Routine verification of RapidArc® plans using Epiqa™

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Epiqa™ is a program that allows to convert a dosimetric image acquired by an EPID into a dosemap and to compare the dosemap with a reference dose distribution. It is possible to utilize Epiqa for a verification of static as well as intensity modulated fields, including RapidArc® fields. This text attempts to provide an overview of applied principles, describe the workflow, and discuss obtained results.

MATERIAL AND METHODS

Principle

The conversion of a dosimetric image into a dosemap is only possible if a response of the imager to a beam is known. The EPID's response shows very good linearity, but exhibits rather strong energy dependence, which causes a difference in response to primary and MLC transmitted radiation. Epiqa overcomes this limitation by the calibration process that takes the energy dependence of the detector into account. For the purpose of calibration, a set of integrated images for *open* and *transmission* fields of different field sizes is acquired and consequently imported into Epiqa together with the output factor table (measured by a conventional detector such as ionization chamber) to establish basic algorithm configuration data.

Based on the knowledge of jaws' position and the trajectory of MLC leafs (for an IMRT field), a calibration factor can be determined for every pixel of an EPID by weighting the contribution of primary and transmitted radiation and by applying an interpolation among the data of the calibration dataset. The pixel based calibration relates the readout of a pixel to a dose at the depth of d_{max} in water-equivalent homogenous medium. By applying the conversion to all pixels of the EPID, a planar dose distribution at the d_{max} in water is obtained.

A detailed description of the GLAaS image-to-dose algorithm can be found in [1].

The image-to-dose conversion algorithm (GLAaS) is often confused with portal dose image prediction algorithms (PDIP). As described in the previous paragraphs, the GLAaS derives calibration factors for EPID's pixels using *empirically* measured dataset. The obtained dose map is compared against dose distribution calculated by clinically used dose algorithm (typically AAA). It is therefore an *independent method of verification of the dose distribution* calculated by a treatment planning system and verification of the delivery device performance. The PDIP estimates a response of the imager for the theoretical incidental fluence. In other words, the algorithm predicts a pattern that will be created on the imager and a user has then a possibility to compare it with the real one. This method checks the *reproducibility in delivery of the incidental fluence*, meaning it verifies the technical accuracy

of the delivery (which is usually very good) and not the dose distribution/dose calculation algorithm itself.

Workflow

Measurement preparation

To verify a field using Epiqa, one needs to obtain a dosimetric image of the field. Based on yearly experience with Epiqa, we find the following workflow as the most optimal for our needs:

We make a copy of a plan that needs to be verified and remove all existing reference points, so that the plan's irradiation will not be counted to clinical irradiation of a patient. In RT Chart, we add manually a 10x10 field (with 50 MU). This additional field is used to compensate for daily variation of the linac monitor chamber. Prior to this, the 'Clear 3D Dose Distribution' function with 'Do not clear MUs' option enabled needs to be applied in order not to lose fields' MUs. After the 10x10 field is added, plan needs to be scheduled. We recommend to schedule more than one fraction so that the plan irradiation can easily be repeated if necessary. For all the fields, the 'Integrated image' needs to be added using the 'Show Sequence Image Scheduling' option.

Reference dose distribution preparation - Verification plan

'Create Verification plan' is an Eclipse function. The fields of the verification plan are copied from the original plan, but the original patient CT is replaced with a user defined phantom. For the needs of Epiqa, it is a homogeneous water equivalent cube that needs to be located in respect to the isocenter in such a way that it resembles the EPID's position during verification.

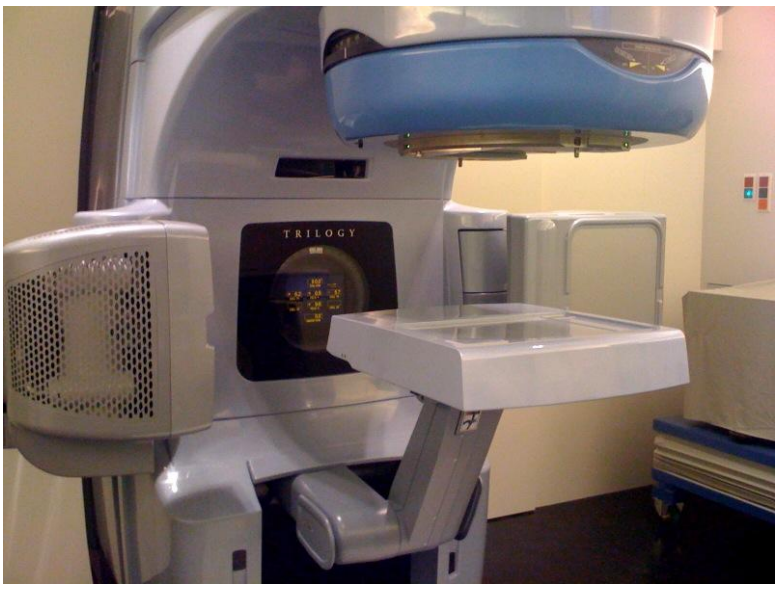

Figure 1: Linac ready for the acquisition of verification images

In our department, we place the active layer of the imager into the isocenter, which corresponds to the EPID position of [0, 0, 0] (Figure 1). As Epiqa converts the

dosimetric/integrated image into the dose at the depth of d_{max}, the SSD needs to be 100 – d_{max}. After dose calculation is done for the verification plan (with MUs copied from the original plan), the reference dose distribution is obtained by exporting planar dose distribution at the depth of d_{max}.

When Epiqa is used for the verification of static or IMRT fields, this procedure is in fact equivalent to the *entrance dose* verification; e.g. field by field verification. In case of RapidArc, the situation is more complex:

The arm of EPID is rigidly connected to a gantry, therefore during the RapidArc irradiation, EPID follows the gantry motion and from the EPID's point of view a RapidArc field appears as a static gantry IMRT field (with the addition of dose rate modulation). When creating a verification plan in Eclipse, user has an option to set the gantry position to a given value. That value must be zero as the beam incidence is always perpendicular to the imager. When this option is selected for a RapidArc field, it becomes a static field (the gantry motion is frozen) with an identical dynamic MLC pattern (and the dose rate modulation) as the original RapidArc field. We refer to the dose distribution obtained for such a field as the *collapsed* RapidArc dose distribution. It is then the collapsed RapidArc dose distribution that is verified by Epiqa.

Measurement

When the plan is approved and scheduled in Time planner, it is possible to proceed with the irradiation. During the irradiation, the EPID needs to be placed into the position in which it was calibrated; which is typically the isocenter position. The couch is completely retracted in the longitudinal direction in order to avoid a collision with the arm. Acquired images are automatically stored in Aria database when the plan is closed in 4DTC application.

Evaluation of the results

In order to evaluate a single field, four files need to be loaded into Epiqa:

1) integrated image of a verified field,
2) integrated image of a 10x10 field,
3) RT plan file containing the plan geometry information,
4) reference planar dose distribution for comparison.

Export of all four files is fully supported inside Aria environment. The integrated images can be exported using either Patient Viewing module or Import/Export workspace of 'RT Chart' application, RT plan and the reference planar dose distribution can be exported from Eclipse.

The integrated image of a 10x10 field serves to eliminate eventual daily output fluctuations of a linear accelerator. The RT plan file contains detailed description of MLC leaf motion that is necessary to determine the calibration factors for pixels. To obtain the reference dose distribution, a verification plan is created in Eclipse as described above.

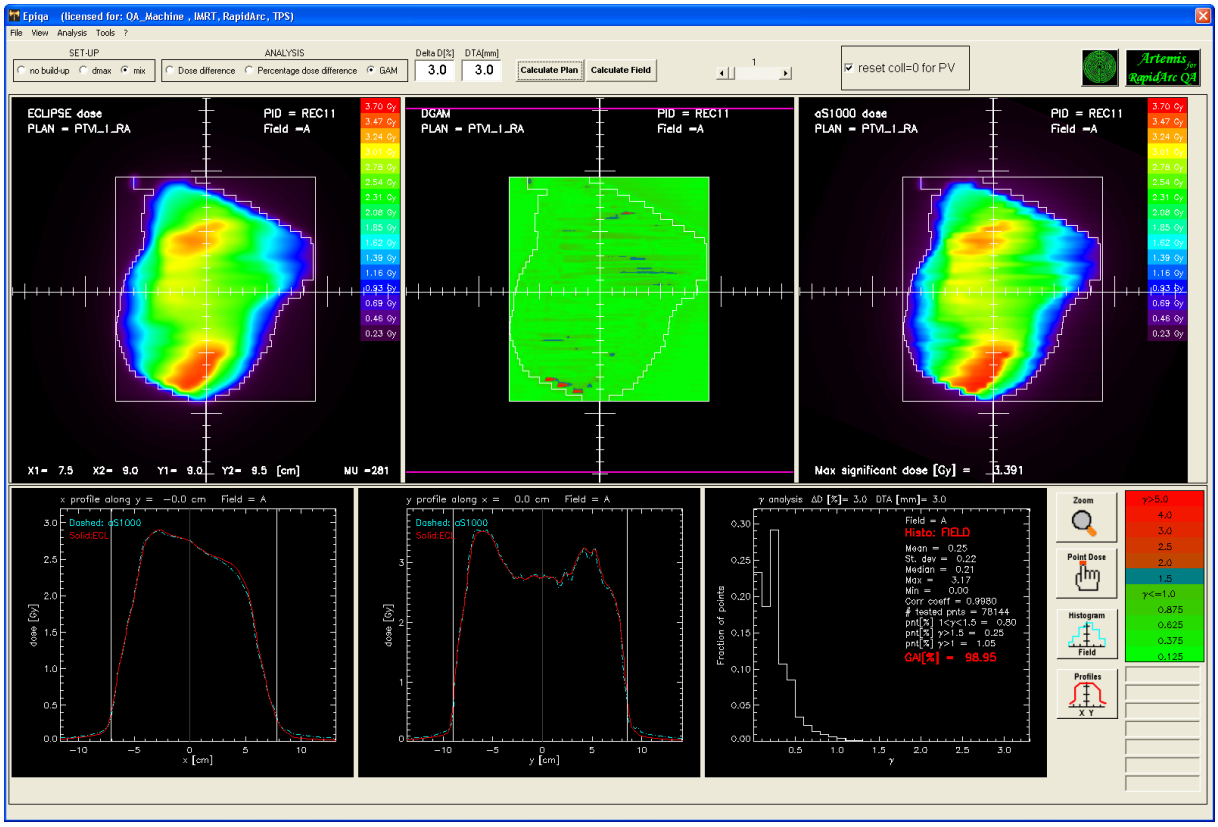

Figure 2: Example of Epiqa results for RapidArc plan

RESULTS AND DISCUSSION

Using EPID for the modulated beam delivery plan evaluation has several important advantages. Probably the most important one is that it offers the high resolution verification – size of a square pixel is 0.39 mm (Varian's Portal Vision^{TM}, model aS 1000) which is comparable to the resolution achieved with film dosimetry as films are usually digitized with 150 dpi (i.e. 0.17 mm). For comparison, the standard calculation grid of AAA algorithm is 2.50 mm (more than 6x smaller in comparison with EPID's resolution) and two most popular 2D ionization chamber arrays have the resolution of 7.00 mm (18x smaller) and 10.00 mm (25x smaller) (Figure 3).

Figure 3: Comparison of resolution. The original image (left) has its resolution 25 times reduced (middle). The image with reduced resolution was interpolated to the resolution of the original image (right).

Thanks to its resolution, Portal Vision dosimetric image is able to capture the *overmodulation* – the status in which real dose modulation is higher than its virtual representation calculated by a treatment planning system. Current technology employed for delivery of IMRT and RapidArc fields can yield dose distributions with very sharp dose peaks which cannot be sufficiently described by treatment planning system due to the limited resolution of the calculation grid. This can be potentially dangerous, as the smearing effect of the coarse calculation grid may introduce a systematic error into the calculated dose distribution. To keep the consistency between the calculated and delivered dose distribution, amount of field modulation needs to be evaluated and kept controlled by applying suitable measures during plan optimization process.

Another practical advantage of EPID based verification is its availability and the simplicity of use. An EPID is present in a treatment room and it only needs to be placed into a defined position, which can be done remotely from a control room. There is neither phantom nor additional connection of devices necessary. The level of the automation of the procedure allowed us to integrate the acquisition of integrated images into our clinical routine. Our Time planner contains short time slots for patient plan verification and the acquisition of integrated images is done by the personnel responsible for patient irradiation.

The main limitation of using Epiqa is that it works only in calibrated geometries (multiple calibration positions are possible), it cannot depict errors connected to the accuracy of patient's setup and it cannot evaluate influence of inhomogeneities or the presence of a treatment couch. This, however, are not serious restrictions for the tool that serves for a routine plan verification.

Collapsed RapidArc plan

As mentioned before, when used for verification of RapidArc fields, it is the collapsed RapidArc dose distribution that is verified, which has entirely different character than the patient dose distribution (Figure 4).

The dose distribution of a collapsed plan is usually very well delimited. Its area is comparable with the field size of a RapidArc field and the accumulated dose (in comparison to the patient dose distribution) is relatively high as all the control points contribute roughly to the same place of EPID.

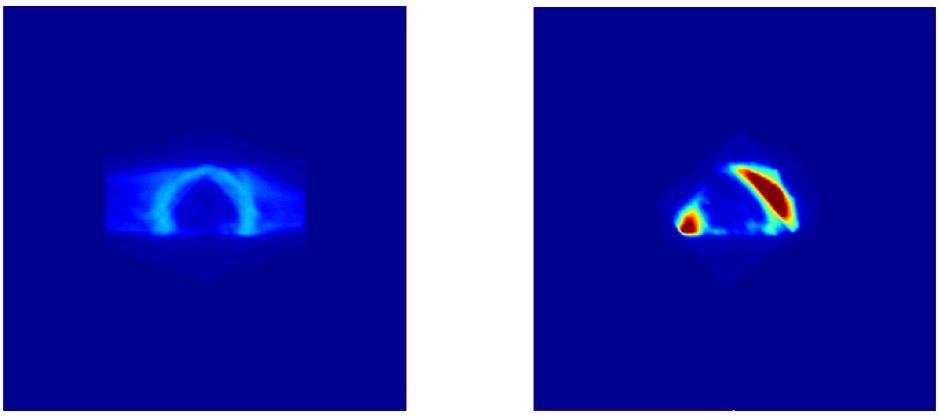

Figure 4: Coronal view of patient dose distribution (skull irradiation) (left) and its collapsed dose distribution (right).

The patient dose distribution at any of the three principal planes is spread over larger area (this is especially true for the transversal plane), meaning that the density of information embedded in the dose distribution is lower. Meanwhile in case of the collapsed plan, the beam axis enters perpendicularly to the collapsed plane for ALL control points, for the sagital and coronal plane the angle of incidence differs and causes a varying sensitivity of these planes to control points. The transversal plane is oriented parallel to the rotational plane of a RapidArc field and has therefore equal sensitivity. Nevertheless, it intersects only with a portion of the modulated field, which in theory can lead to a situation that a potential problem escapes detection. From this point of view, any patient plane verification of a RapidArc field is limited

As already indicated, the virtual plane of the collapsed distribution has equal sensitivity to all control points and it "monitors" the entire area of the field at every control point. Certain concerns arise from the fact that contributions from all control points get integrated on top of one another and an error in the delivery of one control point can get hidden in the background of the others control points and/or get compensated by an inverse error in another control point.

Due to these concerns, a theoretical study that evaluates the sensitivity of the collapsed plans was done:

For several qualitatively different clinical RA plans with (prostate, oesophagus, skull) the patient and the collapsed dose distribution has been calculated in Eclipse using AAA 8.2.23 with calculation grid of 2.5 mm.

The plans were exported from Eclipse and their leaf positions and dose rate have been altered on the level of control points.
Using the script, the function $f = \sin\left(\frac{2\pi \times cp}{177}\right)$, where cp = 1-177 is the index of a given control point, has been superimposed on every leaf position from A as well as B bank. At the initial position, gantry at 180 degrees, there is no change in the MLC aperture. As the gantry moves counter clockwise during delivery, the MLC aperture is gradually shifting in the positive direction, reaching the maximal offset of 1 mm at 90 degree gantry angle. After this point, the introduced offset is gradually decreasing until 0 mm for the gantry at 0 degrees. The same occurs for the remaining half of the arc with the opposite phase. The MLC aperture is shifting from its original position in the negative direction (Figure 5).

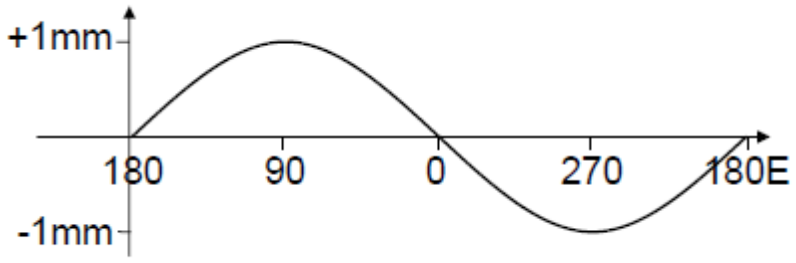

Figure 5: MLC leaf shift function used in the study

Apart from changing MLC leaf positions, the differential output delivered between two consecutive control points has been randomly altered. If the total output delivered during RapidArc treatment is normalized to 1, then the average contribution per single control point

is 1/177 (0.0056). The set of random changes of differential output has been generated as normal distribution with the mean of 0 and the sigma 10% of 0.0056.

The modified plans have been imported back to the TPS and the patient and the collapsed dose distribution have been recalculated.
Patient dose distribution of the original and the modified plan has been compared in coronal, transversal, and sagital plane in terms of local dose changes (relative to maximum dose in the evaluated plane). The original and modified collapsed plan dose distributions have been compared in the same fashion. For the comparison, only the doses above 5% of the maximum dose in the plane were considered.

The frequency histograms of dose difference maps comparing the original and modified plan (figures 6, 7, 8) demonstrated that the occurrence of changes in the collapsed dose distribution is similar to the one in the patient dose distribution. For the prostate and oesophagus RapidArc plan, the collapsed distribution reacted most sensitively to the introduced changes. In case of the skull plan, the induced changes in two patient planes were more pronounced than in the collapsed plane. In general, the amount of changes in all four investigated planes was comparable.

It should be noted that this investigation was done for one plan modification and the behaviour of collapsed dose distribution would have to be investigated for a variety of modifications in order to draw a general conclusion.

In case of patient distribution, a direct link can be made between the information about the dose and an anatomic location. This possibility is in case of the collapsed distribution limited and the result needs to be interpreted as “an indirect indicator”.

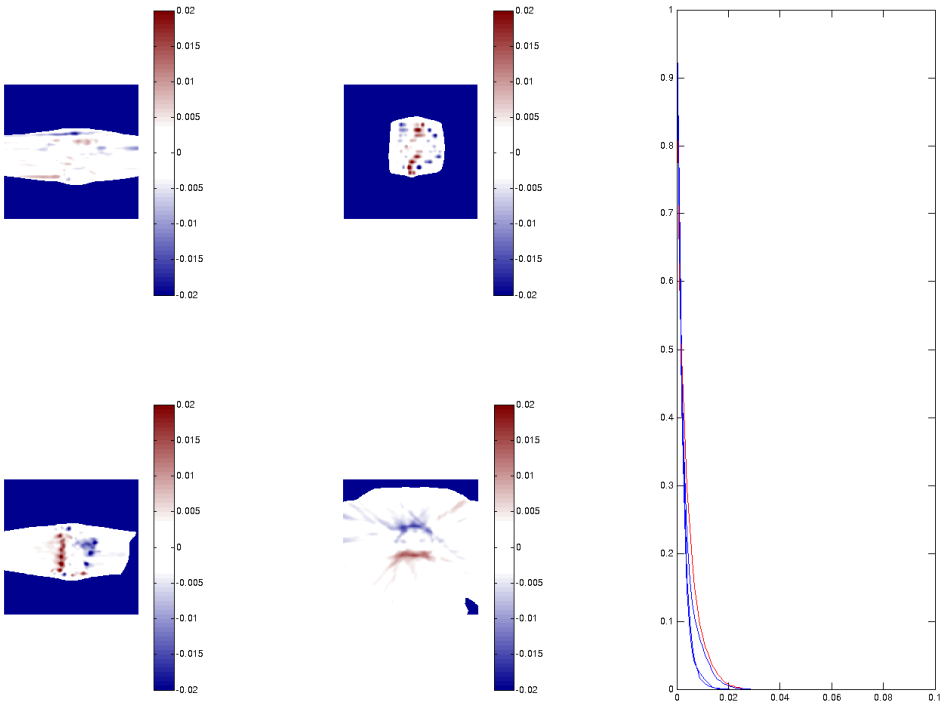

Figure 6: Planar dose changes for a PROSTATE plan. upper left: coronal plane, upper right: collapsed plane, lower left: sagital plane, lower right: transversal plane, right: histogram of dose changes – relative

frequency of dose changes (percentage of maximum dose in the investigated plane), blue curves – patient planes, red curve - collapsed plane.

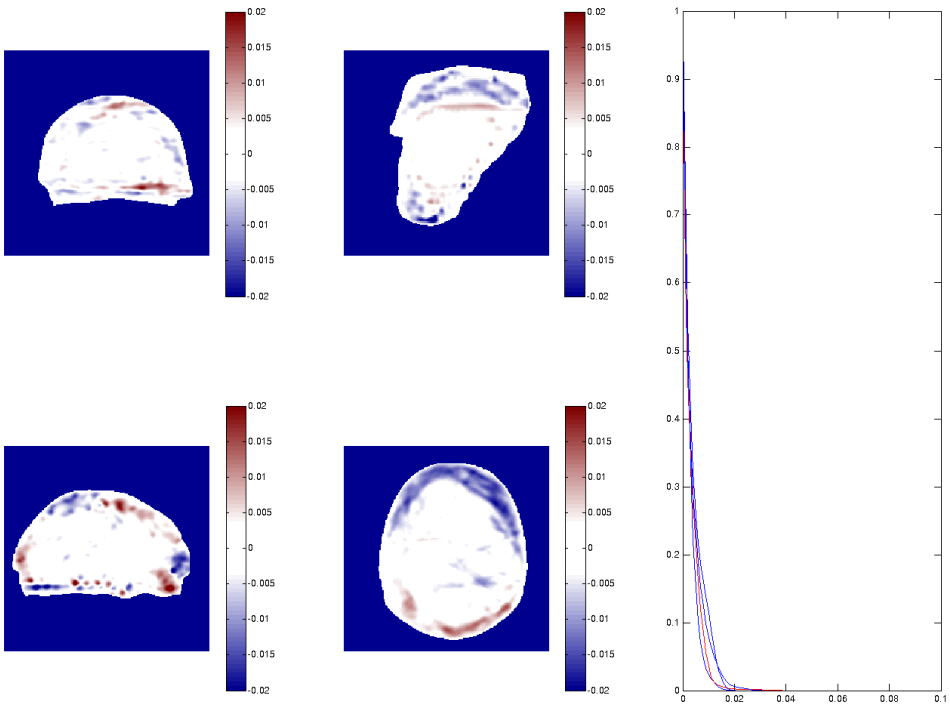

Figure 7: Planar dose changes for a SKULL plan.

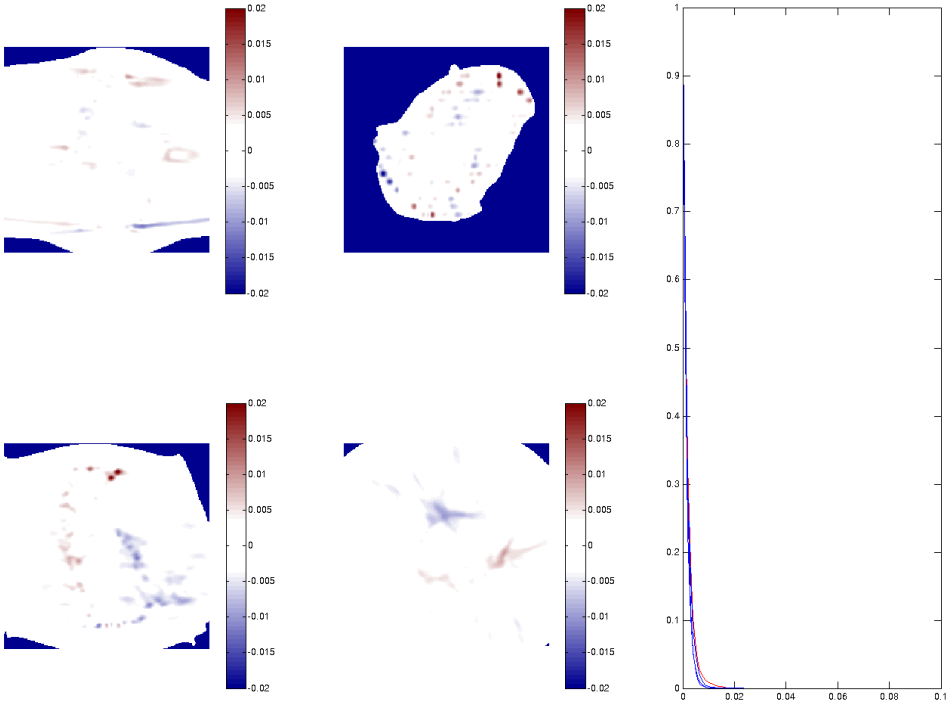

Figure 8: Planar dose changes for an OESOPHAGUS plan.

Clinical results and comparison with a 2D array

Epiqa was used to evaluate 25 clinical RapidArc plans in total. To evaluate the agreement between the measured collapsed plan dose distribution and its calculated reference, the gamma analysis with 3% dose difference and 3 mm distance to agreement criteria was used.

The choice of the gamma criteria was selected based on the knowledge of similar response of the patient and collapsed dose distribution to the introduced changes (see above).

The results vary between 93.1 % and 99.0 %, with the mean of 96.8 % (1 SD = 1.9 %). The same set of treatment plans was also verified using the tandem 2D chamber array Seven29 (PTW) and dedicated octagonal phantom Octavius (PTW), with the horizontally and vertically oriented 2D array. The gamma analysis with the same criteria has been used.

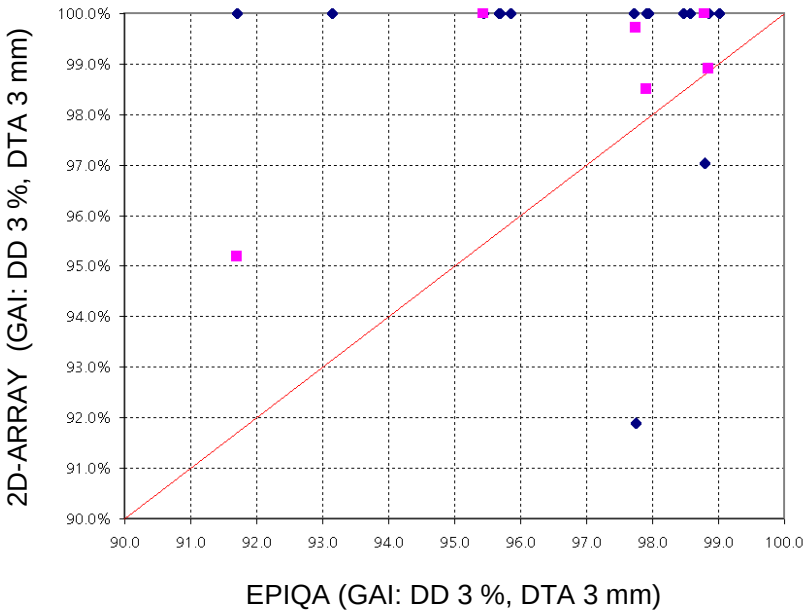

Figure 9: Plot of Epiqa versus 2D-array results of verification of clinical RapidArc plans.

The collapsed plan based verification shows to be more sensitive than the 2D array based verification. Only in 4 out of 25 investigated patient plans the gamma score of the 2D array verification was worse than the gamma score of the collapsed dose distribution (Figure 9). In these cases, the low score was clearly a result of the imperfection of the detector – strong angular dependence for oblique irradiation – that was further enhanced by proportionally higher dose contribution from the directions oblique to the verified plane. Figure 10 shows reference dose distribution and the gamma map (3 % DD, 3 mm DTA) for the verification of horizontal and vertical plane of a RapidArc plan. In this case, a RapidArc with an avoidance sector on patient's left side was verified. The 2D-array's underestimation of lateral irradiation creates a track of failed points for the contribution from control points with an oblique incidence upon the 2D-array. Verified dose distribution passes at all points for vertically oriented 2D-array, where the oblique contribution was small.

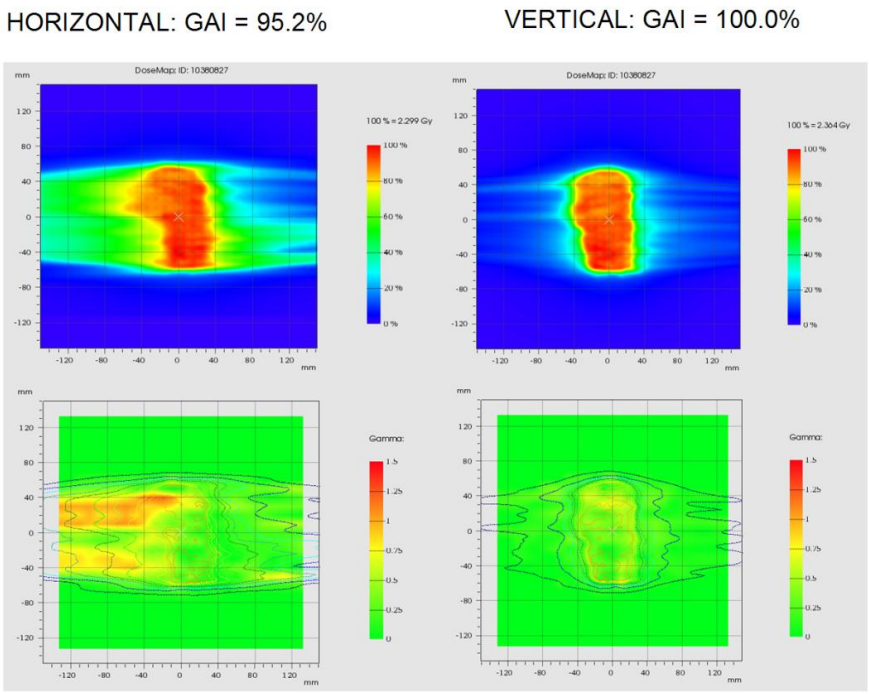

Figure 10: A clinical example of a "bad" result of the 2D-array verification.

One should also consider how many planes need to be verified, when planar patient dose distribution is verified. When planar dose distribution is verified for an isocentric plane, the significance of individual control points of a RapidArc field is not uniform. A standard RapidArc plan has 177 control points, therefore if similar dose contribution is assumed for simplicity, in the proximity of the isocentrum, one control point contributes 1/177 of dose to this volume and even large errors in one control point will not have a significant influence on the final dose accumulated in this volume. However, as the distance from the isocentrum increases, the control points aligned parallel with the plane gain gradually on significance. If an error occurs in one of these control points, it will have an impact on larger area. As demonstrated above, this is a very unfortunate effect for 2D arrays that suffer from underestimation of a response for oblique irradiation. Collapsed plans verified by Epiqa have in the first approximation intrinsically same sensitivity to all control points of a RapidArc plan.

Efficiency

The following table tries to summarize all the steps necessary to perform the verification of a RapidArc plan using Epiqa and time required for their execution:

Generation of the verification plan	1 min
Calculation of dose distribution for the verification plan	17 min
Export of RT and RD DICOM files	1 min
Irradiation of the verification plan	
(RA field + 10x10 field) including detector setup	3 min
Export of RI DICOM files	1 min
Import of RT, RD, and RI files and evaluation in Epiqa	2 min

Total QA time per plan	25 min

Dose distribution calculation of the verification plan is a fully automated step and does not require a presence of a user. The speed of calculation strongly depends on the selected calculation grid and the computational power of a workstation. This value was obtained for AAA 8.2.23, grid 2.5 mm, calculated with the DELL Precision T5400 workstation.

CONCLUSION

Based on the yearly experience of using Epiqa, it can be concluded that Epiqa is an efficient method for a routine verification of intensity modulated fields.

Our results show that an appropriate detector resolution is necessary for a critical verification of modulated fields. 2D chamber arrays fail to provide this prerequisite, which results in their lower sensitivity. The resolution of film dosimetry is on par with Epiqa and due to its universality and the ability to verify any arbitrary plane, it is the superior method for a detailed dosimetric analysis of intensity modulated plans. However, the simplicity of use of Epiqa overcomes the work extensiveness of film dosimetry and makes it a promising system for the routine verification.

Concerning RapidArc verification, i.e. the collapsed plan verification, our theoretical study together with the direct comparison of Epiqa and 2D-array results provide an evidence that Epiqa can serve as a tool for clinical validation of RapidArc plans. However, a comparison with film dosimetry and/or more extensive theoretical study would be adequate.