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Volume modulated arc therapy

Commissioning of volumetric modulated arc therapy (VMAT) in a dual-vendor environment

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Abstract

Methods and results for commissioning of the complete VMAT delivery chain are presented for the combination of Nucletron's Oncentra MasterPlan® v3.3 with Elekta's Mosaiq® v1.6 and SynergyS® linac. VMAT specific linac commissioning included determination of the size of the minimal dynamic leaf gap. Dosimetric validation of the complete treatment chain was performed using a 2D-ionization-chamber-array and showed excellent dosimetric results.

Keywords

- Volumetric modulated arc therapy (VMAT);
- Commissioning;
- Clinical implementation

Volumetric modulated arc therapy (VMAT) is an advancement of intensity modulated radiation therapy (IMRT) which allows irradiation with simultaneously varying dose rate, gantry speed, collimator, and leaf positions. Various treatment planning studies have been published showing the potential of VMAT to deliver plans with a quality comparable to IMRT in shorter treatment time [2], [5], [12], [13], [14], [16], [18], [21], [22], [23], [24], [25], [26], [27], [28] and [30]. Clinical implementation of VMAT, however, requires not only sufficient plan quality but also commissioning of the complete delivery chain including treatment planning, data transfer to the record and verify system, and delivery on the linear accelerator (linac). Ling et al. [19] and Bedford and Warrington [1] proposed procedures for VMAT specific commissioning and quality assurance (QA) of linear accelerators to ensure correct synchronization of the simultaneously varying parameters. Reports about commissioning of the complete delivery chain, can be found for single-vendor system combinations, i.e. Eclipse with Varian linacs [17] or ERGO++ with Elekta linacs [15] and [29]. First dosimetric experience with VMAT in a multi-vendor environment has been published for a pre-clinical version of Pinnacle® (Philips Healthcare, Andover, MA), combined with Mosaiq® (IMPAC Medical Systems, Sunnyvale, CA) and a Trilogy® linac (Varian Medical Systems, Palo Alto, CA) [11].

A new VMAT treatment planning tool implemented in Oncentra® MasterPlan v3.3 (Nucletron BV, Veenendaal, Netherlands) has been clinically released in December 2009. This publication reports about commissioning of this new VMAT treatment planning option, combined with the record and verify system Mosaiq® v1.6 (IMPAC Medical Systems, Sunnyvale, CA/Elekta Ltd, Crawley, UK) and a Synergy®S linac (Elekta Ltd, Crawley, UK).

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Procedures are based on the recommendations of AAPM for commissioning of the complete IMRT delivery chain [9] and [10] and adapted to the requirements of VMAT. Results of the commissioning are presented, focusing on the overall performance of the system.

Material and methods

Material

Linear accelerator

A Synergy®S linear accelerator with 6MV photons equipped with a BeamModulator™ head is used for VMAT delivery. The multileaf collimator (MLC) consists of 40 leaf pairs of 4 mm width at isocenter. Leaf interdigitation is allowed without limitations, i.e. each leaf can travel across the whole field size, independently of the position of neighboring leaves. Accuracy of leaf positioning is 0.25 mm at isocenter.

Nominal values of VMAT specific parameters required for beam data modeling in Oncentra® MasterPlan are: Minimum and maximum number of monitor units (MU) per degree of gantry rotation 0.10 MU/° and 20.0 MU/° respectively, minimum MU per cm leaf travel 0.30 MU/cm, maximum gantry speed 6.00°/s. Maximum leaf speed is 2.4 cm/s, the dynamic minimum leaf gap 0.14 cm, and the static minimum leaf gap 0.0 cm. The maximum nominal dose rate is 500 MU/min. 7 fixed dose rate levels are available, each half the dose rate of the next higher level, continuous variation is not possible. Actual dose rates may differ from nominal dose rates by ±25%. During VMAT delivery the fastest combination of dose rate, gantry speed, and leaf speed is automatically selected by the linac control system Precise Desktop® 7.

Dosimetry system

A MatriXX Evolution 2D-ionization-chamber-array (chamber volume 0.08 cm^3, center-to-center distance 7.62 mm) with gantry angle sensor (IBA Dosimetry, Schwarzenbruck, Germany) was used for absolute dosimetry [7] and [31]. The measurement is driven by the software OmniPro I'mRT v1.7, which also allows comparison of measured versus calculated data. Dose measurement is performed in the so called "movie mode", acquiring a series of dose matrices called "snaps", typically one every 200 ms, simultaneously recording the gantry angle for each snap with the gantry angle sensor attached to the gantry. Each snap can then be corrected for angular dependencies using a correction factor matrix implemented in the software. The corrected snaps are summed up to the dose of the complete plan.

Treatment planning system (TPS)

Treatment planning is performed with Oncentra® MasterPlan v3.3 SP1. For beam data modeling the above-mentioned VMAT specific parameters of the linac have to be defined. Since the TPS only allows for 5 different dose rates, two dose rates had to be omitted. We kept the 5 higher and omitted the two lower dose rates, because according to the literature the main advantage of VMAT as compared to IMRT is the short treatment time, which would be prolonged if higher dose rates would be omitted.

User defined parameters for the optimization include collimator angle, start gantry angle, rotation direction, arc length, gantry angle spacing between subsequent control points (2°, 3°,

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4° or 6°), maximum delivery time, number of arcs, and constrained leaf motion in cm/°. Gantry speed, leaf positions and dose rate are subject to optimization. Optimization starts with a fluence optimization for 15 equispaced beams. Two IMRT segments are created per gantry angle to achieve a higher modulation as compared to just one segment and keep the amount of leaf travel within an acceptable range as compared to a higher number of segments. The segments are then spread out evenly and cloned to achieve the required gantry angle spacing as defined by the user. Based on this starting point direct machine parameter optimization is performed, followed by a final accurate dose calculation and segment weight optimization [4] and [8]. Continuous delivery is thus discretized and approximated by the calculation of static beams separated by the user defined gantry angle spacing.

During optimization a fast pencil beam algorithm based on simplified value decomposition [3] and [4] is used to decrease time required for optimization. For final dose calculation the user can choose between pencil beam and collapsed cone algorithm. A second optimization run is recommended, which uses the result of the accurate dose calculation as a starting point and minimizes differences to the desired dose. This procedure doubles the optimization and calculation time but is strongly recommended in order to improve results [32].

Record and verify system

Treatment plans are transferred from the planning system to the record and verify system Mosaiq® v1.6 in DICOM RT format and sent from the Mosaiq® sequencer to the linac control system Precise Desktop® 7. Each DICOM RT VMAT plan exported from Oncentra® MasterPlan is described by a series of control points, defining gantry position, MLC position, number of MU, and dose rate. Mosaiq®, however, requests to select a predefined dose rate for the complete arc. The linac then automatically selects the fastest combination of gantry speed, MLC speed and dose rate, using the nominal dose rate value defined in Mosaiq® as upper limit.

Methods

Linac commissioning

An extensive commissioning procedure for VMAT on Elekta linear accelerators has been proposed by Bedford and Warrington [1]. We mainly followed the recommendations given in this publication and adapted the procedure to our environment. To keep the description short only essential differences to the tests published in [1] are described here:

1.Since sliding window IMRT without simultaneous gantry rotation is not clinically available for the Elekta Synergy®S, separate comparison of calculated and measured sliding window dose was not performed.

2.MLC calibration tests were performed during simultaneous gantry rotation by acquiring electronic portal images.

3.The AAPM recommends checking the size of the dynamic leaf gap for dynamic IMRT [10]. Since this also applies to VMAT, the following test was included: Seven test plans were created moving a small slit of 1.4–2.0 mm across the field during a 180° rotation. The aim of

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the test was to determine the smallest size of a moving slit which is correctly delivered by the linac.

Commissioning and QA of the delivery chain

Three VMAT commissioning plans were created for the target types most frequently treated with IMRT at our department, i.e. (a) prostate cancer, (b) metastases in the lumbar vertebra, treated as simultaneous integrated boost (SIB), and (c) hypopharynx/larynx cancer, details are given in [8]. Based on the report by Feygelman [11], gantry angle spacing was set to 4°. Leaf motion was constrained to 0.5 cm/° based on recommendations of Nucletron. The plans were transferred to a CT scan of the MatriXX Evolution 2D-array set up in between slabs of RW3 for measurement in one coronal plane, doses were calculated with a dose grid resolution of 0.15 cm in the measurement plane, keeping all other parameters identical to the patient plan. Dose calculations were performed with the pencil beam algorithm, because collapsed cone convolution reports dose to medium, i.e. to air inside the ionization chambers, whereas the 2D-array is calibrated to measure dose to water. The isocenter was positioned in the center of the measurement area if possible, but moved if necessary to avoid measuring in a high dose gradient area. The plans were then delivered to the phantom. Measurements were corrected for angular dependencies and couch attenuation in OmniPro I'mRT v.1.7 and compared to the calculated dose matrices by gamma evaluation [20] with a dose tolerance of 3% of the maximum dose and a distance to agreement (DTA) of 3 mm. Evaluation was performed once over the whole area in order to be able to detect deviations also in the periphery and once for the area with dose values above 10% of the maximum dose as recommended in [9]. No increased dose tolerances were applied for low dose regions. The gamma criterion was considered to be fulfilled if $\gamma < 1$ for at least 95% of the detectors [9] and [10]. In addition the gamma value averaged over all measured pixels was calculated. This value gives information about how close the calculation is to the measurement averaged over the area of measurement. The lower the value is the better the agreement. For an average gamma value of 1, the average agreement corresponds to the allowed tolerance, i.e. in this case 3% and 3 mm. Results of the gamma evaluation are reported for the three commissioning plans and the first clinical VMAT plan verifications, in total 18 plans: 8 cases of prostate cancer, 5 cases of head and neck cancer and 5 cases with vertebral metastases.

Stability of VMAT treatments during repeated fractions was assessed by performing the same individual plan verification several times: twice without any changes, twice with 5 interruptions of 30 s each and restart of the beam, and once with complete termination and resumption of the treatment. In addition three different maximal dose rate values were selected in Mosaiq®. The whole procedure was performed for two different patient plans, one dual arc and one single arc plan.

Results

Linac commissioning

The results of linac commissioning are similar to the ones already published by Bedford and Warrington [1], and within the proposed tolerances. Therefore no details are given here in the interests of brevity.

Verification of the size of the minimal dynamic leaf gap showed that even though the dynamic leaf gap in the linac control system was set to 1.4 mm, the moving slit could only be

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irradiated, if the width was 1.8 mm or larger. Taking the accuracy of leaf positioning of 0.25 mm into account, the minimal size of the dynamic leaf gap was set to 2.0 mm in the treatment planning system, to ensure deliverability of the plans.

Commissioning and QA of the delivery chain

Fig. 1 shows the result of the gamma evaluation of the three commissioning plans described in [8]. All 18 plan verifications passed the gamma test (Table 1), no difference could be observed for different target or plan types. Mean delivery time was 3.5 min.

All stability tests showed only minor dose deviations <1% of the maximum dose in all detectors: Maximum dose deviation was 0.8% of the maximum dose for irradiation at different maximum dose rates, and 0.5% for repetition with and without interruption and restart or complete termination and resumption. Gamma evaluation was within tolerances for all measurements. Results are shown in Fig. 2 for the dual arc case.

Discussion

Linac specific commissioning followed mainly the procedure described by Bedford and Warrington and showed good results within the proposed tolerances [1]. Dosimetric validation of dynamic MLC (dMLC) delivery without simultaneous gantry rotation was not performed since dMLC delivery is not clinically available except for VMAT for Elekta linear accelerators. A new test was designed to determine the minimal dynamic leaf gap of the MLC, which has not been reported for VMAT on Elekta machines to our knowledge. It could be observed that dynamic fields could only be irradiated correctly if opposing leaves were separated by a gap which was 0.4 mm or 30% larger than the nominal value in the linac control system. To ensure safe delivery of VMAT plans the size of the minimal dynamic leaf gap in the treatment planning system was set to the experimentally determined value.

For the commissioning of the complete delivery chain by integral plan verification, three different target types and beam parameters were used, which allows one to catch possible malfunctions even if they occur in certain cases only [6]. All verifications including the first clinical cases, repetitions of measurements with interruptions and restart of the treatment, and repetitions with different maximum dose rates passed the criterion of at least 95% of the pixels to be within 3% dose tolerance and 3 mm DTA. The excellent dosimetrical results confirmed the findings of Feygelman [11] that the use of a gantry angle spacing of 4° in the dose calculation is a sufficient approximation of the continuous delivery. Dedicated planning studies are currently ongoing to identify the optimal planning parameters, which also include the influence of gantry angle spacing on plan quality and verification for the respective target type. They are, however, beyond the scope of this study.

Individual plan verification for VMAT takes less time than for IMRT due to reduced delivery times. However, individual plan verification is still a time consuming task, due to the time required for phantom setup, pre-irradiation, and calibration of the 2D-array. The QA procedure can in our opinion be reduced to a VMAT specific linac QA in combination with a regular integral check of the whole delivery chain and an independent monitor unit calculation, once enough confidence has been built for the individual system combination. A detailed protocol for VMAT specific linac QA can be found in [1] and has therefore not been included in this publication.

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Conclusion

Clinical implementation of VMAT for the combination of Oncentra® MasterPlan, Mosaiq® record and verify system, and Elekta Synergy®S did not cause any major problems. Individual plan verification showed good agreement of calculated and measured dose in all cases, demonstrating the high quality of the whole delivery chain. To ensure correct delivery of VMAT it is recommended to determine the real size of the minimal dynamic leaf gap and to adjust the value in the treatment planning system accordingly.

Competing interests

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Figures

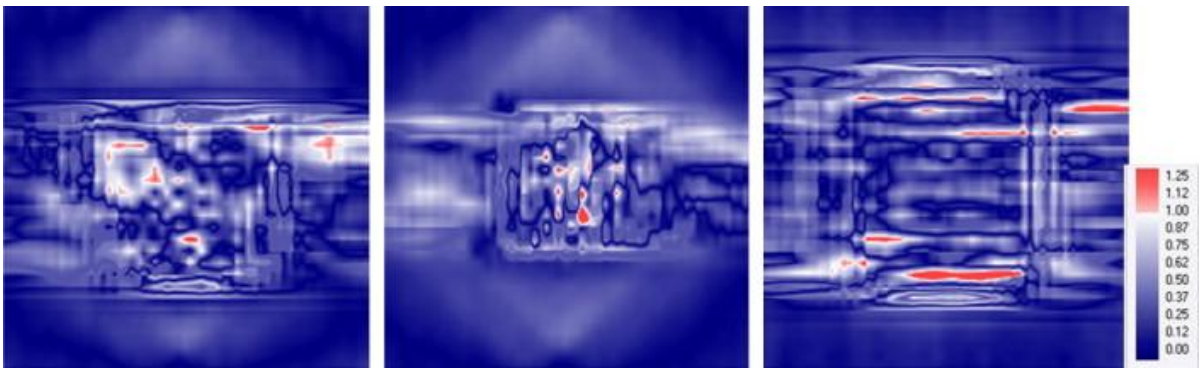

Fig. 1.

Gamma evaluation with 3% dose tolerance and 3 mm DTA for the plan verification of the three commissioning plans: single arc VMAT for prostate cancer with a pass rate of 99.8% and an average gamma value of 0.24 over the whole area (left), single arc VMAT for simultaneous integrated boost treatment of vertebral metastases with a pass rate of 99.7% and an average gamma value of 0.28 (middle) and dual arc VMAT for hypopharyx/larynx cancer with a pass rate of 98.4% and an average gamma value of 0.30 (right).

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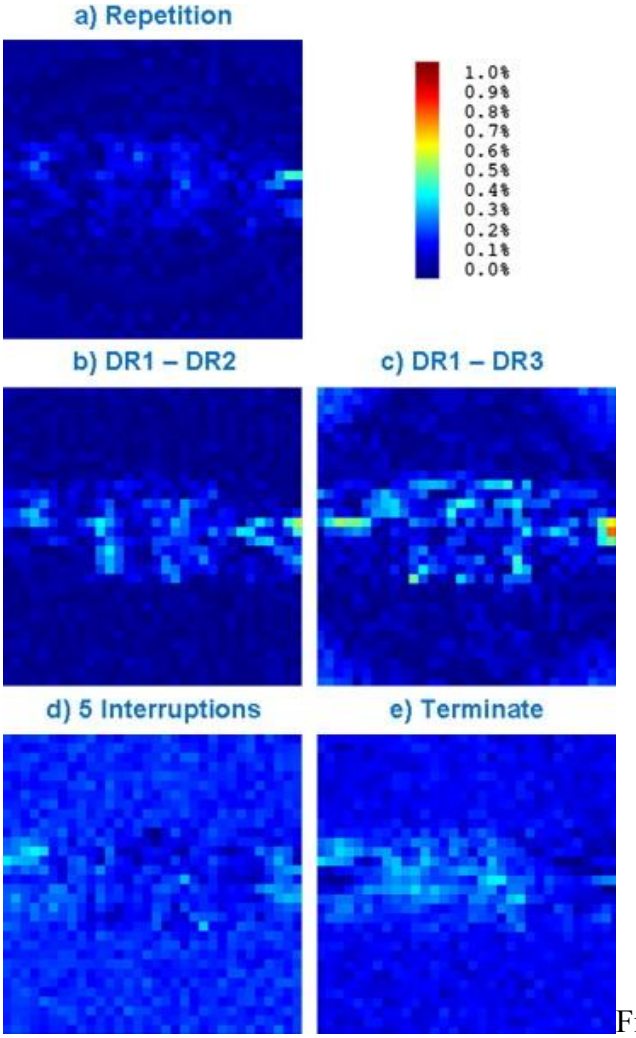

Fig. 2.

Dose differences for the verification of a dual arc plan repeated (a) without any changes, (b) with a change of nominal dose rate from DR1 = 500 MU/min to DR2 = 250 MU/min, (c) with a change of nominal dose rate from DR1 = 500 MU/min to DR3 = 125 MU/min, (d) with 5 interruptions of 30 s duration each, and (e) with complete termination and restart of the treatment.

Table 1

Results of individual plan verification averaged over all 18 plans.

Dose range	Average pass rate[a]	SD[b]	Min pass rate[a]	Average gamma
>10% of maximum dose	98.7%	1.0%	96.6%	0.38
All dose levels	99.3%	0.5%	98.2%	0.28

[a] Pass rate: percentage of points passing gamma criteria of 3%/3mm

[b] SD: standard deviation

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