ELSEVIER

Radiotherapy and Oncology 65 (2002) 53–70

RADIOTHERAPY & ONCOLOGY
JOURNAL OF THE EUROPEAN SOCIETY FOR THERAPEUTIC RADIOLOGY AND ONCOLOGY

www.elsevier.com/locate/radonline

Acceptance tests and quality control (QC) procedures for the clinical implementation of intensity modulated radiotherapy (IMRT) using inverse planning and the sliding window technique: experience from five radiotherapy departments

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Received 29 October 2001; received in revised form 2 July 2002; accepted 9 July 2002

Abstract

Background and purpose: An increasing number of radiotherapy centres is now aiming for clinical implementation of intensity modulated radiotherapy (IMRT), but – in contrast to conventional treatment – no national or international guidelines for commissioning of the treatment planning system (TPS) and acceptance tests of treatment equipment have yet been developed. This paper bundles the experience of five radiotherapy departments that have introduced IMRT into their clinical routine.

Methods and materials: The five radiotherapy departments are using similar configurations since they adopted the commercially available Varian solution for IMRT, regarding treatment planning as well as treatment delivery. All are using the sliding window technique. Different approaches towards the derivation of the multileaf collimator (MLC) parameters required for the configuration of the TPS are described. A description of the quality control procedures for the dynamic MLC, including their respective frequencies, is given. For the acceptance of the TPS for IMRT multiple quality control plans were developed on a variety of phantoms, testing the flexibility of the inverse planning modules to produce the desired dose pattern as well as assessing the accuracy of the dose calculation. Regarding patient treatment verification, all five centres perform dosimetric pre-treatment verification of the treatment fields, be it on a single field or on a total plan procedure. During the actual treatment, the primary focus is on patient positioning rather than dosimetry. Intracavitary in vivo measurements were performed in special cases.

Result and conclusion: The configurational MLC parameters obtained through different methods are not identical for all centres, but the observed variations have shown to be of no significant clinical relevance. The quality control (QC) procedures for the dMLC have not detected any discrepancies since their initiation, demonstrating the reliability of the MLC controller. The development of geometrically simple QC plans to test the inverse planning, the dynamic MLC modules and the final dose calculation has proven to be useful in pointing out the need to remodel the single pencil beam scatter kernels in some centres. The final correspondence between calculated and measured dose was found to be satisfactory by all centres, for QC test plans as well as for pre-treatment verification of clinical IMRT fields. An intercomparison of the man hours needed per patient plan verification reveals a substantial variation depending on the type of measurements performed.

Keywords: Intensity modulated radiotherapy; Acceptance tests; Quality control procedures; Inverse planning; Sliding window

1. Introduction

It is widely accepted that the clinical implementation of intensity modulated radiotherapy (IMRT) necessitates new and additional tests of treatment equipment, commissioning procedures and routine quality control procedures. The exact nature of these tests and procedures varies according to the method applied for IMRT implementation. Although fluence optimisation can also be obtained through forward planning, most attention has been focussed on inverse plan-

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0167-8140/02/$ - see front matter
PII: S0167-8140(02)00174-3

ning algorithms. For delivery of IMRT fields, the two main modalities available at present are the sliding window and the step and shoot technique. The former is referred to as dynamic since the collimator leaves are moving during the actual irradiation; the latter is denoted as static as the modulated fluence is obtained through subsequent delivery of multiple static segments. The first step in the commissioning procedure of a treatment planning system (TPS) is always verification of the basic beam data. If one then chooses for implementation of IMRT using inverse planning and the sliding window technique, essentially three additional quality control procedures are necessary.

– Quality control of the inverse planning (IP) module; These dedicated optimisation modules are linked to or integrated in existing treatment planning systems to obtain optimised fluence distributions according to user defined requirements on dose homogeneity in target volume and to constraints on critical organs.

– Quality control of the sequencer or leaf motion calculator; The optimised two-dimensional fluence matrices obtained with the IP modules need to be converted into motion of the leaf pairs. The thus produced actual fluence distributions should approximate the optimised fluence distributions to the best possible degree, taking the physical characteristics of the multileaf collimator (MLC) (leaf transmission, tongue and groove effect, rounded leaf end transmission, etc.) into account. This conversion is done by software modules called sequencers or leaf motion calculators. By using forward calculation it should subsequently be possible to calculate a final dose distribution from the actual fluence distributions, i.e. taking the specifications/limitations of the multileaf collimators into account.

– Quality control of the dynamic multileaf collimation; The leaf motion file drives the dynamic modules of the multileaf collimator to deliver the actual fluence distribution. Important parameters in the dynamic dose delivery process are the positional accuracy of the leaves and the accepted tolerance on the deviation between programmed and actual leaf position.

This paper describes the tests of treatment equipment and the quality control procedures developed over the last years in five radiotherapy departments that implemented IMRT using commercial software for inverse planning and the sliding window treatment modality. These departments have a similar configuration since they adopted the Varian solution for IMRT: the inverse planning software is the Helios® software which produces optimised fluence distributions and which is fully integrated in the treatment planning system Cadplan®.

Optimised, desired fluences are modified into actual, physically deliverable fluences by using a leaf motion calculator, also integrated in the Cadplan system. When an IMRT plan is exported to the VarisVision® record and verify (R&V) system, the leaf motion file produced by the leaf motion calculator is included for each IMRT field. At the treatment unit, the fields are automatically downloaded from the R&V system to the MLC controller. The latter ensures a real time verification as the leaf motion file drives the multileaf collimator in the dynamic mode.

The five radiotherapy departments encompass all treatment energies (6, 15, 18 and 20 MV), multileaf collimators (52, 80 and 120 leaves) and portal imaging devices available in the Varian assortment.

The aim of this paper is to present the results obtained at two levels.

Concerning the acceptance of the treatment planning system – focussing on the IP module, leaf motion calculator and subsequent dose calculation – each department has developed its own tests. Multiple phantoms have been prepared to run simple plans to explore the capabilities of the inverse planning modules in combination with the leaf motion calculator and to assess the accuracy of the dose calculations.

Secondly, at the level of quality control procedures the following topics are presented.

Quality control procedures of equipment in the five centres (daily QC, weekly QC, etc.), patient pre-treatment verification (film dosimetry, ionisation chamber measurements and portal imaging dosimetry) and finally patient treatment verifications. An analysis and comparison of these quality control procedures is presented.

2. Material and methods

2.1. IMRT equipment at all five facilities

An overview of the equipment used for IMRT verification and treatment in the five facilities is displayed in Table 1. All linacs are Varian units, equipped with the different existing multileaf collimators and different electronic portal imagers (EPIDs). In most centres, the contouring platform for radiation oncologists is SomaVision®, linked to Cadplan® for planning purposes; the Helios® software for inverse planning is integrated into Cadplan. Record and verify functions are performed by VarisVision®, connected to Cadplan and to the treatment units. Regarding QC equipment, common to all centres are the use of verification films (Kodak X-Omat® and EC® verification films) for relative dosimetry and the use of ionisation chambers for absolute dosimetry. Centre specific dose detectors include thermoluminiscent detectors (TLD's), linear ionisation chamber arrays (1D and 2D), polymeric gel (BANG®) and a liquid filled EPID equipped with an acquisition mode for dynamic dose delivery.

2.2. The Helios inverse planning modules and leaf motion calculator

The optimum field fluences are calculated by the inverse planning algorithm originally developed at the Memorial Sloan Kettering Cancer Centre (MSKCC) [17,18]. Forward dose calculation is done by the photon single pencil beam

Table 1
Overview of equipment for IMRT treatment delivery and verification in the five different departments

Department	Leuven	Berlin	Helsinki	Reggio Emilia	Copenhagen
Treatment unit incl. MLC type available energy and EPID	Clinac 2100C/D 80 leaf MLC 6 MV, 18 MV Portal Vision (Mark2, replaced by aS500 in July 2001)	Clinac 2300C/D Clinac 2100C/D 52 leaf MLC 6 MV and 20 MV Portal Vision (Mark2)	Clinac 2100C/D 120 leaf MLC 6 MV and 18 MV Portal Vision (Mark 2)	Clinac 600C/D 80 leaf MLC 6 MV Portal Vision (Mark2)	Clinac 2300C/D 120 leaf MLC 6 MV and 18 MV Portal Vision (aS500)
		Clinac 600C/D 52 leaf MLC 6 MV Portal Vision (Mark2)	Clinac 600C/D 80 leaf MLC 6 MV Portal Vision (Mark 2)	Clinac 2100C/D 120 leaf MLC 6 MV and 18 MV Portal Vision (aS500)	
Absolute dosimetry					
Single ionisation chambers	NE 2571 PTW 31002 (0.125 cm^3)	PTW 31002 (0.125 cm^3) PTW 31003 (0.33 cm^3)	NE 2571 Wellhöfer IC15 (0.13 cm^3)	PTW 31002 (0.125 cm^3) PTW Pin Point (0.015 cm3) NE 2571 Scanditronix RK (0.125 cm^3)	NE 2571
Ionisation chamber array	–	–	Wellhöfer 23IC array	1D PTW LA48 2D PTW 256	
Solid state detectors	–	PTW diamond detector (TM60003, 6.1 mm^3)	–	PTW p diode (1 mm^3) Scanditronics p diode (shielded) PTW diamond detector (TM60003, 6.1 mm^3)	
TLD	–	–	Rados Dosacus automatic reader ($Li_2B_4O_7$ TLD pellets)	–	Harshaw LiF TLD rods and chips + Harshaw5500 Reader
EPID	Transit Dosimetry Software on Mark2 and aS500	–	–	–	
Polymeric gel	–	BANG gel	–	–	
Relative dosimetry					
Film Filmscanner	X-Omat Verification films (Kodak) Vidar XR12	X-Omat Verification films (Kodak) Lumisys Luniscan 50	X-Omat Verification films (Kodak) Vidar XR10	X-Omat Verification films (Kodak) Vidar VXR12 Plus	EC Verification film (Kodak) Vidar VXR12 Plus

model developed by Storchi et al. [19,20]. The optimisation process uses the conjugate gradient method [18], stabilised by removing the possibility of negative dosage. The objectives of optimisation are specified as dose-volume constraints on the different organs or structures, with relative weights being assigned to each of the individual constraints. Whether a volume is defined as a target volume or as an organ at risk is solely dependent on the way the dose-volume constraints are specified, thus allowing multiple targets into the optimisation routine. Helios allows only soft constraints, i.e. all constraints may be violated albeit with a penalty attached [11]. The inhomogeneity correction factors taking the electron densities into account are calculated by means of the modified Batho power law [3].

Once the optimal field fluences have been established, the leaf motion calculator (LMC) converts the fluences into leaf motions. Although having undergone several modifications (regarding, e.g. reduction of treatment time and dose delivery in areas of low dose), the LMC modules are based on the original work of Haas et al. [9,10].Cadplan/Helios supports two techniques for the dose delivery of an IMRT treatment: the sliding window technique and the multiple static segments technique. All five centres have opted for the sliding window technique. When calculating the leaf motions, the LMC takes into account the leaf transmission as well as the leakage through the rounded leaf edges of the Varian MLC. Compensation for the latter is approximated by shifting the leaf pairs closer together over a distance referred to as the dosimetric leaf separation [14]. Additionally, a minimum leaf gap is defined in the MLC configuration setting the minimum separation between opposing, moving leaves at all times during the treatment. This parameter has been introduced to avoid leaf collisions and reduce motor wear. When the minimum leaf separation inhibits the required narrowing of the leaf separation by the dosimetric leaf separation, the rounded leaf edges can not be compensated for but are taken into account into the calculation of the actual fluence. The tongue and groove effect is not accounted for [8] since priority is given to minimise the treatment time rather than to synchronise leaf motions. With the leaf motion pattern established, the actual fluence distribution is automatically calculated, taking into account the above mentioned MLC characteristics. The dose distribution in the phantom/patient is subsequently derived from these actual fluence distributions by using forward calculation. If needed, static beams can also be added in the forward calculation. The influence of the static beams, however, is not taken into consideration during inverse planning.

2.3. Configurational MLC parameter derivation

To derive the leaf transmission and the dosimetric leaf separation requested in the TPS configuration, two fundamentally different approaches can be used. Firstly, the values are derived through measurement of the physical characteristics of the MLC, independent of the TPS. Alternatively, parameter values can be fitted for which the correspondence between measurement and TPS dose calculation is optimal. Combining the results of both approaches gives insight into the question whether the TPS describes the dose distribution sufficiently accurate with the independently derived physical characteristics.

In the first approach, similar measurements have been performed in all five centres. The average leaf transmission was measured for all energies as the ratio of the dose delivered through fully closed and fully opened static MLC fields. The five centres used a variety of field sizes and measured the leaf transmission at different depths. When relying on point dose measurements, averaging over inter- and intraleaf transmission is obtained by the use of large diameter ionisation chambers (e.g. NE2571) or measurement at multiple off-axis positions, perpendicular to the direction of leaf motion. In Leuven and Copenhagen, the average leaf transmission was also determined from statistical analysis on the ratio of two-dimensional absolute dose distributions for both treatment energies acquired by means of the EPID (with a total of 2.8 cm build-up) and film (with 3 cm build-up), respectively.

In Leuven, the dosimetric leaf separation was measured as described by LoSasso et al. [14], i.e. through extrapolation to zero dose of the dose versus field size, defined by the MLC. In Berlin and in Copenhagen, a sweeping gap method was developed: several dynamic MLC motion files were created to force all leaf pairs to move with a fixed gap and constant velocity over the field. The gap width was varied between 0.01 and 0.2 cm. For each dMLC field, the monitor units were adjusted to keep the absolute velocity constant. For each dynamic field, the dose was determined in air by means of an ionisation chamber or diamond detector, with sufficient build-up, positioned free at the isocentre. The dosimetric leaf separation was then determined by extrapolation of the chamber reading (corrected for leaf transmission) versus leaf gap to zero chamber reading. In Reggio Emilia, the methods proposed by Arnfield et al. [2] and LoSasso et al. were both used. In addition, as described by Klein et al. [12], a single film was irradiated with a static field in which different leaf gaps were set ranging between 1.4 and 2.8 mm. The dosimetric leaf separation can be derived through extrapolation (to zero gap) of the line profile through the middle of the various leaf pairs. In Helsinki, no direct measurement of the physical dosimetric leaf separation was performed.

In addition to the above described tests, optimal numerical values for the MLC configuration can be derived through comparison of calculated versus measured dose for different MLC parameter values. For this purpose, special IMRT plans can be created to easily detect the discrepancies between measurement and TPS in case of sub-optimal MLC parameter values. As an example, a test was developed in which the optimisation software was requested to produce a uniform, low dose delivery

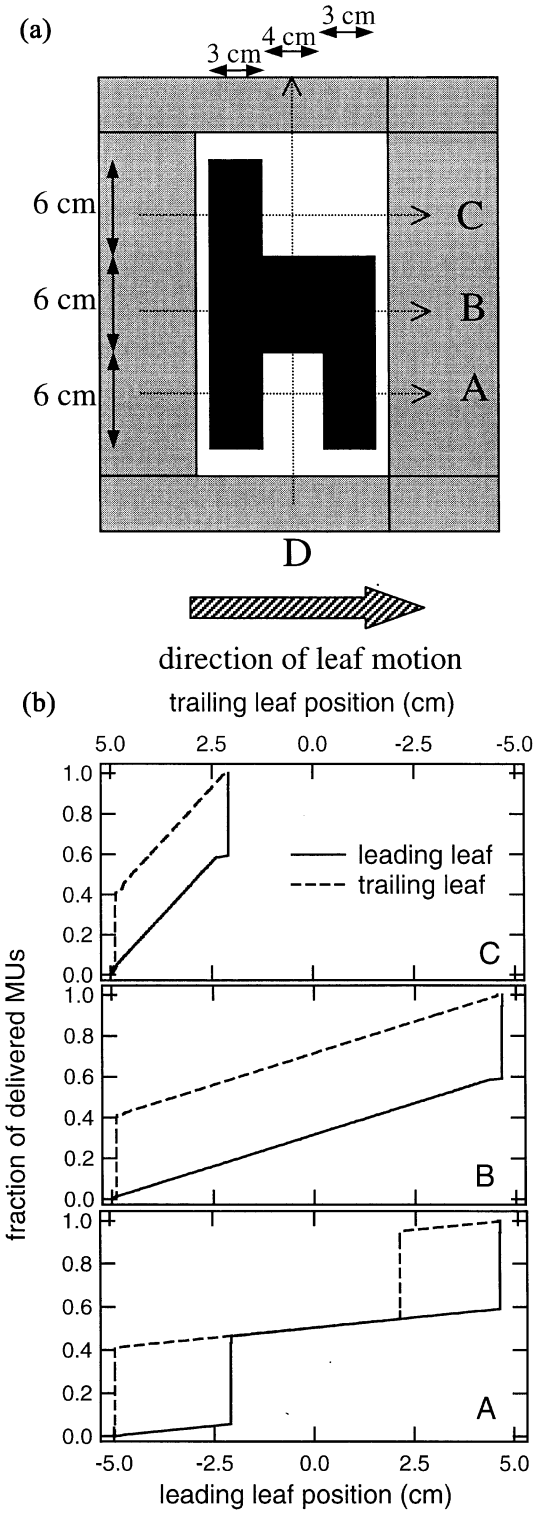

Fig. 1. (a) Schematic representation of the artificially created chair-like optimal fluence matrix. Dimensions are defined at isocentre and the direction of leaf motion is indicated by the large arrow. Also indicated are arrows along which line profiles (A–D) are extracted for analysis of the MLC parameters. The main collimator blocks are represented in grey, the area of zero optimal fluence is left blank while the black chair characterises an homogeneous optimal fluence (equal to unity). (b) Movement tracks of the leaf pairs along the lines A–C (derived for a leaf transmission of 1.5% and dosimetric leaf separation of 1.5 mm).

through a single dynamic field on a rectangular phantom (Berlin). Hence, the dLMC is forced to create a leaf motion plan delivering the dose through a constant, narrow opening between opposed leaves. By comparing the calculated versus delivered absolute dose (e.g. on the beam axis), the MLC parameter values are tested for their adequateness. However, as this test does not separate the impact of leaf transmission from dosimetric leaf separation, the transmission value as derived through measurement is kept constant and only the dosimetric leaf separation is modified. To be able to separate both effects in a single test and to have better control over the final leaf motion, eliminating the influence of the actual optimisation algorithm, an alternative test was designed in Leuven. Because it is not possible for the standard user to program a leaf motion file and have the TPS calculate the resulting dose distribution, an artificial optimised fluence matrix was created to force the leaf motion calculator into a well synchronised movement pattern. The optimised fluence matrix is illustrated in Fig. 1, with the direction of leaf motion as indicated in the figure. The chair-like fluence can be divided into three main zones: in the upper area (characterised by line profile C), the back of the chair is transferred into dose through synchronous movement of the upper leaf pairs, while the zero dose region in the optimised fluence is transformed into an actual fluence purely corresponding to leaf transmission since this area is at all times covered by the leaves of the right MLC carriage. The intent of the central part (encompassing line profile B) is to create an area of homogeneous dose for accurate absolute dose verification with, e.g. an ionisation chamber. In the lowest part, the zero fluence in between the legs of the chair will force the leaves to move over this area at maximum speed and with minimal leaf gap (i.e. 0.05 cm), to enforce minimal dose delivery regardless of the configurational values for leaf transmission and dosimetric leaf separation. The movement tracks of a leaf pair in each area is given in Fig. 1b (derived for a leaf transmission of 1.5% and a dosimetric leaf separation of 1.5 mm). The actual fluence will be a composite of leaf transmission and leakage through the leaf opening. At minimal leaf gap, any inaccuracies connected to the modelling of the rounded leaf ends, will be at its largest. Modification of the MLC configuration parameters will not alter the motion of the leaves over both zero dose areas in the optimal fluence, but will result in a different actual fluence, affecting the calculated dose. Through comparison of calculated versus measured dose for different MLC parameter values, optimal values can be defined. In the Leuven measurements, leaf transmission and dosimetric leaf separation were varied from 1 to 3% and from 1.5 to 3 mm, respectively. These 'chair' measurements were performed with film in a multipurpose phantom [5] at different depths (3, 10 and 20 cm). Additional ionisation chamber measurements (NE 2571) on the beam axis provided absolute dose data, used to convert the film measurements from relative to absolute dose profiles.

2.4. Acceptance of Helios/Cadplan

2.4.1. QC test plans

In all centres, various QC IMRT-plans were developed on different phantoms to assess the capability of Helios to produce requested dose patterns and to verify the accuracy of the dose calculation. An example is shown in Fig. 2, showing thin rectangular target volumes as drawn in Leuven onto the CT images of the multipurpose phantom [5]. The corresponding dose demands are indicated for all target volumes, the constraints entered into the optimisation module were a maximum and minimum dose of the prescribed dose $\pm 1\%$, respectively, with identical weights attached to all constraints. Plan (a) was designed to produce different but homogeneous doses to three adjacent target volumes at the same depth while plan (b) aims to produce the same (homogeneous) dose to three different target volumes at different depths. Plans (c) and (d) probe the capability of the TPS to account for oblique surfaces and heterogeneities (air and cork), respectively. The straightforward geometry of the plans allows easy dosimetric analysis through extraction of line profiles, making verification less susceptible to slight positional mismatches between film and TPS. Film measurements (Kodak X-omat verification films) were performed in a plane perpendicular to the beam axis, at a depth of 10 cm in the phantom (except for plan (c) where the depth on the beam axis is 6.7 cm), and compared to TPS calculations in the plane of measurement. The investigation was initially done in Leuven for 6 and 18 MV radiation beams. Subsequently, plan (a) was reproduced in the other centres for intercomparison.

Different QC plans were developed in Reggio Emilia (Fig. 3) based on single or multiple bars (of varying widths and separated from each other at distances of 2–30 mm), simulating alternating target volumes with critical structures in between. These target volumes and critical organs were

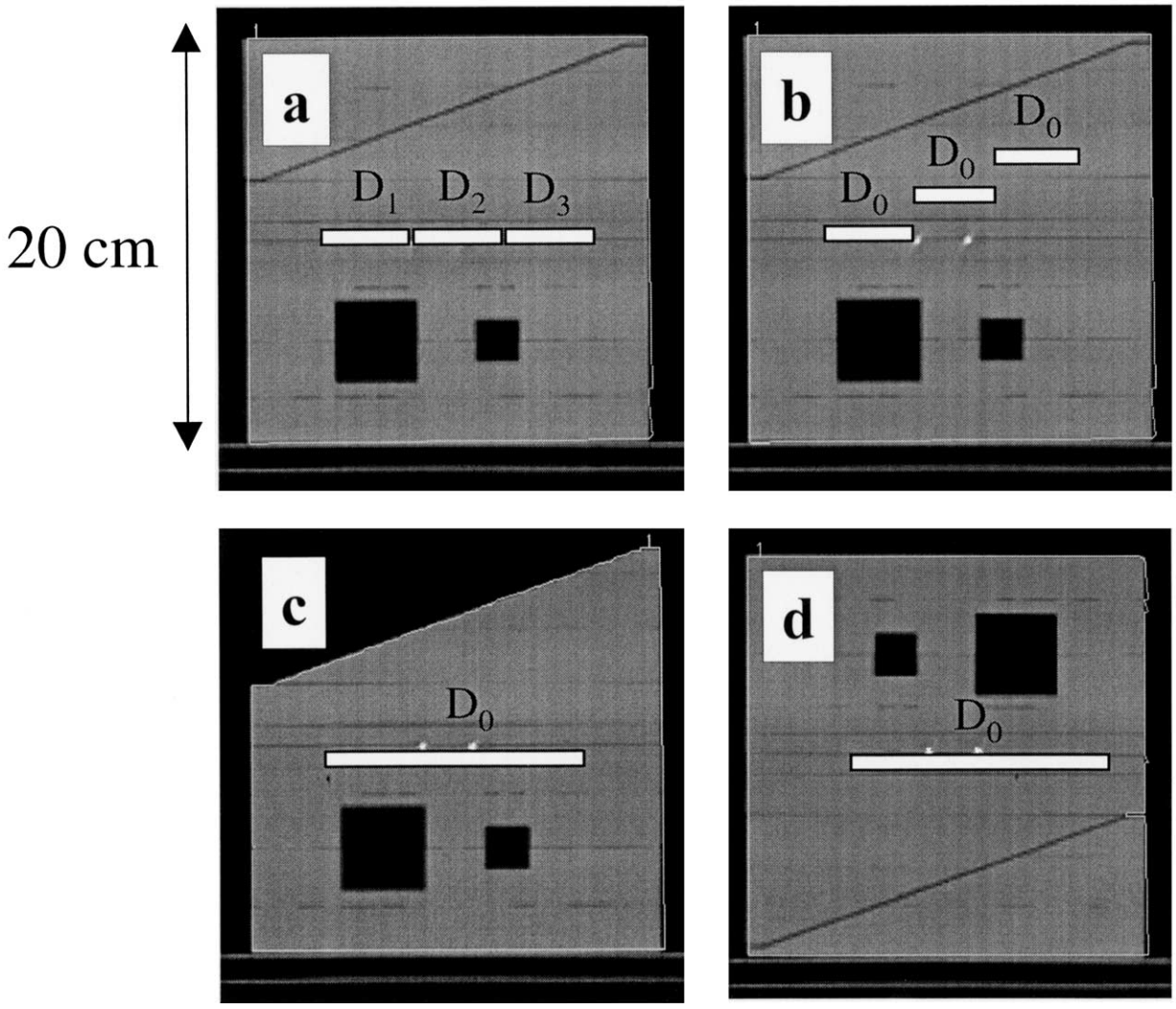

Fig. 2. CT image of the multipurpose phantom in different set-ups as used for the development of IMRT QA test plans in Leuven. The dose demands per fraction on the rectangular target volumes as drawn onto the different CT images are set to (a) $0.99 < D_1 < 1.01$, $1.98 < D_2 < 2.02$ and $2.97 < D_3 < 3.03$ Gy; and for (b), (c) and (d) $1.98 < D_0 < 2.02$ Gy. Identical weights are assigned to the minimum and maximum dose constraint.

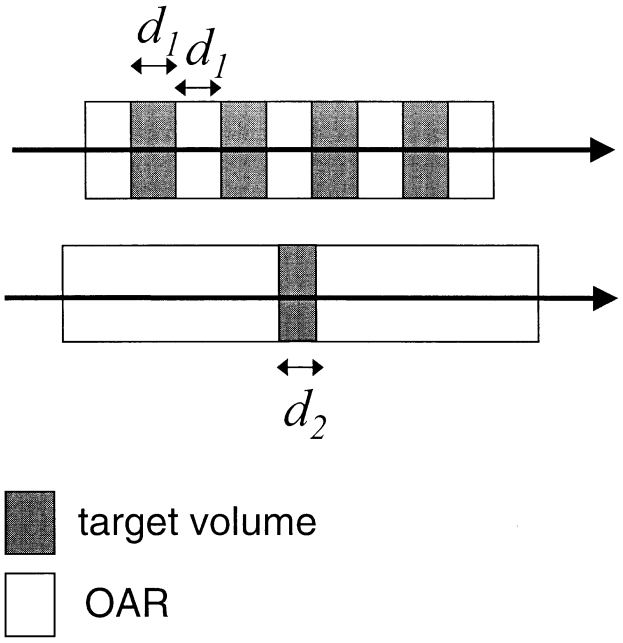

Fig. 3. Schematic outline of the definition of target volumes and organs at risk as developed in Reggio Emilia. The arrow indicated the direction of leaf movement. Different widths and separations were used ($d_1 = 0.5$, 1 and 2 cm) for the alternating volumes. The single target volumes were optimised for target widths $d_2 = 0.2$, 0.5, 1 and 2 cm.

drawn into a poly(methyl methacrylate) (PMMA) phantom at depths of 5, 10 and 20 cm. After optimisation, dose calculation was compared to film measurement in the PMMA phantom.

The Cadplan/Helios acceptance in Copenhagen was carried out by means of film and TLD measurements in a solid water phantom (Gammex RMI) consisting of six slabs of $30 \times 30 \times 2$ cm^3 and five slabs of 2 mm thickness each. In each 2-mm slab, sixteen holes were drilled in a 6×6 cm^2 matrix to contain a total of 80 TLD chips (LiF (Harshaw), 1 mm thickness, 5 mm diameter). A series of test plans were produced; to determine the homogeneity of IMRT delivery with multiple beams, cubic shaped volumes were defined and assigned different doses. Films were positioned perpendicular to the beam axis and the relative dose distribution was verified for each field separately by means of line profiles. Subsequently, the full treatment plan was delivered to the phantom containing the TLD's probing the homogeneity of the dose delivery. Absolute point dose measurements were also compared to the point doses reported by the TPS.

2.4.2. Clinical test plans

Following the artificial tests, designed to focus on specific optimisation, dosimetric problems using extreme geometries and/or dose constraints, more clinical configurations were tested.

Dosimetric checks on single fields exported from hypothetical patient plans onto home made phantoms (as described in the above paragraph) have been performed in all centres, either with TLD's, solid state detectors, ionisation chamber inserts and/or film. In Helsinki and Reggio Emilia, measurements with ionisation chamber arrays were performed in water phantoms.

Clinical treatments were simulated on an Alderson phantom in Berlin and Helsinki. The simultaneous modulated accelerated radiotherapy (SMART) prostate treatment technique as simulated in Berlin, is described in detail in ref. [4]. Relative dose distributions were measured with film placed between the Alderson slices and compared to TPS calculations in each slice. In Helsinki, absolute point dose measurements were performed for a similar test on an Alderson phantom loaded with TLD's. In Reggio Emilia, similar tests were done using a geometrical cubic and cylindrical (head & neck phantom PTW 40014-40015) solid-water phantom with film placed between the slabs or with a 1D linear array inside (LA48).

Full three dimensional dosimetric verification was performed by means of BANG polymeric gel in Berlin: a complex seven field naso-pharyngeal IMRT treatment plan was made, treated and measured on the cylindrically shaped gel phantom [13].

2.5. Quality control procedures of the dynamic MLC

In all five facilities, the protocols for quality control of the dynamic MLC are based on the tests described by Chui [6] and LoSasso [14]. Some of the tests have undergone slight modifications and additional tests have been developed.

As a routine quality check on the positional accuracy of the leaves, several tests have been selected. The choice of test as well as the frequency with which each is performed in the different centres, are outlined in Table 2.

2.5.1. Sweeping gap test

An important test, as described by LoSasso et al. [14], consists of a sweeping gap of 0.5 cm creating a uniform dynamic field of 10×10 cm^2. With the ion chamber placed on the beam axis, LoSasso et al. state that variations of less than 0.1 mm in the gap width of the central leaf pair can be intercepted; a positional difference of 0.04 mm results in a difference of 1% in dose delivery. To exclude variations of an origin other than a varying gap width, the measured dose is normalised to the dose measured for a static 10×10 cm^2 field. This test is performed at a gantry angle of 0° as well as 90° to check the possible effect of gravity.

2.5.2. Fence test

Since the ionisation chamber measurement is not sensitive to variations of gap width at a distance of more than ± 2 cm from the measurement point, a second test is performed in which the alignment of the outside leaf pairs with respect to the central leaf pairs can be verified. In this second test, all leaf pairs move simultaneously at constant speed creating a low uniform background. Leaf stops during irradiation

Table 2
Overview of the tests included in the protocols for QA of the dMLC and the frequency with which each test is performed in the different departments

MLC adjustment	Leuven	Berlin	Helsinki	Reggio Emilia	Copenhagen
	During maintenance	During maintenance	During maintenance	During maintenance	During maintenance
Sweeping gap: → Positional accuracy of central leaf pairs	Weekly at gantry 0° and 90° (ion chamber in daily block)	Three monthly at gantry 0°, 270° and 90°)	Weekly at gantry 0° (ion chamber in daily block)	Daily at gantry 0° monthly at gantry 0°, 90° and 270° (LA 48 in PMMA phantom)	–
Fence test: → Alignment of all leaf pairs	Weekly (EPID) 6 weekly (film)	Weekly (film)	Weekly (film)	Daily (film)	Six weekly or before new treatment start (film)
Stepwise dose delivery: → Stability of leaf speed	Six weekly (film)	Three monthly	Two monthly	Three monthly (film, use of 2D array in progress)	Six weekly or before new treatment start (film)
Stepwise dose delivery with beam interrupts: → Effect of acceleration and deceleration	Six weekly (film)	Three monthly	Two monthly	Three monthly (film, use of 2D array in progress)	Six weekly or before new treatment start (film)

are inserted at predefined positions creating lines of increased dose. If leaf positions are accurately aligned, the resulting dose pattern will have a fence-like appearance, showing dark lines regularly placed at equal distances over a light background. A positional error of 0.2 mm (or more) can visually be detected on film as an irregularity in the dark lines. Although the test was originally intended to be performed by means of a photographic film, for the weekly check Leuven makes use of the liquid filled portal imager in dosimetric mode [21]: the acquired dosimetric image is immediately subtracted from a carefully verified reference image, detecting anomalies of the same magnitude as can be visually intercepted on film. Although the use of the portal imager considerably reduces the time required to perform this test, the size of the imaging plane limits the test to a field span of 30 cm at isocentre, thus excluding the outer five leaves at both ends of the MLC carriage. Therefore, during extensive quality control of the linac, the above test is performed by means of a film, visualising all leaves. The same approach is adopted in Reggio Emilia by means of a 2D array of ionisation chambers.

2.5.3. Stepwise dose delivery test

In all centres, an additional check focussing on the stability of the leaf speed is performed on a regular basis. During this test, described by Chui et al. [6], all leaf pairs move with a constant but different speed, generating a stepwise dose delivery of well defined intensity levels. The effect of acceleration and deceleration is verified by running the same test while enforcing beam interrupts during delivery. The resulting dose profiles are queried for irregularities resulting from the beam interrupts.

2.6. Patient treatment verification

2.6.1. Pre-treatment verification

For pre-treatment verification of IMRT with the Varian solution two new tools are presently available in the TPS.

(A) Firstly, Cadplan offers the possibility to import IMRT fields from a patient plan onto a phantom. The dose distribution in any plane of the phantom can subsequently be calculated and exported in ASCII format, allowing comparison with measured data in data processing software. All five centres made use of this tool to perform treatment verification prior to the first treatment session.

Each IMRT field in the patient plan is imported onto a phantom (be it a specially designed polystyrene rectangular phantom, a stack of polystyrene or solid water slices or a water phantom) and the normalisation of this single field test plan is such that the monitor units are identical to those of the corresponding field in the original patient plan. The dose calculated in the plane of measurement is extracted from the TPS, either through point doses, line profiles or two dimensional dose matrices, and compared to the acquired data, either through point dose measurements (ionisation chambers, TLDs, diodes and diamond detectors), one- and two-dimensional ionisation chamber array measurements or film irradiation.

The actual evaluation of the QC data is centre specific, depending on the used measurement method. In Berlin, the absolute dose is verified by an ionisation chamber (0.125 cm^3, PTW 31002) measurement positioned in some homogeneous part of the IMRT dose distribution. The relative dose distribution obtained with film is evaluated by means of isodose overlays and calculation of the so-called gamma-index [15]: acceptance criteria of 3% dose difference and 2 mm distance to agreement are adopted.

A near identical approach is used in Leuven, except that the absolute point dose measurement is always performed on the beam axis, regardless of whether or not this is a high gradient and/or low dose area; two orthogonal line profiles through the isocentre are routinely extracted for comparison.

In Helsinki, the absolute dose verification concerns two orthogonal line profiles, determined by means of the linear ionisation chamber array (CA24, Wellhöfer) in a water phantom at a depth of 5 cm. Additionally, a two dimensional verification is done through visual comparison of an acquired film versus the optimised fluence file.

Pre-treatment verification in Reggio Emilia encompasses film and ionisation chamber array (1D or 2D) measurements in a solid water phantom. Both measurements are compared with the planar dose distribution calculated by the TPS, using commercial software to match isodose shape and shift (RIT113 or PTW Verisoft). Intensity modulated fields of high complexity, i.e. containing multiple high dose gradient areas, are double-checked in a water phantom by means of solid state detectors (a p-type diode or a diamond chamber) in a water phantom; one line profile along the trajectory of one leaf pair is measured. The acceptance criteria were set at 3% dose difference in uniform dose regions and 3 mm distance to agreement in high gradient regions.

Only in Copenhagen, the complete treatment plan is transferred to a solid water phantom to verify the summed up dose distribution by means of 80 TLD's placed into the phantom. Additionally, individual field checks are performed by means of film.

(B) As a second tool for pre-treatment verification, the TPS offers the possibility to predict the portal dose distribution at the level of the portal film or EPID, using the model developed by Pasma et al. [16]. These new modules in Cadplan have been tested in Leuven. In parallel to the above described method, the intensity modulated fields were also delivered to the portal imager without a patient or phantom in between. The images were acquired with a dosimetric acquisition mode especially designed for this purpose, as described in [21]. A polystyrene build-up plate of 2 cm thickness was placed on top of the detector housing, providing a total of 2.8 cm water equivalent build-up (including the build-up inherent to the detector housing). The acquired data are compared to the predicted portal dose images, calculated at a water equivalent depth of 2.8

mm. Hence, two dimensional absolute verification can be performed. All measurements are performed at a gantry angle of 0°. Although gravitational effects on the positioning of the leaves are thus not included, the verification becomes not only faster, but also more accurate since bulging of the liquid need not be corrected for.

Regarding the delivery of the pre-treatment verification fields, in Leuven, Berlin and Helsinki the complete treatment plan is exported from the TPS to the patient record in the R&V system and delivered as such at the linac (permitting only overrides on the table parameters and the gantry angle). For this purpose, extra treatment sessions not accumulating any dose to the target volume(s) are scheduled. The actual treatment scheduling for the patient is done once the dynamic dose delivery has been approved. Hence, the dosimetric field verification inherently implies verification of the data transfer. In Reggio Emilia, the leaf motion files are extracted from the TPS and R&V database, respectively, and transferred to the linac, where they are delivered with the correct amount of MUs and the jaw settings as in the treatment plan, but bypassing the R&V system.

2.6.2. Treatment verification

In all five centres, verification during the actual treatment mostly focuses on patient positioning.

In Berlin, Leuven and Reggio Emilia, two orthogonal static fields (6 MV) are used to check the positioning of the patient daily: prior to the delivery of the intensity modulated fields, the bony structures are verified with respect to the field outline through comparison of a reference digitally reconstructed radiograph (DRR) and a portal image. While in Berlin this verification is performed by a radiation oncologist, in Leuven and Reggio Emilia, it is the responsibility of the radiographer to acquire and to evaluate the measurement. Automatic matching tools available in the Vision environment are used to optimise this procedure. These fields are only delivered with a minimum amount of dose (typically 5 MUs for a liquid filled (Mark2) EPID to minimise their effect on the dose distribution, 2 MU for an aSi (aS500) EPID).

In Leuven and Berlin, the patient is repositioned before IMRT delivery if positional deviations exceed 5 mm in lateral, vertical or longitudinal direction. Positional deviations are stored over the course of the treatment within the Vision database, allowing a post-treatment evaluation of the actual delivery.

Positioning of the patients in Berlin and Helsinki is weekly verified at the simulator using two orthogonal films: deviations exceeding 3 mm are corrected for.

The procedures for patient set-up verification in Reggio Emilia are site-dependent. For eye treatments with IMRT, set-up is verified on the simulator three times on 3 consecutive days, before the actual treatment initiation. Subsequently, the positional accuracy is verified three times during the first treatment week. Deviations smaller than 1.5 mm are not corrected for. During prostate, breast and head & neck IMRT treatments, orthogonal set-up images are acquired thrice during the first treatment week and twice a week during the rest of the treatment. Tolerance levels are 5 mm for prostate and breast patients, while 3 mm accuracy is requested for the head & neck patient set-up. As an additional treatment verification procedure in Reggio Emilia, the dynamic log files created by the dMLC controller at the end of every IMRT field delivery, are analysed. These log files contain the actual and planned leaf position for every leaf and at all times during the treatment. Dynamic log file analysis is performed for only one IMRT field per patient daily, alternating fields in order to verify each field on a regular basis. The daily acquired log file is compared to the log file generated during pre-treatment verification.

In two centres, additional focus goes to dosimetric verification.

In Leuven, 2D dosimetric measurements during the actual treatment are performed by means of the EPID. The daily acquired dose distributions are compared to the corresponding portal dose distribution, calculated by the TPS. Furthermore, their reproducibility over the course of the treatment is investigated.

In Copenhagen, in vivo dose verification of IMRT is performed on all head and neck patients. Before treatment, a naso-oesophageal tube (Maersk Medical A/S) is inserted as deep as needed to extend across the treatment volume and a CT-scan is acquired to accurately mark the position of the tube. During treatment, cylindrical TLD rods of 6×1 mm are placed into the tube. Immediately after treatment, orthogonal images are made at the simulator to verify the position of each TLD. Corresponding point doses are extracted from the TPS and compared to the measurements

3. Results

3.1. Configurational parameters in the Helios inverse planning modules and leaf motion calculator

The final values for the MLC characteristics as used by the five centres are displayed in Table 3, also including other relevant configurational parameters. Using these parameter settings, all centres obtain satisfactory absolute and relative dosimetric accuracy (e.g. a dose difference of 3 % and distance to agreement of 2 mm) as will be demonstrated in Sections 3.2 and 3.4.

As an example to use test fluences to assess configurational parameters, measured profiles from the chair like optimal fluence is shown in Fig. 4. Optimal agreement between calculation and measurement in absolute as well as relative terms is obtained for an average leaf transmission of 1.8%, in combination with a dosimetric leaf separation of 2.0 mm. The largest deviation for the absolute dose on the beam axis within the span of the used parameter values was 3.7%, observed for 3% transmission and 3 mm dosimetric

Table 3
Configurational MLC parameters as used in the different departments

	Leuven	Berlin	Helsinki	Reggio Emilia	Copenhagen
Leaf transmission (%)	1.8 (for 6 and 18 MV)	1.8 (for 6 and 20 MV)	1.5 (for 6 MV) 1.6 (for 18 MV)	1.75 (for 6 MV)	1.7 (for 6 and 18 MV)
Dosimetric leaf separation (mm)	2 (for 6 and 18 MV)	2.6 (for 6 and 20 MV)	1.9 (for 6 and 18 MV)	2 (for 6 MV)	2.5 (for 6 and 18 MV)
Minimum leaf gap (mm)	0.5	0.5	1.0	0.5	0.6
Maximum leaf speed (mm/s)	20	25	20	20	25
Dose rate (MU/min)	300	200 (for CLINAC 600C/D) 600 (for CLINAC2100 and 2300C/D)	200 (for CLINAC 600C/D) 400 (for CLINAC2100C/D)	400	300

leaf separation. It is important to note that the calculations were performed with the modified scatter kernels rather than with the original scatter kernels as derived from the beam profiles, as will be discussed in the successive paragraph, describing the acceptance of the Helios/Cadplan system.

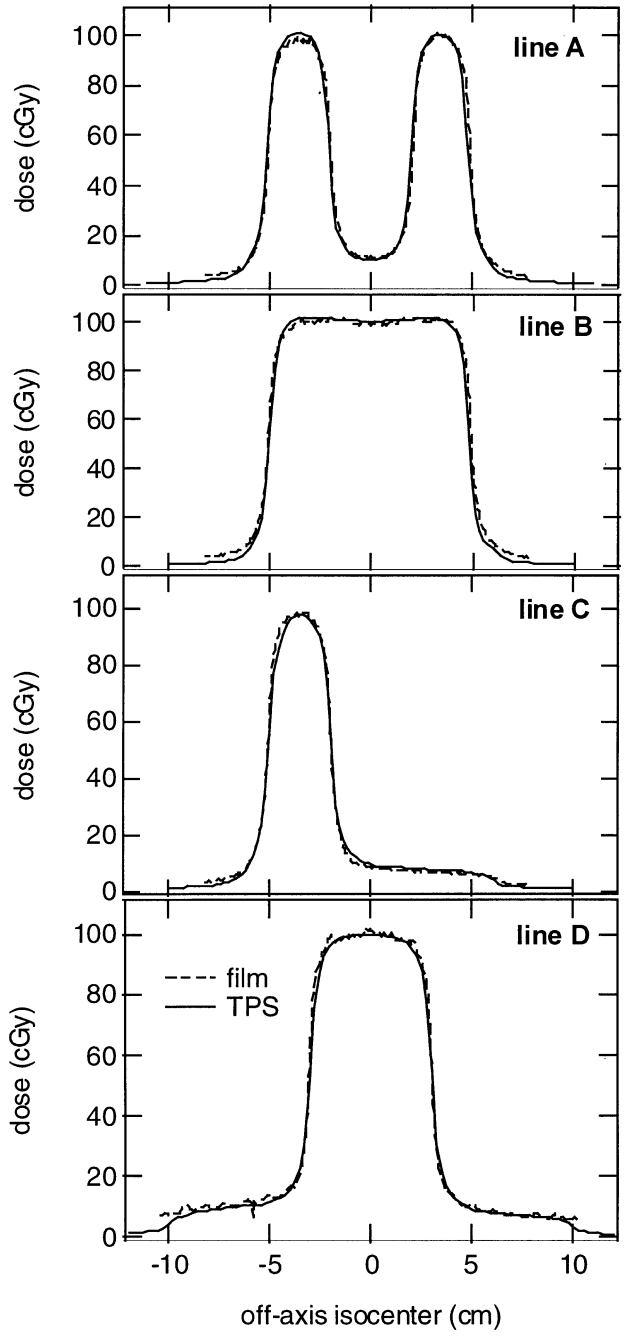

Fig. 4. Comparison between film measurements – rescaled to absolute dose values by means of an ionisation chamber measurement at isocentre – and line profiles calculated along the lines indicated in Fig. 1. The displayed data are those for which the agreement between calculation and measurement was found to be optimal, i.e. for an average leaf transmission of 1.8% and a dosimetric leaf separation of 2.0 mm (Leuven).

3.2. Acceptance of the TPS

3.2.1. QC test plans

Results on the four QC plans developed in Leuven reveal that, although the inverse planning system corrects well for different depths, oblique surfaces and heterogeneities, local peaks of overdosage (10–20%) occurred in all measured line profiles while unreported by the planning system. Large discrepancies are primarily situated near steep dose gradients. This is illustrated in Fig. 5 for the QC plan delivering different doses to adjacent rectangular target volumes as outlined in Fig. 2(a). Similar effects were obtained in all five radiotherapy departments: although the deviations were large in Leuven and Reggio Emilia, they were acceptable in Berlin and quite small in Helsinki. The reason behind the discrepancies between measurement and calculation was found to lie in the centre specific scatter kernels used for dose calculation by means of the single pencil beam model [20]. The scatter kernels are derived through deconvolution of the configurational beam profile data, measured for different field sizes at five different depths. The penumbra of the measured beam is broadened because of the ionisation chamber diameter. This is subsequently translated into a broadening of the single pencil beam scatter kernel. Although the thus produced kernels are usually satisfactory for static beam delivery, they can be inadequate for calculating dose distributions out of intensity modulated fluencies. Moreover, since the single pencil beam model is used by the Helios modules during plan optimisation as well as during the final dose calculation by Cadplan, inadequate conversion from fluence to dose at high dose gradients not only fails to report on dose peaks, it actually forces the

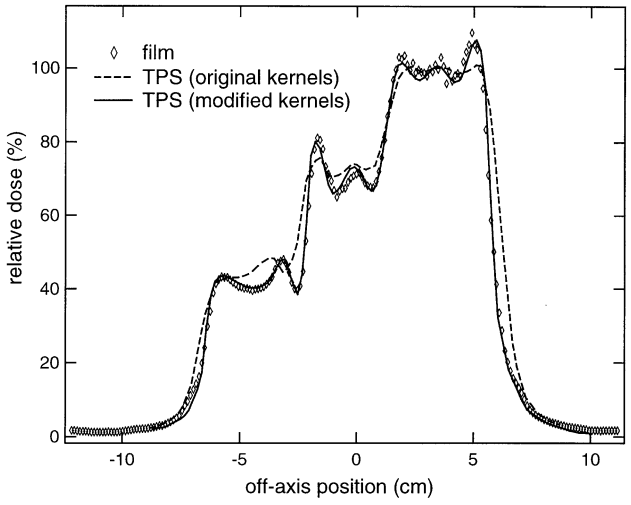

Fig. 5. Results on the QA test plan outlined in Fig. 2(a) (Leuven). The dashed line is the line profile calculated by the TPS by means of the original single pencil beam kernels, showing significant disagreement with the film measurement (symbols). The solid line displays the line profile recalculated by the TPS by means of the modified kernels (without re-running the optimisation algorithm).

inverse planning algorithm to produce erroneously high peaks in the optimal fluence distribution.

Therefore, in Leuven the original scatter kernels were iteratively altered until the recalculated dose distribution (without re-optimisation, i.e. based on the same leaf motion file and corresponding actual fluence distribution) converged to the measurement. This procedure was repeated at different depths and for both energies. The convergence was evaluated by means of the QC plan displayed in Fig. 1(a). A line profile extracted from the dose distribution recalculated with the modified kernels is superimposed on the original calculation and measurement in Fig. 5. Reoptimisation of all QC plans with the modified kernels shows an enhanced homogeneity in the actual delivery as compared to the results obtained with the original scatter kernels. More specifically, the dose overshoot at the edges of the target volumes is decreased, although not entirely eliminated. (This characteristic has been removed in the currently available Helios version (6.3.5) through the use of smoothening filters in the optimisation algorithm, resulting in an enhanced dose homogeneity in the target volume.) Additionally, comparison of calculation versus measurement for small static open fields exhibits improvement when the modified kernels are used during calculation. The reverse approach was used in Reggio Emilia, optimising the kernels on small static fields, independent of the Helios configurational parameters. Profiles were measured for small static field (2×2 and 4×4 cm^2) in the same configurational setup as used during commissioning of the beam data. Because of the high spatial resolution required, measurements were performed by means of film and solid state detectors. The field outline was defined by the main collimators and by static MLC leaves, respectively. Since the resulting profiles were very similar when taking the leaf transmission (and rounded leaf edge) into account, further optimisation was performed solely on the measurements for which the field outline was determined by the main collimator settings. The kernel shape was optimised by means of an external convolution process, performed at different depths. With the thus produced kernels, the QC test plans were rerun and results (Fig. 6) showed considerable improvement in the correspondence between dose calculation and dose measurement.

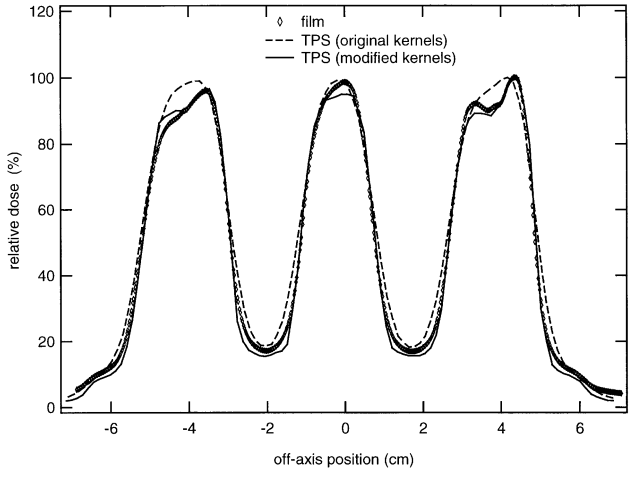

Fig. 6. Results on the QA test plan outlined in Fig. 3 (Reggio Emilia), the film measurement is compared to the calculated dose profile before and after kernel modification.

In order to avoid the above mentioned scatter kernel problem, users are advised to measure the basic beam data with a detector of the smallest possible diameter (i.e. a PTW Pin Point ionisation chamber or a solid state detector) and to evaluate the accuracy of the derived scatter kernels carefully by, e.g. the above mentioned tests.

3.2.2. Clinical test plans

The isodose overlays and the gamma evaluation of calculated and measured dose distributions for the IMRT prostate in multiple planes in the Alderson phantom show good agreement (4% dose difference, 3 mm distance to agreement), as displayed in Fig. 7. The same conclusion can be drawn from the BANG gel experiment simulating the nasopharyngeal treatment. Although the inverse planning demands were complex, requiring strongly modulated IMRT fields, agreement between calculation and measurement is excellent [13].

3.3. QC of the dMLC

Over a time span of one year, the performed film checks ('fence test', 'stepwise dose delivery test' with and without beam interrupt) have not detected any deviations in MLC positioning in any of the centres. Film or EPID tests have not revealed any deviations in leaf alignment, assuring a positional reliability better than 0.2 mm. The ionisation chamber measurements ('sweeping gap') were reproducible within 2%. The good functionality of the dMLC was also confirmed through analysis of the dynamic log files created by the dMLC controller at the end of every QC field delivery.

3.4. Treatment verification

3.4.1. Pre-treatment verification

Dose distributions acquired from the film measurements showed good agreement with the TPS calculations in all centres. Fig. 8 displays two typical examples of the evaluation method used in standard routine.

In Helsinki, for the nasopharyngeal treatment field displayed in Fig. 8(a), in addition to the acquired film and the calculated fluence distribution, line profiles acquired by means of the linear ionisation chamber array are displayed. In the dose distributions (calculated and measured), the location of the spinal cord and the parotid glands can be distinguished.

For the IMRT eye treatment as performed in Reggio Emilia, a line profile through the isocentre is displayed in Fig. 8b: the accuracy of the TPS dose calculation was confirmed within 2% and 2 mm distance to agreement by means of several point

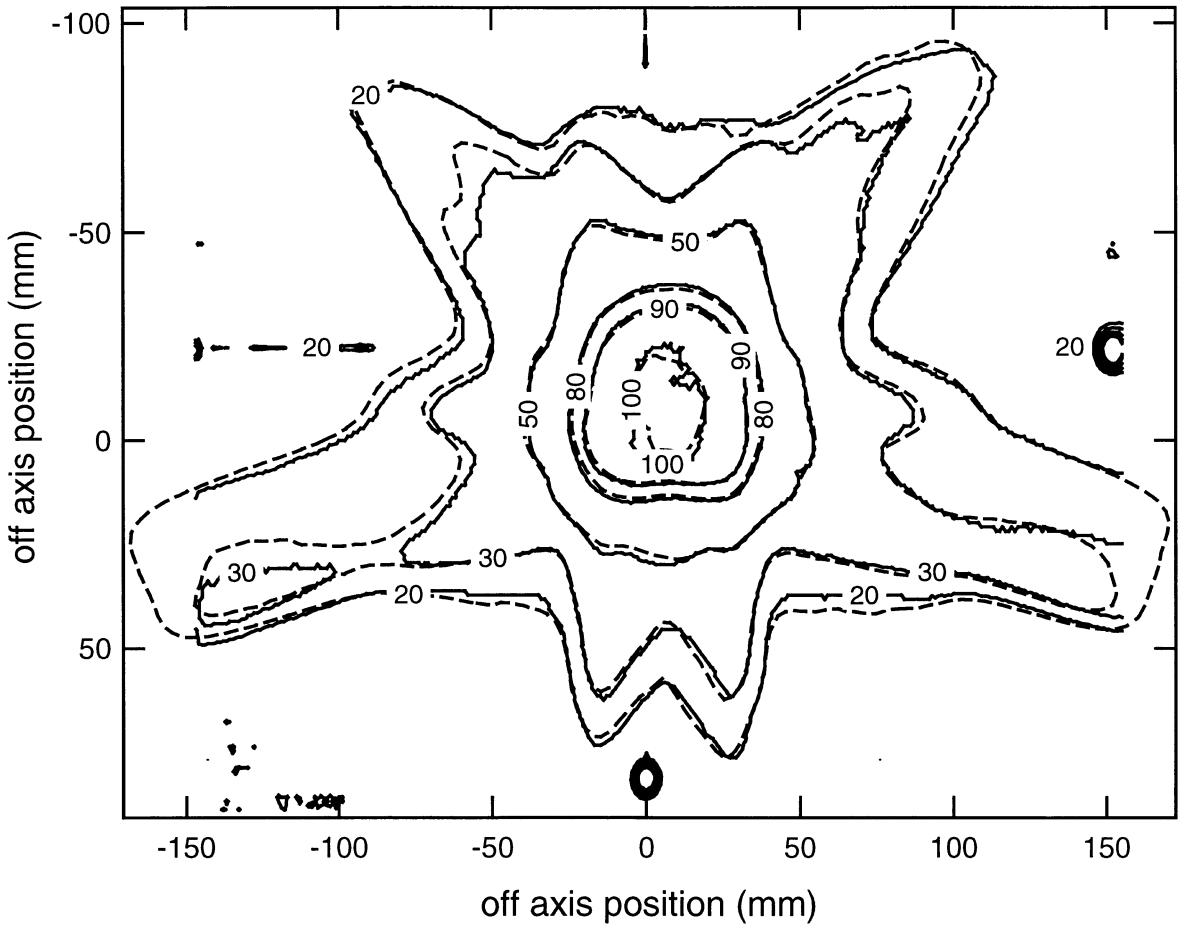

Fig. 7. Isodose overlay of measured (film) and calculated dose distribution of a prostate treatment on an Alderson phantom (Berlin).

detectors. In all five centres, isodose overlays and line profiles were evaluated visually and judged satisfactory. In Leuven and Berlin, a quantitative gamma analysis is performed routinely. Fields are accepted if only small areas exceed the acceptance criteria of a dose difference of 3% and a distance to agreement of 2 mm. Like the performed relative dosimetry, absolute dose measurements proved to be in good agreement with the TPS (within 2%). Exceptions (i.e. deviations up to 6%) have been observed when the point of measurement lies at or close to a steep dose gradient. Ideally, the point dose should be measured at a plateau in dose distribution, but this is not done in all centres because it is unpractical in clinical routine.

In addition in Leuven, EPID and predicted images were routinely compared by means of isodose overlays and two orthogonal line scans through the beam axis, in the same manner as film verification [21]. The main difference lies in the fact that absolute verification is now inherently included in the two dimensional comparison. Agreement is again evaluated satisfactory, in absolute as well as in relative terms (3% dose difference, 2 mm distance to agreement).

3.4.2. Treatment verification

Intercomparison of the dosimetric EPID measurements acquired daily during treatment in Leuven indicate that the reproducibility of the dose delivery is better than 1%. Differences between two portal dose measurements exceeding 1% are related to changes in patient anatomy (e.g. rectal filling) or treatment couch position rather than dose delivery of the accelerator [7].

In Copenhagen, analysis of the TLD readings from six patients (15 fractions and 153 measurements) show an average ratio of the measured versus planned dose of 0.99 ± 0.06. Fig. 9 shows the TLD readings performed on a rhinopharynx patient with an oesophageal tube; the solid lines show the acceptance interval taking into account a TLD variation in sensitivity of 5% as well as a positional inaccuracy of 3 mm. The latter is derived from the TPS as the maximum and minimum calculated dose within a sphere of 3 mm around the assumed measuring point. The right end of the graph shows the opening of the tube, hence the steep dose fall.

4. Discussion

The authors believe that IMRT will become standard practice in the coming decade since many tools to perform IMRT are presently provided by the manufacturer as stan-

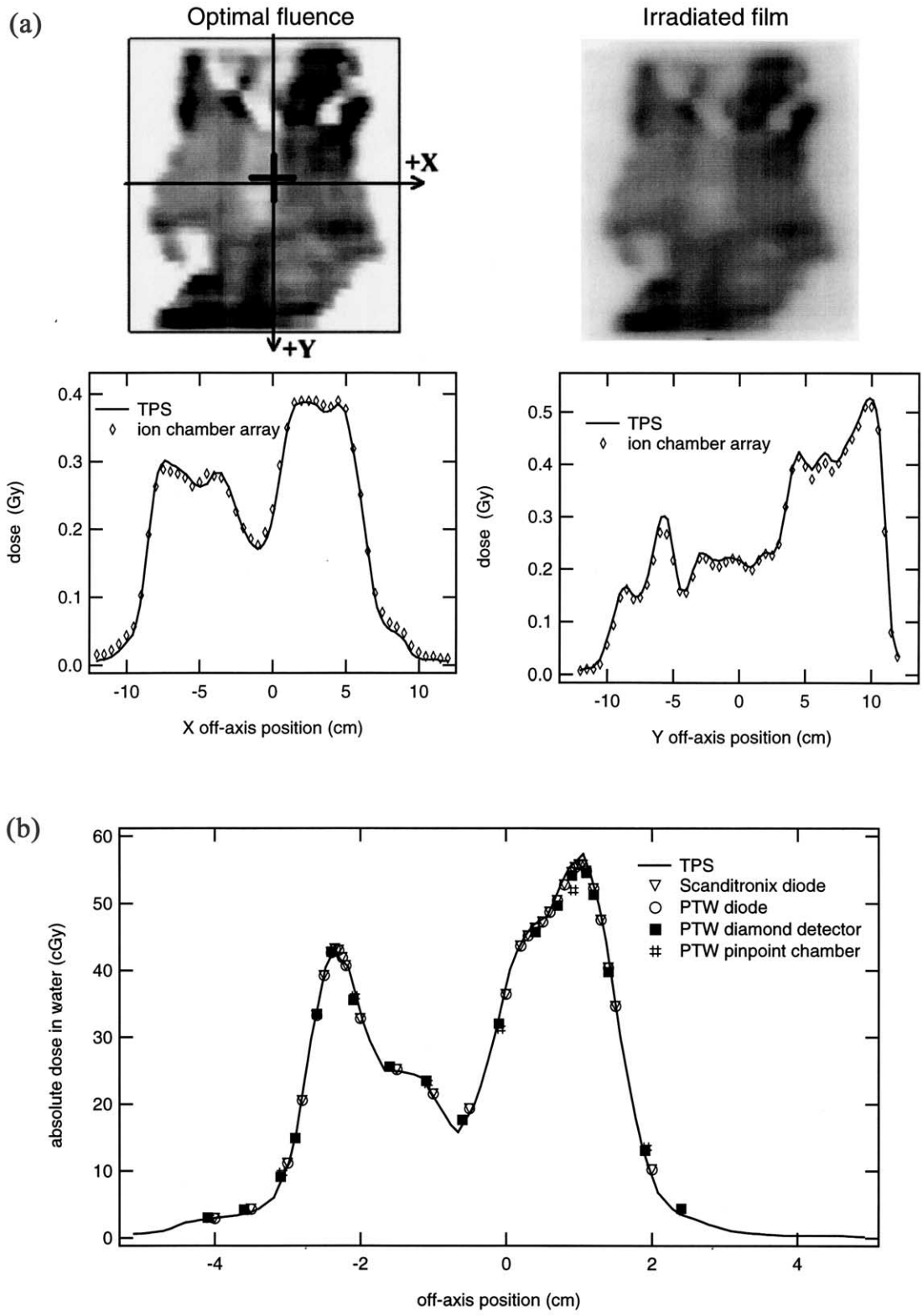

Fig. 8. (a) Pre-treatment QA example of Helsinki: optimal fluence and irradiated film for one field of a head & neck treatment plan with the corresponding orthogonal absolute dose profiles at the depth of 5 cm (calculated dose = solid line, measured dose = dashed line). (b) Pre-treatment QA example of IMRT eye treatment (line profile) performed in Reggio Emilia.

dard tools for radiotherapy. This availability of IMRT equipment enables smaller centres with limited resources to plan/schedule their roadmap for the implementation of IMRT. However, the authors would like to stress that the implementation of IMRT should not be underestimated and that IMRT itself should not be oversimplified and considered as, e.g. the implementation of a sophisticated wedge. The authors have experienced that the implementation of IMRT still contains certain pitfalls and still represents an important effort in terms of man hour.

Apart from the QC issues, the process of setting optimisation criteria and interpreting dose volume histograms and dose distributions differs significantly from the process of conventional forward treatment planning. Although not within the scope of this paper, it should be emphasised that a close interaction between the radiation oncologists and the planning physicist is an essential part of the clinical implementation.

From a physical point of view, new parameters have been introduced in the process of treatment delivery like minimum leaf gap, dosimetric leaf separation, etc. A general conclusion that can be drawn from Table 3 is that the variations detected between the five centres for these new parameters do not lead to clinically significant differences, thus assessing to some extent the stability of these systems. Looking at the average parameter values, one can, e.g. state that a dosimetric leaf separation of typically 2.2 mm and a leaf transmission of 1.75% for these systems are 'good' standard value; radiotherapy centres using a value significantly deviating from this standard value should carefully try to identify the reason for this deviation. Although the tongue and groove effect is not accounted for and can produce a local underdosage of 29% in extreme conditions [8], the authors have only occasionally observed it in the clinical treatment plans. Most of the time, the interleaf transmission and tongue and groove effect – at least partially – compensate each other. On the other hand, it should be mentioned that the stability of other new parameters introduced in the process were not investigated in this study. A typical example is the stability of the obtained fluence distribution as a function of the constraints; how much do the fluences change if one slightly modifies the constraints on target volume in critical organs? Furthermore, it is also possible to modify the constraints during the optimisation iterations, allowing real time interaction with the optimisation process, but making this question even more complex. Further studies are needed to investigate these issues.

There has been a consensus among the authors that the use of simple QC plans to test the inverse planning, leaf motion calculator and dynamic multileaf collimation is an easy method to test the system under extreme conditions and to detect discrepancies between predicted dose distribution and delivered dose distribution. Delivery of simple plans as shown in Fig. 5 has pointed out in three out of five centres significant deviations between prediction and delivery. In this case fine tuning of the kernels has strongly reduced these deviations. However, it should be stressed that these deviations might go undetected in the overlay of isodose distributions with the inappropriate isodose lines set. It should also be noted that these discrepancies are smaller in clinical cases where the system is used in less extreme conditions.

The algorithm used for optimisation as well as forward planning in this paper is based on a photon single pencil

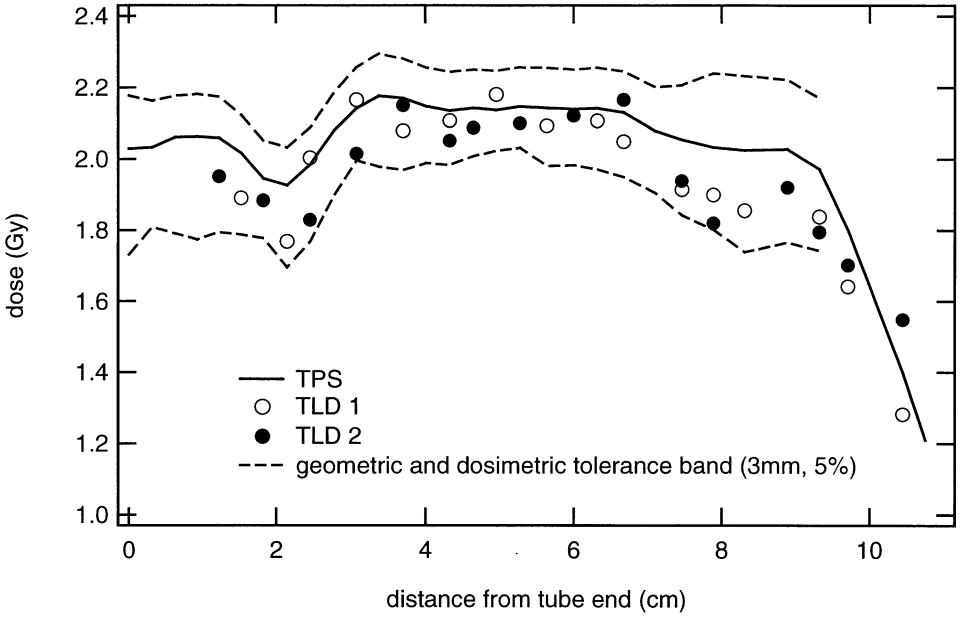

Fig. 9. TLD readings of in vivo dose measurement with an oesophageal tube performed on a rhinopharynx patient during two subsequent treatment sessions. The solid lines represent the acceptance interval taking into account a TLD variation in sensitivity of 5% as well as a positional inaccuracy of 3 mm.

beam model, where homogeneities are accounted for by the modified Batho Power law. The correction method is strictly one dimensional and it has some limitations in the modelling of electron transport, in particular in low density media for field sizes or fluence maps where the criterion of lateral electron equilibrium is not fulfilled. Because of this limitation, care should be taken with IMRT dose plans involving large volumes of low density tissue or air cavity [1].

Other simple plans like, e.g. the 'chair' plans (Figs. 1 and 4) have shown to permit the user to assess the correctness of the new parameters introduced in the leaf motion calculator and the dynamic multileaf collimator with a single test. The files needed to produce this chair-like plan are available upon request to the corresponding author.

Regarding the quality control of the equipment for IMRT, the five centres have copied the various tests performed at MSKCC in New York, which were published in the papers from Lo Sasso et al. and Chen Chui et al. It is noteworthy to mention that presently (i.e. for starting dates on dMLC testing in 1998 for Berlin, in July 1999 for Helsinki, in May 2000 for Leuven, and in July 2000 for Reggio Emilia and Copenhagen) no disfunctioning or significant deviations out of the tolerances were observed in any of the tests described in Table 2. However, the authors do not want to draw any conclusions or make any recommendations at this moment on the type and the frequency of the tests to be performed as minimal QC procedures for IMRT with this equipment.

Regarding the pre-treatment verification, the authors do not believe that gel dosimetry offering a full 3D representation of the IMRT treatment is a mandatory part in the patient specific verification. However, they are convinced that at least for a cohort of patients the individual fields should be verified by film or EPID dosimetry. The overall experience from the five centres is that there is a need for new tools to compare and to evaluate two dimensional dose distributions, i.e. the measured dose distribution and the predicted dose distribution. One such method is the gamma evaluation as proposed by Low et al. [15] in which dose differences and distance-to-agreement differences are combined to evaluate whether a measured dose distribution is acceptable. Such a gamma evaluation is presently used in Berlin and in Leuven [7]. Typical criteria of acceptance are a dose difference of 3% and a distance to agreement of 2 or 3 mm (partially depending on the positional accuracy of the verification tool such as the EPID). An important issue regarding the dose difference acceptance criterion should however be made. Routinely, the dose difference criterion is defined relative to the total dose delivered on the beam axis. Firstly, should there be a strong dose gradient on the beam axis, this can result in artificially unacceptable gamma evaluation reports when both the measurement and the dose calculation are normalised in this high gradient area. Furthermore, in contrast to conventional static field delivery, the dose on the beam axis is no longer necessarily a representative dose for the rest of the IMRT field. For example, should there be an area of low dose on the beam axis (e.g. because of an organ at risk), a 3% dose difference criterion of such a low dose would correspond to an unrealistically strict absolute dose tolerance for the high dose areas of the IMRT field. For these reasons, the normalisation point for measurement and calculation is in some cases moved to a low dose gradient area or to the dose maximum of the IMRT field. Hence, the authors would like to argue that, towards the future, unambiguous conventions regarding the dose difference criteria for IMRT fields would be valuable for reporting on the dosimetry of IMRT fields.

Regarding the workload for pre-treatment verification, the mean physicist's time typically needed per patient is: 6 h in Leuven (IC, film dosimetry), 6 h in Berlin (IC, film dosimetry), 3 h in Helsinki (film (visual), IC or linear array), 10 h in Copenhagen and 40 h in Reggio Emilia (IC, film). The latter is taking into account that in Reggio Emilia, sometimes two or three IMRT plans are verified for each patient. However, in Leuven this could be reduced to 30 min by replacing film and IC dosimetry with the use of the EPID in dosimetrical mode [21]. Hence, the five centres are convinced that the EPID in dynamic, dosimetric mode will become the faster and more practical device for IM treatment QC. Although the use of films, in combination with absolute dose measurements is equally effective, it is considerably more time consuming. The EPID has the advantage of being integrated into the accelerator equipment and the acquisition software is linked to the R&V system as well as the TPS.

Acknowledgements

The realisation of this work was made possible through support from Varian Medical Systems. The authors acknowledge the other centres of the Helios users group for fruitful discussions over the last years and they would like to thank Dr Kaissl for his continuous, enthusiastic assistance.

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