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Original article

Radiotherapy

Comparison of EPID portal dosimetry verification and RadCalc dose verification for VMAT treatment plans

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Introduction. Dosimetry verification is required before starting each treatment. The legal regulations do not clearly define one method of plan verification. Therefore, it is allowed to perform measurements (electronic portal imaging device [EPID]) or calculations using an independent system. Portal dosimetry using EPID matrices was compared with the RadCalcTM system v. 7.1.4.1, performing independent dose distribution calculations.

Materials and methods. Treatment plans were made for 150 patients treated with the photon 6MV VMAT technique. Three groups of patients were studied: those treated for breast cancer, those treated for prostate cancer, and those irradiated to the prostate area with nodes. Then, the dosimetry verification was carried out on the accelerator using the EPID portal and compared with the independent RadCalc software calculation results.

Results. Comparison of tumor proportion score (TPS) *vs.* EPID and *vs.* RC calculations for breast, prostate, and prostate with nodes showed no significant statistical differences. Regardless of the size (volume) of the clinical target volume (CTV) area, no significant difference was observed, although there was a greater agreement for large CTVs compared to small ones. Similarly, there was no significant difference in the compared methods based on depth, but there was a better agreement for small depths than large ones.

Conclusions. Verification methods in the study groups showed compliance of the measured (EPID) and calculated (RadCalc) doses with the values planned in the TPS. This confirms that verification for patients treated with radiotherapy can be performed with any of these methods. However, for radiosurgical techniques, it is better to use the EPID method because the RadCalc method may give false negative results.

Key words: verification, electronic portal imaging device, RadCalc

Introduction

Cancer radiotherapy techniques have made significant progress in recent years. Conformal stationary techniques have been replaced by dynamic techniques like intensity modulated radiation therapy (IMRT) and volumetric modulated arc therapy (VMAT). These dynamic techniques are now a daily standard in many oncology centers in Poland. Before starting treatment, dosimetry verification is necessary. The legal regulations do not specify a single method of plan verification, so measurements or calculations can be done through various methods.

So far, the most commonly used at the Maria Sklodowska-Curie National Research Institute, Gliwice Branch, was portal dosimetry using electronic portal imaging device (EPID) matrices. In Varian Medical Systems accelerators, the portal matrix is a part of the therapeutic apparatus located perpendicularly to

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Figure 1. TrueBeam therapy accelerator (Varian Medical Systems, Palo Alto, USA) with: 1 – kV lamp; 2 – kV radiation detector; 3 – accelerator head; 4 – MV radiation detector (EPID); 5 – therapeutic table

the axis of the beam (fig. 1). It is also used to verify the correct positioning of the patient during treatment.

The treatment planning system performs a verification plan by calculating the fluence map for each irradiation field. Such a plan allows for irradiation of the EPID matrix without the patient before the first therapeutic session. Modern EPID devices are matrices of semiconductor detectors that record the radiation generated by the accelerator, measured in a plane perpendicular to the beam axis of this radiation (measurement of the so-called fluence maps) [1–7]. The signal is collected and saved from all detectors from the active measurement area. Each field of treatment is checked separately. The next step is to compare the measured fluence map with the calculated one. The assessment is based on the gamma index, which verifies compliance with the measurement in the specified range of dose and location. [1–9]

The gamma index calculates the difference between the dose calculated and measured at the same point (dose difference [DD]) and the distance (distance to agreement [DTA]) between points with the same dose. By determining the acceptable difference (DD) in the dose and the distance (DTA), we define the sphere within which the points located meet the compliance criterion: TPS calculations – measurement; then the value of the coefficient is less than 1 [1–7]. The advantage of this method is that it does not require any phantom, and the assessment of treatment plans is quick. It only requires access to the accelerator, which may be difficult in the case of a large number of patients. An additional disadvantage of this method is that the measurements are dependent because the calculations, measurements, and comparisons are made using software from the same manufacturer [10, 11].

RadCalc^{TM} v. 7.1.4.1 (LifeLine Software, S. Broadway Ave. Suite, USA) performs independent dose distribution, monitor units (MU) or point dose calculations for 2D and 3D treatment plans. It provides the ability to verify dynamic plans, including IMRT and VMAT. The vendor ensures that the algorithms used ensure quick, easy, and accurate verification of the dose distribution. Verification of plans in the RadCalc program allows one to disqualify plans that do not meet the adopted criteria. The use of the software does not "block" the operation of the accelerator. You should ask yourself in what situations you can abandon the measurement method on the device and use the RadCalc program. The answer would significantly improve the organization of physicists' work related to treatment planning [12].

The aim of the study was to compare two methods for assessing the compliance of dose distribution calculations with the actual dose. These methods include comparison of fluence maps measured with the EPID matrix and independent RadCalc calculations. The EPID matrix performs measurements in the 2D plane, and we have several measurement points at our disposal. Meanwhile, the RadCalc method is based on measurement at one point, and basically calculates the dose at that point. Of course, the RadCalc software has the option to compare fluence maps that were measured using the EPID matrix, but the measurement would also have to be performed on the accelerator. The purpose of introducing RadCalc software for use as an independent verification system was to reduce the load on the accelerator with verification measurements.

You should be aware that these are two different methods of verifying the calculations performed, but in clinical practice, both methods are used independently of each other to assess compliance. Therefore, the question arises whether a positive verification result in one method can be confirmed in the other. Will the obtained matches be the same? In other words, if accepting the approval of the plan for implementation on the basis of the EPID measurement, is there any certainty that by performing the measurement using the RadCalc method, and *vice versa*, this plan will also be approved for implementation.

Therefore, the question is whether these two methods of verifying calculations, EPID *vs.* RadCalc, are equivalent in assessing treatment plans.

Materials and methods

The analyzed group included 150 patients divided into 3 equal groups according to the treated location:

- 50 patients aged 38 to 82 (mean age 60) were diagnosed with left breast cancer. The area of planning target volume (PTV) drawn by the physician, covering the left breast with the margin determined according to the treatment protocol, was irradiated. Each patient had a VMAT treatment plan with a maximum accelerating potential of 6 MV, consisting of 4 therapeutic fields. The total dose for PTV irradiation is

50 Gy, in fractional doses of 2 Gy. The critical structures were: the left lung, the right lung, the heart, and the spinal canal.

- 50 patients aged 63 to 88 (mean age 74) were diagnosed with prostate cancer and lymph nodes. The treatment plan was divided into two stages. In the first stage, the prostate gland with nodes was irradiated to a total dose of 44 Gy in fractional doses of 2 Gy, and in the second stage, the prostate itself was irradiated to a total dose of 78 Gy, also in fractional doses of 2 Gy. The study included the first stage of treatment. The area of PTV drawn by the clinician, including the prostate and lymph nodes, was irradiated with a margin determined according to the treatment protocol. Each patient had a VMAT treatment plan with a maximum accelerating potential of 6 MV, consisting of 4 therapeutic fields. The critical structures were: the bladder, the rectum, the penile bulb, the femoral heads and the bowels.
- 50 patients aged 56 to 89 (mean 73) were diagnosed with prostate cancer (without lymph nodes). The area of PTV drawn by the physician, covering the prostate with the margin determined according to the treatment protocol, was irradiated. Each patient had a VMAT treatment plan with a maximum accelerating potential of 6 MV consisting of 2 or 3 therapeutic fields. The total dose for PTV irradiation is 76 Gy in fractional doses of 2 Gy. The critical structures were: the femoral heads, the bladder, the bowels, the rectum and the penile bulb.

Above treatment locations were selected due to the size of the irradiated field and the depth of the therapeutic dose definition point. Accordingly: mammary gland – a large fields, small depth; prostate gland with nodes – large field and great depth; prostate – a small field of great depth.

The clinical target volume (CTV), drawn by a clinician, was determined for each case. In the case of the prostates, the volumes of the close-fitting critical organs, i.e. the bladder and rectum, were additionally determined to investigate whether this affected the final results. An additional parameter was to determine the depth (distance from the contour of the body to the point) at which the reference point is located and the distance equivalent to water (water-equivalent distance). The calculation of the water-equivalent distance is based on two principles:

- the calculation uses the linear attenuation curves,
- the water-equivalent distance of a single point is calculated along that fanline of the treatment field that goes through the selected point, measured from the point where the fanline crosses the body outline or bolus to the selected point [13].

Treatment plans were made in the Eclipse™ v. 16.1 (Varian Medical Systems, Palo Alto, USA). After the attending physician approved the plan, a verification of the plan was prepared using two methods: EPID portal measurements and the independent RadCalc™ software (LifeLine Software, S. Broadway Ave. Suite, USA). Then the obtained verification results were compared with each other.

For measurements made on the accelerator, the criteria for assessing the gamma plan were adopted: DD = 3% and DTA = 2 mm (dose and its location). The plan must meet the accepted criteria for accepting the plan of compliance with the plan generated in the treatment planning system: 95% of the analyzed area, a threshold of 5%, margin around the field designated by the MLC 1 cm. Otherwise, the plan is rejected as not meeting the acceptable difference between calculation

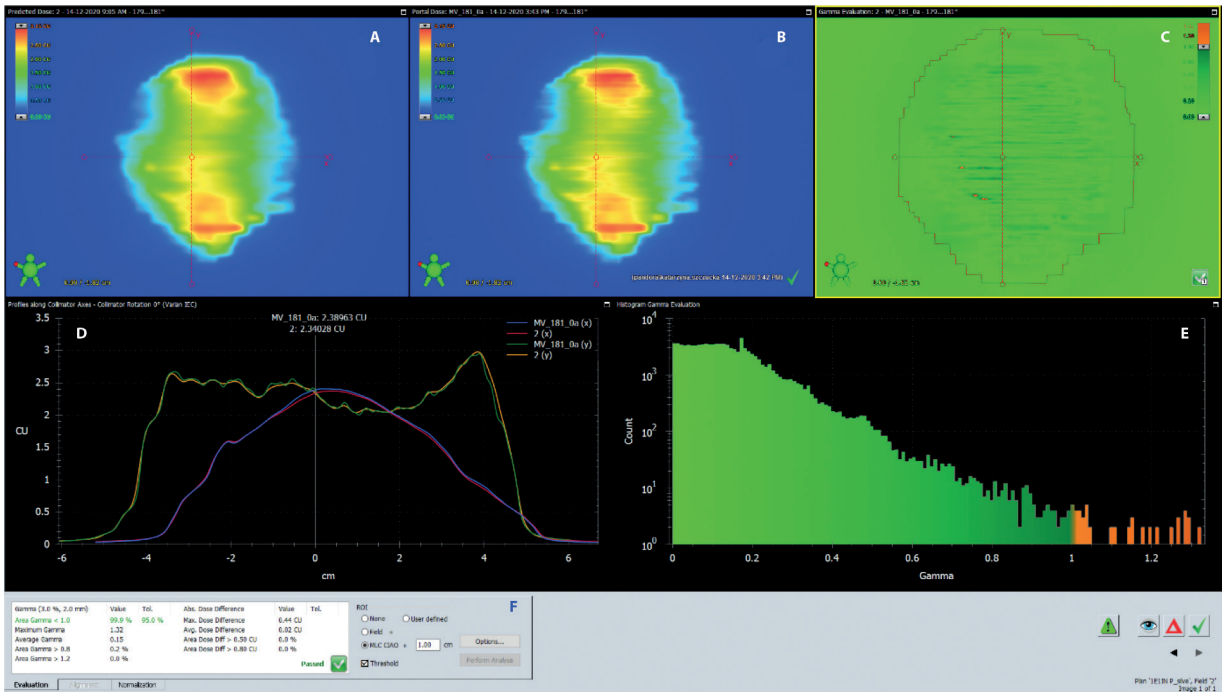

Figure 2. Graphical analysis of measured (**A**) and calculated (**B**) fluence maps based on gamma index (**E**); **C** – differences between measured and calculated fluence maps; **D** – fluence distribution along the axis; **F** – parameters of statistical analysis

and measurement. An example of the EPID measurement result with the determined gamma index is shown in figure 2. The gamma-local index was analyzed with a threshold level of 5% and a 1 cm margin around the MLC. Such values of DD and DTA were selected because the criterion of 4% and 4 mm in 97% [13] of the analyzed field is met by all analyzed cases.

The RadCalc software uses a modified Clarkson integration technique to calculate the contribution of the diffuse dose for individual fields to the isocenter. The input data required by the algorithm is the treatment plan data, i.e. Dynamic multileaf colimator (DMLC) files, jaw settings, monitor units (MUs) for each field, depth to isocentre for each field, and location of each measurement point. The RadCalc software uses independently measured beam data (Sc – in-air output ratio), phantom scatter factor (Sp), tissue phantom ratio (TPR), dose per monitor unit $(D/MU)_{ref}$ and includes the effects of multileaf collimator transmission and radiation field shift (difference in magnitude between the light field and the radiation field caused by transmission through the multileaf collimator leaves). RadCalc allows you to verify dose distributions based on point values. Checking the plan involves selecting a point in the PTV area in the planning system. For the purposes of the study, points were placed in three different locations (cranial, central, and caudal). In the case of the breast, the points were cranial and caudal to the isocenter by approx. 6.5 cm, in the case of prostate irradiation without lymph nodes approx. 3 cm, and in the case of the prostate with lymph nodes – approx. 7 cm. The central point was separated from the isocentre by a maximum of 2 cm. (fig. 3) [11].

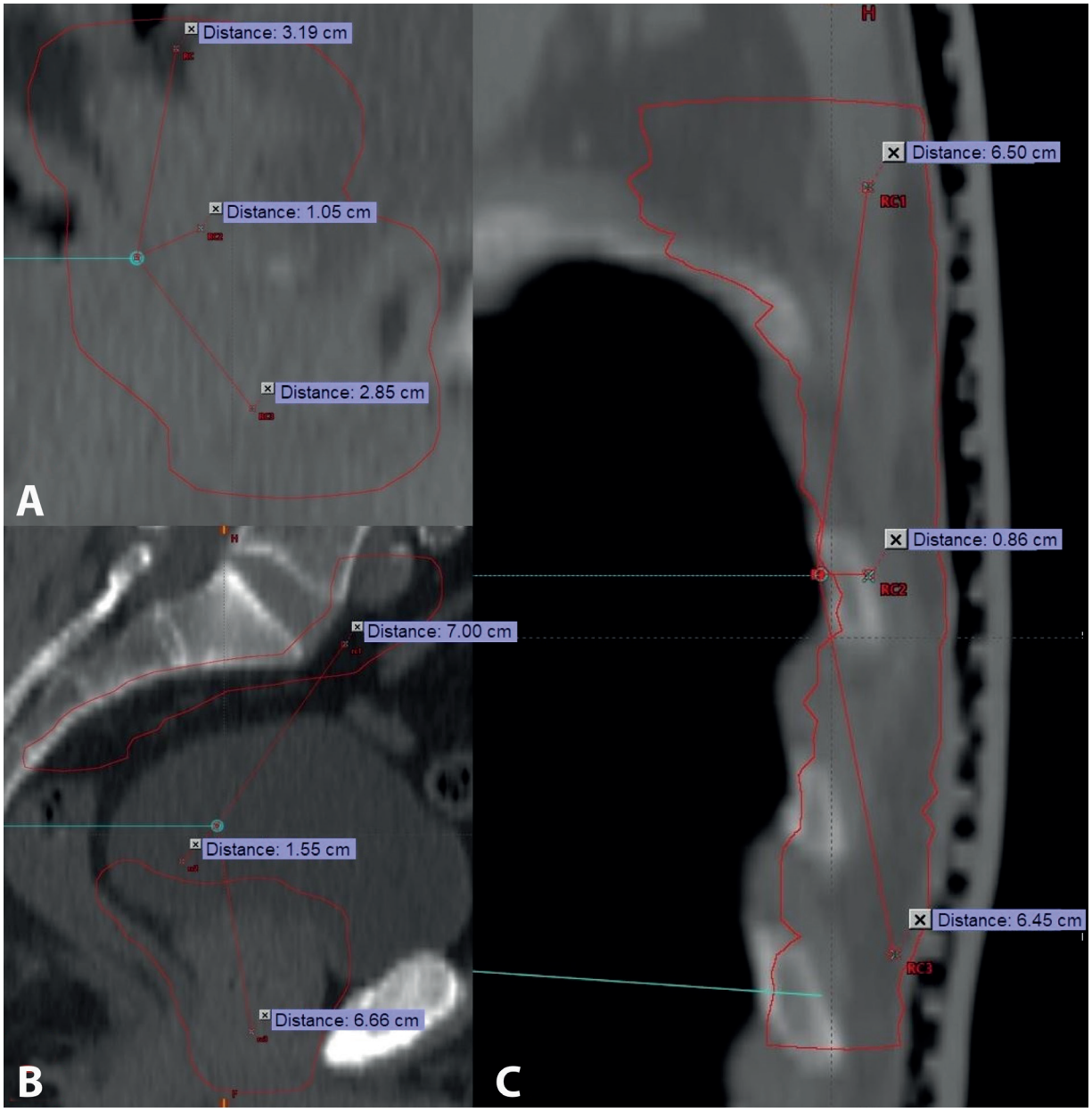

Figure 3. Arrangement of reference points in the sagittal plane in the PTV areas along with the distance from the isocentre; **A** – prostate; **B** – prostate with nodes; **C** – breast

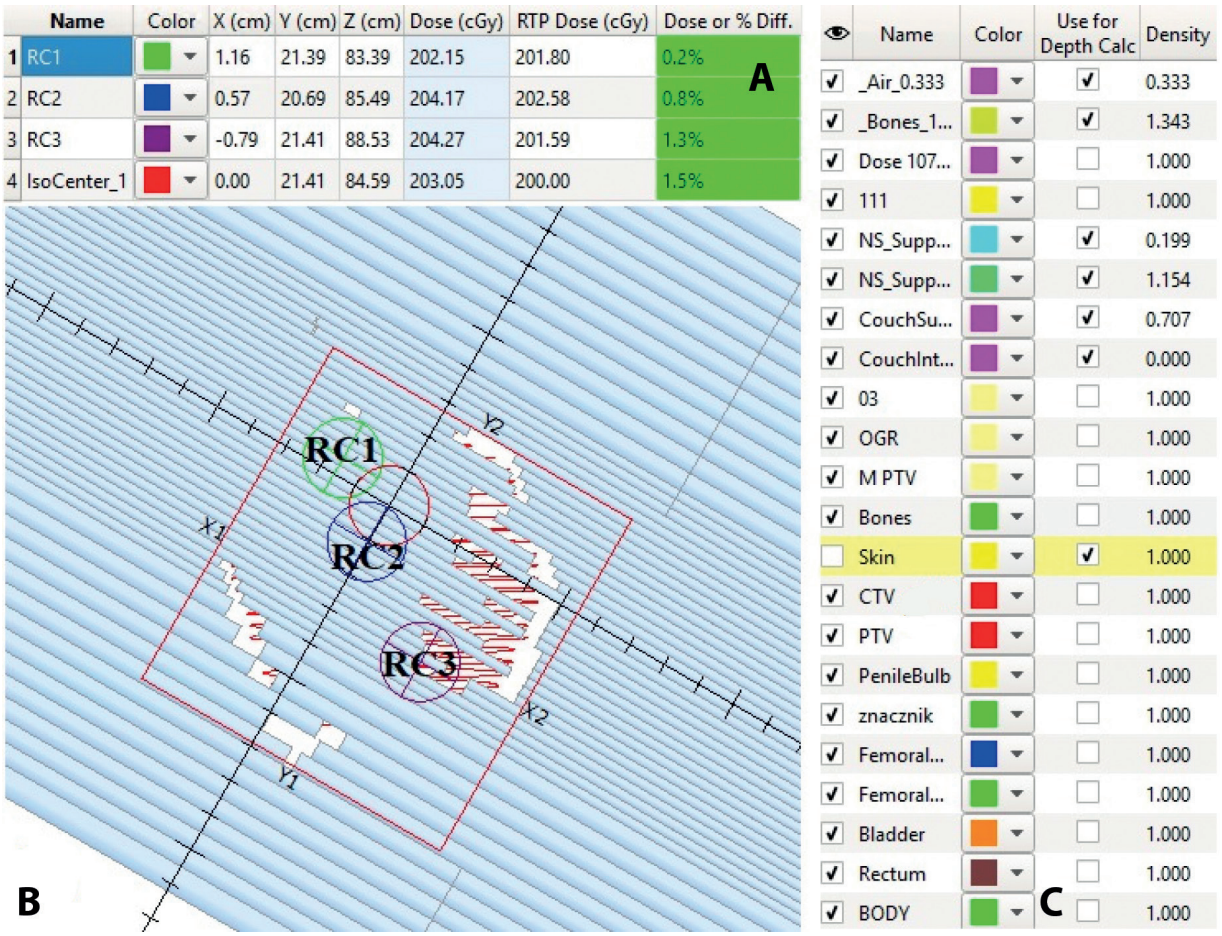

Figure 4. Screenshot from the RadCalc system; **A** – presentation of differences in doses at individual points and isocenter; **B** – distribution of points in the treatment area; **C** – determination of the average density of the drawn structures

The prepared plan is exported to RadCalc, which treats the patient's body as a homogenous medium with the same density as water. Structures with densities different than water, such as air, bone, and other components, require an assigned average density. After recalculating the plan, the dose at reference points should not differ by more than 5%, indicating a 95% agreement level (fig. 4) [8].

In summary:

- for EPID verification, the measured fluence map will be considered consistent with the calculations if, in 95% of the analyzed field, the dose differences are not greater than 3% and the dose shifts are smaller than 2 mm (local gamma analysis),
- for RadCalc verification, if the average difference between the calculated and measured dose is less than 5%, indicating a 95% agreement level.

If the verification plans meet these two conditions, we consider that these methods can be used alternately. The Mann-Whitney U statistical test was used to compare the two groups with a significance level of $p = 0.05$. The null hypothesis assumed that the compared sets were different. Rejection of this hypothesis requires that $p > 0.05$.

Results

Two analyzes were performed for selected treatment plans (portal verification and RadCalc calculations). The averaged results are presented in tables I–III.

Breasts

Both techniques in selected patients showed agreement between the measured (EPID) and calculated (RadCalc) doses with the values planned in the TPS. For EPID measurements, the average value was 98.93% of the analyzed field, which met the criteria of 3% and 2 mm. For point dose calculations made with RadCalc software, the average agreement was 98.90%. Comparing the compliance of the dose distributions / doses planned and measured / calculated, it can be concluded that both methods showed very similar compliance and met the accepted compliance criteria. In the case of EPID measurements, the compliance criterion is 95% of the analyzed field. The chart below (fig. 5) shows that the average results of measurements and calculations, along with the uncertainty, coincide with each other. Statistical tests performed do not show a statistically significant difference between these groups. This means that treatment plan compliance assessment methods can be used interchangeably.

Table I. Average results of measurement and calculation agreement for the breast treatment area

Measurements EPID 3% 2 mm					Calculations RadCalc				
avg. field dimensions (cm)		avg. measurement (%)	std. deviation	avg. diff. (%)	compliance (%)	std. deviation	avg. depth (cm)	avg. eq. path length (cm)	vol. CTV (cm^3)
X	Y								
15.80	21.10	98.93	0.87	0.64	98.90	0.74	7.22	5.64	936.17

Table II. Average results of the measurement and calculation agreement for the prostate treatment area

Measurements EPID 3% 2 mm					Calculations RadCalc						
avg. field dimensions (cm)		avg. measurement (%)	std. deviation	avg. diff. (%)	compliance (%)	std. deviation	avg. depth (cm)	avg. eq. path length (cm)	vol. CTV (cm^3)	vol. bladder (cm^3)	vol. rectum (cm^3)
X	Y										
10.20	10.00	99.58	0.55	2.85	96.89	1.05	16.65	15.88	74.07	307.52	65.50

Table III. The average results of the agreement of measurements and calculations for the prostate treatment area with nodes

Measurements EPID 3% 2 mm					Calculations RadCalc						
avg. field dimensions (cm)		avg. measurement (%)	std. deviation	avg. diff. (%)	compliance (%)	std. deviation	avg. depth (cm)	avg. eq. path length (cm)	vol. CTV (cm^3)	vol. bladder (cm^3)	vol. rectum (cm^3)
X	Y										
17.20	20.40	99.31	1.13	1.41	98.34	1.01	16.72	15.80	378.50	331.13	72.50

Prostate

As in the previous case, both techniques in selected patients showed compliance with the measured and calculated doses with the planned values. For EPID measurements, the average value was 99.58% of the analyzed field, which met the criteria of 3% and 2 mm. For point dose calculations performed with RadCalc software, the average agreement was 96.89%. Comparing the correspondence between dose distributions/doses planned and measured/calculated dose distributions, it can be concluded that both methods showed a similar agreement and met the accepted compliance criteria. In the chart below (fig. 6), it can be seen that in this case a better average result was obtained for the EPID measurement, while the dispersion of the average values of measurements and calculations coincides. The performed statistical tests do not show a statistically significant difference between the results obtained for different methods.

Prostate with lymph nodes

Again, both techniques showed agreement between the measured and calculated doses and the planned values. For EPID measurements, the average value was 99.31% of the analyzed field, which met the criteria of 3% and 2 mm. For point dose calculations performed with the RadCalc software, the average agreement was 98.34%. Comparing the compliance of the dose distributions / doses planned and measured / calculated, it can be concluded that both methods showed very similar compliance and met

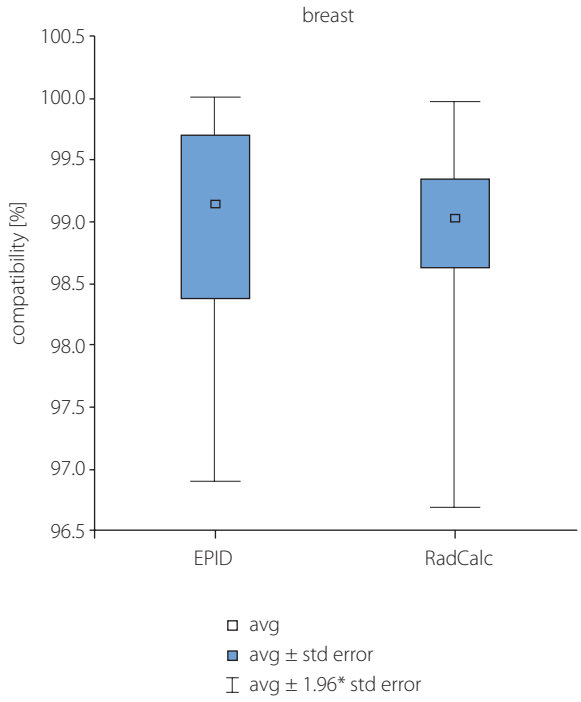

Figure 5. Box-plot chart showing the average results of measurements and calculations for the breast area

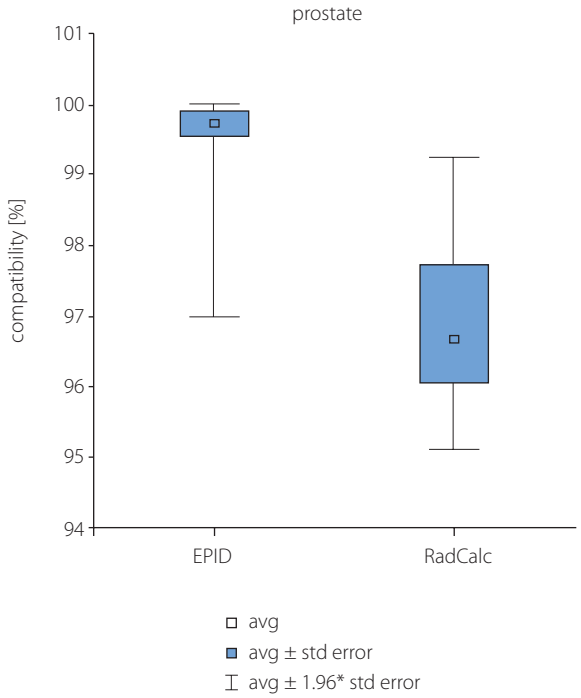

Figure 6. Box-plot chart showing average measurement and calculation results for the prostate area

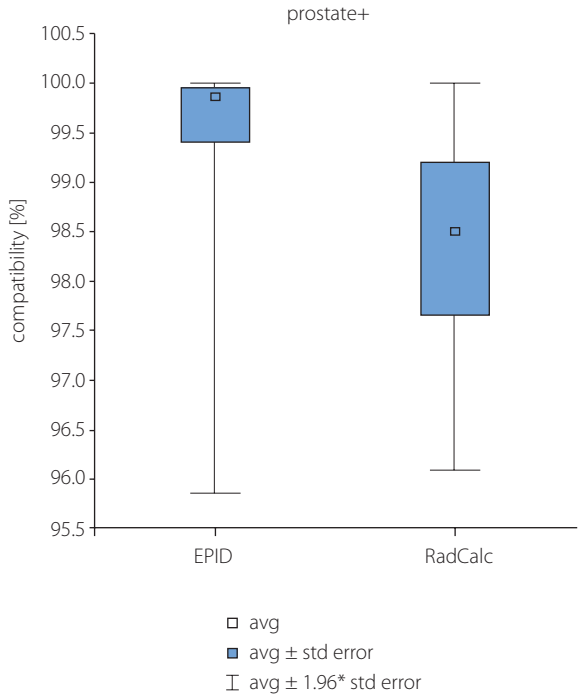

Figure 7. Box-plot showing average measurement and calculation results for the noded prostate area

the accepted compliance criteria. In the chart above (fig. 7), it is evident that in this case the EPID measurement achieved a slightly better average result, and the dispersion of the average values of measurements and calculations also coincides.

Discussion

The paper compares two treatment plan verification methods to assess whether they can be used interchangeably in the treatment quality assurance process. The EPID measurement method is performed on the accelerator, which means that it is excluded from clinical use, while RadCalc allows for independent calculations without switching off the accelerator, which allows patients to be irradiated at the same time. Both methods for all 150 patients showed agreement at the level above 95%, which allows the implementation of the plan on the accelerator.

All results were statistically analyzed using Statistica™ v. 13.3 (TIBCO Software Inc., Hillview Avenue, Palo Alto, USA). The non-parametric U Mann–Whitney test for independent samples allowed us to observe that:

1. comparison of the EPID *vs.* RC method for breast, prostate, and prostate with nodes does not show statistical significance,
2. there is no statistically significant difference between EPID *vs.* RC depending on the size (volume) of the CTV area. However, a greater agreement was observed for large CTVs than for small ones,
3. there is no statistically significant difference between EPID *vs.* RC as a function of depth. However, for small depths, there is better agreement than for large ones.

Table IV shows the differences in the obtained results depending on the volume of the CTV area and the depth of the reference point.

The smallest difference between EPID and RC is in the breast area with a large CTV area and small depth, and the largest in the case of large depth and small field, i.e. the prostate area without lymph nodes.

For small CTV volumes, it is more difficult to select a point "around" where there is a small dose gradient. The dose is inhomogeneous, which means that each shift of the point can cause "large" differences in the read dose. Greater depths

Table IV. Differences in EPID *vs.* RC results depend on the volume of the CTV area and the depth of the reference point

	Min. path length (cm)	Max. path length (cm)	Avg. path length (cm)	Min. CTV (cm^3)	Max. CTV (cm^3)	Avg. CTV (cm^3)	EPID *vs.* RadCalc (%)
breast	3.4	8.3	5.6	279.5	2847.4	936.2	0.9
prostate	13.5	18.9	15.9	10.4	186.4	74.1	2.8
prostate+	13.4	21.0	15.8	215.5	561.3	378.5	1.5

may result in an imprecise calculation of the water equivalent depth, so there may be larger differences than in the case of small depths, for which the difference between physical and equivalent depth is smaller.

Conclusions

The work confirmed that the verification techniques used in the study groups showed compliance with the measured (EPID) and calculated (RadCalc) doses with the values planned in the TPS. This allows us to state that the verification of compliance of the calculations (TPS) with the measurement (EPID) / calculations made by an independent software (RadCalc) for patients treated with external beams can be performed by each of these methods. However, for radiosurgical techniques, when the dimensions of the treated volume are small, it is better to use the EPID method because the RadCalc method may give false negative results. Thus, when using RadCalc calculations, the best "set" will be a large irradiation volume at a shallow depth, while for EPID measurements, it will be a small irradiation volume and a large depth.

Article information and declarations

Data availability statement

Raw data were generated at Maria Sklodowska-Curie National Research Institute, Gliwice Branch. Derived data supporting the findings of this study are available from the corresponding author on request.

Ethics statement

This material is the authors' own original work, which has not been previously published elsewhere. The paper is not currently being considered for publication elsewhere. The paper reflects the authors' own research and analysis in a truthful and complete manner. All authors have been personally and actively involved in substantial work leading to the paper, and will take public responsibility for its content.

Author contributions

Adam Gądek – collecting data, measurement data analysis, RadCalc calculation data analysis, compiling and comparing data, comparison of results, writing a paper.
Dominika Plaza – collecting data.
Łukasz Sroka – collecting data.
Marta Reudelsdorf-Ullmann – collecting data.
Krzysztof Ślosarek – statistical analysis of data, substantive correction of the article, work approval.

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Conflict of interest

None declared

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References

1. Ślosarek K, Gądek A, Reudelsdorf-Ullmann M, et al. The prototype of EPID-based in vivo dose verification for VMAT treatments in patients with prostate cancer. NOWOTWORY Journal of Oncology. 2023; 73(1): 10–17, doi: 10.5603/NJO.a2023.0002.
2. Radwan M, Grządziel A, Hawrylewicz L, et al. Wpływ energii wiązek fotonowych na rozkład dawek dla planów IMRT i VMAT. Nowotwory. Journal of Oncology. 2014; 64(3): 230–236, doi: 10.5603/njo.2014.0037.
3. Ślosarek K, Plaza D, Nas A, et al. Portal dosimetry in radiotherapy repeatability evaluation. J Appl Clin Med Phys. 2021; 22(1): 156–164, doi: 10.1002/acm2.13123, indexed in Pubmed: 33314643.
4. Ślosarek K, Szlag M, Bekman B, et al. EPID in vivo dosimetry in RapidArc technique. Reports of Practical Oncology and Radiotherapy. 2010; 15(1): 8–14.
5. Grządziel A, Bekman J, Winiecki K. Przegląd metod weryfikacji konformalnych planów radioterapeutycznych. Inżynier i Fizyk Medyczny. 2015; 4(2): 99–105.
6. van Elmpt W, Nijsten S, Petit S, et al. 3D in vivo dosimetry using megavoltage cone-beam CT and EPID dosimetry. Int J Radiat Oncol Biol Phys. 2009; 73(5): 1580–1587, doi: 10.1016/j.ijrobp.2008.11.051, indexed in Pubmed: 19306755.
7. Fidanzio A, Cilla S, Greco F, et al. Generalized EPID calibration for in vivo transit dosimetry. Phys Med. 2011; 27(1): 30–38, doi: 10.1016/j.ejmp.2010.02.002, indexed in Pubmed: 20199885.
8. Kung JH, Chen GT, Kuchnir FK. A monitor unit verification calculation in intensity modulated radiotherapy as a dosimetry quality assurance. Med Phys. 2000; 27(10): 2226–2230, doi: 10.1118/1.1286553, indexed in Pubmed: 11099189.
9. Klimas A, Grządziel A, Plaza D, et al. EPID – a useful interfraction QC tool. Polish Journal of Medical Physics and Engineering. 2019; 25(4): 221–228, doi: 10.2478/pjmpe-2019-0029.
10. Ślosarek K. Weryfikacja realizacji technik dynamicznych w radioterapii. Inżynier i Fizyk Medyczny. 2013; 2(5).
11. Malicki J, Ślosarek K. Planowanie leczenia i dozymetria w radioterapii. Via Medica, Gdańsk 2016.
12. Manual, "RadCalc User Manual Version 7.1 Rev. D", LifeLine Software Inc.
13. Manual, "Eclipse Photon and Electron Algorithms Reference Guide", Varian Medical Systems.