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Quality assurance in radiotherapy by identifying standards and monitoring treatment preparation

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Abstract

Background and purpose: Due to the complexity of the treatment preparation in radiotherapy, a number of errors go undetected until after the first treatment session. Some of these errors could easily have been noticed before treatment if an objective filter existed in addition to human supervision. With this in mind, a conceptually novel extension to conventional quality assurance procedures was explored to create a global platform monitoring treatment preparation by comparison with the existing local standards.

Materials and methods: The feasibility of developing such a platform was evaluated for a test case on a cohort of 202 patients having received breast irradiation. By statistical analysis of the treatment parameters, mean values and tolerance levels could be defined for most parameters based on the observed standard deviations. Useful correlations were traced providing us with a means to automatically track errors, the detection of which would otherwise solely depend upon the alertness of the supervisor.

Results and conclusions: Apart from its possibilities as a mere quality control tool, the platform, developed in the framework of EQUART (European Quality Assurance Program in Radiotherapy by Monitoring Treatment Preparation), can be incorporated in the treatment preparation chain, providing standard setup values for the simulation. A crucial achievement of EQUART lies in the fact that filtering out of errors occurs prior to treatment initiation.

Keywords: Radiotherapy; Quality assurance; Record and verify

1. Introduction

Treatment preparation and delivery of radiotherapy is a complex process, due to the large number of links in the chain (localization, simulation, dosimetry and treatment) and the large number of parameters in each link (about 50 parameters for each treatment field). Every step in the process may generate erroneous data (simulator, treatment planning system, 'record and verify', treatment unit, etc.) and every data transfer is error prone. Depending on its organization and the available equipment, the generation and transfer of information as well as errors will differ between departments. The growing complexity of the process implies an increased probability of errors and accidents, and requires the development of improved control mechanisms to ensure optimal treatment quality. At present, most radiotherapy centres have some procedures to monitor treatment delivery (portal imaging, in vivo dosimetry) but fewer mechanisms to monitor treatment preparation, although the latter is at least of equal importance. Record and verify (R&V) systems have been used in recent years for day to day monitoring of the treatment parameters [1] and although such systems reduce random errors in the delivery process (without pre-treatment monitoring), computerized transfer and application of treatment parameters can increase the amount of systematic errors in delivery by assuring consistent use of any erroneous parameters throughout the course of the treatment.

This paper will demonstrate that it is possible to identify standard values for a wide variety of treatment parameters, which will allow the development of a platform for automatic pre-treatment quality control. For many radiotherapy sites this is made feasible by the existing standardization in dose prescription (either on clinical experience or on international recommendations), in treatment field configuration and in patient dosimetry. When one of the parameters takes an inconsistent value, out of the tolerance associated to the mean value and confidence limits, this would be an indication of potential errors. Hence, a global platform monitoring radiotherapy treatment by comparison with the existing local standards, will detect many of the errors and potential accidents, prior to the first treatment delivery. Such a system should operate as follows.

Firstly, mean values for the different treatment para-

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meters, derived through statistical analysis within a radiation therapy division, can be used as initial setup value in the phase of treatment simulation.

Secondly, after simulation and planning but before treatment delivery, all parameters can be downloaded and compared with the corresponding standard values, with tolerance levels based on the observed standard deviations, hence erroneous or out of the ordinary values would be detected. This approach would be a two-fold addition to the presently existing control procedures such as in vivo dosimetry and portal imaging: some not easily detectable parameters can be checked (e.g. the wedge orientation) and erroneous delivery of the first fraction can be prevented.

Moreover, monitoring standards and recording them as a function of time, may be used to detect changes in procedures at different levels in the process. Monitoring the standard deviations of the delivered treatment parameters as a function of time contains information on the improvements of the precision.

In order to test these basic ideas, a feasibility study has been performed on a cohort of 202 patients treated for breast cancer over the last year in our department. The patient data were retrieved from the archives of an R&V system and a statistical analysis (calculation of mean and standard deviations) of the various parameters and functional correlations was performed.

2. Materials and methods

In the radiotherapy department of the University Hospital of Leuven, the R&V system (Veriflex™, Nucletron Oldelft) is connected to both the simulators and the treatment units. Most of the parameters are stored in the R&V system during the simulation phase, e.g. gantry angle, collimator angle, field size and table parameters. Since there is no link between the R&V and the treatment planning system other parameters have to be entered or adjusted manually after the actual dosimetric planning (e.g. treatment unit, modality and energy, monitor units, dose per fraction, adjusted collimator rotation).

From the R&V system, 202 patients treated for breast cancer were retrieved. They were treated with two tangential wedged fields with a fixed SSD technique. Gantry and collimator angle, field size and table parameters are decided upon during simulation. The choice between wedge angles is based upon a comparison of the corresponding isodose distributions at the treatment planning system. Two wedge angles (15 and 30°) are commonly used. These are created by delivering a fraction of the total number of monitor units with an internal 60° wedge and the remainder with an open field. Since the collimator rotation defines the orientation of the wedge, this parameter needs to be adjusted manually in the R&V system after the actual treatment planning. Most of the patients are treated with a 6 MV photon beam. At the first treatment session port films are taken for a visual evaluation, while a dosimetric verification is performed by entrance dose measurements on the beam axis using silicon diodes. If necessary, individualized blocks may be added to the treatment field. The dose delivered to these patients is 50 Gy in 25 fractions (2 Gy/fraction). For the analysis, the patients were ordered so that the first 149 patients were treated with a wedge 15°; while the patients ranked from 150 to 199 were treated with a wedge 30°; the last three patients were treated with 18 MV. For each wedge-angle, the patients were arranged in order of increasing monitor units with wedge.

3. Results

3.1. Mechanical parameters

Fig. 1a presents the distributions obtained for the gantry angle: four regions are identified corresponding to the four possible field setups: for the left medial field (mean 314.6°, SD: 7.1°), for the left lateral field (mean 140°, SD: 7.2°) for the right medial field (mean 45.5°, SD: 6.5°) and for the right lateral field (mean 220.4°, SD: 6.7°). In Fig. 1b, all values of the collimator angle are plotted for the various patients; two possible regions of values are identified for the collimator angle corresponding to two opposed orientations of the wedge (the wedge and collimator rotate in tandem): a mean value of 95.2° (SD: 4.1°) for the left medial field and the right lateral field and a mean value of 264.9° (SD: 4.1°) for the right medial field and the left lateral field. The field width (mean 9.3 cm) and the field length (mean 17.1 cm) have broad distributions (not shown), each with a standard deviation of 1.5 cm. For a few patients, a discrepancy of about 5 mm was found between the medial and lateral field width.

Fig. 2a shows the distribution of the lateral table para-

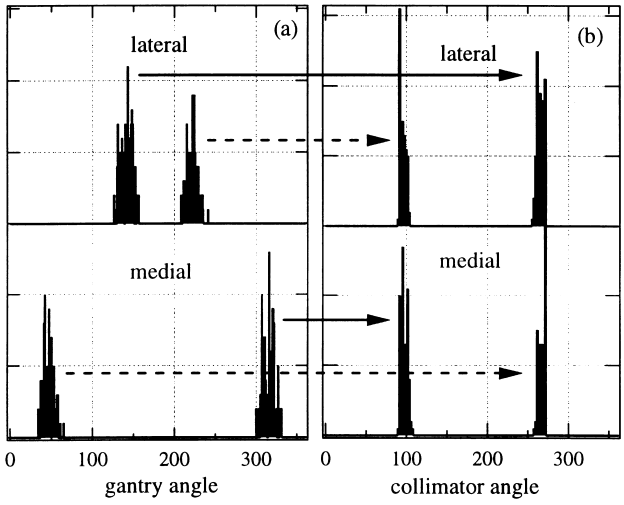

Fig. 1. Distribution of (a) gantry and (b) collimator angles obtained on 202 patients receiving breast irradiations. Solid arrows connect the gantry angle peak with the matching peak of the collimator rotation for irradiation of a left breast. Dashed arrows correspond to irradiation of a right breast.

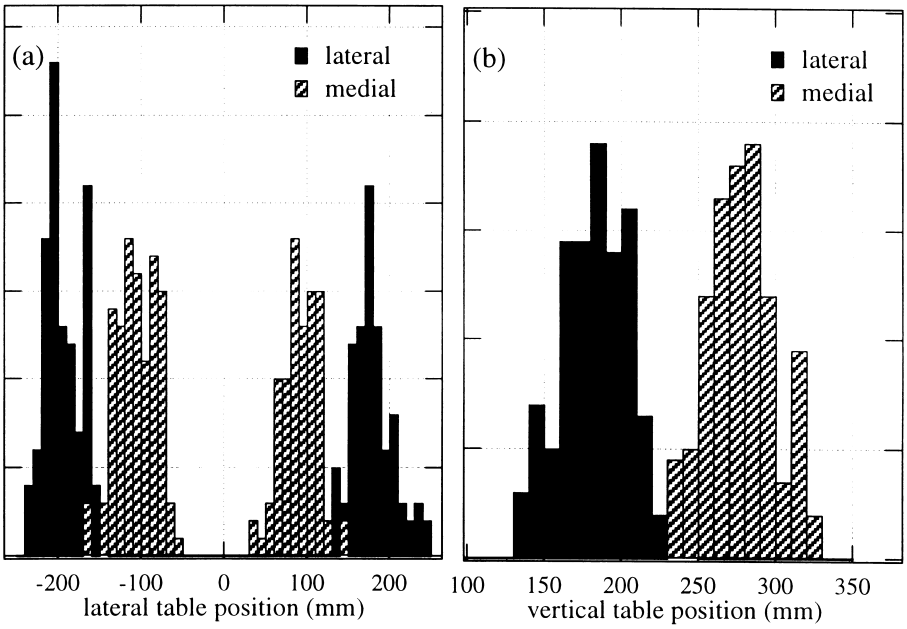

Fig. 2. Distribution of (a) lateral table position and (b) table height for the four possible field setups.

meters for the four possible field setups. In all cases, the standard deviation of this distribution is about 2 cm. Fig. 2b gives the distribution of table height for the lateral (mean: 18.2 cm; SD: 2.2 cm) and the medial fields (mean: 27.7 cm; SD: 2.2 cm). Similarly longitudinal parameters of the table positioning have been recorded; both for the medial fields as for the lateral fields the mean value is 31.5 cm with a standard deviation of 1.8 cm.

3.2. Dosimetric parameters

Fig. 3 gives the dose specification depth vs. patient number for the lateral (crosses) and medial field (circles). The mean dose specification depth is 6.4 cm with a standard deviation of 1.2 cm. Note that for two cases, a discrepancy of more than 3 cm is observed between the medial and lateral dose specification depth, suggesting an error in setup.

Fig. 4a shows the total number of monitor units (MU) of all patients plotted as a function of the increasing MU

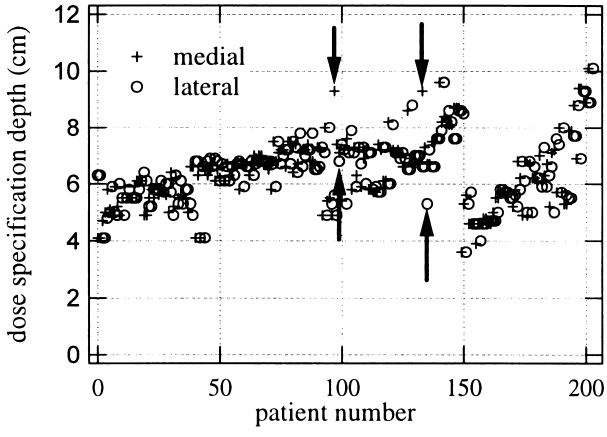

Fig. 3. Dose specification depths for the lateral and medial fields. Discrepancies of more than 3 cm between two corresponding fields are marked with arrows.

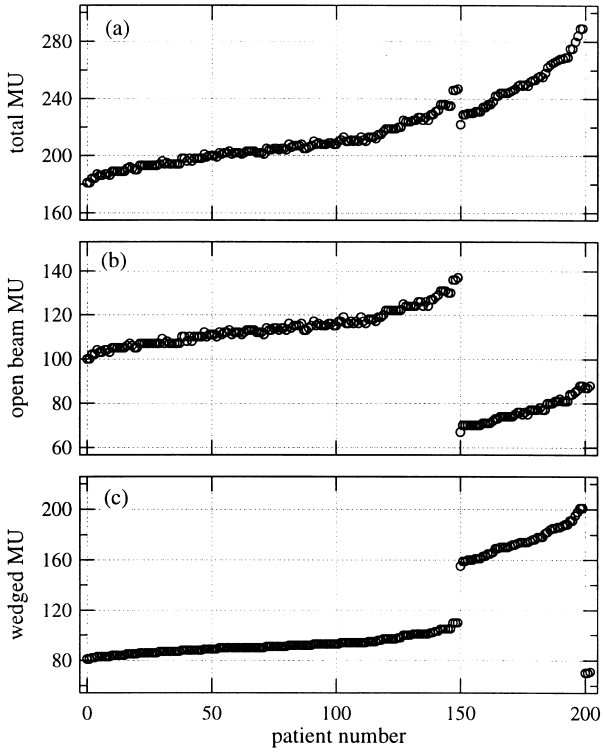

Fig. 4. (a) Total, (b) open beam and (c) wedged monitor units for all patients.

values. Fig. 4b,c give the corresponding MU values of the open and 60° wedged beams, respectively.

4. Discussion

Table 1 summarizes the measured standards (mean and standard deviations) for the medial and the lateral fields for the treatment of breast cancer in our institution. The Table illustrates how some parameters or standards as used in our department may be exploited directly to set up initial values for the simulation and to verify whether the final, adjusted values are still within the tolerance margins (tolerance margins are suggested for each parameter in Table 1, typically varying between two and three times the standard deviation). If not, deviations would immediately be brought to the attention of the radiation oncologist, physicist and/or radiation technologist. Gantry and collimator rotation, for example, show very narrow distributions with similar standard deviations for medial and lateral fields (for both left and right breasts), making them ideally suited for automatic setup and verification of possible adjustments after planning. Although the mean values for the width and the length of the field distributions may be used for simulator setup purposes, the distribution is a broad one and large tolerance margins should be allowed. However, field dimensions of the lateral and medial field should be identical. The small discrepancies observed for two patients between the medial and the lateral field width were due to a correction of the lateral field width following examination of the portal images after the first fraction and finding mere displacement of the lateral field insufficient.

Apart from the incorporation of the statistical distribution parameters into a setup and/or verification platform, some correlations between different parameters exist and can be exploited for more advanced verification.

The distribution of the gantry angles (Fig. 1a) for the medial and lateral fields of both left and right breast treatments shows four very narrow and well separated peaks, providing us with a straightforward method of identifying the treatment field, i.e. medial or lateral, and the breast planned for treatment, i.e. left or right. This can prove especially useful in automatically checking the wedge orientations as follows. The narrow distribution of the two possible collimator angles (Fig. 1b) is important from a dosimetric point of view since the collimator angle defines the orientation of the wedge. Major errors resulting from erroneously putting the wedge in the opposite direction during planning or during parameter transfer to the R&V system, could be intercepted by linking the value of the collimator angle to the value of the gantry angle, since each field setup has a uniquely defined wedge orientation (e.g. a medial field for a right breast (mean gantry angle 45.5°) implies a mean collimator rotation of 265.7° (SD: 3.9°)). Also, large gaps of forbidden values exist for the collimator angle (e.g. a value of 0°, would imply that the collimator angle in the R&V was not properly transferred after the actual planning). At present depending on the alertness of the supervising physicist, the detection of these errors could be guaranteed by a software interface checking the parameters on consistency. It is worthwhile mentioning that the computerized verification does not imply that the use of the wedge or its orientation is automatically programmed in the R&V.

When evaluating the distribution of the dose specification depth separately for breasts treated with wedge 15° and wedge 30° it appears that both distributions cover the same region of dose specification depths, confirming that there is no correlation between the size of the breast and the choice of the wedge; the latter is only determined by the actual shape of the breast.

The correlation between the delivered monitor units and the dose specification depth is illustrated in Fig. 5: the loga-

Table 1
Measured standards (mean and SD) and suggested tolerance levels for the treatment of breast cancer

Parameter	Medial fields		Lateral fields		Tolerance level
	Mean	SD	Mean	SD	
Gantry right breast (°)	45.5	6.5	220.4	6.7	15
Gantry left breast (°)	314.6	7.2	140.1	7.1	15
Collimator (°)	264.9	4.1	95.2	4.1	10
Field width (cm)	9.3	1.6	9.3	1.6	4
Field length (cm)	17.1	1.5	17.1	1.5	4
Vertical table position (cm)	27.7	2.2	18.2	2.2	5
Longitudinal table position (cm)	31.5	1.8	31.5	1.8	4
Lateral table position right breast (cm)	8.8	1.9	17.5	2.2	5
Lateral table position left breast (cm)	−10.4	2.1	−19.4	2.2	5
Table angle (°)	0	0	0	0	0
Total MU	216.4	23.6	217.4	24.5	80
Wedge MU (15°)	91.7	6	91.7	6	20
Wedge MU (30°)	174.3	11.4	174.3	11.4	20
Dose specification depth (cm)	6.4	1.2	6.4	1.2	4
Dose per fraction (Gy)	1	0	1	0	0

rithm of the monitor units corrected for the output factors of the equivalent field sizes is plotted as a function of the dose specification depth for the patients treated with a wedge 15°. Six regions of parameter values are identified, corresponding to three categories: the total number of monitor units, the number of monitor units with the wedge 60°, and the number of monitor units delivered with the open beam. Within each category, the upper regions of permitted values can be assigned to irradiation treatments in which blocks were used and the absorption factor of the tray had to be taken into account. The slopes of the curves are identical (0.047 ± 0.003 cm^{-1}) in agreement with the tissue absorption coefficients found in literature for water in this range of energies. It also follows that, although the actual shape of the breast determines the choice of the wedge, once this choice has been made, the total number of monitor units follows in a straightforward way from the dose specification depth and the equivalent square field size (i.e. the shape of the breast does not influence the number of MU significantly).

In addition, the ratio of wedged to total MU is a constant for each wedge angle (0.445 ± 0.005 and 0.694 ± 0.005 for wedge 15 and 30°, respectively), determined by the wedge transmission factor. Although an estimate of the MU based on the dose specification depth and the equivalent square field size provides a more accurate check, a simple verification of the ratio would assure consistency between the wedge choice and the MU ratio.

Monitor unit calculation and wedge choice for a breast irradiation in our institution are based on two or three CT-slices. The dose specification depth is determined from the CT-slice containing the entrance points of the beam axes (i.e. at $z = 0$ cm). Verification of the use of the correct CT-slice can be based on the following correlation between treatment parameters. As a consequence of the use of a fixed SSD technique, the breast thickness measured between the entry points of the medial and the lateral fields can be obtained by applying Pythagoras' law to the lateral and vertical table parameters of the medial and the lateral fields (Fig. 6a). This calculated thickness should correspond in a first approximation to twice the value of the dose specification depth. This is not entirely correct since the axes of the two tangential beams are not coinciding, as shown in Fig. 6a. The deviations resulting from this approximation were verified for several patients and found to be no larger than 2 cm. The difference Δ between the estimated thickness and twice the dose specification depth is shown for all patients in Fig. 6b. The mean deviation is -0.3 cm with a standard deviation of 1.2 cm. Important discrepancies of more than 3 cm are observed for eight patients. We suspect these deviations are due to the use of the wrong CT-slice (e.g. at $z = +5$ cm instead of $z = 0$ cm) for the determination of

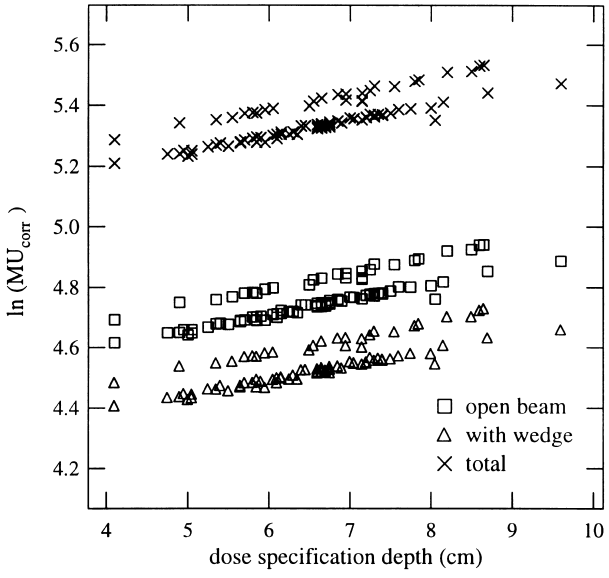

Fig. 5. Logarithm of the monitor units (total number of MU, wedged MU and open beam MU) corrected with the output factors of the equivalent field size, plotted as a function of the dose specification depth (for wedge 15°).

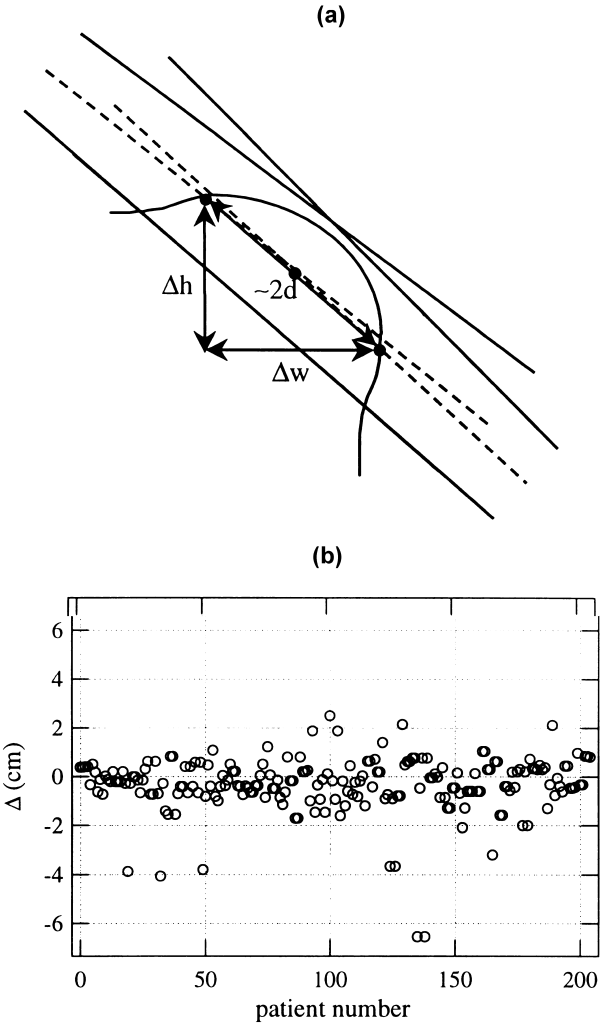

Fig. 6. (a) Schematic representation of a breast irradiation indicating the opposed beams and the lateral and vertical table parameters. (b) Difference Δ between the estimated thickness and twice the dose specification depth, calculated for all patients.

the dose specification point. Detection of such errors is important since they could easily lead to mistakes of over a few cm in the dose specification depth, resulting in an erroneous MU calculation and a wrong dose distribution. In most cases, the breast thickness is larger on the $z = 0$ cm slice than on the outer slices (e.g. $z = +5$ or -5 cm), so underdosage will occur. In the present day quality assurance procedure, this can go unnoticed by the supervising personel (e.g. radiation physicist, radiographer, …). Other methods, such as in vivo entrance dose measurements, will not detect it either since the calculation of the expected outcome signal of the diode is based upon the erroneous number of MU.

In the framework of the European Quality Assurance Program in Radiotherapy by Monitoring Treatment Preparation (EQUART), the results presented above can be used to create a platform for automatic quality control. Although some of the values and correlations will be specific to the standard treatment methods of the department, the feasibility study shows that within a radiotherapy division a platform can be developed and incorporated into the present day clinical routine as outlined in Fig. 7. The implementation must be such that a two-fold goal is achieved: the amount of erroneous entries must be reduced to a minimum and errors that do occur must be intercepted as soon as possible.

Minimization is achieved by loading standardized setup values from the EQUART platform to start off with on the simulator. The final treatment parameters determined during simulation (i.e. gantry angle, collimator angle, field size, table parameters, SSD,…) are automatically stored into the R&V system. Before the patient is removed from the simulator table, the entered values should be processed by

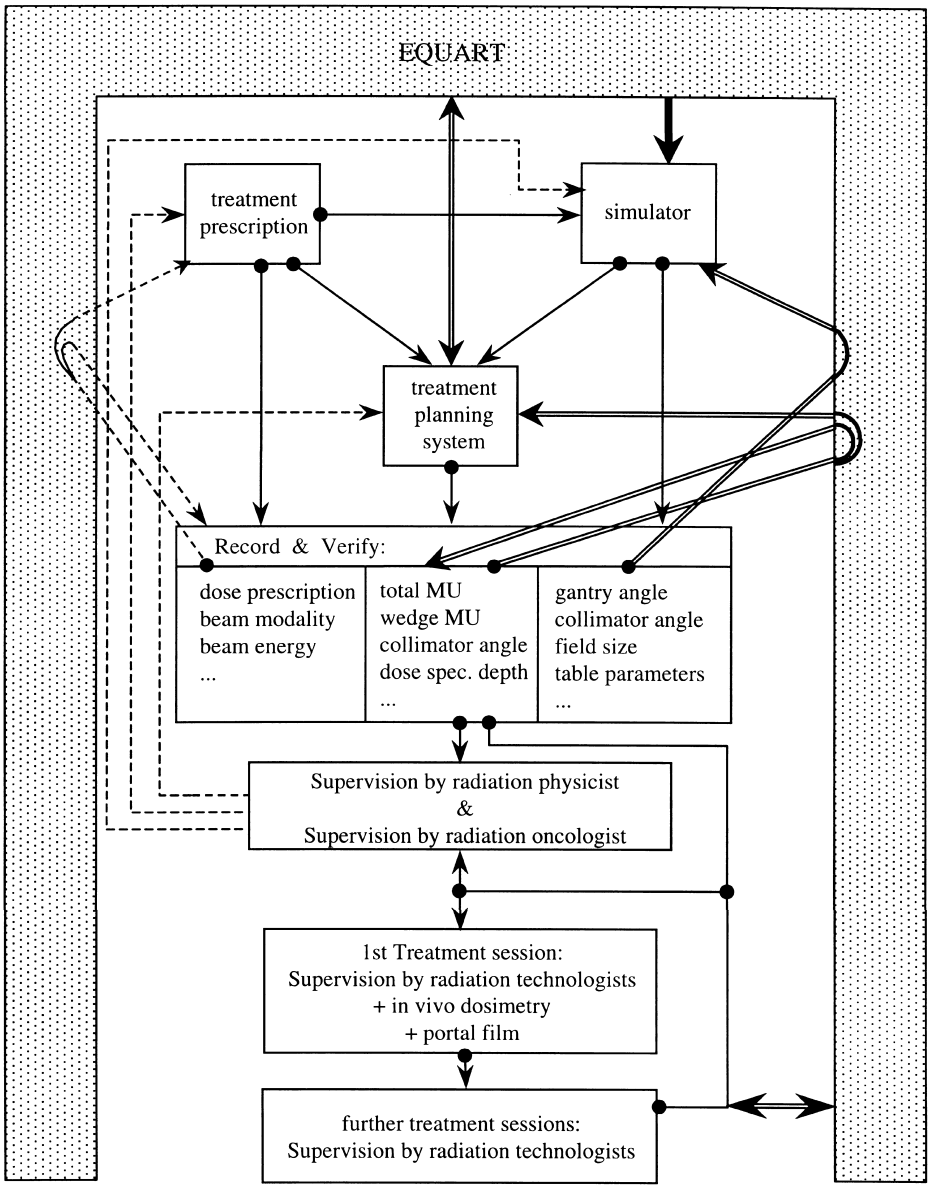

Fig. 7. Schematic overview of the implementation of the EQUART platform into the clinical routine.

the EQUART platform yielding a warning in case inconsistencies or abnormalities are detected. Hence, corrections can immediately be performed by the same personnel and without having to reschedule the patient for resimulation. If justified, the warning can be overridden by the supervising radiation physicist and/or radiation oncologist after thorough verification. Parameter values determined during planning (total MU, wedge MU, adjusted collimator angle, dose specification point,…) are double checked as soon as they have been entered (manually) into the R&V. Typing errors are easily intercepted and can be corrected at the spot, while more serious errors may require return to the treatment planning system. (If there exists a direct connection between simulator, TPS and accelerator, transcription errors should be eliminated.) In principle, the EQUART platform can also contain standards for dose prescription, which can be compared with the dose prescription parameters entered into the R&V.

As a consequence, the treatment parameters as stored in the R&V system (i.e. as used for the actual irradiation) will have passed the EQUART filter before supervision by the medical radiation physicist and radiation oncologist. Although the R&V system continues to fulfill its role of assuring consistent use of the parameters specific to every patient, EQUART can further be used to double check the R&V data when they are loaded before each treatment session.

5. Conclusion

We have shown that present day R&V systems can be successfully exploited to obtain standards for treatment parameters in a radiotherapy division. We have illustrated how some errors can be avoided through the use of these standards as initial setup values for simulation and how others can be detected by utilizing the correlations between different parameters. Some of the errors might not be found otherwise. We have also discussed how these results can be incorporated in a larger quality control platform.

We are at present extending this program to other sites as well as other techniques (e.g. intensity modulated radiotherapy)

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