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EPID in vivo dosimetry in RapidArc technique

Krzysztof Slosarek, Marta Szlag, Barbara Bekman, Aleksandra Grzadziel*

Centre of Oncology – Maria Sklodowska Curie, Memorial Institute, Branch Gliwice, Radiotherapy and Brachytherapy Planning Department, Poland

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ABSTRACT

Aim: The aim of the study was to estimate the dose at the reference point applying an aSi-EPID device in the course of patient treatment.

Materials and methods: The method assumes direct proportionality between EPID signal and dose delivered to the patient reference point during the treatment session. The procedure consists of treatment plan calculation for the actual patient in the arc technique. The plan was realized with an elliptic water-equivalent phantom. An ionization chamber inside the phantom measured the dose delivered to the reference point. Simultaneously, the EPID matrix measured the CU distribution. EPID signal was also registered during patient irradiation with the same treatment plan. The formula for in vivo dose calculation was based on the CU(g) function, EPID signal registered during therapy and the relation between the dose and EPID signal level measured for the phantom. In vivo dose was compared with dose planned with the treatment planning system.

Irradiation was performed with a Clinac accelerator by Varian Medical Systems in the RapidArc technique. The Clinac was equipped with an EPID matrix (electronic portal image device) of aSi-1000. Treatment plans were calculated with the Eclipse/Helios system. The phantom was a Scanditronix/Wellhöfer Slab phantom, and the ionization chamber was a 0.6 ccm PTW chamber.

Results: In vivo dose calculations were performed for five patients. Planned dose at the reference point was 2 Gy for each treatment plan. Mean in vivo dose was in the range of 1.96–2.09.

Conclusions: Our method was shown to be appropriate for in vivo dose evaluation in the RapidArc technique.

1. Introduction

Verification of dynamic methods in radiotherapy (RT) is a critical step in medical physicist practice. Despite many available methods, dose verification in dynamic techniques presents a challenge to the quality assurance team.

The present range of verification methods in intensity modulated radiotherapy (IMRT) allows one to perform pretreatment dose control rather than in vivo dosimetry.

The methods individually are insufficient to assure accurate dose delivery verification.[1]

Traditional treatment verification can be done by single-point measurement in a phantom. Additionally, dose

* *Corresponding author at*: ul. Wybrzeze Armii Krajowej 15, Gliwice 44 – 101, Poland. Tel.: +48 32 278 80 18; fax: +48 32 278 80 71.
E-mail address: martaszlag@o2.pl (M. Szlag).

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distribution control can be accomplished by testing of agreement between calculated and measured dose distribution in corresponding planes. For this purpose largely utilized are amorphous silicon electronic portal imaging devices (aSi-EPID).[2–9]

Although acquisition of a fluence map itself does not provide absolute dose measurements, it is capable of providing relative dose measurement. Correlation of the portal dosimetry and ion chamber dosimetry enables precise determination of the dose. For in vivo dosimetry purposes, dosimetric properties of EPID and point dose measurement worked together are used. Namely, the image from the EPID can be converted into the absolute dose.[10]

Characteristics of aSi-EPID and its usefulness for IMRT dosimetric purposes have been quite extensively discussed. Linearity of dose response, field size dependence and independence on beam energy have been proven.[3–7,9,11,12]

A novel solution of dose delivery is offered in the RapidArc technique. It is an extension of IMRT, where the dose is optimized during inverse planning and then realized in a single dynamically modulated arc. While the gantry is rotating, MLC leaves are moved, modulating dose distribution continuously.[10,13] This new modality demands a reliable form of verification process. Therefore substantial questions are: is RapidArc a safe delivery method, and what approach is required for RapidArc IMRT delivery verification?

According to the preliminary reports RapidArc is an appropriate technique in some tumour locations and increases flexibility in generating highly conformal treatment. Reducing the overall treatment time, increased conformity and organs at risk (OARs) sparing are mostly emphasized.[14–19] The first reports on dose verification indicate auspicious abilities of portal dosimetry conducted for RapidArc fields.[10,13]

In this paper the authors have tried to demonstrate the usefulness of aSi-EPID for RapidArc dosimetric verification.

The signal detected by EPID is expressed in calibration units (CU).[4,12,20] First, the relation between the signal and the dose delivered from the photon beam was measured. The signal was registered with the presence of an absorbent (layers of the phantom). The number of CU was described as a function of the absorbent thickness, located between the source and the EPID cassette. These data were then used for assessment of the dose absorbed in patient tissues. In order to do that, an assumption was made that there is proportionality of the EPID signal measured during the treatment session and the dose absorbed in the patient's body.

Plans calculated for the patients are transferred to the phantom shape and realized in accordance with calculated geometry. During the gantry rotation the EPID signal is acquired and the absolute dose at the reference point in the phantom is measured using the ion chamber. Then the patient is irradiated with EPID signal acquisition simultaneously. The concept of dose determination in the patient is based on the following issues that need to be considered: (i) the dependence between EPID signal and absorbing layers' thickness, (ii) the relationship between dose measured by the ion chamber in the phantom and EPID signal, and finally (iii) EPID signal measured during patient treatment session. These three elements allow one to carry out in vivo dosimetry with the help of a portal cassette.

The aim of the study was to estimate the dose at the reference point (in the patient's body) applying the aSi-EPID device in the course of patient treatment with the RapidArc technique.

2. Materials and methods

Our method enables us to perform in vivo dosimetry in the RapidArc radiotherapy technique. In general, in vivo dosimetry in teleradiotherapy is performed indirectly, with detectors located on the body surface. In our study an EPID cassette was used to evaluate the dose delivered to a specific point located in the patient's body (reference point) during arc therapy. The experiment of in vivo dose evaluation was performed in three steps. First, the dosimetric characteristic of the EPID detectors was estimated; then, the relation between the absolute dose measured with the ion chamber in a water-equivalent phantom and EPID signal registered during phantom irradiation was evaluated; and finally, the EPID signal was measured during an actual radiotherapy session. The analysis of the measured quantities led to the formula for calculation of the in vivo dose delivered during treatment.

2.1. *EPID dosimetry—basic assumptions*

In this part of the experiment we tested the linear relation between treatment time, dose at the reference point and EPID signal. We also measured the EPID signal's dependence on the thickness of absorbent located between the source and the detector's matrix.

In our experiment we assumed that the dose at point P (the reference point) located inside the patient's body is directly proportional to the number of monitor units (MU) and calibration units (CU—the level of the EPID signal) (Fig. 1).

This assumption is valid only for a homogeneous density of the irradiated volume. The patient's body consists of different tissue types of varied density. However, assuming that the gantry and EPID cassette make a 360-degree turn on the accelerator axis we may approximate that density of the patient's body is homogeneous. The in vivo dosimetry method reported in this paper can be applied under the condition that the treatment plan is realized in one 360-degree turn. During the entire gantry rotation each point in the patient is located between the EPID and the reference point (Fig. 2).

In vivo dosimetry and dose calculations with the portal cassette require knowledge of the dosimetric characteristics of the EPID detectors. Therefore, the actual experiment was preceded with measurement of the EPID signal as a function of MU and irradiation field size. EPID signal was found to be directly proportional to MU number for different field sizes and for different photon energies.[12] The graph shown in Fig. 1 presents the linear relation between MU and CU.

2.2. *EPID signal dependence on the absorbent thickness*

The EPID signal depends on the monitor unit and is also correlated with the radiation absorption in the patient's body. To apply the EPID for in vivo dosimetry we need to test the

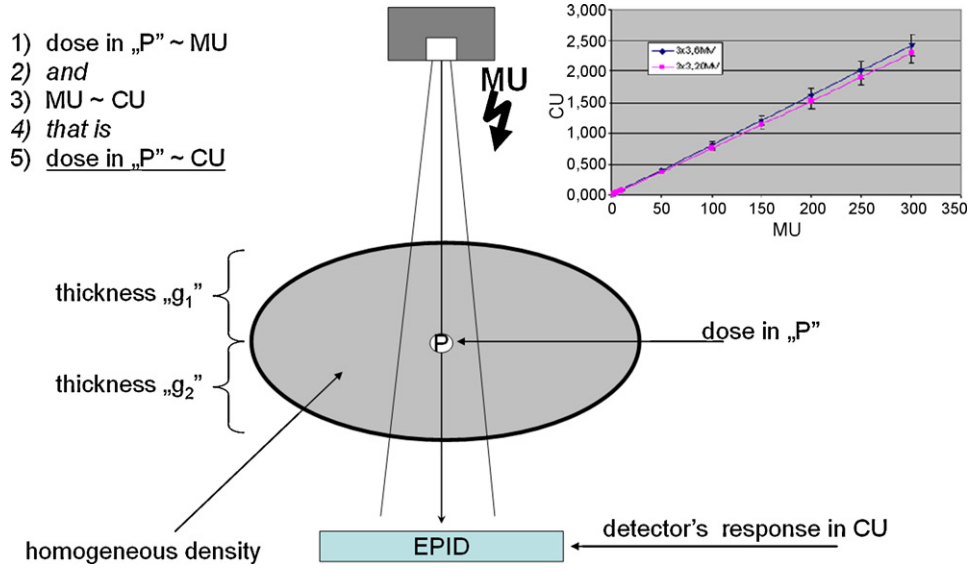

Fig. 1 – Absolute dose delivered to the reference point (P) located inside the treated volume is directly proportional to the number of monitor units (MU). The reference point coincides with the isocentre point. Direct proportionality was found between EPID response (CU level) and MU for different energies and field sizes (graph in the upper-right corner). Then, for a homogeneous density, single beam and static technique, EPID signal is considered to be proportional to the dose at point P.

dependence of EPID signal on thickness of the absorbing material.

Layers of the phantom plates were placed on the therapeutic table perpendicularly to the beam axis. Source axis distance irradiation technique (SAD) was used in this experiment. CU values were measured while number of MU, field size and distance (*f*) between the lowest surface of the absorbent and the EPID were constant during the experiment (Fig. 3). The layers ranged in thickness from 0 to 18 cm with an increment of 1 cm. All measurements were performed with a photon beam of 6 MV and with aS1000 operating in "integrated image" mode. This mode continuously acquires an image over the entire time of beam delivery.

CU(*g*) exponential function (Eq. (1)), derived from the experimental values, was found to describe the detector response

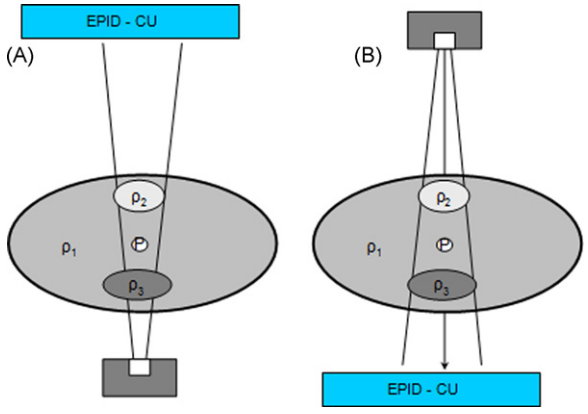

Fig. 2 – In the static technique the in vivo dose in A differs from the dose in B even though the same treatment time was applied. Inhomogeneities of the density inside the irradiated volume influence the EPID response. In A and B structures of different densities (ρ_2 and ρ_3) are located behind and in front of point P, which alters the correlation between MU, in vivo dose and CU values. In the arc technique, both A and B situations are included in the 360-degree turn. Rotation on the accelerator axis averages the inhomogeneities inside the volume and retains the correlation between MU, P dose and EPID response.

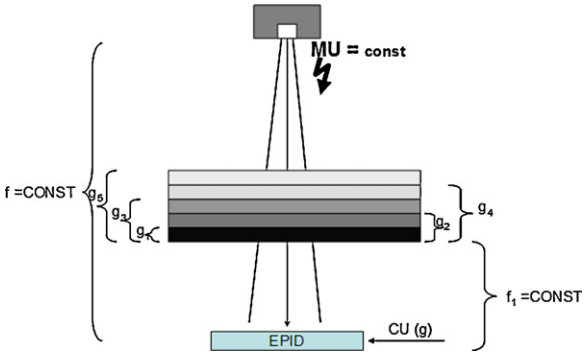

Fig. 3 – Thickness of the absorbing material located between the source and EPID cassette influences the signal level of EPID. Signal level decreases when increasing the absorbent thickness. To evaluate the CU dependence on the absorbent thickness (*g*) we measured the EPID signal for *g* values ranging from 0 to 18 cm. An amorphous silicon portal imaging device (aSi-EPID) of type aS1000 was applied. Single beam of 6 MV photon energy and constant number of MU equal to 200 were applied. Field size was 10 cm × 10 cm. Distance between EPID cassette and the source (*f*) was 140 cm. f_1 was constant in this part of the experiment and equal to 40 cm.

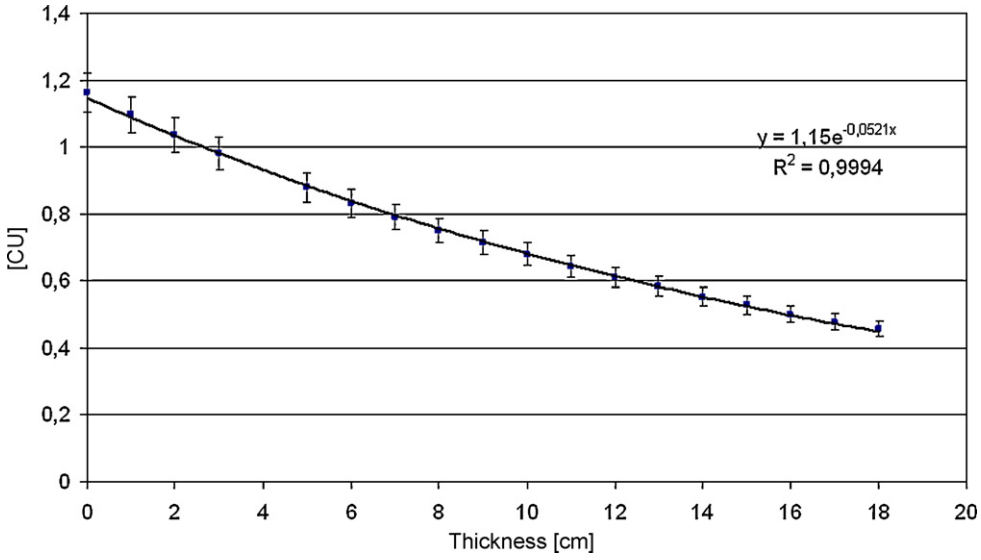

Fig. 4 – Exponential function CU(g) = $\mu \cdot \exp(-\delta \cdot g)$ expresses the dependence of EPID signal on absorbent thickness. Coefficient μ represents the CU(g) dependence on MU and δ represents the CU(g) dependence on the distance between the lowest surface of the phantom and the EPID matrix (f_1). In this experiment μ and δ are equal to 1.15 and 0.05 respectively and describe CU(g) function unambiguously owing to the constant geometry of the phantom in respect to the EPID matrix and the constant number of monitor units.

depending on absorption in the material (Fig. 4).

$$CU(g) = 1.1471 \cdot \exp(-0.0521 \cdot g_{avg}) \quad (1)$$

2.3. *Absolute dose measurement vs. EPID signal*

To evaluate the in vivo dose based on the EPID signal registered for the actual treatment plan we need to find the relation between this quantity and between the dose measured in the water phantom and the EPID signal registered during phantom irradiation.

In this part of the experiment the treatment plan of the prostate case was applied to irradiate the elliptic slab phantom (which was a water-equivalent phantom) in order to compare the EPID response with the dose measured with the ion chamber located at the reference point of the phantom.

Actual treatment plan was calculated with the Eclipse/Helios (Varian) treatment planning system (TPS) for linear accelerator Clinac 23EX Shilette (Varian) using the dynamic RapidArc technique. This TPS worked with an AAA algorithm. The grid of computation was set to 0.25 cm. The plan was optimized for a 6 MV photon beam. The treatment plan was then recalculated according to the phantom geometry, considering homogeneous density of the phantom volume. The dose measured at the phantom reference point (P_{1m}) differed from the dose calculated for the patient's anatomy, while the specific features of the plan, i.e. gantry start and stop angle, gantry and leaves speed, leaves' positions, dose rate and MU were retained. EPID signal (CU_{1m}) and dose at the phantom reference point (P_{1m}) were measured simultaneously during phantom irradiation (Fig. 5). Those quantities were used for further calculations of the in vivo dose delivered during patient therapy.

2.4. *EPID in vivo dosimetry—formula for in vivo dose calculation*

This part of the experiment assumed calculation of the absolute in vivo dose at the reference point delivered during therapy for the actual patient. Five patients were randomly selected for the experiment. The dose distribution for each patient was computed in TPS so that the planned dose at the reference point for each patient was 2 Gy. Planned dose and calculated one were compared. All statistics and graphs were performed in Excel—Office application.

During radiotherapy the EPID matrix registered an integral signal (CU_{2m}). Treatment time was identical with the irradiation time during phantom measurement and the same treatment parameters were applied (Fig. 5).

The relationship between in vivo dose (P_{2c}) and dose measured with the ion chamber during phantom irradiation (P_{1m}) can be expressed by the formula:

$$P_{2c} \cdot B = P_{1m} \cdot A \quad (2)$$

where A and B were defined as CU ratios:

$$A = \frac{CU_{1c}}{CU_{1m}} \quad \text{and} \quad B = \frac{CU_{2c}}{CU_{2m}};$$

CU_{1c} and CU_{2c} were the EPID responses derived from the CU(g) formula developed in the first part of this paper. In the TPS, average equivalent thicknesses (g_{avg}) were calculated for both the elliptic phantom and for the patient's body. Calculated g values were introduced to the CU(g) equation. The resultant CU values (CU_{1c} and CU_{2c}) describe the level of radiation absorption in the phantom and in the patient's body for constant treatment time.

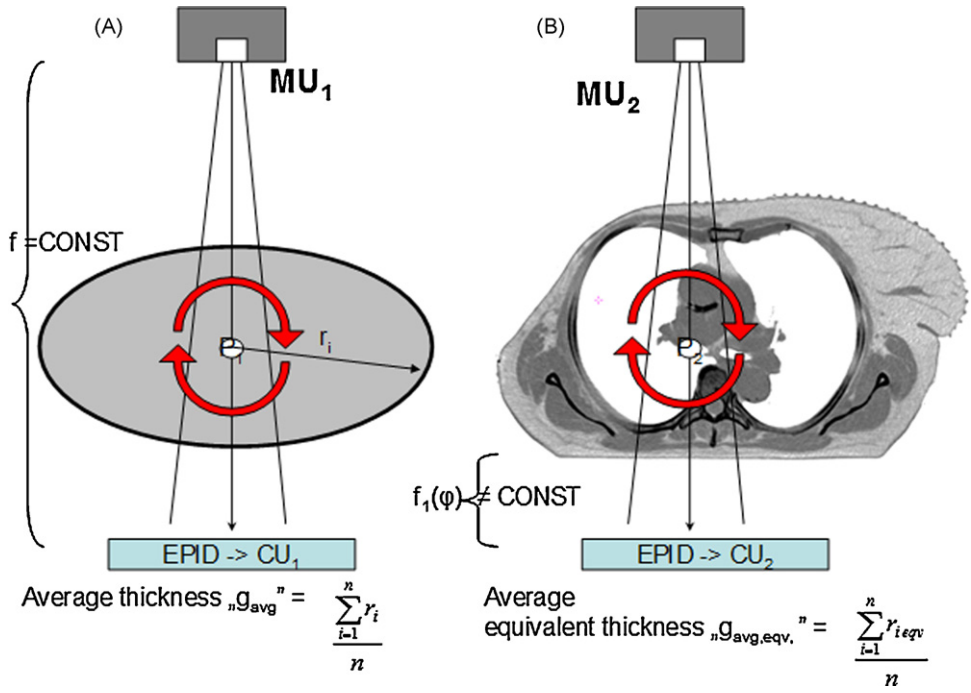

Fig. 5 – (A) The appropriate elliptic slab phantom (Scanditronix Wellhöfer I'mRT Phantom) and 0.6 ccm PTW ion chamber (Scanditronix Wellhöfer) were used for measurements. The ion chamber located at point P registered the absolute dose during irradiation (P_{1m}). At the same time the detector's matrix measured the EPID signal (CU_{1m}). The image was acquired at source—EPID distance (*f*) at 140 cm in the "integrated image" mode. f_1 varies with the gantry angle and depends on the phantom geometry. For the phantom volume g_{avg} defined as the mean distance between point P and the phantom surface was calculated. (B) EPID signal (CU_{2m}) registered during the treatment session was used for evaluation of the in vivo dose (P_{2c}) delivered to the patient reference point. Average equivalent thickness ($g_{avg\text{-}eqv}$) of the patient's body was computed for CU_{2c} calculations. During gantry rotation f_1 changes its value and modifies the EPID response.

Additionally, calculated CU values normalized the measured CU in respect to the constant geometry of irradiation. In this part of the experiment the distance between the EPID and the external surface of both phantom and patient varies with the gantry angle and depends on the shape of the irradiated volume. It influences the EPID response. For this reason coefficients A and B were introduced to the P_{2c} formula.

We may conclude that both coefficients express different conditions in both parts of the experiment. Finally, dose at the reference point for the patient during therapy can be evaluated with the formula:

$$P_{2c} = \frac{P_{1m} \times (CU_{1c} \times CU_{2m})}{(CU_{2c} \times CU_{1m})} [Gy] \quad (3)$$

where P_{2c} is the dose value delivered to the reference point during patient therapy, CU_{2m} is the EPID signal measured during patient irradiation while CU_{2c} is the EPID signal calculated based on CU(*g*) function for average patient's thickness. P_{1m} is the absolute dose measured in the water-equivalent phantom. CU_{1m} is the EPID signal registered during phantom irradiation and CU_{1c} is the calculated EPID response based on the CU(*g*) function and average thickness of the phantom.

3. Results

In this study, we tested a new in vivo dosimetry method in the dynamic arc technique for measurement of the dose delivered to the reference patient point. We applied our method to compare the dose planned in TPS with the actual dose measured during irradiation.

Dose measured in a water-equivalent phantom and CU values registered during therapy and during phantom irradiation were used for P_{2c} calculations. All those values calculated for each patient are shown in Table 1. Absolute difference between planed dose and calculated P_{2c} was not higher than 0.09 Gy.

4. Discussion

A significant advantage of this work is the determination of the new in vivo dosimetry tool for the quality assurance procedure in the dynamic radiotherapy technique. This method provides measurable benefits following from in vivo dosimetry performed during the course of radiotherapy.

The formula for evaluation of the dose delivered during irradiation (P_{2c}) was based on the dose measured in a water-equivalent phantom with an ion chamber and signal

Table 1 – Dosimetric data for analyzed patients. CU values measured during patient and phantom irradiation and dose measured in phantom were used to calculate the in vivo dose delivered to the reference patient point. Additionally, the table presents phantom and patient equivalent average thickness which were used for CU calculation based on the CU(g) formula.

Patient number	Planned dose in reference point calculated in TPS [Gy]	Dose measured in P point in phantom P_{1m} [Gy]	Dose in P point in phantom calculated in TPS P_{1c} [Gy]	Average thickness in phantom g_{avg} [cm]	CU measured in phantom CU_{1m}	CU measured in patient CU_{2m}	Average equivalent thickness in patient $g_{avg\text{-}eqv}$ [cm]	Dose calculated in the reference point P_{2c} [Gy]
1 (R)	2	2.07	2.10	13.4	0.58	0.54	14.2	2.01
2 (W)	2	2.13	2.26	13.4	0.43	0.35	16.5	2.01
3 (P)	2	1.97	2.07	13.4	0.59	0.57	14.2	1.96
4 (H)	2	2.05	2.19	13.4	0.49	0.44	15.0	2.02
5 (B)	2	2.18	2.29	13.4	0.57	0.46	16.5	2.09

registered during irradiation with an EPID cassette, which is an integral part of the radiotherapy device. Data analysis showed that the difference between the dose calculated at the reference point and planned in the TPS is insignificant in respect to the accuracy of the measurement.

We believe that the presented method has the potential to provide an analytic tool in the quantitative evaluation of radiotherapy in the dynamic arc technique.

5. Conclusion

In vivo dosimetry in the dynamic radiotherapy technique allows dose evaluation delivered to the patient during therapy. The presented method increases the quality and safety of radiotherapy by controlling the correct operation of the treatment devices and dose delivered during each treatment session.

REFERENCES

1. Intensity Modulated Radiation Therapy Collaborative Working Group. Intensity-modulated radiotherapy: current status and issues of interest. *Int J Radiat Oncol Biol Phys* 2001;**51**:880–914.
2. Greer PB. Correction of pixel sensitivity variation and off-axis response for amorphous silicon EPID dosimetry. *Med Phys* 2005;**32**:3558–68.
3. Vieira SC, Dirkx ML, Heijmen BJ, et al. SIFT: a method to verify the IMRT fluence delivered during patient treatment using an electronic portal imaging device. *Int J Radiat Oncol Biol Phys* 2004;**60**:981–93.
4. Van Esch A, Depuydt T, Huyskens P. The use of an aSi-based EPID for routine absolute dosimetric pre-treatment verification of dynamic IMRT fields. *Radiother Oncol* 2004;**71**:223–34.
5. McCurdy BMC, Luschka K, Pistorius S. Dosimetric investigation and portal dose image prediction using an amorphous silicon electronic portal imaging device. *Med Phys* 2001;**28**:911–24.
6. Winkler P, Hefner A, Georg D. Dose-response characteristics of amorphous silicon EPID. *Med Phys* 2005;**32**:3095–105.
7. Greer PB, Popescu CC. Dosimetric properties of an anamorphous silicon electronic portal imaging device for verification of dynamic intensity modulated radiation therapy. *Med Phys* 2003;**30**:1618–27.
8. Cozzi L, Fogliata A, Nicolini G, et al. Pre-treatment verification of intensity modulated photon beam with films and electronic portal imaging—two years of clinical experience. *Med Phys* 2004;**14**:239–50.
9. El-Mohri Y, Antonuk LE, Yorkston J, et al. Relative dosimetry using active matrix flat-panel imager (AMFPI) technology. *Med Phys* 1999;**26**:1530–41.
10. Piermatei A, Fidanzio A, Azario L, Grimaldi L, D'Onforio G, Cilla S. Application of a practical method for the isocenter point in vivo dosimetry by a transit signal. *Phys Med Biol* 2007;**52**:5101–17.
11. Steciw S, Warkentin B, Rathee S, Fallone BG. Three-dimensional IMRT verification with a flat panel EPID. *Med Phys* 2005;**32**:600–12.
12. Grządziel A, Smolińska B, Rutkowski R, Slosarek K. EPID dosimetry—configuration and pre-treatment IMRT verification. *Rep Pract Oncol Radiother* 2007;**12**:307–12.
13. Nicolini G, Vanetti E, Clivio A, et al. The GLAaS algorithm for portal dosimetry and quality assurance of RapidArc, an

intensity modulated rotational therapy. *Radiat Oncol* 2008;**9**:3–24.
14. Otto K. Volumetric modulated arc therapy: IMRT in a single gantry arc. *Med Phys* 2008;**35**:310–7.
15. Shaffer R, Morris WJ, Moiseenko V, et al. Volumetric Modulated Arc Therapy and conventional Intensity-modulated Radiotherapy for simultaneous maximal intraprostatic boost: a planning comparison study. *Clin Oncol (R Coll Radiol)* 2009;**21**:401–7.
16. Lagerwaard FJ, Meijer OW, van der Hoorn EA, Verbakel WF, Slotman BJ, Senan S. Volumetric modulated arc therapy for vestibular schwannomas. *Int J Radiat Oncol Biol Phys* 2009;**74**:610–5.
17. Verbakel WF, Cuijpers JP, Hoffmans D, Bieker M, Slotman BJ, Senan S. Volumetric intensity-modulated arc therapy vs. conventional IMRT in head-and-neck cancer: a comparative planning and dosimetric study. *Int J Radiat Oncol Biol Phys* 2009;**74**:252–9.
18. Cozzi L, Dinshaw KA, Shrivastava SK, et al. A treatment planning study with RapidArc and fixed field IMRT for cervix uteri radiotherapy. *Radiat Oncol* 2008;**89**:180–91.
19. Fogliata A, Clivio A, Nicolini G, Vanetti E, Cozzi L. Intensity modulation with photons for benign intracranial tumors: a planning comparison of volumetric single arc, helical arc and fixed gantry techniques. *Radiat Oncol* 2008;**89**:254–62.
20. Varian Vision Help, The Dosimetry Workspace v. 7.3.10, SP 3.