ESTRO project

IMRT treatment planning—A comparative inter-system and inter-centre planning exercise of the QUASIMODO group

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Abstract

Background and purpose: The purpose of this work was a comparison of realistic IMRT plans based on the same CT-image data set and a common predefined set of dose objectives for the planning target volume and the organs at risk. This work was part of the larger European QUASIMODO IMRT verification project.

Materials and methods: Eleven IMRT plans were produced by nine different European groups, each applying a representative set of clinically used IMRT treatment planning systems. The plans produced were to be deliverable in a clinically acceptable treatment time with the local technical equipment. All plans were characterized using a set of different quality measures such as dose-volume histograms, number of monitor units and treatment time.

Results: Only one plan was able to fulfil all dose objectives strictly; six plans failed some of the objectives but were still considered to be clinically acceptable; four plans were not able to reach the objectives. Additional quality scores such as the number of monitor units and treatment time showed large variations, which mainly depend on the delivery technique.

Conclusion: The presented planning study showed that with nearly all presently available IMRT planning and delivery systems comparable dose distributions could be achieved if the planning goals are clearly defined in advance.

Keywords: Intensity-modulated radiation therapy; treatment planning; multi-centre intercomparison.

Intensity-modulated radiation therapy (IMRT) is a treatment technique where not only the beam apertures are shaped to the irregular form of the target volume, but where the photon intensity across the beam area is also varied to shape the dose distribution to a higher conformity. The use of IMRT improves the dose distribution within the patient, especially if the target has a complex three-dimensional shape, e.g. a concave part that surrounds a critical structure. This treatment technique comes with a large variety of different plan optimization procedures and delivery techniques, which are fundamentally different from each other [1,5,6,9,11]. Consequently, the resulting dose homogeneity in the planning target volume (PTV) and the dose distribution in the organs at risk (OAR) might depend on the specific planning–delivery system combination. Additionally, also the site-specific strategy might influence the end result [3]. Assessing the performance of these different combinations of equipment installed at different centres, with their inherent variability of features and restrictions, is therefore only possible by evaluation of the resulting treatment plans. Unlike in most treatment planning studies where one aspect of the treatment planning—e.g. dose calculation [12], delivery technique [2] or optimisation procedure [7,13]—is evaluated, the concept proposed in this study is designed to reveal if at any centre the software and hardware combination gives acceptable results in the hands of the user. Following this concept a CT-dataset of a phantom simulating a simplified pelvis together with contours of a concave PTV that surrounds a cylindrical OAR was provided to each participating centre.
The centre was asked to design a treatment plan for this fictive case with their equipment used in clinical practice following the planning strategy of their choice. A number of general dosimetric objectives had to be fulfilled to ensure inter-centre comparability of the results. To assess the feasibility and the adequateness of the proposed objectives, the design was tested amongst the QUASIMODO-network members, having experience in IMRT planning and delivery applying a variety of treatment planning systems and irradiation equipment. This paper elucidates the concept and results of such an inter-centre treatment planning study, and evaluates the applied dosimetric objectives.

Materials and methods
The QUASIMODO network
The QUASIMODO (QUality ASSurance of Intensity-MODulated beams in radiation Oncology) network consists of fifteen radiotherapy institutions from nine European countries [14]. These centres can be considered as the group of radiotherapy institutions that started with the clinical implementation of IMRT in Europe. One of the activities of the QUASIMODO network was to perform an intercomparison of a dosimetric verification of a complete IMRT treatment. For this purpose a fictive clinical case in a pelvic phantom was defined with fixed optimisation objectives that had to be achieved. Each participating centre planned and delivered an IMRT treatment with its own equipment. The results of the dosimetric verification as part of that comparison have been described elsewhere [10]. In the current paper an analysis of the produced treatment plans itself is presented. The experience obtained during this comparison, the results of the treatment plan analysis as well as of the dosimetric verification part, will help us in drafting guidelines for the verification of IMRT.

Centres and treatment planning systems
Nine European centres participated in the planning study. They are listed in Table 1 together with the characteristics of the applied treatment planning systems, IMRT techniques and irradiation equipment. All centres had experience with IMRT planning and delivery, although their clinically applied procedures might be different from the ones used for this study. Due to the specific concave shape of the target volume and the position of the organ at risk (see Section The anthropomorphic phantom), it was for instance impossible to use for this case the ‘class solution’ applied for IMRT of prostate cancer, as applied in some centres.

Commercially available as well as in-house developed inverse planning systems were used in this study. All centres applied MLC-techniques with either multiple static segment (MSS) or dynamic MLC (DMLC) delivery. From one centre additionally an intensity-modulated arc technique (IMAT) was included. In total eleven different plans were analyzed.

The study design
For this exercise a complete CT image set of an anthropomorphic pelvic-like phantom with a complex target structure and an embedded organ at risk was sent to all participants. Details of the phantom and the structures are described in Section The anthropomorphic phantom.

All participants were asked to create an intensity-modulated plan, which had to be deliverable under the local clinical conditions and which had to fulfil several rather

<table>
<thead>
<tr>
<th>Plan number</th>
<th>Participating centre</th>
<th>TPS</th>
<th>Treatment technique a</th>
<th># of fields</th>
<th>MLC type</th>
<th>Beam quality</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Nederlands Kanker Instituut, Amsterdam, The Netherlands</td>
<td>Pinnacle V6.2b</td>
<td>MSS</td>
<td>9</td>
<td>Elekta</td>
<td>18MV</td>
</tr>
<tr>
<td>2</td>
<td>Charité Berlin CCM, Berlin, Germany</td>
<td>Eclipse/Helios V7.1.35</td>
<td>DMLC</td>
<td>7</td>
<td>Varian 52-MLC</td>
<td>20MV</td>
</tr>
<tr>
<td>3</td>
<td>UZ Gent, Ghent, Belgium</td>
<td>Pinnacle + in-house optimization</td>
<td>IMAT</td>
<td>4 arcs</td>
<td>Elekta</td>
<td>18MV</td>
</tr>
<tr>
<td>4</td>
<td>UZ Gent, Ghent, Belgium</td>
<td>Helax-TMS V6.1.a</td>
<td>MSS</td>
<td>9</td>
<td>Elekta</td>
<td>18MV</td>
</tr>
<tr>
<td>5</td>
<td>Lund University Hospital, Lund, Sweden</td>
<td>Helax-TMS V6.1.a</td>
<td>MSS</td>
<td>7</td>
<td>Elekta</td>
<td>10MV</td>
</tr>
<tr>
<td>6</td>
<td>Lund University Hospital, Lund, Sweden</td>
<td>Nucletron Oncentra (OTP) V1.2</td>
<td>MSS</td>
<td>9</td>
<td>Elekta</td>
<td>10MV</td>
</tr>
<tr>
<td>7</td>
<td>Christie Hospital NHS Trust, Manchester, UK</td>
<td>Pinnacle V6.2b</td>
<td>MSS</td>
<td>9</td>
<td>Elekta</td>
<td>8MV</td>
</tr>
<tr>
<td>8</td>
<td>S. Maria Nuova Hospital, Reggio Emilia, Italy</td>
<td>Cadplan/Helios V6.3.6</td>
<td>DMLC</td>
<td>9</td>
<td>Varian 120-MLC</td>
<td>6MV</td>
</tr>
<tr>
<td>9</td>
<td>Hospital Virgen Macarena, Sevilla/ERESA, Valencia, Spain</td>
<td>Helax-TMS V6.1.a</td>
<td>MSS</td>
<td>9</td>
<td>Siemens</td>
<td>6MV</td>
</tr>
<tr>
<td>10</td>
<td>Universitaetsklinik Tuebingen, Germany</td>
<td>Hyperion</td>
<td>MSS</td>
<td>9</td>
<td>Elekta</td>
<td>15MV</td>
</tr>
<tr>
<td>11</td>
<td>UMC Utrecht, Utrecht, The Netherlands</td>
<td>Plato ITP</td>
<td>MSS</td>
<td>9</td>
<td>Elekta</td>
<td>10MV</td>
</tr>
</tbody>
</table>

The plan numbers are used as reference in all subsequent tables and figures.

a MSS = Multiple Static Segments; DMLC = Dynamic MLC; IMAT = Intensity-Modulated Arc Therapy.
strict dose objectives as good as possible. The dose objectives are discussed in Section Planning procedure and documentation of the results. The planning itself had to be performed by an experienced planner.

Using a specially designed EXCEL data sheet, a standardized data set was collected from all centres. The data set should allow answering the following questions:

- Is the treatment planning system able to fulfil the given dose objectives?
- What was the number of monitor units necessary to deliver the IMRT fields by the method used?
- What was the total treatment time necessary to deliver all intensity-modulated fields from first beam on to last beam off?

The anthropomorphic phantom

A specially designed anthropomorphic phantom (the so-called CarPet phantom, Fig. 1) made of water-equivalent material was CT-scanned and pre-contoured in Ghent. Two contours were pre-defined (see Fig. 1):

- The planning target volume (PTV) is drawn as horseshoe-shaped contour in 52 slices. In the longitudinal direction of the CarPet phantom an anterior-posterior shift is applied to the respective contours by 0.25 cm/cm distance.
- Within the PTV, an embedded circular organ at risk (OAR) is drawn. The distance between the OAR and the PTV is only 1.0 cm.

The CT-images with the pre-contoured structure data were delivered as either DICOM-RT or RTOG data format to the participating centres. In addition to the pre-defined contours each centre was asked to create a body contour and a contour for the ‘healthy tissue’ defined as body contour without PTV and marked as Body\PTV in all subsequent sections.

To avoid systematic errors caused by different HU to electron density conversions within the various planning systems, all centres were advised to use an electron density of 1.0 relative to water or alternatively to switch off the tissue inhomogeneity correction of their planning system.

The chosen phantom design can be considered as an extreme type of prostate treatment. The idea behind this choice of PTV an OAR was that in this way the limitations of the various techniques/planning systems could be better evaluated than using a more realistic clinical situation.

Planning procedure and documentation of the results

Together with the phantom and contour data all centres received detailed instructions how to perform the treatment planning. An important requirement was that each centre was only allowed to prepare a plan that was deliverable within an acceptable time under local clinical and technical conditions.

Beam numbers and beam entrance directions were not restricted, except that only co-planar beams were allowed. The centres were asked to use the highest available photon quality. The dose per fraction to be given was 2.00 Gy (100%). To have comparable results, all groups were asked to normalize their plans to the mean dose in the PTV, i.e. $D_{mean}(PTV) = 100\%$ or 2.00 Gy.

All dose values for the final data compilation are given in dose per fraction.

Because of the diversity of the different planning systems, no optimization constraints were pre-defined for the inverse planning process itself. Each group was free to use the best solution for its treatment planning system. Also the inverse planning process itself was not restricted. It was for example allowed to use ‘dummy contours’ or contour enlargements during the inverse planning procedure, e.g. to avoid local dose maxima or to overcome TPS specific optimization problems [7].

The dose distribution of the optimized plan was recalculated by all centres including the influence of the segmentation determined by the leaf sequencer. Only these final dose distributions were analysed and compared in the present study.

Explicit dose objectives were defined for the two pre-contoured structures (PTV and OAR) and for the body contour without PTV (Body\PTV) as listed in Table 2. Each group was asked to achieve these objectives as good as possible. The dose objectives for the PTV and OAR were chosen to test the systems for a rather extreme situation. Because the distance between the border of the PTV and OAR is 1.0 cm, the dose restriction to the OAR can be rather

![Fig. 1. Axial and sagittal views of the CarPet phantom with the pre-contoured structures.](image-url)
severe. This situation is different from a prostate treatment
where part of the rectum is often included in the PTV.

For the final analysis the following data were requested
from each centre:

† Dose distributions of the three orthogonal slices through
the isocentre (TIF or DICOM format).

† Cumulative dose-volume histograms of the three relevant
structures (i.e. PTV, OAR and Body\PTV).

† The Excel data compilation sheet.

Quantitative analysis

Dosimetric data of the pre-defined structures

For the three pre-defined structures, the following
dosimetric data were extracted from the collected data
sets and compared to the corresponding dose objectives
(in brackets):

• For the PTV, the partial volumes \( V_{95} (\geq 99\%) \) and \( V_{105} (> 5\%) \).

• For the OAR, the partial volume \( V_{70} (< 1\%) \).

• For the structure Body\PTV, the partial volumes \( V_{80} (< 15\%) \), \( V_{100} (< 2\%) \), and the maximum dose \( D_{\text{max}} (< 105\%) \).

Here and throughout the whole text \( V_{xx} \) is defined as the
partial volume of either a PTV or an organ at risk, which
receives at least \( xx\% \) of the prescribed dose.

Quality score \( S_D \)

To quantitatively compare different plans against
the same dose objectives, we introduce a quality score \( S_D \) that is
defined as follows:

\[
S_D = \sum_C \left\{ \begin{array}{ll}
|M_j - C_j| & \text{if objective is violated} \\
0 & \text{else}
\end{array} \right.
\]

\( C_j \) is the objective \( j \); \( M_j \) is the corresponding plan value
(see Table 2). The summation is over all six objectives. For a
plan which fulfils all objectives, \( S_D = 0 \).

Normalized monitor unit factor

To compare the required number of monitor units of each
centre independently of the different local beam calibra-
tions, all centres were asked to provide also the number of
monitor units necessary for the delivery of a dose of 2.00 Gy
at 10 cm depth in water for a 10 \( \times \) 10 cm\(^2 \) field at SSD= 90 cm. The total number of monitor units of the IMRT-plan
was then determined relative to that reference number of
monitor units, giving the normalized monitor unit factor.

Results

Delivery techniques

The different delivery techniques are listed in Table 1:
Seven centres created plans with multiple static MLC segments
(MSS); two groups used dynamic MLC (DMLC) delivery, while
the Ghent group additionally produced an IMAT plan.

Interestingly only equidistant beam arrangements with
either seven or nine beams were chosen, using either a 0 or
180° initial beam angle. The only exception was the IMAT
plan which used four arcs with gantry angles varying between
136 and 244°.

Although the centres were asked to use the highest
available photon beam quality, no clear preference for a
specific photon beam quality can be observed; all typical
photon beam qualities between 6 and 20 MV are represented.

Dose distribution: quantitative analysis

PTV

The values of \( V_{95} \) and \( V_{105} \) are listed in columns 2 and 3 of
Table 2. Six plans were able to reach the overdose
requirement \( V_{105} < 5\% \), five plans miss it, four of them by
more than 3\%. Only two plans are in addition able to fulfil

Table 2

Compilation of the relevant dosimetric data of the three contoured structures for all plans

<table>
<thead>
<tr>
<th>Plan #</th>
<th>PTV</th>
<th>OAR</th>
<th>Body\PTV</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>( V_{95} (%) )</td>
<td>( V_{105} (%) )</td>
<td>( V_{70} (%) )</td>
</tr>
<tr>
<td>1</td>
<td>98.4</td>
<td>9.3</td>
<td>0.2</td>
</tr>
<tr>
<td>2</td>
<td>98.4</td>
<td>2.1</td>
<td>0.8</td>
</tr>
<tr>
<td>3</td>
<td>100.0</td>
<td>0.0</td>
<td>0.0</td>
</tr>
<tr>
<td>4</td>
<td>82.9</td>
<td>14.1</td>
<td>0.0</td>
</tr>
<tr>
<td>5</td>
<td>83.3</td>
<td>18.7</td>
<td>1.7</td>
</tr>
<tr>
<td>6</td>
<td>93.3</td>
<td>6.3</td>
<td>7.8</td>
</tr>
<tr>
<td>7</td>
<td>97.9</td>
<td>0.8</td>
<td>5.9</td>
</tr>
<tr>
<td>8</td>
<td>99.7</td>
<td>1.1</td>
<td>6.7</td>
</tr>
<tr>
<td>9</td>
<td>84.8</td>
<td>18.0</td>
<td>0.0</td>
</tr>
<tr>
<td>10</td>
<td>95.5</td>
<td>0.0</td>
<td>0.5</td>
</tr>
<tr>
<td>11</td>
<td>98.2</td>
<td>2.5</td>
<td>1.4</td>
</tr>
</tbody>
</table>

The dose objectives, which should be satisfied by the treatment plans, are also listed. Bold and underlined numbers indicate results that fail
the corresponding objective by more than 3% or less than 3%, respectively.
the underdose requirement (i.e. $V_{95} \geq 99\%$). The other nine plans are not able to meet it; five of them by more than 3%. The three plans with the largest PTV underdosage additionally show the largest overdosage.

**OAR**

In column 4 of Table 2 the resulting values of $V_{70}$ are listed for all plans. Six plans reach the dose objective of $V_{70} < 1\%$. Three plans fail the OAR dose objective by more than 3%, the remaining two miss it by less than 3%.

**Body without PTV (Body\PTV)**

The results for the structure Body\PTV are listed in columns 5–7 of Table 2:

- Only one plan is not able to fulfil the dose objective $V_{80} < 15\%$, but even that plan misses it by less than 3%.
- For two plans $V_{100}$ is slightly larger than the required 2%, all others are able to stay within the required limit.
- Nearly all plans have difficulties to avoid small hot spots in the healthy tissue: Only two plans are able to fulfil the $D_{\text{max}}$ requirement, i.e. to stay below 105%. One plan misses it by less than 3%, all others show a quite large overdosage.

**Dose-volume histograms**

For all plans, the cumulative dose-volume histograms (DVHs) of the three structures PTV, OAR, and Body\PTV are depicted in Fig. 2.

**Time requirements, monitor unit factor and number of segments**

The time needed to perform the complete treatment plan was reported by four centres (#2, 8, 9, and 11) to be between two to three hours, all others needed more than three hours. The optimization time alone varied between less than 30 min for centres #2, 10 and 11 and more than 90 min for centres #3, 4, and 5: The reported mean delivery time (measured from first beam on to the last beam off) was 19 min with a standard deviation of 9.5 min; it varied from 7 min (centre #9) to 33 min (centre #7).

The normalized MU factors are shown in Table 3. All plans have normalized MU factors $>1$ as expected for IMRT delivery; the numbers vary from 2.5 to 7.3 (mean value = 3.5, standard deviation = 1.6). The highest values are produced by the DMLC plans.

For the MSS plans also the total number of required beam segments is listed in Table 3. They vary from 24 to 142 (mean value = 107.5, standard deviation = 51.0).

**Quality index $S_D$**

In Fig. 3 the quality score $S_D$ of each plan is shown. The quality score is subdivided into its four components, i.e. the underdosage score of the PTV and the overdosage scores for PTV, OAR, and Body\PTV. Note that plan #3 that fulfils all plan objectives has a value $S_D = 0$. There is a clear grouping of plans having $S_D$ values of lower or around 10 (plans #1-3, 7, 8, 10, and 11) and plans with significantly higher $S_D$ values of more than 20 (plan #6) or even more than 30 (plans #4, 5, and 9).
Discussion

One way of analysing an inter-centre comparison of dose plans using different planning systems and delivery techniques is to rank the quality of the dose distribution of the different plans. Table 2 together with Figs. 2 and 3 give a good overview how good a plan is able to achieve the predefined dose objectives.

Interestingly only the IMAT plan (plan #3) was able to pass all criteria. One reason for that good result is the specific geometric arrangement of the PTV and the OAR, which is perfectly adapted to the IMAT technique. However, also for more clinically relevant situations the IMAT technique may prove to be superior compared to the MSS approach, especially in situations where organs at risk are embedded in a large concavity of the PTV [4,5,16].

The three Helax plans (plans #4, 5, and 9) and the OTP plan (plan #6) show large deviations from the required dose objectives; especially the HELAX plans had difficulties to reach the PTV over- and underdosage objectives independently of the centre that created the plan. Most probably these plans would have been rated as being not acceptable for patient treatment, while the smaller objective violations of the other plans may still be accepted in a real clinical situation.

Interestingly there is no correlation between the chosen photon beam quality and the quality of the dose distribution. This result is in agreement with other studies that demonstrated no clear advantage in applying higher photon beam energies for IMRT of prostate tumours [15]. The DVHs presented in Fig. 2 give additional information about similarities and differences between the various plans. While the DVHs of the Body\PTV are quite similar for all plans, the DVHs of the PTV and the OAR show considerable differences. The reason for these differences is related to the compromise between target coverage, the dose outside the PTV, the number of beams and the number of monitor units accepted by the various centres. Also the quality of the leaf sequencer in the planning system for the accompanying MLC-type might have influenced the final result. For example in the OTP system, the fluence matrix is modified considerably after the MLC constraints have been taken into account by the sequencer.

Besides the quality of the dose distribution, another interesting criterion for judging IMRT plans is the number of monitor units required to deliver a given dose, which is related to the whole body dose [8]. Typically, an IMRT plan needs more monitor units than a conventional plan, at least if no wedges are employed, which is confirmed in our study (see Table 3). The resulting plans show large normalized MU-factor variations with the highest values being produced by the two DMLC plans (plans #2 and #8). The lower normalized MU factor of the Cadplan plan (plan #8) compared to the Eclipse plan (plan #2) is caused by the fact, that Cadplan uses a fixed, heavy fluence smoothing while for Eclipse the user can select different fluence smoothing levels. Fluence smoothing reduces the fluence complexity and consequently leads to less monitor units. On the other hand, the final dose distribution may suffer from this smoothing in areas where high dose gradients are required. Consequently, the direct comparison of the dose distributions of the Cadplan and Eclipse plans as presented in Table 2 and Fig. 2, results in a better ranking of the Eclipse plan especially with respect to the OAR dose objective.

Finally it should be noted that in the present study plans with comparable overall quality score could be obtained using the MSS approach, having in general a lower normalized MU-factor.

Another quality parameter is the number of segments for those plans that use the MSS approach. Table 3 shows that

<table>
<thead>
<tr>
<th>Plan number</th>
<th>Normalized MU factor</th>
<th>Number of segments</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>2.8</td>
<td>91</td>
</tr>
<tr>
<td>2</td>
<td>7.3</td>
<td>DMLC</td>
</tr>
<tr>
<td>3</td>
<td>3.6</td>
<td>IMAT</td>
</tr>
<tr>
<td>4</td>
<td>2.9</td>
<td>120</td>
</tr>
<tr>
<td>5</td>
<td>2.5</td>
<td>90</td>
</tr>
<tr>
<td>6</td>
<td>2.3</td>
<td>105</td>
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<td>4.3</td>
<td>203</td>
</tr>
<tr>
<td>8</td>
<td>5.5</td>
<td>DMLC</td>
</tr>
<tr>
<td>9</td>
<td>2.3</td>
<td>24</td>
</tr>
<tr>
<td>10</td>
<td>2.5</td>
<td>85</td>
</tr>
<tr>
<td>11</td>
<td>2.9</td>
<td>142</td>
</tr>
</tbody>
</table>

For the IMAT and DMLC plans no segment numbers are given.

Fig. 3. Quality score $S_D$ for all plans. $S_D$ is subdivided into its four components, i.e. the underdosage score of the PTV and the overdosage scores for OAR, Body\PTV and PTV.
the applied number of segments varies considerably; from 24 to about 200. Due to the horseshoe shape of the target volume and the proximity of the OAR, most planning systems need a large number of segments which is, however, counterbalanced by the additional requirement that the produced plan should be deliverable under the local clinical conditions. It should furthermore be realised that more segments might also result in additional time for quality control of these more complex beam intensities. Interestingly there is no clear correlation between larger segment numbers and better dose distributions. Especially one of the Pinnacle plans (plan #1) and the Hyperion plan (plan #10) needed less than 100 segments and were nevertheless able to produce good plans.

Although nearly all plans were not able to fulfil all objectives strictly, most of the plans would nevertheless be considered as being clinically acceptable. This planning study therefore clearly demonstrates that even with a heterogeneous set of IMRT planning and delivery systems it is possible for a given clinical problem to produce treatment plans with comparable results, even if the plans may exhibit a larger diversity than conventionally planned dose distributions.

In this study the treatment planning data provided by the participants were compared. One might argue that the actual delivery of these plans might result in different values of PTV coverage and dose outside the PTV. The majority of the plans analysed in this study were, however, also verified by means of ionisation chamber measurements and film dosimetry [10]. A general conclusion of that verification study was that the agreement between measured and computed dose distributions was better than might be expected for such a wide range of planning and delivery system combinations. Some systematic differences, mainly due to the delivery part and not the planning process, could be identified. The outcome of this planning study therefore reflects the situation if these centres would participate in a common clinical study applying IMRT.

Conclusions

This planning study showed that with a number of commercially available, as well as in-house developed, IMRT planning and delivery systems, comparable dose distributions can be achieved, if the planning goals are clearly defined in advance. The results arrange themselves mainly into system-dependent clusters with respect to target coverage, dose to OAR and whole body dose, and number of monitor units.

The presented methodology—together with the dosimetric verification part [10]—may turn out to be a valuable tool for the preparation and quality assurance of multi-centre studies of IMRT treatments.

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