDs of each patient varied from 0.950 to 1.082 in this plane.

For the points outside the implant, in the border plane, the mean ratio was 1.241 (± 0.313, 1 SD) for all 60 TLD

measurements. We must note that these measurements are performed in a region with a high-dose gradient and that small errors in determining the distances of the tubes to the wires lead to large inaccuracies in the calculation of the dose. An analysis of the ratio determined/stated dose for only the middle three TLDs in each tube shows the same result as for all five TLDs per string: 1.250 ($\pm$0.294, 1 SD). Thus, indeed the determination of the distance to the implant is critical, not the positioning of the string in the tube.

The spread in the results of the Rando Alderson phantom measurements (see Fig. 7) is much smaller than that obtained with the patients: 0.954 ($\pm$0.036, 1 SD) for all points in the tumour plane. For the largest part this is due to the greater accuracy in the determination of the relevant distances of the TLDs with respect to the position of the wires. The mean value of all points is somewhat lower than that obtained with the patient measurements. This also holds when only the middle three TLDs in the strings are considered: 0.956 ($\pm$0.024, 1 SD).

A few comments can be made with respect to the accuracy of the calculations. It seems justifiable to use the source strength calibration of iridium-192 of the supplier (11), provided a check is performed in a well-type ionization chamber as is the routine procedure in Tilburg. This relative measurement generally can show agreement with the stated activity within, to our experience, approximately 3%. It avoids for example typing errors that can occur in a calibration report, as once was seen in a source delivery in Tilburg. The activity of iridium-192 was assumed to be uniformly distributed over the active length of the wires. The influence of possible non-uniformity of the linear activity in an implant of several wires was, however, considered to be negligible (12). Furthermore, in the calculation procedure a few assumptions are made that influence the accuracy. In practice there is no water equivalence of the breast tissue and the phantom material. This may lead to a lower scatter contribution, especially in the case of the phantom's beeswax material. Nor is there any full scatter condition. The influence of this effect is difficult to establish, since the distance of the implant to the skin has to be taken into account. The implantations may have had an imperfect geometry, but in a review of the radiographs taken, only minor torsion and non-parallelism of the implant were seen. Finally, the calculation programme itself may contain certain approximations, but these are considered to be minimal. In our case the results of calculations have been compared with published tables. It is estimated from an analysis of these effects that they contribute each for an estimated 1–3% to the overall accuracy (13). Among these effects, the missing scatter is of greatest importance.

In the total uncertainty of the results presented here there is also a contribution of the TLD calibration for iridium-192 energy and the correction factor for supralinearity discussed above. In view of the fact that for brachytherapy the criteria for the accuracy of physical procedures are generally taken wider than for external beam therapy, it is concluded that the deviations of several per cent between measured and calculated dose are certainly acceptable in the clinical practice. We thus feel that it is justified to state that there is a clinically acceptable agreement between the calculated and the measured dose in this interstitial part of the treatment. As discussed above, for the measurements in the border plane the results in this plane are too much influenced by the difficulties we had in the determination of the distances. These results have in fact no value.

From the averaged results of the external beam dosimetry it is concluded that there is a good agreement between measured and stated dose, as calculated with a two-dimensional dose planning system. In the middle part of the breast the ratio is close to unity, while in the peripheral parts the ratios are a few per cent below unity. The accuracy of the dose calculation with the 2-D system is within acceptable limits, although individual patients may show larger deviations, due to patient set-up and patient movement. In general, there are small differences between the results obtained with the Rando Alderson anatomical phantom and those obtained with the patients. As expected, the spread in the results obtained with the patients is significantly larger than that with the phantom. Phantom measurements alone cannot predict this result. The dosimetry for interstitial therapy with iridium-192 shows a clinically acceptable agreement between measured and computed dose for points within the treatment volume.

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