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# Patient-Specific Dosimetric Validation of Pelvic IMRT and VMAT Plans Using a Custom-designed Female Pelvic Phantom and Arc-CHECK QA System

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**ABSTRACT**

***Introduction:*** To ensure the accuracy of advanced radiotherapy techniques in the therapy of female pelvic malignancies using radiotherapy, comprehensive quality assurance protocols and patient-specific dosimetry was performed using a custom-designed female pelvic (CDFP) phantom and Arc-CHECK.

***Material and Methods:*** Volumetric modulated arc therapy (VMAT) and Intensity modulated radiation therapy (IMRT) plans originally developed for patients with cervical cancer were transferred to the CDFP phantom and Arc-CHECK. The doses for patient-specific quality assurance (PSQA) of advanced techniques were calculated using different algorithms in treatment planning system (TPS). To acquire dose measurements, a 0.600 cc ion chamber, Sun Nuclear 125c (SNC125c) and a pinpoint 0.015 cc chamber were employed. The percentage deviation between the computed and administered dose was calculated.

***Results:*** Percentage discrepancies between planned and administered doses were analyzed. The maximum percentage deviation, mean ± standard deviation(SD) differences for 0.6 cc ion chamber and a pin-point 0.015 cc chamber were found to be -3.6%, -0.89% ± 1.59 and 3.51%, 1.10% ± 1.31 for the IMRT treatment technique and -3.32%, -0.84% ± 1.53 and 3.6%, 1.25% ± 1.34 for the VMAT treatment technique using AAA algorithms using 6MV beam for CDFP phantom respectively. The maximum of percentage deviation, mean ± SD differences for 0.6 cc ion chamber and a SNC125c chamber were found to be -3.40%, -0.273% ± 2.161 and 3.107%, -0.028% ± 2.046 for CDFP phantom and -2.72%, -0.35% ± 1.41 and 2.74%, 0.197% ± 1.50 for Arc-CHECK using VMAT treatment technique using 6MV beam and Monte Carlo algorithm respectively.

***Conclusion:*** The inherent properties of anthropomorphic phantoms like the CDFP, such an anatomical fidelity and tissue equivalence, make them extremely useful in the quality assurance radiotherapy-programs. Their application increases the accuracy of dosimetric validation and therefore, these phantoms are applicable in the use of high-accuracy treatment modalities such as IMRT and VMAT.

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## Introduction

External beam radiotherapy (EBRT) is the technique when high-energy X-rays are directed from the outside the body to destroy the cancer cells. Recent planning and imaging technologies allow clinicians to determine the angle and distance of these beams with appropriate precision to optimize dose to the tumor and reduce the dose to the surrounding normal tissues[1,2].

In the context of device design, anthropomorphic means that it is made in the shape and size of the human pelvic region and mimicking biological material properties. An anthropomorphic phantom is a device designed to mimic the features of a human body and made from biological tissues, tissue substitutes, and synthetic materials [3]. Heterogeneous means that the phantom comprises regions of different densities, compositions, or structures. In the context of the device design, heterogeneous implies that the phantom is not of the same material and does not have uniform composition or other properties, just like the female pelvic region is not uniform in composition. An anthropomorphic heterogeneous female pelvic phantom is a specialized device in radiotherapy used to virtually present the human female pelvic region in dosimetric and treatment planning matters. The portion phantom

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include of the rectum, bladder femur heads, pelvic bones, and surrounding soft tissues [4,5].

PSQA in radiotherapy is a process to verify that a complex, personalized radiation treatment plan is delivered accurately to the patient, focusing on dose accuracy, information transfer, and machine performance. They can be an actual measurement of radiation using dosimeters. IMRT and VMAT both are sophisticated radiation treatment methods. That offer highly conformal dose distributions with increased target volume coverage and sparing of normal tissues compared to three- dimensional (3D) conformal radiation and conventional approaches. Treatment administration entails varying MLC leaf position, gantry rotation speed, and dose rate from a single arc to numerous arcs, depending on the treatment complexity [6].

The treatment procedure is divided into three stages: utilizing the TPS, plan transfer to the delivery system, and dose delivery. Errors in any of these stages can lead to adverse outcomes in treatment delivery. Therefore, it is mandatory to do PSQA of all the IMRT and VMAT plans using various dosimeters to ensure the precise treatment plan delivery.

To improve results in radiation therapy, the International Commission on Radiation Units and Measurements (ICRU) has recommended general dose accuracy of no more than 5%. (ICRU 83) [7]. Recently, the medical physics community has published updated guidelines aimed at optimizing PSQA practices. These guidelines focus on enhancing the consistency and accuracy of PSQA processes, while also providing clear frameworks for interpreting and integrating PSQA results into clinical workflows. Such developments are essential for improving treatment safety, accuracy, and patient outcomes in advanced radiotherapy techniques[8].

Davidson et al. developed two heterogeneous anthropomorphic QA phantoms to validate the delivery of IMRT dose [9]. While material that is either solid water or water has been used in human body, the percentage of the human body that is water is raised. The Alderson-Rando physical phantom to simulate in target organs dose that was being delivered with absorbed dose [10].

Neha et.al. also validated 30 PSQA RapidArc plan based on point dosimetry using 0.6cc ionization chamber on phantom [11]. Physical phantoms typically made of water-equivalent materials or materials that incorporate water have been employed mostly for PSQA [12,13].

The main goal of current research work was to evaluate PSQA on custom-designed female pelvic (CDFP) phantom and Arc-CHECK in radiotherapy centers using different ionization chambers of different volumes and advanced radiation therapy techniques namely IMRT and VMAT.

## Materials and Methods

### *Phantom Setup*

#### *Custom-designed female pelvic (CDFP) phantom*

A custom-designed female pelvic phantom was fabricated using epoxy and hardener, paraffin-wax, water, and polyvinyl chloride (PVC), which replicates the diverse organs of female pelvic. Fiducial markers were thoroughly placed on the exterior surface of CDFP phantom, in order to provide consistent anatomical reference points to register accurately the treatment and planning clearly based on the image guidance. In particular, one fiducial marker was placed to the anterior surface, and two markers were added on the right and left side of this phantom similarly as clinically relevant anatomical landmarks. Such fiducials acted as reference points during the contouring and beam set-up in the treatment planning process in the TPS.

#### *CT Simulation and Data Import*

A CDFP phantom was imaging with SOMATOM go.UP computed tomography (CT) simulator (Siemens Healthineers, Germany). CT scan settings utilized were 110 kilovoltage peak kVp and 130 milliampere-seconds (mAs) with a 2mm slice thickness that would allow high-resolution volumetric data. To serve the aim of point dose verification, the phantom was provided with cavities which were meant to be used to hold all three 0.6cc Farmer type ionization chamber, SNC125c and 0.015cc pinpoint ionization chamber. With these detectors accurate dosimetry of local areas of clinical interest could be obtained. The phantom data set CT image was imported into the Eclipse TPS (Version 15.6, Varian Medical Systems, CA) and MONACO TPS (Version 6.1.4.0, Elekta Solutions AB, Stockholm Sweden) performed using the standard DICOM (Digital Imaging and Communications in Medicine) protocol designed so that interoperability and faithful data transfer are achieved.

#### *Treatment Plan and Dose Calculations*

An extensive experimental investigation was carried out to evaluate effectiveness of advanced conformal radiotherapy technologies with the using of CDFP phantom based on the dosimetric accuracy.

A total of 20 (n = 20) VMAT PSQA plans of patients diagnosed with carcinoma of the cervix were retrospectively selected for analysis. These PSQA plans were generated using the MONACO TPS on Elekta Infinity machine employing Monte Carlo Algorithm for dose calculation. The planning parameters were standardized for all cases to ensure uniformity in plan evaluation. Each VMAT plan consisted of two coplanar arcs: the first delivered in a clockwise direction from 190° to 170°, and the second in an anticlockwise direction from 170° to 190°. The plans were optimized with a dose calculation grid resolution of 3 mm × 3 mm, a statistical uncertainty of 1% per calculation, and a minimum segment width of 0.5 cm.

The verification of these treatment plans was carried out using the CDFP phantom and the commercially

available Arc-CHECK™ diode array system (Sun Nuclear Corporation, USA) equipped with a multi-plug insert for ionization chamber measurements.

In addition, a total of 60 PSQA (IMRT=30; VMAT=30) plans of patients diagnosed with carcinoma of the cervix were retrospectively selected for analysis. These were generated for Vital Beam Linac (Varian Medical Systems, CA) using Eclipse TPS. The IMRT plans consisted of 9-fields with 40 degrees of gap angles in fixed positions and used to deliver a dose. On the other hand, VMAT method used was dual arc technique: the parameters of the first arc were a clockwise movement of $181^0$ to $179^0$, and the second one was an anticlockwise path of $179^0$ to $181^0$. This was done by dynamically adjusting the collimator angles to $15^0$ to $45^0$, in order to maximize dose conformity and spare the surrounding organs at risk. The beam energy of all treatment plans involved use of 6 megavolt (MV) photons. To enable a good model representation of the dose distribution, a dose calculation grid definition was provided with a 2.5 mm x 2.5 mm spatial resolution. The verification of these treatment plans was carried out using the CDFP phantom.

This retrospective dosimetric study used anonymized patient treatment planning data and there was no direct patient and animal involvement in this study, so approval of ethical committee was not required.

### *PSQA Verifications*

#### *PSQA Absolute dosimetry Infinity Linac*

The accuracy of dose calculation performed using Monaco TPS equipped with Monte Carlo algorithm was validated against the measurements made using 0.6 cc Farmer-type ionization chamber (SNC) and SNC125c (SNC) chamber of volume 0.125 cc in CDFP and Arc-CHECK phantom, for VMAT plans delivered on Elekta Infinity Linac.

All ion chambers used in the investigation were having valid calibration in terms of absolute dose to water, and their calibrations were traceable to a secondary standard laboratory. These chambers were placed at appropriate position in the selected holes within the CDFP/Arc-CHECK phantom to ensure authentic in-phantom dosimetry. The selected holes corresponding to the ion chamber positions were carefully aligned within the central region of the CDFP phantom to ensure accurate dose measurement. Ion chambers were positioned at the geometric center of the Arc-CHECK device through the use of a multi-plug insert. The measured point doses were subsequently compared with the corresponding treatment planning system (TPS) calculated doses to evaluate the dosimetric accuracy. In order to maintain consistency between phantom based and clinical dose assessments, duplicate beam configurations (radiation field setup, Arc parameters, gantry angles, and collimator rotation and couch position) of the original patient specific treatment plans were applied in the procedure used to plan the CDFP phantom and Arc-CHECK. In this approach computed dose was compared with administered dose under the same geometric and technical circumstances.

#### *PSQA Absolute dosimetry on Vital Beam Linac*

The accuracy of dose calculation performed using Eclipse TPS equipped with AAA algorithm was validated against the measurements made using 0.6 cc Farmer-type (SNC, USA) and 0.015cc Pin-Point chambers (PTW Freiburg, Germany) ion chambers in CDFP, for both IMRT and VMAT plans, respectively.

The distribution of dose was retrospectively calculated on CDFP phantom and Arc-CHECK CT dataset of the phantom in the TPS using different algorithm for each of the treatment plans. Such recalculated plans were then administered on the phantom via the linear accelerator. The volumetric active area in both ionization chambers was outlined on the CT scans of the phantom in the TPS to calculate the dose at the measuring points in the chamber which, in this case, were the chamber measurement points. The resulting dose determined at these specified volumes was then matched up with the respective known dose of dosimetric verification [14].

In this Study, we used different treatment plans of IMRT and VMAT plan to validate phantom. Dose to water, $D_{w,Q,}$ was derived from ionization chamber measurements following recommendations of IAEA TRS 398 Code of Practice as shown in equation 1 [15,16].

$$D_{w,Q} = M_Q \times N_{D,w,Q0} \times k_{Q,Q0} \times K_{TP} \quad (1)$$

Where, $M_Q$- define electrometer reading, $N_{D,w,Q0}$ - IC calibration factor, and $k_{Q,\ Q0}$ -Beam quality correction factor, respectively. $K_{TP}$ –Temperature-pressure correction factor[17].

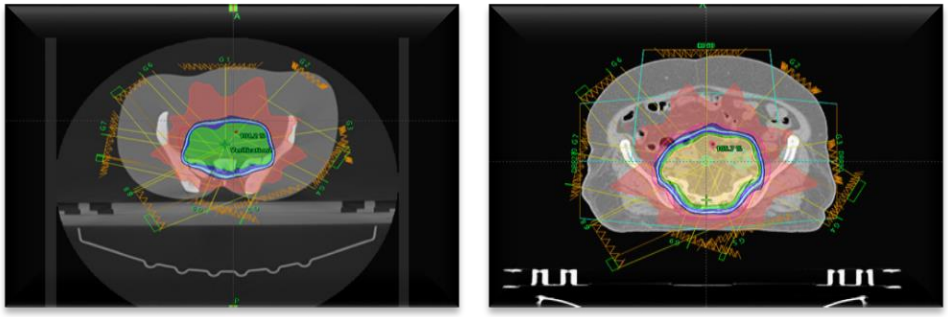
The % variation between the measured dose on linear accelerator and the computed dose on TPS was calculated by the following formula using equation 2 [11,14];

$$Percentage\ variation = 100 \times \left(\frac{D_{IC} - D_{TPS}}{D_{TPS}}\right) \quad (2)$$

Where, $D_{IC}$ and $D_{TPS}$ present the IC measured dose and dose estimated by a Treatment planning system.

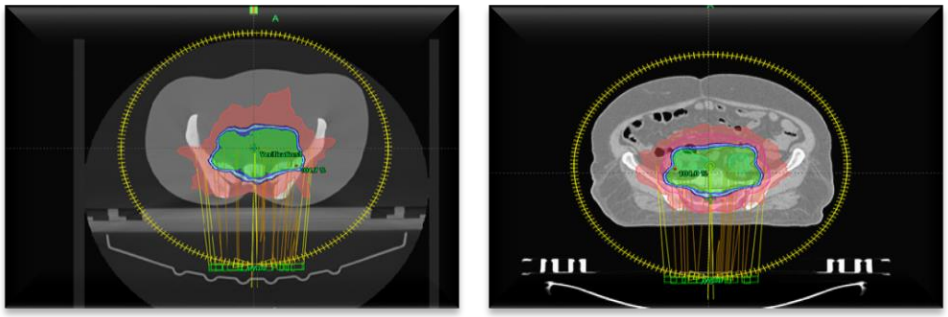
## Results

The Figure 1.a and 1.b represent the IMRT dose distribution on CDFP phantom and patient's DICOM image, respectively. Similarly, the Figure 2.a and 2.b represent the VMAT dose distribution on CDFP phantom and patient's DICOM image, respectively. Figure 3.a and 3.b show the dose distribution and dose-volume histogram (DVH) on CDFP phantom and Arc-CHECK phantom (Axial, sagittal, and coronal CT slices with dose overlay in color scale, showing spatial dose distribution in the phantom with dosimeter and dose-volume histogram (DVH) for the total volume), respectively.



(a) (b)

Figure 1. a) Dose distribution of 9 field-gantry IMRT on a scanned CDFP phantom in Eclipse TPS. b) Dose distribution of 9 field-gantry IMRT on patient's CT scan in Eclipse TPS.



(a) (b)

Figure 2. a) Dose distribution of 2 arcs VMAT on a scanned CDFP phantom in Eclipse TPS. b) Dose distribution 2 arcs VMAT on a patient's CT scan in Eclipse TPS.
CDFP- Custom-designed Female Pelvis
TPS- Treatment Planning System
VMAT- Volumetric Arc Therapy
IMRT- Intensity Modulated Radiation Therapy

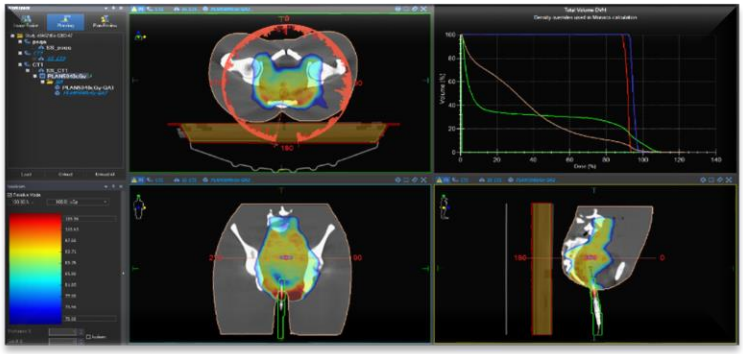


Figure 3.a) Dose distribution and dose-volume histogram (DVH) of CDFP Phantom (Axial, sagittal, and coronal CT slices with dose overlay in color scale, showing spatial dose distribution in the phantom with dosimeter and dose-volume histogram (DVH) for the total volume.

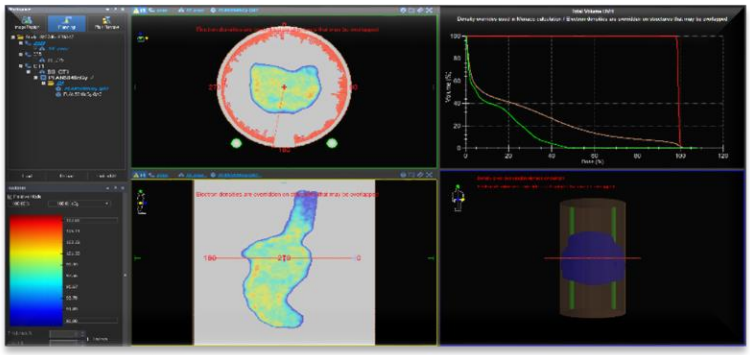


Figure 3.b) Dose distribution and dose-volume histogram (DVH) of Arc-CHECK (Axial, sagittal, and coronal CT slices with dose overlay in color scale, showing spatial dose distribution in the phantom and dose-volume histogram (DVH) for the total volume.

Table-1. Comparison of TPS calculated with measured using 0.6cc ion Chamber and SNC125c chamber for Volumetric Arc Therapy (VMAT) treatment Plans using CDFP phantom and Arc-CHECK using Monaco TPS.

| | CDFP Phantom | | | | | | Arc-CHECK | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 0.6cc Cylindrical Chamber | | | SNC125c | | | 0.6cc Cylindrical Chamber | | | SNC125c | | |
| Sr. No. | TPS Measured (cGy) | IC Measured (cGy) | % of Variation (%) | TPS Measured (cGy) | IC Measured (cGy) | % of Variation (%) | TPS Measured (cGy) | IC Measured (cGy) | % of Variation (%) | TPS Measured (cGy) | IC Measured (cGy) | % of Variation (%) |
| 1 | 138.4 | 133.69 | 3.403 | 146.8 | 144.99 | 1.233 | 100.3 | 100.82 | -0.518 | 102 | 103.55 | -1.520 |
| 2 | 241.8 | 238.05 | 1.551 | 209 | 207.22 | 0.852 | 224.4 | 230.42 | -2.683 | 213.7 | 208 | 2.667 |
| 3 | 170.1 | 175.2 | -2.998 | 190 | 194.53 | -2.384 | 157.3 | 157.65 | -0.223 | 154.7 | 155 | -0.194 |
| 4 | 190.7 | 193.17 | -1.295 | 190.8 | 190.95 | -0.079 | 208.9 | 213.45 | -2.178 | 208.8 | 209.74 | -0.450 |
| 5 | 159.2 | 158.18 | 0.641 | 159.6 | 157.19 | 1.510 | 175.7 | 177.68 | -1.127 | 175.9 | 177.35 | -0.824 |
| 6 | 165.2 | 160 | 3.148 | 113 | 110.14 | 2.531 | 148.4 | 145.36 | 2.049 | 148.4 | 144.84 | 2.399 |
| 7 | 163.7 | 170.4 | -4.093 | 164.9 | 168.59 | -2.238 | 177.4 | 179.03 | -0.919 | 177.6 | 176.14 | 0.822 |
| 8 | 245 | 252.7 | -3.143 | 245 | 253.01 | -3.269 | 259.5 | 256.9 | 1.002 | 261.3 | 256.86 | 1.699 |
| 9 | 129.3 | 133 | -2.862 | 121 | 117.24 | 3.107 | 154.2 | 150 | 2.724 | 155.9 | 153.72 | 1.398 |
| 10 | 189.8 | 189.7 | 0.053 | 188.5 | 186.36 | 1.135 | 205.4 | 206.41 | -0.492 | 202.6 | 200 | 1.283 |
| 11 | 179.6 | 181.09 | -0.830 | 182.9 | 188.08 | -2.832 | 159.5 | 164.23 | -2.966 | 159.5 | 163.26 | -2.357 |
| 12 | 169.3 | 169.44 | -0.083 | 170.6 | 170.29 | 0.182 | 185.5 | 186.54 | -0.561 | 184.2 | 183.05 | 0.624 |
| 13 | 172.3 | 173.55 | -0.725 | 172.3 | 167.92 | 2.542 | 186.2 | 188.2 | -1.074 | 186.7 | 187.38 | -0.364 |
| 14 | 127.6 | 131 | -2.665 | 120 | 123.62 | -3.017 | 191.9 | 189.71 | 1.141 | 227.9 | 221.64 | 2.747 |
| 15 | 167.8 | 164.03 | 2.247 | 168.9 | 171.85 | -1.747 | 130.6 | 129.84 | 0.582 | 126.5 | 130.03 | -2.791 |
| 16 | 189.8 | 189.7 | 0.053 | 170.6 | 170.29 | 0.182 | 185.5 | 186.54 | -0.561 | 184.2 | 183.05 | 0.624 |
| 17 | 179.6 | 181.09 | -0.830 | 172.3 | 167.92 | 2.542 | 186.2 | 188.2 | -1.074 | 186.7 | 187.38 | -0.364 |
| 18 | 159.2 | 158.18 | 0.641 | 190.8 | 190.95 | -0.079 | 177.4 | 179.03 | -0.919 | 208.8 | 209.74 | -0.450 |
| 19 | 165.2 | 160 | 3.148 | 159.6 | 157.19 | 1.510 | 259.5 | 256.9 | 1.002 | 175.9 | 177.35 | -0.824 |
| 20 | 179.6 | 181.09 | -0.830 | 164.9 | 168.59 | -2.238 | 157.3 | 157.65 | -0.223 | 154.7 | 155 | -0.194 |

Table-2. Comparison of TPS calculated with measured using 0.6cc ion Chamber and pinpoint chamber for Intensity modulated Radiation Therapy (IMRT) and Volumetric Arc Therapy (VMAT) using CDFP Phantom using Eclipse TPS.

| Sr. No. | IMRT | | | | | | VMAT | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 0.6cc Cylindrical Chamber | | | 0.015cc Pinpoint Chamber | | | 0.6cc Cylindrical Chamber | | | 0.015cc Pin Point Chamber | | |
| | TPS Measured (cGy) | IC Measured (cGy) | % of Variation (%) | TPS Measured (cGy) | IC Measured (cGy) | % of Variation (%) | TPS Measured (cGy) | IC Measured (cGy) | % of Variation (%) | TPS Measured (cGy) | IC Measured (cGy) | % of Variation (%) |
| 1 | 150.5 | 151.27 | -0.51 | 149.8 | 148.12 | 1.12 | 149.96 | 151.09 | -0.75 | 149.85 | 148.65 | 0.80 |
| 2 | 148.2 | 146.89 | 0.88 | 148.1 | 147.54 | 0.38 | 149.09 | 147.25 | 1.23 | 150.1 | 147.51 | 1.73 |
| 3 | 150.6 | 154.12 | -2.34 | 149.8 | 145.52 | 2.86 | 149.87 | 153.84 | -2.65 | 150.14 | 145.21 | 3.28 |
| 4 | 148.2 | 152.46 | -2.87 | 148.11 | 147.98 | 0.09 | 149.24 | 152.69 | -2.31 | 149.21 | 147.25 | 1.31 |
| 5 | 147.69 | 152.21 | -3.06 | 146.8 | 141.85 | 3.37 | 147.15 | 151.61 | -3.03 | 146.87 | 142.56 | 2.93 |
| 6 | 146.83 | 145.34 | 1.01 | 147.1 | 146.1 | 0.68 | 147.72 | 146.21 | 1.02 | 147.87 | 145.95 | 1.30 |
| 7 | 149.97 | 153.76 | -2.53 | 148.87 | 143.89 | 3.35 | 149.24 | 152.67 | -2.30 | 149.21 | 144.56 | 3.12 |
| 8 | 142.96 | 141.85 | 0.78 | 141.99 | 138.95 | 2.14 | 143.69 | 142.82 | 0.61 | 144.1 | 139.21 | 3.39 |
| 9 | 147.32 | 146.52 | 0.54 | 147.1 | 148.21 | -0.75 | 146.78 | 146.21 | 0.39 | 146.4 | 147.87 | -1.00 |
| 10 | 143.65 | 143.98 | -0.23 | 142.99 | 141.1 | 1.32 | 142.92 | 144.05 | -0.79 | 142.21 | 139.5 | 1.91 |
| 11 | 144.56 | 149.85 | -3.66 | 144.1 | 141.31 | 1.94 | 145.45 | 150.28 | -3.32 | 144.81 | 142.25 | 1.77 |
| 12 | 148.96 | 147.46 | 1.01 | 148.15 | 143.4 | 3.21 | 150.01 | 147.96 | 1.37 | 149.9 | 145.25 | 3.10 |
| 13 | 147.53 | 146.25 | 0.87 | 147.21 | 148.01 | -0.54 | 148.92 | 147.54 | 0.93 | 148.7 | 149.1 | -0.27 |
| 14 | 146.67 | 150.67 | -2.73 | 145.98 | 140.85 | 3.51 | 145.94 | 149.12 | -2.18 | 146.87 | 141.58 | 3.60 |
| 15 | 145.76 | 150.87 | -3.51 | 145.17 | 141.89 | 2.26 | 145.22 | 149.53 | -2.97 | 144.8 | 141.82 | 2.06 |
| 16 | 148.84 | 151.76 | -1.96 | 148.68 | 144.87 | 2.56 | 149.73 | 152.71 | -1.99 | 149.89 | 144.76 | 3.42 |
| 17 | 147.58 | 146.65 | 0.63 | 147.31 | 145.85 | 0.99 | 147.04 | 146.11 | 0.63 | 147.87 | 146.98 | 0.60 |
| 18 | 141.69 | 140.77 | 0.65 | 141.54 | 142.02 | -0.34 | 140.96 | 140.24 | 0.51 | 141.96 | 142.1 | -0.10 |
| 19 | 146.58 | 149.99 | -2.33 | 146.49 | 146.01 | 0.33 | 147.62 | 150.36 | -1.86 | 148.87 | 148.1 | 0.52 |
| 20 | 145.43 | 149.28 | -2.65 | 144.58 | 143.52 | 0.73 | 144.7 | 148.96 | -2.94 | 145.93 | 144.1 | 1.25 |
| 21 | 144.95 | 149.36 | -3.04 | 144.54 | 143.57 | 0.67 | 145.84 | 150.24 | -3.02 | 144.81 | 143.9 | 0.63 |
| 22 | 148.59 | 149.25 | -0.44 | 147.97 | 145.81 | 1.46 | 148.05 | 148.67 | -0.42 | 147.87 | 146.88 | 0.67 |
| 23 | 147.05 | 145.65 | 0.95 | 148.01 | 149.06 | -0.71 | 146.75 | 145.02 | 1.18 | 148.92 | 149.74 | -0.55 |
| 24 | 152.02 | 153.21 | -0.78 | 150.49 | 148.98 | 1.0 | 151.56 | 153.08 | -1.00 | 150.42 | 148.97 | 0.96 |
| 25 | 151.01 | 149.31 | 1.13 | 148.98 | 148.21 | 0.52 | 150.76 | 149.07 | 1.12 | 148.54 | 147.88 | 0.44 |
| 26 | 146.53 | 147.8 | -0.87 | 153.11 | 154.33 | -0.8 | 146.09 | 147.08 | -0.68 | 152.95 | 153.99 | -0.68 |
| 27 | 145.8 | 147.85 | -1.41 | 147.03 | 147.46 | -0.29 | 145.22 | 147.06 | -1.27 | 147.83 | 148.03 | -0.14 |
| 28 | 149.89 | 150.96 | -0.71 | 148.53 | 146.47 | 1.39 | 149.04 | 150.01 | -0.65 | 148.83 | 146.98 | 1.24 |
| 29 | 148.78 | 147.73 | 0.71 | 151.21 | 152.01 | -0.53 | 148.02 | 147.01 | 0.68 | 151.45 | 152.05 | -0.40 |
| 30 | 151.5 | 152.27 | -0.51 | 150.8 | 151.12 | 1.12 | 150.96 | 152.09 | -0.75 | 150.85 | 149.65 | 0.80 |

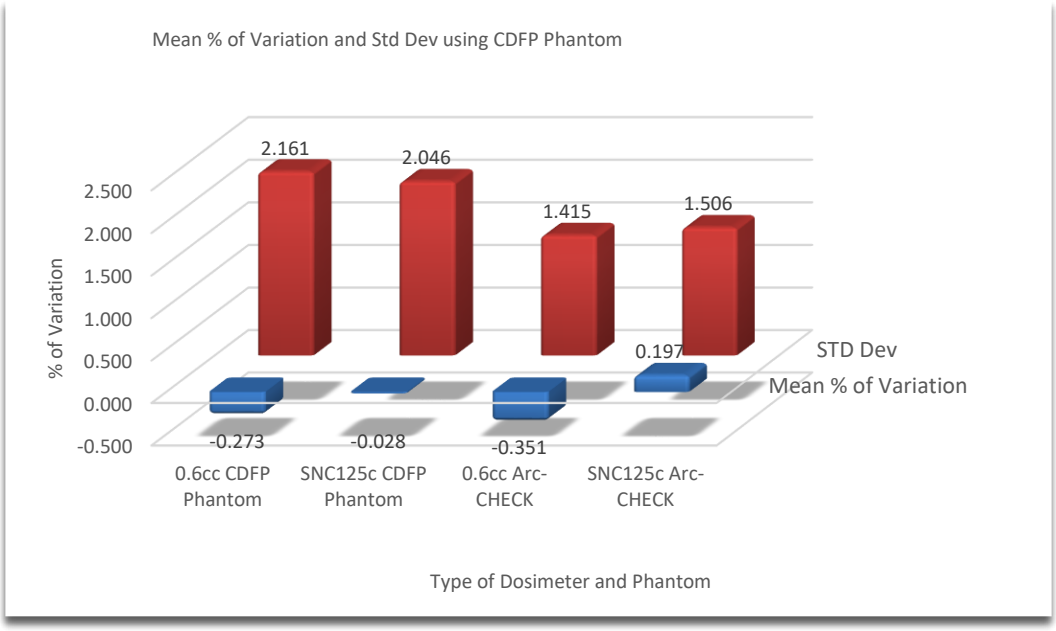



Figure 4. Mean % of Variation and Standard Deviation (Std. Dev) using CDFP phantom and Arc-CHECK % of Variation- Percentage of Variation CDFP- Custom designed female pelvis

***PSQA Absolute dosimetry on Infinity Linac***

Table 1 shows the Monaco TPS calculated dose and ion chamber measured dose for VMAT PSQA plans delivered on CDFP phantom and Arc-CHECK phantom using 0.6 cc and SNC125c chamber, respectively. For PSQA delivery on CDFP phantom, the average deviations were -0.273 % with SD of 2.16 (maximum deviation of -3.40 %), and -0.028 % with SD of 2.04 (maximum deviation of 3.1%) for 0.6 cc and SNC125c ion chamber, respectively. Similarly, PSQA delivery on Arc-CHECK phantom, the average deviations were -0.351 % with SD of 1.41 (maximum deviation of 2.72 %), and 0.197 % with SD of 1.50 (maximum deviation of 2.74%) for 0.6 cc and SNC125c ion chamber, respectively. Mean % of Variation and SD using CDFP Phantom and Arc-CHECK as shown in figure 4.

***PSQA Absolute dosimetry on Vital Beam Linac***

Table 2 shows the Eclipse TPS calculated dose and ion chamber measured dose for IMRT and VMAT PSQA plans delivered on CDFP phantom for 0.6 cc and 0.015cc pin-point chamber, respectively. For IMRT PSQA delivery on CDFP phantom, the average deviations were -0.899 % with SD of 1.59 (maximum deviation of -3.66 %), and 1.01 % with SD of 1.31 (maximum deviation of 3.51%) for 0.6 cc and 0.015 cc pinpoint ion chamber, respectively. Similarly, VMAT PSQA delivery on CDFP phantom, the average deviations were -0.840 % with SD of 1.53 (maximum deviation of -3.32 %), and 1.25 % with SD of 1.34 (maximum deviation of 3.51%) for 0.6 cc and 0.015 cc pinpoint ion chamber, respectively.

These findings suggest reasonable concordance between the TPS-computed and machine-measured dose when using both ion chambers with IMRT and VMAT treatment deliveries at relatively small differences amounting to chamber volume and spatial resolution.

## Discussion

The implementation of patient-specific quality assurance (PSQA) is crucial in ensuring the precision of radiation treatment [8]. Before examining further potential contributing elements, such as verifying the chamber placement in the phantom plan, the first step would usually be to ensure the measurement setup was accurate. All plans met the ±5% (ICRU83) acceptability criteria and in this study our results were maximum variation of ±4% and mean percentage of variation were within ±2%. The Medical Physicist would look into any failing results in the institutional PSQA protocol [7].

Point dose measurements performed in a water-equivalent phantom are consistent and useful method that is widely used, particularly for advanced radiotherapy techniques viz. IMRT and VMAT in PSQA [18]. However, verification using heterogeneous phantoms is increasingly important due to the complex density variations present in patient anatomy. The observed deviations in dose measurements between computed and measured values in the CDFP phantom could have potential clinical implications. Higher deviations could lead to suboptimal treatment delivery, affecting treatment outcomes and patient safety. To verify the accuracy of the dose calculated by AAA algorithm in each patient's case, the PSQA should be performed using a heterogeneous phantom that replicates the density of the human body.

In our study, the variation in percentage dose differences between the 0.6 cc Farmer, 0.015 cc pinpoint, and SNC125c ionization chambers is mostly

linked to the variation in sensitive volume, spatial resolution and positioning uncertainties and volume-averaging effects. The 0.6 cc Farmer chamber was found to have lower mean deviations and high reproducibility of either IMRT or VMAT plan due to the larger sensitive volume averaging the dose to a broader area and thus the effect of local dose gradients and minor setup uncertainty are reduced[17,19].

Conversely, the 0.015 cc pin-point chamber showed a much greater sensitivity to variations in dose due to the small sensitive volume and greater sensibility to positioning errors, especially when using highly modulated IMRT and VMAT dose distributions. SNC125c chamber had middle-level performance, between the spatial resolution and measurement stability, which aligns with the literature stating that this chamber is appropriate on both CDFP phantom and Arc-CHECK based PSQA measurements[12]. In all detectors, VMAT had a slight higher variation than IMRT, which is due to the more complicated nature of its delivery and steeper dose gradients of the VMAT techniques[20]

Gurjar et. al., studied radiation dosimetry for a modern radiotherapy technique using a real tissue phantom and an average percentage variations between the computed and measured doses was found to be 2.48% ( (SD): 0.74), 2.36% (SD: 0.77), 3.62% (SD: 1.05), and 3.31% (SD: 0.78) for 3DCRT (head phantom), IMRT(head phantom) 3DCRT (tissue phantom), and IMRT(tissue phantom) respectively [21]. In the study of Yadav et.al, relative dosimetry was carried out for several target areas utilizing Rapid Arc and IMRT treatment modalities employing a 0.600 cc ion chamber and for VMAT PSQA plans using the CDFP phantom, the % difference between the computed and measured dose was 10.67% at the highest, 2.31% at the minimum, and 6.89% at the mean, SD of 2.565[14].

In our study, Monte Carlo algorithm presented similar or even better agreement than AAA, which confirms their high capacity to simulate heterogeneity of tissues and scatter interaction. The CDFP phantom, characterized by its realistic fidelity to anatomy and heterogeneity, further allowed the dosimetric validation to be done under conditions that are highly similar to those of the patient geometry. This is very beneficial especially in female pelvic malignancies where the movements of the organs, changes in density, and complicated structures of the anatomic bodies, determine the distribution of doses. These findings indicate that while AAA provides clinically acceptable accuracy for routine patient-specific quality assurance, Monte Carlo based dose calculations offer superior dosimetric accuracy and robustness, thereby enhancing confidence in dose delivery for complex treatment scenarios involving highly modulated beams and heterogeneous anatomies[22].

Dubey et. el., performed a dosimetric comparison of AAA and AXB algorithms to pretreatment QA plans of 35 lung cancer patients revealed lower dose mean percentage variations among measured and planned doses using AXB than AAA (2.19% vs. 2.61%) in Heterogeneous thorax phantom and (1.64% vs 1.79%) in Homogeneous slab phantom[23]. Gangwar et al. investigated the discrepancies between ion chamber measured dose and dose calculated by the Eclipse treatment planning system for ten clinical cases. Their results showed good agreement between measured and calculated doses, with mean deviations of 2.1 ± 0.6% for 6 MV flattening-filter (FF) beams and 1.7 ± 0.8% for 6 MV flattening-filter-free (FFF) beams[24]. Kishore et al. have studied a comparison between dose calculated using the AAA and the dose measured using the ionization chamber at 8cm of the phantom in two different phantom media and the mean percentage difference dose calculated were -1.28 ± 0.19% for the homogeneous PMMA phantom and −2.70 ± 0.70% for the heterogeneous PWP phantom [25].

In this retrospective analysis of 304 RPC thorax phantom irradiations using 6 MV beams, Monte Carlo (MC) algorithms showed the highest dose calculation accuracy (mean deviation 0.6%), while pencil beam (PB), convolution/superposition (CS), and anisotropic analytic algorithm (AAA) systematically overestimated target center dose by 4.9%, 3.7%, and 3.7% respectively, with no significant accuracy difference between IMRT and 3D-CRT[22]. Yadav et al., designed phantom using wax, pelvic bone, borax powder, and water to mimic biological tissues, demonstrated relative electron densities closely matching those of patient anatomy, with a mean dose deviation of 2.13% (within ±3% tolerance) and gamma index passing rates exceeding 90% for all IMRT plan verifications[26]. The study demonstrated that the indigenous pelvic phantom accurately replicated pelvic tissue electron densities, with planned and measured doses showing good agreement across algorithms, where the highest deviation was 3.09% (single field, Superposition) and the lowest was -0.08% (opposite field, Convolution), all within the ±5% tolerance recommended by the ICRU[27].

Our results found that Arc-CHECK phantom measurements on the Infinity linac showed slightly better consistency than the CDFP phantom, as shown by the lower standard deviations for both chamber volumes. This could be because of the Arc-CHECK homogeneous geometry and CDFP phantom composition and geometry which replicate human anatomy. Kumar et al. studied that inhomogeneous phantoms exhibited larger dose discrepancies compared to homogeneous phantoms. The doses measured by the ion chambers were compared to the doses calculated by the AAA and the percentage error was found to be in good agreement, which allowed concluding that the phantom may be used on a routine basis in order to provide patient-specific QA[28]. The Arc-CHECK is mainly made for checking relative doses, but the absolute point-dose measurements from this study showed mean deviations that were similar to those from the CDFP phantom. This shows that it can be used for

absolute dosimetry if the right correction factors and chamber positioning are used[28].

Also, the maximum and mean of percentage deviation differences were found to be -3.6% and 1% for the IMRT treatment technique and 3.6% and 1.04% for the VMAT treatment technique in Vital Beam LINAC respectively. In our study point dosimetry was carried out for VMAT and IMRT treatment modalities employing a 0.6 cc ion chamber and 0.015 cc ion chamber respectively using CDFP phantom, the results of maximum, mean percentage difference between the planned and measured dose and standard deviation were significant compare to Yadav et al. [29] and Gurjar et al.[27] study, as in this study The CDFP phantom closely resembles the female pelvic tissue anatomy.

It is probable that the clinical applicability of these phantoms will be enhanced and the outcomes of radiation therapy patients will be improved through larger-scale validation and additional research.

## Conclusion

The current study demonstrates the significance of accurate radiation dose administration in the treatment of cervical carcinoma with advanced radiation therapy techniques using CDFP phantom. The absolute mean of % variation and SD of IMRT and VMAT techniques gives better outputs. The outputs of the current study demonstrate the developed CDFP phantoms are suitable for dosimetric studies of pelvic treatments to enhance the accuracy and precision of the treatment delivery. The results highlight the robustness of the CDFP phantom in realistically representing pelvic anatomy and tissue heterogeneities, leading to clinically relevant dose verification outcomes.

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