JBUON 2016; 21(5): 1104-1112
ISSN: 1107-0625, online ISSN: 2241-6293 • www.jbuon.com
E-mail: editorial_office@jbuon.com

ORIGINAL ARTICLE

In vivo dosimetry in the field junction area for 3D-conformal radiation therapy in breast and head & neck cancer cases: A quality assurance study

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Summary

Purpose: *To investigate the accuracy of field junctioning planning techniques (monoisocentric and rotating couch technique) for 3D-conformal radiotherapy (3D-CRT).*

Methods: *In vivo dosimetry has been performed using thermo-luminescence dosimeters (TLDs) in 10 head and neck cancer patients (treated with monoisocentric technique) and 10 breast cancer patients (treated with rotating couch technique) irradiated with a 6 MV photon beam. Entrance dose measurements were performed in selected regions including the field junction area.*

Results: *The mean deviation between measured and expected dose in the region of junction was significantly higher in breast cases compared to head and neck irradiation (-2.8±15.4% and 0.2±8.2 % respectively; Mann-Whitney U test: p=0.002). A comparison between lateral head and neck fields and tangential breast fields revealed that the latter was associated with larger dose discrepancies (-2.2 ± 4.6% vs -3.5 ± 5.7% respectively; Mann-Whitney U test: p=0.029).*

Conclusions: *The results indicate the superiority of monoisocentric technique compared to the rotating couch technique in terms of dose delivery accuracy for treatments with field junctioning planning techniques.*

Key words: *in vivo dosimetry, junctions, 3D-conformal radiotherapy, TLD*

Introduction

Computer-assisted treatment planning is a fundamental process in modern external radiation therapy. Since the introduction of treatment planning systems (TPS) in the clinical routine, a number of planning techniques has been evolved, beginning with the 3D-CRT, which became the base of the contemporary more sophisticated treatment modalities (intensity modulated radiation therapy-IMRT, volumetric modulated arc therapy-VMAT etc). Many of the current 3D-CRT treatment techniques have been developed to overcome technical difficulties, emerging from linear accelerator's restrictions and the diversity of planning treatment volumes (PTVs).

Irradiating tumors using field junctioning (or field matching) techniques is a well-known and commonly performed practice in the clinical routine of 3D-CRT [1-9]. It can be applied in PTVs containing primary tumors and nearby drained lymphatic nodes that fail to be irradiated uniformly by undivided photon fields, due to their shape and anatomical distribution [10]. Field matching can be achieved either preserving or not the same isocenter of the component fields. Despite the

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Received: 15/04/2016; Accepted: 08/05/2016

efficiency of this field set-up, junctioning planes are very sensitive even to minor dislocations of the patient on treatment couch and can be easily turned into areas of unacceptable dose gradient [11].

The quality assurance (QA) process is essential in delivering either a qualified dose distribution or validated irradiation to the patient [12,13]. *In vivo* dosimetry is an available tool to verify that the "ideal" field matching, designed *in silico*, is being applied to the patient with precision and reproducibility on a daily basis. It could be performed with various types of detectors (TLD), radiochromic films, semiconductor diodes, etc) [14]. In our institution, as a routine QA procedure, *in vivo* measurements are carried out via thermo-luminescence dosimetry to patients who were treated with the use of field junctioning techniques.

The purpose of this study was to evaluate the precision of dose delivery to the area of interest (field junction), as well as at other sites of the tumor.

Methods

Tld calibration

A total of 50 GR200A TLDs (LiF: Mg, Cu, P) (Solid Dosimetric Detector & Method Laboratory-DML, Beijing, China) in the physical form of discs (4.5x0.8 cm) were calibrated. The annealing procedure performed by an ETT annealing oven (Fimel, Vélizy, France), and the optical signal was retrieved by an LTM Manual TLD reader System (Fimel, Vélizy, France). The entire procedure was realized for 6 MV photon measurements at the linear accelerators of our department (Clinac 600C & Clinac 2100C, Varian Medical Systems, Palo Alto, California, U.S.A.). Calibration was carried out along with suitable polymethylmethacrylate (PMMA) (physical density=1.190 gr/cm^2) build-up cups. The choice of build-up cup thickness (1 cm) was a compromise between satisfying electronic equilibrium at 6 MeV photon energy beams and the minimum possible distortion of the treatment beam profile. The cups were designed to have a cylindrical shape (radius=1.2 cm) in order to enclose evenly the disc-shaped detectors.

The handling of the detectors was based on the procedure described in detail by Van Dam and Marinello [14]. Calibration was performed in the reference conditions of field size of 10x10 cm, source-skin distance (SSD)=100 cm, no application of wedge nor block tray and 15 cm of backscatter material (PMMA plates).

Study population

The study cohort included a total of 20 patients. The patient population was divided into two groups of 10 patients, according to the primary site of disease, either breast or head and neck. This categorization coincides with the different field matching techniques that were used (rotating couch technique-breast or monoisocentric technique-head and neck). Both clinical cases were treated by 6 MV photon energy beams. *In vivo* dosimetry occurred at least 5 times during their treatment course. To avoid the cumulative distortion of the beam profile throughout the whole treatment time, the dosimetry sessions were performed with a time interval of 2-3 days.

TLD positioning

Head and neck tumors were treated by two lateral fields (right and left) in the region of head, that are junctioned with an anterior-posterior (AP) field in the supraclavicular region. The fields were matched using asymmetric collimation. Therefore, all three fields preserved the same isocenter (monoisocentric technique). This treatment planning technique is commonly referred to as the "half-beam" technique. The treatment

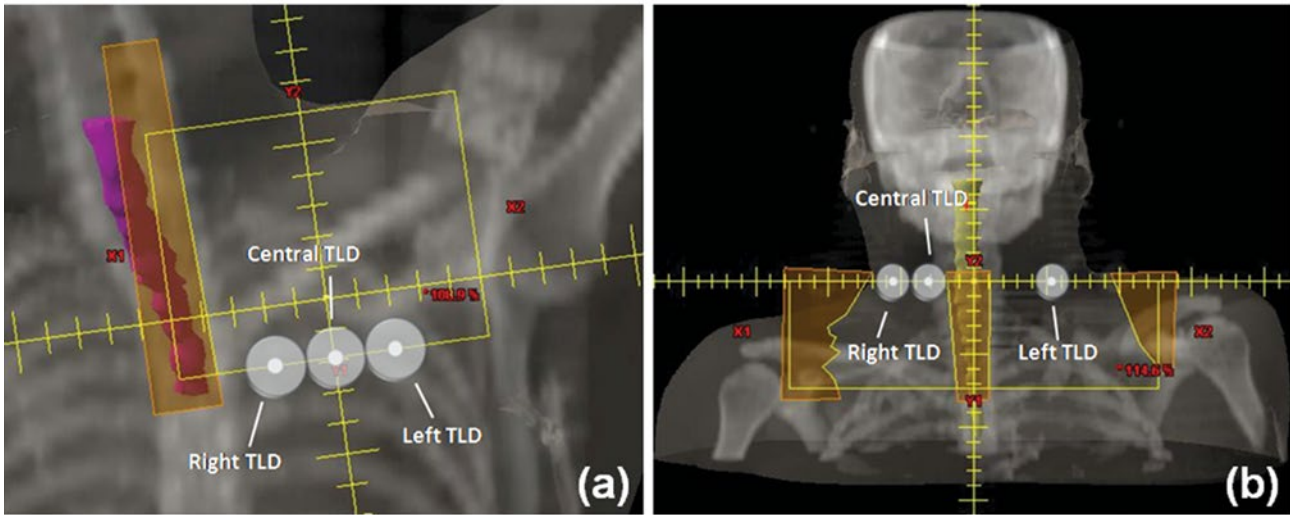

Figure 1. TLD positioning in the junctioning line **(a)** for breast cancer patients and **(b)** for head and neck cancer patients.

set-up involved patient immobilization utilizing thermoplastic masks. Six dosimeters in total were utilized at each patient. One dosimeter was located in the region of each irradiation field (three in total) while the other three were located along the visible junction line.

Whole breast irradiation was performed by two tangential fields. The supraclavicular nodes were "sterilized" with an anterior field which was matched with the two tangential beams by turning the treatment couch (90 degrees). The gantry was also tilted accordingly in order to achieve beam diverging in the edges of the fields (rotating couch technique). TLDs were positioned in the centre of each field and at the isocenter's vertical projection of the tangential fields on patient's skin. Finally, three equally spaced dosimeters were positioned along the junction line (Figure 1a).

The i*n vivo* entrance dose measurements were compared to the corresponding theoretical values, obtained from the TPS software Eclipse V.7.5, with pencil beam convolution (PBC) photon dose calculation algorithm (Varian Medical Systems, California, U.S.A.). In order to determine accurately the location of point dose measurements in TPS, TLD positioning rules were developed. The dosimeters were positioned on premarked places which could be easily determined in the computed tomography (CT) images of the patient (e.g. radio-opaque markers –Ball bearings/BBs.

For head and neck cases the junction-line-TLDs were positioned at the transversal plane that contained the isocenter (Figure 1b). On the other hand, for breast cases, the field junctioning line was not vertical to the longitudinal axis and not parallel to any CT slice (Figure 2). Consequently, the points of measurement on the junction appeared in TPS at more than one CT slice. To avoid dose-indicator cursor misplacement, the following relationship was invented (see Appendix, equation):

$$N_{TLDSL} = (N_{JSL} \times d_{TLD})/ds \quad (1)$$

where,

N_{TLDSL} is the number of the CT slices that contains TLD

N_{JSL} is the number of slices in which the junctioning line extends

d_{TLD} is the length of the line that contains TLD

d_S is the length of the junctioning line (normally it coincides with the lower dimension of the supraclavicular field).

Taking into account that the detectors were equidistant on the skin and setting as '*k*' the half of the difference between junction and TLD slices (Figure 2, equation 3, Appendix)

$$k= (N_{JSL}-N_{TLDSL})/2 \quad (2)$$

the correct measurement point on the CT reconstructed image was located every *k*-th slice, counting from the first CT slice in which junctioning is extended.

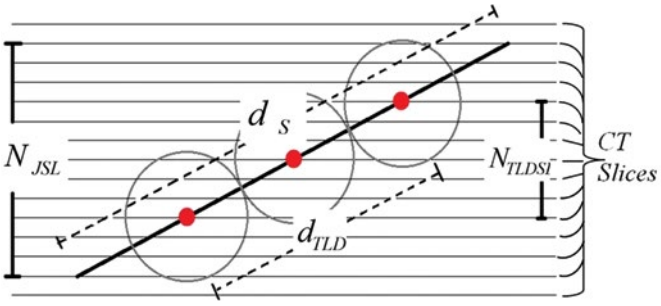

Figure 2. Determination of TLD position in treatment planning system (TPS) according to the CT slices that intersect the diagonal line of junction. The central dots indicate the dosimeter placed on skin, while the circles around each dot represent the build-up cup.

The measured values of dose were actually referring to spots laying 1.4 cm under the patient's surface. Therefore, the exact determination of the measurement points in TPS occurred by locating each TLD place on the skin and drawing a vertical to surface line of 1.4 cm deep in tissue. Each theoretical value was recorded. The measured values of dose were normalized to the theoretical ones derived from the TPS software.

Radiotherapy technique and clinical evaluation

For treatment planning purposes, each patient underwent a CT scan of the region of interest. For the breast cancer cases, the CT slices included the supraclavicular area, the ipsilateral axilla and the chest wall to 2 cm beneath the sixth rib, with 0.3 cm spacing between slices. Concerning the head and neck cases, the CT slices included the whole area from the top of the cranium down to the 6th thoracic vertebra. The CT datasets were then transferred to the Prosoma® virtual simulation and contouring system through the DICOM network. All contouring of target volumes and normal structures (organs at risk-OARs) were performed. Concerning the breast, OARs included the ipsilateral and contralateral lung, heart, spinal cord, brachial plexus and thyroid gland. Considering the head and neck cases, OARs included the spinal cord, parotids, eyes, inner ear, thyroid gland and lungs (left and right). Clinical target volume (CTV) and planning target volume (PTV) were drawn according to the ICRU criteria [10,15]. For the treatment technique, histograms were generated; a number of parameters, including mean, median and maximum dose were evaluated. The patient setup was monitored weekly using portal films. The target dose of 2 Gy per fraction was administered daily and was prescribed up to 95% at the International Commission on Radiation Units and Measurements reference point, at the intersection of the central axis of the treated beam in the midplane of the target volume. All patients were treated on a Varian Clinac 600C and Clinac 2100C linear accelerators, with 6MV photon beams (Varian Medical Systems, Palo Alto, California, USA).

Especially for the breast cases, the CTV was the entire area of the breast. The borders of the chest wall

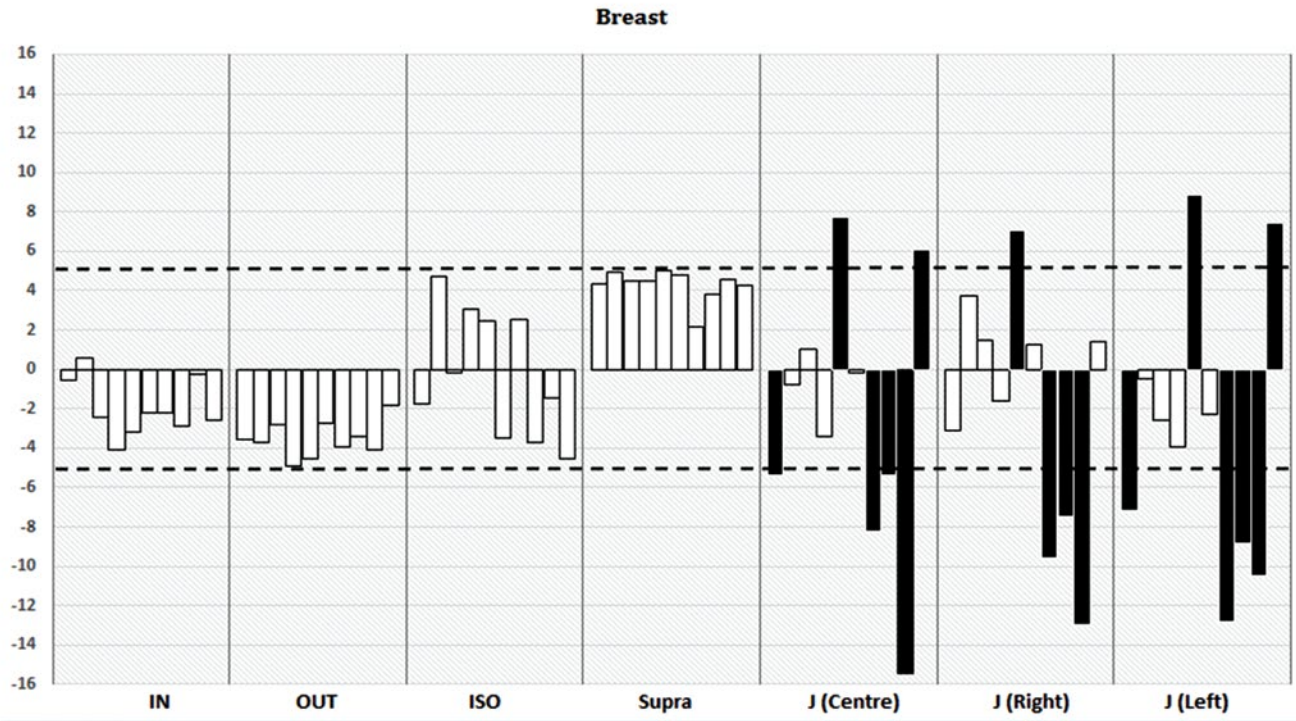

Figure 3. Deviation between measured and expected doses per individual field and per individual patient for breast cancer. Each bar represents the mean value of at least 5-point dose measurements. The black bars represent the deviation values which exceeded the ICRU recommended range of 95-105% of the prescribed dose.

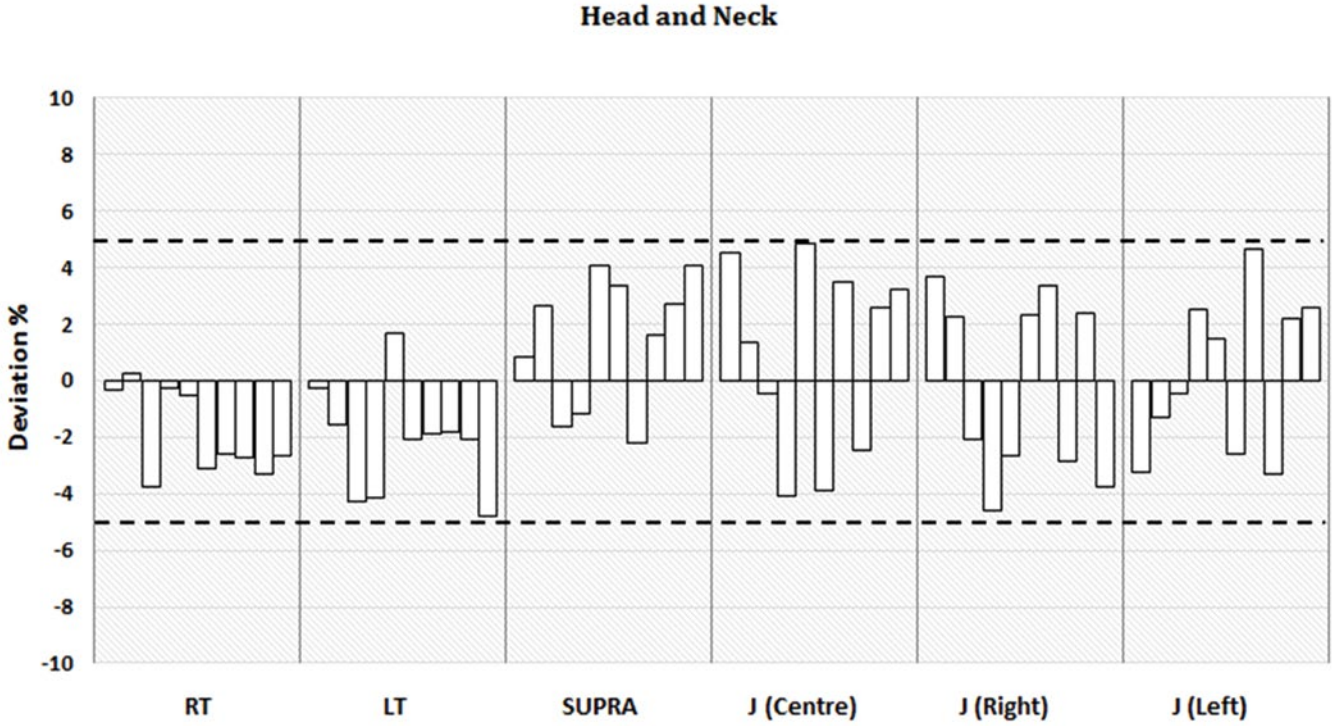

Figure 4. Deviation between measured and expected doses per individual field and per individual patient for head and neck cancer. Each bar represents the mean value of at least 5 point dose measurements.

target were the median border of the mediastinum, the midaxillary line, 2 cm beneath the contralateral inframammary fold and the superior border of the breast target was the head of the clavicle or the second intercostal space. Isocenter was typically placed in the center of the treatment field. The PTV was the CTV plus 1 cm for safety margins, according to our clinical protocol. In general, 1-2 cm of the underlying lung in the treatment field was acceptable. Concerning the irradiated volume for regional lymph nodes, all patients

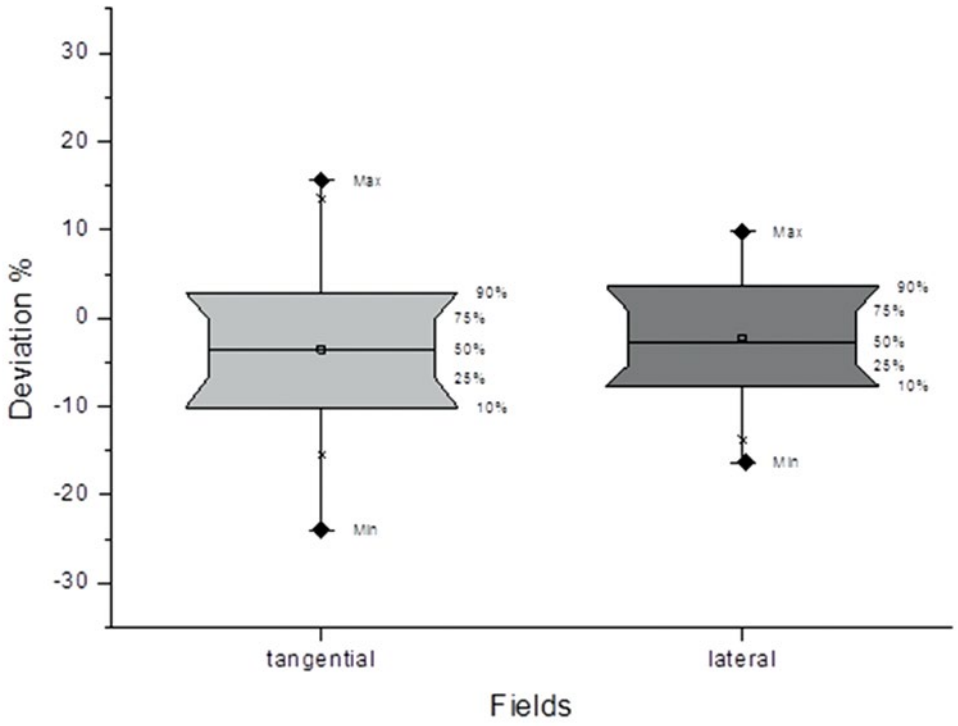

Figure 5. Comparison of lateral and tangential entrance dose deviations between TLD-measured and expected dose.

received radiation therapy from the middle side of level II of the axilla (where the surgeon stopped) until the supraclavicular site (level IV) with the inclusion of level III of axilla. No radiotherapy was given to level I of axilla.

For the evaluation of skin radiation toxicity, we used the EORTC/RTOG acute toxicity criteria [16]. The patients were monitored every week during radiotherapy, and the maximum score was assessed as the final radio-dermatitis score. Special notice was taken for the junction point, where the final score was separately monitored.

Statistics

The statistical differences between calculated doses and measured ones from TLDs were assessed with the Wilcoxon non-parametric test. The differences between deviations for either breast or head and neck cases were assessed with the Mann-Whitney U test. Correlations between doses at the junction and relevant radiation-induced skin toxicity were performed with the Spearman non parametric test. The significance level was set at 0.05. The whole analysis was performed with the SPSS version 10 Software (SPSS Inc., Chicago, IL).

Results

The deviations between calculated and measured dose values in the regions of interest per individual patient and field are presented in Figures 3 and 4 for breast and head and neck tumors, respectively. In the case of breast irradiation, dose deviations in specific points of measurement in the junction area (Junction Centre, Right and Left) were higher compared to the measurement points of isocenter and centres of tangential and supra-clavicular fields, where the action level of ± 5% has not been exceeded. In contrast to breast patients, the entrance dose deviations in head and neck patients fell in any case within the determined action level. In Figure 5 the comparison of dose deviations between the lateral and tangential fields is presented. Dose deviations of the tangential fields were significantly higher compared to the lateral fields (Mann-Whitney U test, p=0.029). A comparison of dose deviations in the junction area between breast and head and neck irradiation is also demonstrated in Figure 6. Dose deviations in the junction area for head and neck cases were significantly lower compared to breast cases (Mann-Whitney U test, p=0.002). The spread of dose deviation values between TLD-measured and calculated dose is greater in breast treatments compared to head and neck treatments. Finally, the percent mean values and standard deviations of the discrepancies between experimental and expected doses, in several specification points for breast and head and neck irradiation, are tabulated in Table 1.

The radiation induced toxicity for either breast or head and neck cases is shown in Table 2, concerning the global score in all anatomical

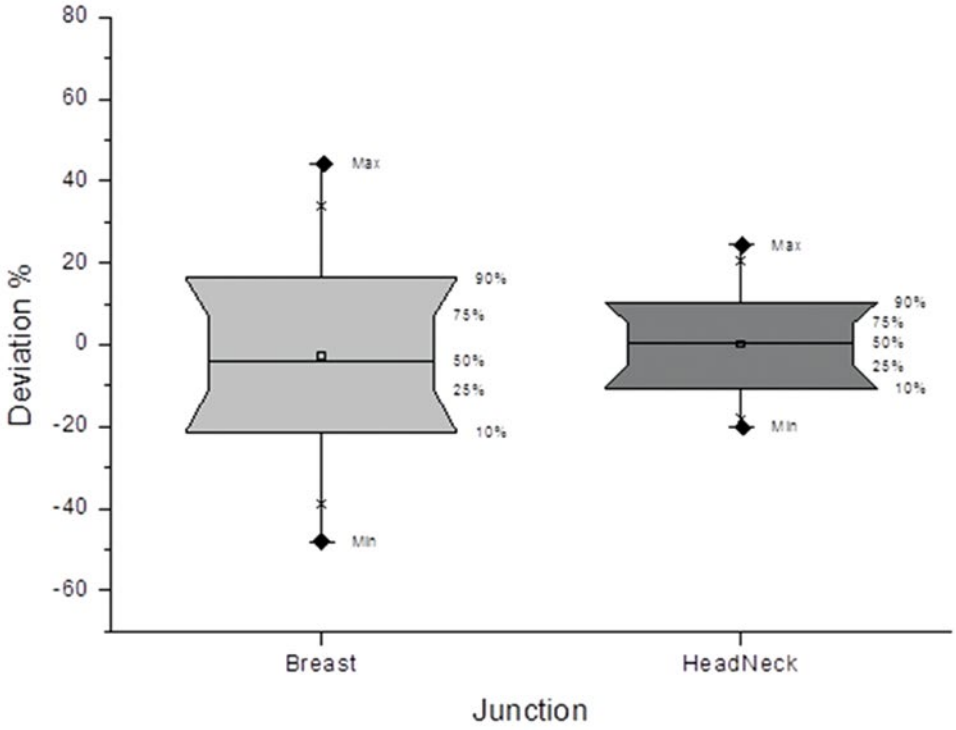

Figure 6. Comparison of breast and head and neck entrance dose deviations between TLD-measured and expected dose in the junction area.

Table 1. Percentage mean and absolute mean values, ranges and standard deviations of the discrepancies between measured and expected dose in several specification points for breast irradiation. In both treatment cases J-Right, J-Centre and J-Left refer to the position of the dosimeters along the junctioning line

Radiation treatment	*Regions of dose measurement*	*Mean deviation (%)*	*Standard deviation*
Breast	IN	-2.78	5.6
	OUT	-4.28	5.67
	ISO	-0.07	6.67
	SUPRA	3.65	5.28
	JUNCTION	-2.77	15.38
Head-neck	RT	-1.75	4.88
	LT	-2.74	4.35
	SUPRA	1.5	6.96
	JUNCTION	0.19	8.19

(IN: internal tangential field, OUT: external tangential field, ISO: isocenter, SUPRA: supra-clavicular field, JUNCTION: junction area) and head and neck irradiation (RT: right lateral field, LT: left lateral field, SUPRA: supra-clavicular field, JUNCTION: junction area)

irradiated areas along with the evaluations at the junction point at the supraclavicular area. The Spearman rho test between the radio-dermatitis score at the junction and the *in vivo* doses at the same anatomical point showed a significant correlation (rho=0.52, p=0.018).

Discussion

This work aimed at the quantification of the total error (systematic and random errors) in the dose delivery chain, especially for irradiation techniques which involve field matching. The impact of the potential errors is maximized in field matching regions, a fact that justifies the increased interest in these specific cases. Field junctioning planes (or slices) could emerge as under- or over-dosed areas in case of patient shifting from the original simulation position. This misplacement can be caused mainly by improper set-up of the patient, normal movements of vital organs (e.g. lungs) and any other kind of voluntary or involuntary movement. According to the derived results the mean deviation in junction areas between measured and theoretical dose values was significantly higher in breast cancer patients treated with the couch rotation technique compared to head and neck cancer patients treated with the monoisocentric technique (-2.8% vs 0.2% respectively, p=0.002). This trend is clearly depicted in Figure 3, where the mean dose deviation in the junction region reached down even to -15.4% for a certain patient. On the contrary, for head and neck treatments (Figure 4), the corresponding mean dose values per patient always lay within the ICRU recommended range of 95-105% of the prescribed dose [17]. This can be attributed to the fact that, in head and neck treatments, where

Table 2. EORTC/RTOG acute skin toxicity scores for either breast or head & neck cases. Global score is for the whole anatomical irradiated area, whereas junction is related to the junction with the supraclavicular field

	Breast		*Head & Neck*	
	Mean score	*SD*	*Mean score*	*SD*
Global score	1.7	0.94	2.2	0.78
Junction	1.6	0.84	2.0	0.81

SD: standard deviation

immobilization was achieved by patient-tailored thermoplastic masks, errors deriving by unconscious movements were restrained. The optimal immobilization in conjunction with the half beam or monoisocentric technique (which does not require any change of the set-up during treatment), minimizes as well the errors originating from possible positioning misplacement. The dosimetric superiority of the monoisocentric technique in head and neck treatments is also confirmed by Zhu et al. [3] and in breast treatments by Assoui et al. [18], since it is associated with more accurate and reproducible dosimetry in the plane of the junction. In both of our cases, the observed variations of dose at the field matching region were higher than the other points of measurement (Figures 3 and 4). This is an evidence that the errors from patient set-up or movement did not affect significantly the dose distribution pattern out of the field junction regions.

According to Figures 3 and 4, the measured-to-expected dose deviation of the lateral-tangential and supra-clavicular fields did not spread over ±5%. Both mean dose deviation values as well as the spread of the deviation values were higher in the tangential fields compared to the lateral fields as it is observed in Figure 5. In particular, a mean deviation of -2.2% and a standard deviation of 4.7% was found in case of lateral head and neck fields while for the tangential breast fields the mean deviation was -3.5% with a standard deviation of 5.7%, respectively. Similarly to our results, a negative mean dose deviation of the tangential breast fields and lateral head and neck fields was also reported in other studies [19-21]. Voordeckers et al. [19] reported a mean deviation of -2.5% and -1.6% for breast and head and neck regions, respectively. These deviations were a result of systematic inaccuracies in the monitor unit calculation algorithm of the TPS which ignores scatter interactions from blocks or missing tissue. Noel et al. [20] also reported sub-unity ratios of experimental and expected entrance dose for breast cancer patients treated with and without the use of wedges (0.982 ± 0.051) and head and neck cancer patients treated with mouldable plastic immobilization masks (0.972 ± 0.058). Furthermore, a mean dose deviation of -1.9 ± 0.2% with a standard deviation of 2.4 ± 0.1% was found for breast cancer irradiation in a study conducted by Cozzi et al. [21]. In contrast, there are studies in the literature that report positive deviations between delivered and calculated entrance doses in case of breast and head and neck cancer patients. According to Fiorino et al. [22] the mean deviation between the *in vivo* entrance dose and the expected one was 0.1% with a standard deviation of 3.5% and 1%, and a standard deviation of 2.8% for breast and head and neck patients, respectively. In the same study significantly high rates of large deviations (>5%) were reported for breast fields (15.2%) against lateral head and neck fields (9%). In the study of Kalef-Ezra et al. [23] the mean entrance doses were 3% higher than those expected in the external tangential breast fields. For the internal tangential fields, the mean dose deviation was 1.3%. Finally, Herbert et al. [24] reported a mean absolute discrepancy between diode-measured and calculated central-axis entrance dose of 4.3 ± 4.0%, with a maximum deviation of 13.4% for tangential 6-MV breast fields. In the same study it was observed that the changing contour of the breast throughout treatment and the effect of wedge compensators on the off-axis contribution introduced significant errors in dose estimation process.

In the case of supraclavicular fields, a systematic overdosage (lower than 5%) was observed in breast cancer patients. This probably could be attributed to the presence of blocks located proximally to the patient body. Therefore, contaminating scatter radiation increased the dose signal of the TLD. In TPS, scatter radiation from the blocks is ignored, leading to systematically lower theoretical entrance dose values. Fiorino et al. [22] demonstrated that fields equipped with blocks were associated with a higher rate of deviations larger than 5% (p=0.0003) and 7% (p=0.01) and a systematic deviation of 1.7% (p=0.0001). Additionally, in the study of Loncol et al. [25] a slight increase of 2-3% was reported for patients treated with blocked fields in comparison with those irradiated without any block or tray.

The aforementioned reasons are not the only

sources of dose discrepancies. There are also minor random errors which cannot be avoided. These could be errors inserted from the PBC dose calculation algorithm and errors related to the treatment unit performance (machine daily output). The obtained data involves also statistical errors resulting from every step of the experimental process. The calibration procedure revealed that the dosimeters' intrinsic accuracy and reproducibility in dose determination inserted an error < ± 2%. Despite the fact that the utilized build-up cups were identical, slightly material inhomogeneities may affect the optical signal-to-dose relationship. During TLD positioning, although the spots of measurements were marked on the patients' skin, some minor displacements of the detectors from session to session were inevitable. Moreover, the exact determination of each point on treatment planning software inserted an additional artifact in the retrieved results.

Conclusions

In vivo thermoluminescence dosimetry is a reliable method for treatment verification, provided that all individual steps of the procedure are carefully performed. The derived results offered us an apparent image of how sensitive field junction areas could be. Any potential fault in the patient set-up, and also the inevitable patient movement, can alter the ideally planned treatment. For this reason, the selection of the appropriate radiation therapy technique in order to achieve reproducibility of the optimal field junction is considered mandatory. The monoisocentric technique seems definitely superior for 3D-CRT of head and neck as well as breast cancer cases, when a supraclavicular field is used.

Therefore, with this study we are sharing our experience in terms of a QA procedure for either breast or head and neck irradiated anatomical areas. And last but not least, the main aspect of the present report was to fully integrate *in vivo* dosimetry in the clinical routine of our radiation therapy unit, in order to achieve a higher level of validation and quality control for 3D-CRT techniques.

Appendix

In the following paragraph, the procedure of the determination of the precise location of the dosimeters in the CT slices of the TPS for breast patients is described.

The junctioning line on skin for breast cases coincides with the lower edge of the supraclavicular field (Figure 3). The junctioning line is encompassed by a certain number of slices (N_{JSL}) of the reconstructed CT images of the patient. All TLDs were placed along the junction line, being included by a number of CT slices (N_{TLDSL}). Three TLDs were utilized in the junctioning region. The central dosimeter was positioned in the middle of this line and the outer TLDs were placed at equal distances from it. The three dosimeters were covering a portion (d_{TLD}) of the full length of the junction projection on the skin (d_s).

Given the slice thickness (ST) of the planning CT acquisition (ST=0.3 cm) and the d_{TLD} length, which was predefined for every measurement (equal to 4 cm), the number of CT slices that contained TLDs was easily calculated by utilizing the properties of the similar triangles.

$$(N_{TLD} \text{ X } ST)/(N_{JSL} \text{ X } ST = d_{TLD}/ds) \quad (3)$$

Where the equation (1) can be derived

$$(N_{TLDSL}=N_{JSL} \text{ X } d_{TLD})/ds) \quad (1)$$

Conflict of interests

The authors declare no confict of interests.

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