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EPID – a useful interfraction QC tool

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Abstract

Biomedical accelerators used in radiotherapy are equipped with detector arrays which are commonly used to obtain the image of patient position during the treatment session. These devices use both kilovolt and megavolt x-ray beams. The advantage of EPID (Electronic Portal Imaging Device) megavolt panels is the correlation of the measured signal with the calibrated dose. The EPID gives a possibility to verify delivered dose. The aim of the study is to answer the question whether EPID can be useful as a tool for interfraction QC (quality control) of dose and geometry repeatability.

The EPID system has been calibrated according to the manufacturer's recommendations to obtain a signal and dose values correlation. Initially, the uncertainty of the EPID matrix measurement was estimated. According to that, the detecting sensitivity of two parameters was checked: discrepancies between the planned and measured dose and field geometry variance. Moreover, the linearity of measured signal-dose function was evaluated.

In the second part of the work, an analysis of several dose distributions was performed. In this study, the analysis of clinical cases was limited to stereotactic dynamic radiotherapy. Fluence maps were obtained as a result of the dose distribution measurements with the EPID during treatment sessions. The compatibility of fluence maps was analyzed using the gamma index. The fluence map acquired during the first fraction was the reference one. The obtained results show that EPID system can be used for interfraction control of dose and geometry repeatability.

Key words: EPID; gamma index; fluence map.

Introduction

Electronic portal devices were proposed for clinical practice at the turn of the 20th and 21st centuries. They were dedicated for the verification of patient setup during the therapeutic session [1,2], as well as for the dose estimation [3-8]. Initially, only a megavolt beam was used both for planar images and volumetric reconstructions CBCT (Cone Beam Computed Tomography). The advantage for CBCT reconstructions is the minimized amount of artifacts from metal objects, compared to the number of artifacts obtained with the use of kilovolt beam. The disadvantages are the worse tissue differentiation and the higher dose delivered to the patient during imaging while comparing with kilovolt beams [9]. In addition, dedicated software was developed to reduce the metal artifacts in acquired images that are produced by high-density materials [10-12]. Till now, this kind of software is available only for computed tomography scanners (CT). It is highly probable that this type of software will be implemented for OBI (On-Board Imaging with kilovolt x-ray beam), which is used in IGRT (Image Guided Radiation Therapy) techniques. Thus, the question appears if megavolt detectors integrated with the therapeutic units still have a future. Certainly, those detectors can be used for dose measurement during the therapeutic sessions. EPID is commonly used to compare the calculated and measured fluence map. It should be noted that such verification procedures are usually done with a patient's absence and are a part of dynamic plans QA [13,14]. Such measurements do not give the information on dose distribution in patient body. The reconstruction of patient dose absorbed in a single fraction requires dedicated software [15-21]. The proposed proceeding would allow correlating the EPID signal collected during the irradiation with the dose in patient body. This would enable EPID dosimetry without new software and hardware usage.

Material and method

The study was performed with aS1200 EPID devices integrated with TrueBeam and Edge accelerators (Varian Medical Systems, Palo Alto, CA, USA). The active panel area is 43.0 × 43.0 cm^2, with a resolution of 1280 × 1280 pixels and with a maximum recording speed of 20 sets of frames per second [22]. During the acceptance tests and commissioning measurements, all EPID matrices were calibrated following the manufacturer's recommended procedures [23].

Phantom set-up

In all measurements, the tissue-like phantom EASY CUBE Body Module S (Lap GmbH Laser Applikationen, Lueneburg, Germany) was used. Additionally, culture flask (Falcon, 25 cm^2, https://en.vwr.com) was filled with water and placed inside the EASY CUBE phantom. Their location can be clearly visible in both kilovolt and megavolt imaging (**Figure 1**). First, the phantom CT imaging was performed using data acquisition and image reconstruction protocols as used clinically for typical head scans. Imaging data were imported into the Eclipse v.13.6 TPS (Treatment Planning System) (Varian Medical Systems, Palo Alto, CA, USA), and the treatment plan was created.

Plan preparation

The treatment field was set up to 15 × 15 cm^2 at the isocenter located on the flask base. For all photon energies X-6 MV, X-15 MV and X-10 MV-FFF the dose distributions were made with 0.5, 1.0, 2.0 and 7.0 Gy dose specified at isocenter. For the filtered and filtered free beams, the dose rate of 600 MU/min and 2400 MU/min were used respectively. Additionally, for all treatment plans the dose at isocenter was measured with 30013 Farmer ionization chamber and T10001 UNIDOS electrometer (PTW-Freiburg, Germany).

EPID method sensitivity

The repeatability of the EPID measurements was checked by irradiating four times the EPID matrix for all the mentioned energies and doses. Fluence maps of the 15 × 15 cm^2 of the field were acquired in the "Integrated Image" measurement mode [23,24]. For the further analysis a 2 × 2 cm^2 region of interest with its center at the isocenter was selected. The agreement of the four measured fluence maps was assessed in the area of interest. The first fluence map was the reference one. The evaluation was conducted with the usage of the gamma index, calculated with the criteria of $\Delta d = 0.5\%$ and DTA = 0.5 mm [25].

Four fluence maps acquired for given energy and dose were the independent group of data. Further, those data were the base for the nonparametric tests.

Linearity

In the region of interest, the mean value of the acquired signals was calculated. The unit of the calculated and measured fluence maps in Varian system is CU (Calibration Units) [24]. The linearity between the number of CU and the dose was checked for all selected beams. Four arbitrary dose values were chosen: 0.5, 1.0, 2.0 and 7.0 Gy.

Dose and geometry change sensitivity

For the X-6 MV beam, the sensitivity for the dose changes was tested. The doses of 0.45, 0.50 and 0.55 Gy at the isocenter for 15 × 15 cm^2 field were prescribed. For these doses the fluence maps were acquired. To assess the differences between the fluence maps of the three doses the gamma index in the area of 2 × 2 cm^2 was calculated. Three pairs of gamma criteria were established: (i) $\Delta d = 0.5\%$ and DTA = 0.5 mm, (ii) $\Delta d = 2.0\%$ and DTA = 2.0 mm, and (iii) $\Delta d = 4.0\%$ and DTA = 4.0 mm. To determine the statistical significance the nonparametric tests method for independent samples (Mann-Whitney U test) was performed.

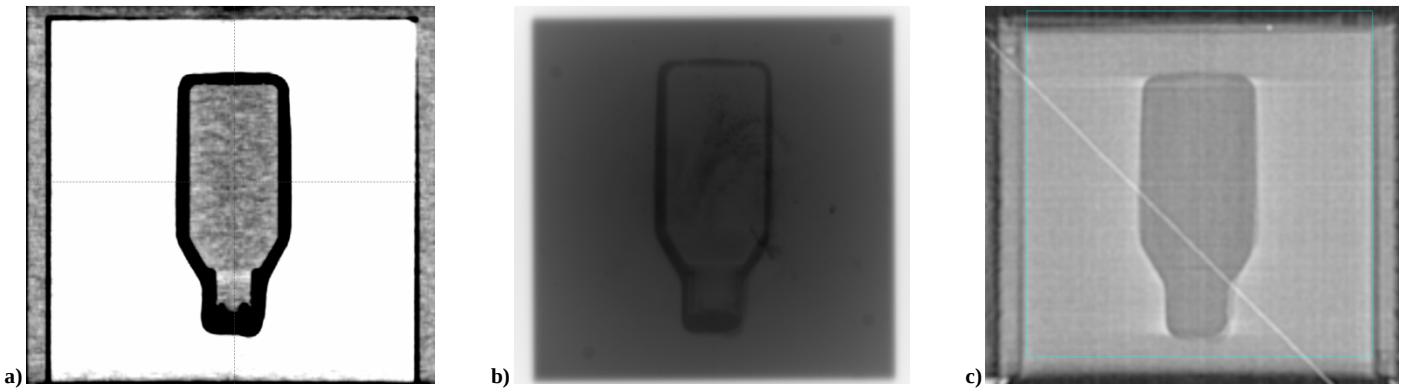

Figure 1. Imaging of the culture flasks in different x-ray beams: kilovoltage (a), megavoltage (b) and digital reconstruction (DRR) obtained from kilovoltage computed tomography (c).

Table 1. Percentage values of the analyzed field that meet the gamma ≤ 1 criteria of Δd = 0.5% and DTA = 0.5 mm, mean values of CU, standard deviation and uncertainty (bold) calculated for three beam energies and four tested doses.

Beam	0.5 Gy				1.0 Gy				2.0 Gy				7.0 Gy			
	%S	CU (mean)	SD (CU)	Δ [%]	%S	CU (mean)	SD (CU)	Δ [%]	%S	CU (mean)	SD (CU)	Δ [%]	%S	CU (mean)	SD (CU)	Δ [%]
X-6MV	98.9	0.103	0.007	**7.3**	100.0	0.204	0.005	**2.7**	100.0	0.406	0.002	**0.5**	100.0	1.430	0.007	**0.5**
X-15MV	98.9	0.132	0.000	**0.2**	99.2	0.265	0.001	**0.3**	99.3	0.531	0.001	**0.2**	99.3	1.861	0.004	**0.2**
FFF-X-10MV	99.7	0.129	0.001	**0.4**	99.8	0.258	0.001	**0.4**	99.8	0.517	0.002	**0.4**	99.8	1.812	0.007	**0.4**

Once more the X-6 MV beam and isocentric 15 × 15 cm^2 field were used for geometry tests. In order to estimate the ability to find a geometric error, the phantom was shifted in the lateral and longitudinal axes by 3.0 mm. The phantom in reference and the shifted position was irradiated and the fluence maps were acquired. Differences between the proper and shifted fluence maps were evaluated with the gamma index in 2 × 2 cm^2 area within four pairs of criteria: (i) Δd = 0.5% and DTA = 0.5 mm, (ii) Δd = 2.0% and DTA = 2.0 mm, (iii) Δd = 4.0% and DTA = 4.0 mm and (iv) Δd = 5.0% and DTA = 5.0 mm.

Then, the received data were statistically analyzed using nonparametric tests for independent samples. Results of the dosimetric and geometric tests were the base of the null hypothesis stated. The numerical values of fluence maps were the analyzed data sets. There were 8 pairs of sets for different dosimetric and geometrical conditions. The null hypothesis stated: if at least 98% of the analyzed field meets the gamma ≤ 1 condition for Δd = 2.0% and DTA = 2.0 mm criteria, then the sets are not identical.

Analysis of clinical cases

The practical usefulness of the EPID matrix as dosimetry system was proved by measurements of the fluence maps. The fluence maps were acquired for 19 fractionated stereotactic plans (VMAT or IMRT). Two measurements were made for 16 patients and three measurements were made for 3 patients. In total, 75 fluence maps were compared and analyzed. For all 87 comparisons were done. Each treatment was realized with the EPID device in mode enabling the measurement of radiation passing through the patient body. The first measured fluence map was the reference one. The next fraction maps were compared to the first one. The gamma index was determined in two ways for (i) Δd = 0.5% and DTA = 0.5 mm, (ii) Δd = 2.0% and DTA = 2.0 mm. For both sets of criteria the mean values of gamma index were calculated.

Moreover, each measured fluence map was exported to Statistica v. 12 (https://www.statsoft.pl) and using Mann-Whitney U test the comparison was made to check whether these sets are identical. The significance criterion was p-value < 0.05. This way the similarity of fluence maps for given fields was checked.

Results

EPID method sensitivity

Table 1 shows the percentage of the analyzed field with the gamma coefficient less or equal than one for the criteria: Δd = 0.5% and DTA = 0.5 mm and the average values of the CU from the area of interest defined as 2.0 x 2.0 cm^2 with the value of the standard deviation. For every energy and dose used in the study, the values of percentage uncertainty (Δ) were calculated. The mean value of the %S calculated for all energy and doses equals 99.1% with the average measurement uncertainty of 1.1%. This value was obtained as the average value of all uncertainties (bold numbers in **Table 1**).

The results of nonparametric tests for independent groups of data showed no statistically significant differences. However, it should be noted that for low energies and doses the measurement uncertainty is greater.

Linearity

The graph of a signal measured by the EPID matrix during irradiation as the function of the dose for photon radiation: X-6 MV, X-15 MV, and X-10 MV-FFF is shown in **Figure 2**. The correlation coefficient $R^2 = 0.9999$ shows a linear dependency of the CU value and the dose value. Performed measurements and calculations confirmed strong linear dependency between the dose and the detector signal, which allows using this device to assess radiation doses.

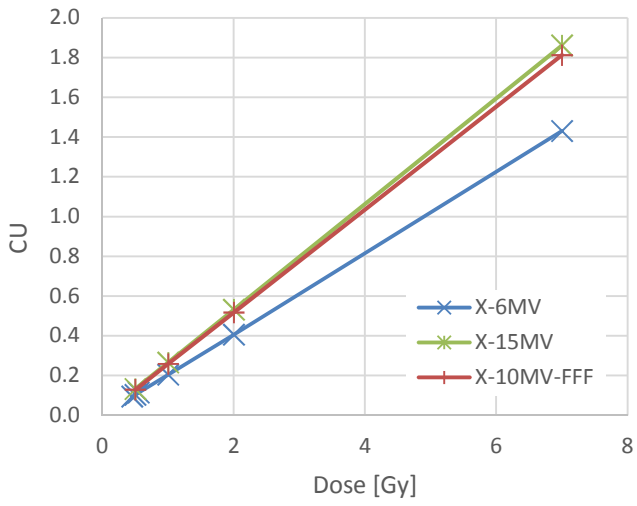

Figure 2. The measured signal as a function of the dose in the range from 0.5 to 7.0 Gy for photon beams: X-6 MV and X-15 MV and X-10 MV-FFF.

Dose and geometry change sensitivity

To evaluate the dose change sensitivity the CU numbers in 2.0 x 2.0 cm^2 central area for 0.50 Gy, 0.45 Gy and 0.55 Gy were used. Differences between pairs of fluence maps were calculated using the gamma index. The analyzed data show a significant statistical difference. The results for three different pairs of criteria are presented in **Table 2**. The tested 10% difference of dose significantly affects the %S that meets the criterion of the gamma index for and $\Delta d = 0.5\%$ and DTA = 0.5 mm. For assumed criteria, less than 10% of the analyzed area meets the condition of gamma value ≤ 1. On this basis, one can state that a change in dose by 10% can be confirmed by measurements made with EPID matrix. Results indicate that the EPID detector is able to assess the value of delivered dose.

To find a geometric error using fluence map measurement, the 3.0 mm phantom shifts were applied. **Table 3** presents the differences between shifted and non-shifted fluence maps calculated with four different gamma criteria. Pairs of fluence maps were acquired for three dose values. The results of geometry change analysis show that for 0.5% and 0.5 mm criterion only 78% of the analyzed field meets the acceptance conditions. Therefore, it can be said that a 3.0 mm shift of the phantom causes the differences in the analyzed signal sets. The results were confirmed by statistical tests.

Table 4 presents the results of comparison of measured fluence maps acquired for three different dose values and two field geometries. Also the calculation of p-value for the Pearson Ch^2 and Ch^2 NW tests is included. The performed tests authorize the rejection of the null hypothesis (Pearson's Ch^2: p = 0.00468; Ch^2 NW: p = 0.00114), and therefore one can say that these conditions are dependent. It means that, when the dose differences between measured fluence maps are less than 2.0% and 2.0 mm for 98% of the analyzed field, then the maps are identical and there is an agreement between those measurements.

Table 2. The percentage value of the surface of the analyzed field (%S) with gamma index ≤ 1 for given pairs of doses and different gamma criteria.

Dose [Gy]	%S gamma ≤ 1			p-value
	Δd[%]/DTA[mm]	Δd[%]/DTA[mm]	Δd[%]/DTA[mm]	
	0.5/0.5	2.0/2.0	4.0/4.0	
0.45 vs. 0.50	7.6	26.6	31.9	0.000
0.45 vs. 0.55	2.5	24.4	32.2	0.000
0.50 vs. 0.55	8.1	27.1	35.1	0.000

Table 3. The percentage value of the surface of the analyzed field (%S) with gamma index ≤ 1 for given doses and different gamma criteria for field shift = 3.0 mm.

Dose [Gy]	%S gamma ≤ 1				p-value
	Δd[%]/DTA[mm]	Δd[%]/DTA[mm]	Δd[%]/DTA[mm]	Δd[%]/DTA[mm]	
	0.5/0.5	2.0/2.0	4.0/4.0	5.0/5.0	
0.45	75.4	92.0	98.2	99.2	0.000
0.50	78.6	91.8	98.3	99.2	0.000
0.55	78.7	91.2	98.3	99.4	0.000

Table 4. The percentage value of the surface of the analyzed field (%S) with gamma index ≤ 1 for given doses and shifts for different gamma criteria and results of nonparametric tests.

Shift	Dose [Gy]	%S gamma ≤ 1			p-value	gamma ≤ 1 for 98.0% of field (2.0%/2.0mm)	Identical fluence maps
		Δd[%]/DTA[mm]	Δd[%]/DTA[mm]	Δd[%]/DTA[mm]			
		0.5/0.5	2.0/2.0	4.0/4.0			
N	0.50	100.0	**100.0**	100.0	0.626	Y	Y
Y	0.50	78.6	**91.8**	98.3	0.000	N	N
N	0.45/0.50	7.6	**26.6**	31.9	0.000	N	N
Y	0.55	78.7	**91.2**	98.3	0.000	N	N
N	0.55	100.0	**100.0**	100.0	0.091	Y	Y
N	0.45/0.55	2.5	**24.4**	32.2	0.000	N	N
N	0.50/0.55	8.1	**27.1**	32.4	0.000	N	N
N	0.45	100.0	**100.0**	100.0	0.464	Y	Y

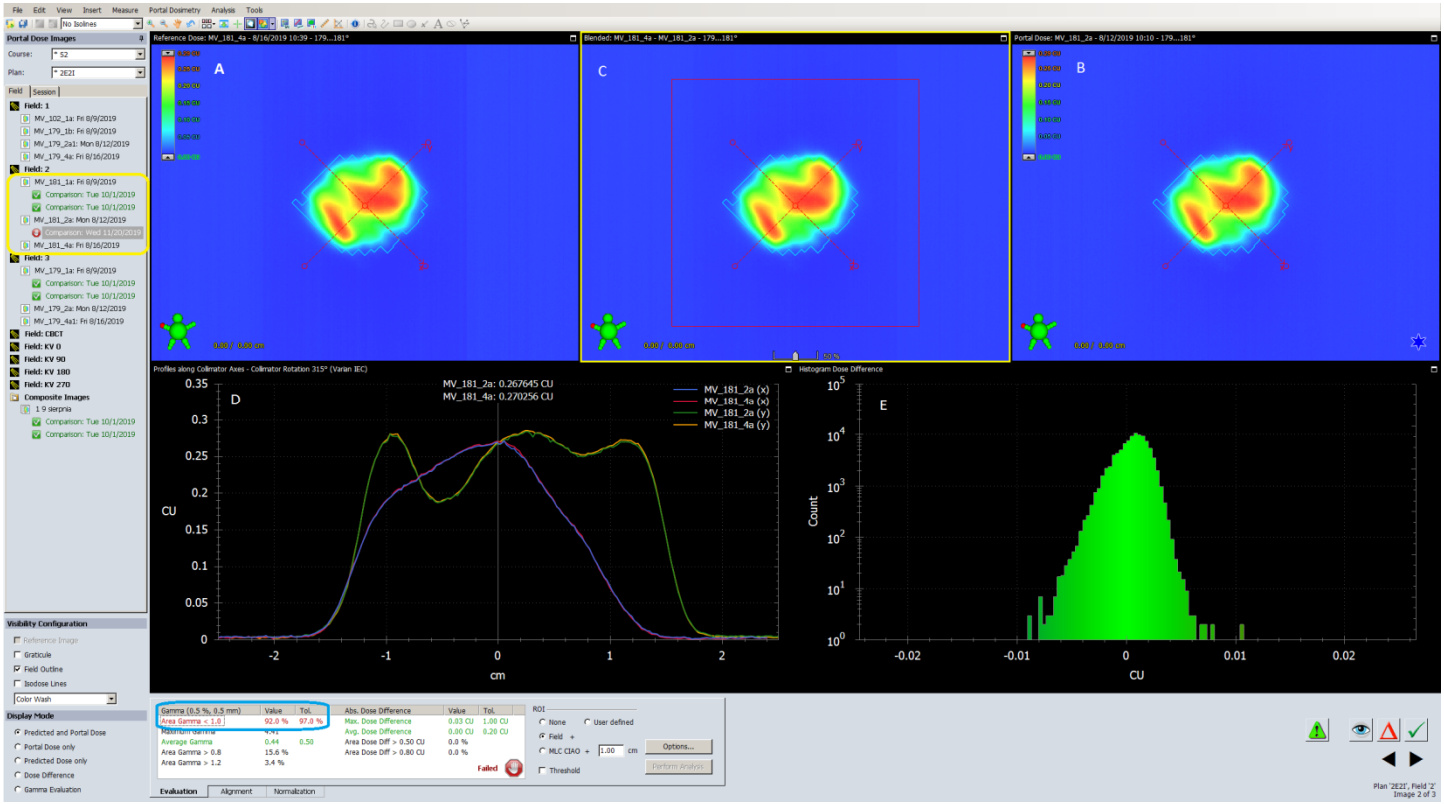

Figure 3. Gamma index analysis for an example patient for Field 2. The yellow selection presents acceptable results for Δd = 2.0% and DTA = 2.0 mm and rejected one for Δd = 0.5% and DTA = 0.5 mm. The blue selection presents 92.0% of analyzed area that meets the gamma criteria Δd = 0.5% and DTA = 0.5 mm. Graphics show: (A) first fraction fluence map, (B) second fraction fluence map, (C) blended, (D) profiles along the collimator axes, (E) histogram of dose difference.

Analysis of clinical cases

Figure 3 shows example patient results of gamma index calculation for the comparison of two fractions. It is shown, that 92% of the analyzed area meets the gamma index ≤ 1 for the criteria of Δd = 0.5% and DTA = 0.5 mm. However, the change in DTA value to 2.0 mm and Δd value to 2.0% caused that 100% of the analyzed area meets the gamma ≤ 1 condition.

In the case, Mann-Whitney U statistics show that for Field 2 p-value is equal to 0.9440, which means that there is no significant statistical difference between two fluence maps. Therefore, one can conclude that the patient was irradiated with Field 2 repeatedly these days.

All the plans were analyzed the same way what gives 87 comparisons of measured fluence maps. Results of patient-specific measurements present the values of the gamma index showing similarity of fluence maps measured during subsequent therapeutic sessions. The maps were compared each other using two criteria: (i) Δd = 0.5% and DTA = 0.5 mm and (ii) Δd = 2.0% and DTA = 2.0 mm. The second evaluation of the identity of the maps was the Mann-Whitney U test. The results are shown in **Table 5**. If gamma index ≤ 1 for at least 98% of the analyzed area with criteria of Δd = 2.0 % and DTA = 2.0 mm, then two sets can be considered as identical. This condition is fulfilled in 73 out of 87 analyzed cases.

Discussion

Dynamic radiotherapy techniques (VMAT and IMRT) require pre-treatment dosimetry verification. The measurement of the fluence map only allows checking if the calculated collimator leaf motion, linac gantry movement, dose rate changes, etc. can be properly realized. It can be also a kind of absolute dosimetry after fulfilling several conditions. For calibration purposes, simultaneous measurements with an ionization chamber and the EPID matrix are necessary. It allows correlating the dose in a phantom with the EPID signal. Also dose distribution from the patient plan has to be converted to the phantom with ionization chamber [26,27]. But it is still not in-vivo dosimetry. The another QA procedure is patient set-up control. The present workflow usually separates the dosimetric verification and patient position check.

Table 5. Results of patient-specific measurements and Mann-Whitney U test.

# patient	%S gamma ≤ 1 Δd[%]/DTA[mm] 0.5/0.5	%S gamma ≤ 1 Δd[%]/DTA[mm] 2.0/2.0	p-value
1 (2 fx)			
field_1	51.7	100.0	0.888
field_2	62.1	100.0	0.871
field_3	78.9	100.0	0.806
2 (2 fx)			
field_1	40.8	97.6	0.330
field_2	43.4	99.7	0.771
field_3	70.1	100.0	0.967
3 (2 fx)			
field_1	99.9	100.0	1.000
field_2	99.4	100.0	0.754
field_3	98.7	100.0	0.890
4 (2 fx)			
field_1	100.0	100.0	0.890
field_2	99.9	100.0	0.751
field_3	100.0	100.0	0.961
field_4	100.0	100.0	0.888
5 (2 fx)			
field_1	99.9	100.0	0.888
field_2	99.9	100.0	0.888
6 (2 fx)			
field_1	69.3	88.1	**0.001**
field_2	69.6	88.3	**0.005**
field_3	72.0	88.6	**0.001**
7 (2 fx)			
field_1	99.4	100.0	0.870
field_2	98.6	100.0	0.891
field_3	99.7	100.0	0.885
field_4	99.5	100.0	0.871
field_5	99.5	100.0	0.891
field_6	99.7	100.0	0.867
8 (3 fx)			
field_7 2->1	99.7	100.0	0.885
field_7 3->1	99.8	100.0	0.873
field_8 2->1	100.0	100.0	0.895
field_8 3->1	99.2	100.0	0.884
field_9 2->1	99.7	100.0	0.896
field_9 3->1	99.8	100.0	0.876
field_10 2->1	99.3	100.0	0.890
field_10 3->1	99.9	100.0	0.895
field_11 2->1	99.6	100.0	0.875
field_11 3->1	99.7	100.0	0.884
field_12 2->1	100.0	100.0	0.873
field_12 3->1	99.0	100.0	0.891
9 (2 fx)			
field_5	88.9	96.8	0.888
field_6	89.6	97.5	**0.021**
10 (3 fx)			
field_1 2->1	49.1	92.6	**0.012**
field_1 3->1	66.7	92.2	**0.006**
field_2 2->1	48.4	92.1	**0.009**
field_2 3->1	64.3	91.3	**0.000**
field_3 2->1	39.7	90.5	**0.046**
field_3 3->1	53.3	88.5	**0.006**

# patient	%S gamma ≤ 1 Δd[%]/DTA[mm] 0.5/0.5	%S gamma ≤ 1 Δd[%]/DTA[mm] 2.0/2.0	p-value
11 (2 fx)			
field_1	88.9	100.0	0.890
field_2	91.6	100.0	0.890
field_3	90.2	100.0	0.890
field_4	92.2	100.0	0.888
field_5	82.5	96.3	**0.007**
field_6	84.3	95.2	**0.011**
field_7	82.2	96.2	**0.008**
field_8	81.2	95.4	**0.005**
12 (2 fx)			
field_1	96.5	100.0	0.808
field_2	96.1	100.0	0.694
field_3	93.1	100.0	0.655
13 (2 fx)			
field_1	99.4	100.0	0.736
field_2	99.6	100.0	0.888
field_3	98.6	100.0	0.888
field_4	99.3	100.0	0.838
14 (2 fx)			
field_1	99.6	100.0	0.909
field_2	99.7	100.0	0.288
field_3	99.7	100.0	0.669
field_4	99.7	100.0	0.874
15 (3 fx)			
field_1 2->1	98.8	100.0	0.899
field_1 3->2	97.8	100.0	0.792
field_2 2->1	98.6	100.0	0.794
field_3 3->2	92.0	98.3	0.944
field_3 2->1	98.4	100.0	0.888
field_3 3->2	97.9	100.0	0.791
16 (2 fx)			
field_1	88.8	99.6	0.625
field_2	88.5	99.3	0.398
field_3	95.2	99.9	0.786
field_4	95.6	99.2	0.431
17 (2 fx)			
field_1	99.2	100.0	0.624
field_2	98.5	100.0	0.817
field_3	99.1	100.0	0.888
field_4	99.0	100.0	0.798
field_5	98.8	100.0	0.888
18 (2 fx)			
field_1	98.9	100.0	0.988
field_2	99.0	100.0	0.931
field_3	98.8	100.0	0.745
field_4	98.6	100.0	0.687
field_5	99.5	100.0	0.735
19 (2 fx)			
field_1	50.7	100.0	0.882
field_2	47.3	100.0	0.992
field_3	48.8	100.0	0.888
field_4	46.0	100.0	0.830

An alternative method of dose measurement can be usage of external detector matrix and dose reconstruction software [28,29]. This processing can be made to assess the compliance of the calculated and delivered dose. Nevertheless, almost every biomedical accelerator (C-arm type) is equipped with EPID array which is an integral element of modern therapeutic units. Thus in the present work the EPID matrix was used.

This work is an attempt to present a method of using the EPID matrix for the measurements of dose and geometry changes. At this point it should be highlighted that in present work the measured dose is not compared with the dose calculated in treatment planning system. The proposed method allows fluence maps measuring in subsequent sessions with the presence of the patient and comparing them with the reference one. It is recommended to utilize the fluence map acquired for the first fraction as the reference data set. As before the required step is patient position verification before each session.

The measurements confirm that simulated dose change causes the expected change in the measured maps. It should be noted, that the displacement of structures relative to the planned position also causes differences in measured fluence maps. It can also be stated that the arrays of the aS1200 EPID detectors are very stable measuring matrices, with a measurement uncertainty of 1.1%.

This work is not about the agreement between measured and calculated dose, but about the repeatability of measurements. The EPID arrays show the linearity of the read signal with the radiation dose. In the tested dose range from 0.5 to 7.0 Gy, the R2 correlation coefficient is equal to one. Analysis of clinical cases indicates that repetitive dose was delivered to the patients undergoing radiosurgical treatment and no shifts in the irradiated area were detected.

Radiosurgical patients are very precisely immobilized so mobility during the therapeutic session is negligible. This is confirmed by imaging performed during each therapeutic session with the OBI device. The proposed method can be used to assess the repeatability of radiation therapy, both in assessing the value of the delivered dose and its location. The further test of the method will be continued for fractionated radiotherapy and with extracranial locations.

Conclusions

The performed measurements, calculations, and analysis indicate that the EPID detector matrix can be used for dosimetric and geometric QC in dynamic stereotactic radiation therapy. This technique could be applied both for dose and geometric changes among treatment sessions.

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