On-line estimations of delivered radiation doses in three-dimensional conformal radiotherapy treatments of carcinoma uterine cervix patients in linear accelerator

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ABSTRACT

Transmission of radiation fluence through patient's body has a correlation to the planned target dose. A method to estimate the delivered dose to target volumes was standardized using a beam level 0.6 cc ionization chamber (IC) positioned at electronic portal imaging device (EPID) plane from the measured transit signal (S_t) in patients with cancer of uterine cervix treated with three-dimensional conformal radiotherapy (3DCRT). The IC with buildup cap was mounted on linear accelerator EPID frame with fixed source to chamber distance of 146.3 cm, using a locally fabricated mount. S_ts were obtained for different water phantom thicknesses and radiation field sizes which were then used to generate a calibration table against calculated midplane doses at isocenter ($D_{iso,TPS}$), derived from the treatment planning system. A code was developed using MATLAB software which was used to estimate the *in vivo* dose at isocenter ($D_{iso,Transit}$) from the measured S_ts. A locally fabricated pelvic phantom validated the estimations of $D_{iso,Transit}$ before implementing this method on actual patients. On-line dose estimations were made (3 times during treatment for each patient) in 24 patients. The $D_{iso,Transit}$ agreement with $D_{iso,TPS}$ in phantom was within 1.7% and the mean percentage deviation with standard deviation is $-1.37\% \pm 2.03\%$ ($n = 72$) observed in patients. Estimated *in vivo* dose at isocenter with this method provides a good agreement with planned ones which can be implemented as part of quality assurance in pelvic sites treated with simple techniques, for example, 3DCRT where there is a need for documentation of planned dose delivery.

Key words: Cervix cancer; clinical dosimetry; conformal radiotherapy; on-line dose verification

Introduction

Outcome of radiation therapy treatment depends on the accuracy of dose delivery to the specified target volume. Uncertainty in dose delivery includes patient and machine specific parameters, for example, outline of patient structure, positioning error, variations in patient geometry from time of planning to the time of treatment, organ motion (internal and external), accuracy of treatment planning system (TPS) dose algorithm, and random variations in linear accelerator (linac) output. With the increase in complexity of treatment techniques such as three-dimensional conformal radiotherapy (3DCRT), intensity modulated radiotherapy, and volumetric modulated arc therapy there is a need to verify the planned dose delivery to the target site as part of verification process.

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Various national and international organizations recommend the need for *in vivo* dosimetry to be carried out on a regular basis as important part of quality assurance.[1-4]

The methods for *in vivo* dosimetry involve physical placement of detectors inside the patient cavities such as mouth, esophagus, vagina and rectum.[5] Next closest approach is by placing dosimeters, such as diodes, thermoluminescent dosimeter (TLD), or metal oxide semiconductor field effect transistors (MOSFET), on the patient's skin or inside the patient to derive the dose at specific points within the patient. However, in clinical practice, placing detectors on the patient's skin at the entrance and/or exit surface of the beam is not always easy or feasible and requires some extra setup time in the treatment room. These detectors offer disadvantage owing to periodic calibrations, correction for temperature, pressure, photon energy dependence, accurate positioning, and estimation of the photon fluence perturbation inside the patient. This explains why "*in vivo*" dosimetry remains limited to the first session of treatment and also why it is still not implemented in every radiotherapy center.[6] Another method, as part of *in vivo* dosimetry, transmission of radiation flux/signal measurement at a point far away from the patient was used in the days of deep X-rays and telecobalt beam treatments when rotation therapy was introduced in radiotherapy.[7] A simple and practical method was devised to obtain the *in vivo* dose in 60 pelvic treatments on the beam central axis using the signal measured by a small air ion chamber positioned along with beam central axis at typical distance of the electronic portal imaging device (EPID) from the source.[8] In another work, an estimation of *in vivo* dose from back projection of transit signal (S_t) measurement with EPID along the central axis of photon beam in patients undergoing conformal radiotherapy for various localizations was presented.[9] During the treatment session, a transit dose is measured with the EPID which is calibrated against an ionization chamber (IC) and the dose in the patient is estimated from the back projection of the portal dose and also validated for different beam energies. These methods can potentially be used to identify changes in tissue thickness and setup errors if any. The improvement of dose delivery accuracy and its efficacy in clinical radiotherapy is highlighted in another report.[10]

International Atomic Energy Agency (IAEA) report recommended implementation of *in vivo* dosimetry in sites with regular body contours such as the pelvis and for simple techniques not involving high dose gradients.[11] In this direction, a few reports describe *in vivo* dosimetry with chemical dosimeter and IC by placement of detectors in vaginal cavity of patients receiving external beam radiotherapy treatment for carcinoma uterine cervix.[12,13] As the above method needs patient's consent and was time consuming, better methodology was found necessary. The present work illustrates our attempt in positioning an ion chamber, positioned on locally fabricated mount fixed at EPID level, along the beam central axis, and estimating the *in vivo* dose at isocenter in a group of carcinoma of uterine cervix patients treated with 3DCRT by accounting water equivalent path length principle.

Materials and Methods

Treatment machine

A medical linear accelerator (model Elekta Compact) having a single 6 MV photon energy, motorized wedge, and 40 pairs Multi-Leaf Collimator (MLCi2) having leaf thickness of 1 cm at 100 cm iso-center available at our center was used. This is routinely operated at 350 monitoring units (MU) per minute, having output 1 centi-Gray (cGy)/MU at isocenter.

Estimation of in vivo dose thorough transit method

S_t is measured at a faraway point along the central axis of the beam, at a distance of 46.3 cm from the isocenter of linac. A metallic mount made up of iron ($\rho \approx 7.85$ g/cc) was fabricated locally and fixed at the level of EPID assembly. This carries a 0.65 cc IC (Model FC65-G from IBA Dosimetry, Germany) with build-up cap on an extended acrylic sheet ($\rho \approx 1.065$ g/cc) of 8 mm thickness which facilitates no metallic interference in the path of beam along the central axis. Figure 1 shows the schematic diagram of the transmission dose measurement setup showing the metallic mount fixed on the linac's EPID frame and the IC with its build-up cap placed on an acrylic sheet. The IC with buildup cap was inserted in an acrylic holder box so that a fixed target to chamber distance of 146.3 cm is maintained for all gantry angulations of linac with this geometry. Figure 2 shows the metallic mount fixed to EPID frame of linac. Therefore, the chamber accurately measures S_t using a Dose 1 electrometer (IBA Dosimetry, Germany) in nano Coulombs (nC), when media (water phantom or patient) is positioned on the linac treatment couch at the iso-center. The geometry of S_t measurements is shown in Figure 3. S_ts for 100 MU delivery were taken with a water phantom (dimensions of 40 cm ×40 cm ×40 cm) positioned on treatment couch in
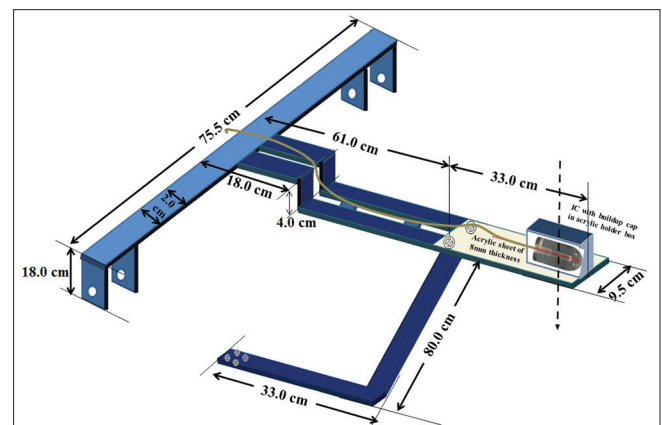

Figure 1: Schematic diagram of the transmission dose measurement setup showing the metallic mount fixed on the linac's EPID frame and the IC with its build-up cap placed on an acrylic sheet

Figure 2: Metallic mount (with ionization chamber in transit position) fixed to electronic portal imaging device of linac
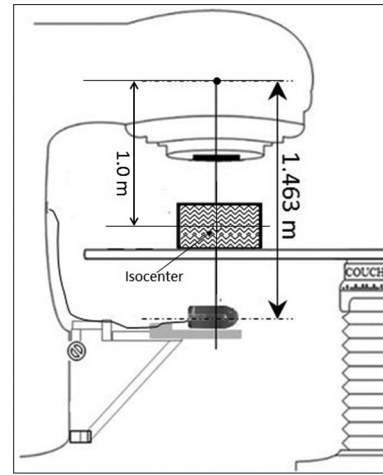

Figure 3: Schematic diagram representing the source to center of ionization chamber (with buildup cap) distance (1.463 m) along central axis kept on an acrylic sheet and water phantom kept at iso-center on treatment couch of linac

isocenteric condition for various water thicknesses (ranging from 6 to 30 cm with a step size of 2 cm) and for square fields (from 5 to 25 cm at intervals of 5 cm). These readings were corrected for temperature, pressure, phantom (base), and couch transmission [Annexure Table 1].

Computerized TPS (CMS XiO®, Elekta Ltd, UK, version 4.80.02) which has Clarkson, convolution, superposition, and fast superposition algorithms, was commissioned with beam data measurements of the linac. Superposition algorithm was used for all dose calculations in this study. Quality assurance of TPS with regard to the calculated dose under different clinical situations was studied in a water phantom, and the measurements were found to be within ±1.5% of TPS calculated values. "Virtual water" phantoms (ρ = 1.0 g/cc) of dimensions 40 cm × 40 cm, with the above-selected thickness were generated in TPS. The midplane doses at isocenter in TPS ($D_{iso,TPS}$) in cGy for 100 MU delivery were recorded from the virtual water phantoms, for various water thicknesses, and field size combinations. A calibration table was generated by taking the ratio of S_t versus $D_{iso,TPS}$ (in nC/cGy) for corresponding water thickness and field size combinations [Annexure Tables 2 and 3].

A code was developed with MATLAB software (version R2015) to estimate the *in vivo* dose at isocenter ($D_{iso,Transit}$) through S_t. This has a database of above measured S_t values and calibration table. Input parameters such as equivalent square field size (Z), temperature, pressure, couch attenuation factor, delivered MUs, S_t reading (in nC), and TPS calculated dose, were given through input window. Corrected transit reading (nC) was calculated from the entered MUs. Water equivalent depth (W_{eq}) was referred from the interpolated values of equivalent square field size (Z) and corrected S_t by searching the analogous index. The estimated $D_{iso,Transit}$ value corresponding to Z and W_{eq} was picked up from the nC/cGy ratio interpolated data.

Validation of MATLAB code with pelvic phantom

Before implementing this method on actual patients, a medium sized female pelvis phantom was used to verify the efficacy of the above-developed code for estimation of $D_{iso,Transit}$ through S_t. This phantom was locally fabricated out of acrylic sheets with inbuilt bladder, rectum tissue structures in wax, femoral heads (Teflon material), and uterus cervix complex (target) that simulated actual patient. This has provision to hold a compact ion chamber (Model CC01 from IBA Dosimetry, Germany) in annular slots. Figure 4 shows pelvic phantom in transverse view with CC01 IC slots. This simulates the treatment setup for carcinoma cervix with a nearly accurate anatomical geometry.

The phantom was scanned under computed tomography (CT) machine (Wipro GE, Model: High Speed) with CC01 in the target slot. Scanned CT images were exported to Focalsim contouring station (Elekta Ltd., Crawley, UK) through digital imaging and communications in medicine (DICOM) network. Contouring of target volume (position of CC01 chamber) was done in all transverse slices.

The contoured images were transferred to CMS XiO® (Elekta Ltd, Crawley, UK) version 4.80.02 TPS for beam placement and dose calculations. A set of four beams with gantry angles 270°, 90° (with field size 15 cm ×12 cm), 0°, and 180° (with field size 12 cm ×12 cm), placing isocenter at the center of the target were placed. A dose of 200 cGy was prescribed to the target which was normalized to the 100% isodose line encompassing the target, and a box technique treatment plan was generated. The mean dose calculated by TPS around the region of the target was noted from the dose volume histogram.

The S_t and the dose at isocenter were taken simultaneously with FC65 and CC01 chambers respectively for all four

beams with pelvic phantom positioned under linac in an iso-centric condition during planning execution. Measured dose at isocenter with CC01 ($D_{iso,phantom}$) was compared with the $D_{iso,Transit}$ obtained from MATLAB code. To check the uniformity of absolute dose measured with CC01 and FC65 chambers, readings were taken separately following IAEA protocol TRS-398 in a water phantom, and a deviation of 0.2% was found from the measurements.[14]

Estimation of in vivo dose at isocenter through transit signal in patients

A total of 24 patients diagnosed with carcinoma uterine cervix who were treated by 3DCRT were included in this study. All patients were immobilized with "Vacloc" device (Klarity Medical, USA) in supine position. CT simulation was carried out for all patients for treatment planning, and the scanned serial images were exported to contouring station using DICOM network. Contouring of tumor volumes and normal structures was done by radiation oncologist. The created clinical tumor volume (CTV) encompassed the gross tumor volume together with nodal basins. The planning target volume (PTV) has a selected margin of 5 mm to CTV to account for inter-fractional and geometric positional uncertainties as per data from the investigating institution. Contoured image data set was transferred to TPS for beams placement. The isocenter was placed at the midplane of physical separation (both anterior-posteriorly and laterally) of patient's planning CT slice which has a central axis for 3DCRT planning in all patients where it falls inside the PTV. Therefore, it was ensured that the dose at the geometric center of the patient (which is same as isocenter) is identical to the homogeneous prescribed tumor dose ($D_{iso,TPS}$) in the 3DCRT planning slice. Four-field (270°, 0°, 90°, and 180°) box technique with all beams conformed to PTV by MLC with a margin of 5 mm was used for all patients. Field infield (subfield) and/or wedge technique were used, as and when required, to reduce the hot spots around target region. A 3DCRT plan was generated with a dose prescription of 2.0 Gray per fraction that was normalized to 100% isodose line covered to PTV. The plan was evaluated and approved by the radiation oncologist and was exported to record and verification (R and V) system (MOSAIQ®) for scheduling and execution.

The lateral and anterior digitally reconstructed radiograph images were exported to EPID (iViewC – camera based) for positional verification before treatment execution. Before the treatment execution, verification of patient's treatment setup under linac was checked with iViewC. Translational (x, y, and z) shifts of 3 mm margin were accepted, and necessary couch corrections were applied as and when required and the scheduled 3DCRT plan was subsequently executed. S_t readings were recorded during treatment for all fields with IC (in transmission geometry as described earlier) and measurements were repeated 3 times (with an interval of 5–6 fractions) during 3DCRT in all 24 patients ($n = 72$ measurements). Schematic representation of the position of IC with buildup cap vis-à-vis treatment head and representative treatment slice of the patient at four gantry angles (180°, 270°, 0°, and 90°) under transit study condition which has isocenter at the midplane of patient's planning CT slice is shown in Figure 5. The method of dose estimates is illustrated in Annexure Table 4.

During transit measurements with patients, the simultaneous measurement of *in vivo* dose at isocenter could not be performed as it was done in pelvic phantom. S_ts were measured only for confirmed fields but not for wedged and subfields. The percentage deviation of $D_{iso,Transit}$ with $D_{iso,TPS}$ calculated from the following equation was noted.

$$\text{Percentage deviation} = \frac{D_{iso,TPS} - D_{iso,transit}}{D_{iso,TPS}} \times 100 \quad (1)$$

The method of estimating 'in vivo' dose at isocentre using transit signal is outlined in Annexure Table 5.

Results

Figure 6 shows the calibration curve of nC/cGy ratio for 100 MU delivery versus thickness of water for different field sizes for estimation $D_{iso,Transit}$. Interpolation (for different field

Figure 4: Pelvic phantom transverse view with CC01 ionization chamber slots
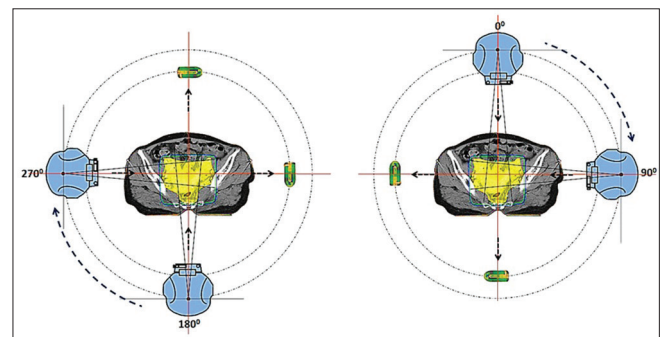

Figure 5: Schematic representation of position of ionization chamber with buildup cap vis-à-vis linac treatment head, and transverse slice of representative treatment slice of patient used as model at four angles (180°, 270°, 0°, and 90°) under transit study condition

sizes and water equivalent thicknesses) was carried out using *polyfit* and *polyval* functions available in the MATLAB code to determine the $D_{iso,Transit}$ in routine clinical situations, is shown.

The *in vivo* dose values ($D_{iso,Transit}$, $D_{iso,Phantom}$ and $D_{iso,TPS}$) obtained with pelvic phantom for four fields are shown in Table 1. The standard deviation of $D_{iso,Transit}$ with $D_{iso,TPS}$ and $D_{iso,Phantom}$ from individual fields was within ± 1.7 and 0.6%, respectively. However, the mean percentage deviation of $D_{iso,Transit}$ with $D_{iso,TPS}$ and $D_{iso,Phantom}$ combined from all fields was 0.9 and 0.4% respectively with pelvic phantom. Table 2 shows the results of estimated $D_{iso,Transit}$ (72 measurements) of 24 patients taken 3 times during treatments along with $D_{iso,TPS}$ values and the percentage deviation (calculated from equation 1) which was varied from -4.84% to 3.65%. The mean percentage deviation with standard deviation (SD) of estimated $D_{iso,Transit}$ with $D_{iso,TPS}$ is $-1.37\% \pm 2.03\%$ ($n = 72$) observed from this group of patients. Figure 7 shows the percentage deviation of estimated $D_{iso,Transit}$ with $D_{iso,TPS}$ in a group of 24 patients, during 3DCRT.

Discussion

The transit dosimetry in different geometries has been attempted by various researchers.[7-10] Goldenberg *et al.*[7] did a study to determine lung correction factors under actual treatment conditions in 8 patients treated for the middle third of the esophagus with cobalt-60 unit rotational therapy. Transit dose measurements by IC were related to direct measurements (temperature corrected) using intraluminal dosimeter and obtained results within 3%. Francois *et al.*[9] verified dose delivered on 38 patients treated with conformal therapy by a transit method. Central axis doses estimated by their formalism were compared with a measured dose which was found within the accepted tolerance of classical *in vivo* dosimetry (SD of 3.5%). A multicenter dose audit using similar transit measurement has shown an efficacy of dose estimation within an action level accuracy of 4%–5% with a measured deviation of 4% for thorax/pelvic treatments.[10] An earlier work[15] described the method of obtaining *in vivo* dose through transmission measurements with IC in a group of carcinoma cervix patients treated under telecobalt unit. An *in vivo* dosimetry system[16] used the measurement of transmission dose after phantom study, applied clinically on 11 patients who were treated for pelvic site with and without bone correction done in TPS. Mean errors were between -5.20% and $+2.20\%$ for AP-PA without bone correction, and between -0.62% and $+3.32\%$ with bone correction. For lateral fields, mean errors were between -10.80% and $+3.46\%$ without bone correction and between -0.55% and $+3.50\%$ with bone correction. It was brought out that transmission method is a useful form of *in*
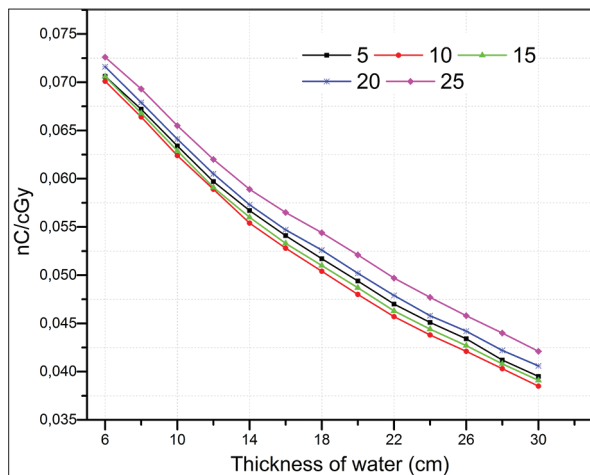

Figure 6: Plot of nano Coulombs/centi-Gray ratio versus thickness of water (in cm) for 100 monitoring units delivery for different field sizes
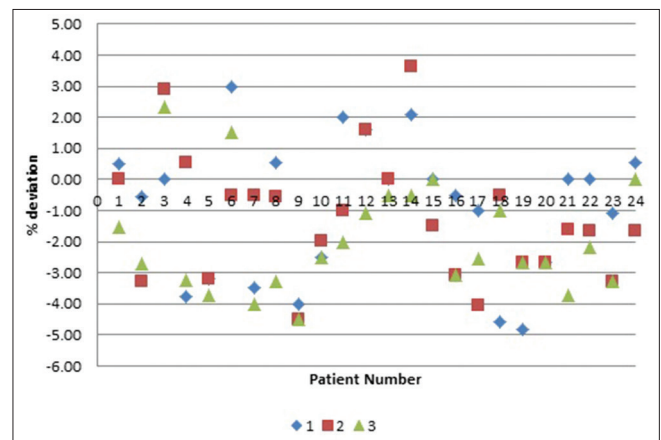
Figure 7: Percentage deviation of estimated $D_{iso,Transit}$ with $D_{iso,TPS}$ in a group of 24 patients (taken 3 times for each patient during the course of three-dimensional conformal radiotherapy)

Table 1: The percentage deviation of *in vivo* dose at isocenter obtained through transit method ($D_{iso,Transit}$) with the values from TPS ($D_{iso,TPS}$) and measured with CC01 ($D_{iso,mid}$) in pelvic phantom

Field number	Gantry angle (°)	*In vivo* dose (cGy)			Percentage deviation	
		$D_{iso,TPS}$	$D_{iso,Phantom}$	$D_{iso,Transit}$	$D_{iso,Transit}$ *versus* $D_{iso,TPS}$	$D_{iso,Transit}$ *versus* $D_{iso,Phantom}$
1	270	48.0	46.9	47.2	−1.7	0.6
2	0	49.0	50.1	49.9	1.8	−0.4
3	90	47.0	47.7	47.8	1.7	0.2
4	180	56.0	56.3	56.9	1.6	1.1
Total		200.0	201.0	201.8	0.9	0.4

Table 2: The estimated D$_{iso,Transit}$ values (obtained in three fractions of all 24 patients) and corresponding D$_{iso,TPS}$ along with the percentage deviation

Patient number	D$_{iso,TPS}$	1		2		3	
		D$_{iso,Transit}$	Percentage deviation	D$_{iso,Transit}$	Percentage deviation	D$_{iso,Transit}$	Percentage deviation
1	1.93	1.92	0.52	1.93	0.00	1.96	−1.55
2	1.84	1.85	−0.54	1.90	−3.26	1.89	−2.72
3	1.72	1.72	0.00	1.67	2.91	1.68	2.33
4	1.86	1.93	−3.76	1.85	0.54	1.92	−3.23
5	1.88	1.94	−3.19	1.94	−3.19	1.95	−3.72
6	2.00	1.94	3.00	2.01	−0.50	1.97	1.50
7	2.00	2.07	−3.50	2.01	−0.50	2.08	−4.00
8	1.83	1.82	0.55	1.84	−0.55	1.89	−3.28
9	2.00	2.08	−4.00	2.09	−4.50	2.09	−4.50
10	2.01	2.06	−2.49	2.05	−1.99	2.06	−2.49
11	2.00	1.96	2.00	2.02	−1.00	2.04	−2.00
12	1.86	1.83	1.61	1.83	1.61	1.88	−1.08
13	1.95	1.95	0.00	1.95	0.00	1.96	−0.51
14	1.92	1.88	2.08	1.85	3.65	1.93	−0.52
15	1.99	1.99	0.00	2.02	−1.51	1.99	0.00
16	1.95	1.96	−0.51	2.01	−3.08	2.01	−3.08
17	1.98	2.00	−1.01	2.06	−4.04	2.03	−2.53
18	1.97	2.06	−4.57	1.98	−0.51	1.99	−1.02
19	1.86	1.95	−4.84	1.91	−2.69	1.91	−2.69
20	1.87	1.92	−2.67	1.92	−2.67	1.92	−2.67
21	1.87	1.87	0.00	1.90	−1.60	1.94	−3.74
22	1.82	1.82	0.00	1.85	−1.65	1.86	−2.20
23	1.83	1.85	−1.09	1.89	−3.28	1.89	−3.28
24	1.80	1.79	0.56	1.83	−1.67	1.80	0.00

The mean percentage deviation with SD of estimated D$_{iso,Transit}$ with D$_{iso,TPS}$ observed in this group is −1.37±2.03% (*n*=72). SD: Standard deviation

vivo dosimetry, because of noninvasiveness and simplicity with no additional efforts. The above authors emphasized that if bone corrections are not applied, the variation in transmission measurement can be as much as 10%. Even without any patient involved, their dosimetry variation of output was 2% over the course of patient treatments. The algorithm used in our study takes care of the inhomogeneity corrections in TPS, and the proposed method was validated in an in-house locally fabricated pelvic phantom before implementing in actual patients. In a recent study, Camilleri *et al.*[17] examined the feasibility of using an EPID-based *in vivo* dosimetry method that enables a point dose delivered to the patient to be calculated from the S$_t$ acquired with an EPID in a group of 53 patients treated by 3DCRT at pelvic site for 211 *in vivo* dose verifications. Excellent agreement was found between dose reconstructed at the isocenter and dose calculated by TPS with a mean deviation of −1.0% ±2.2% (1 SD). *In vivo* dose estimates obtained in this study are in good agreement with the accuracy levels obtained through various methods (done in pelvic malignancies) which are published in literature.[9,10,12,13,15-17] Our experience is limited to only symmetric fields where the central axis goes through the "ion chamber centre" in the exit position. If it is an asymmetric field or very long elongated field, the calibration cannot be extrapolated. The described method

should be read with this limitation, and adequate caution must be exercised while using elongated fields. Wedged fields were not included in the present study, because of calibration differences for skewed isodose patterns. We plan to take up these aspects as a separate study in the future.

Conclusion

The *in vivo* dosimetry has the potential to be useful in clinical settings, especially when treating regions not in close proximity to large tissue inhomogeneity. The proposed method in this study for *in vivo* dose verification has an added advantage because it is very simple to implement and can be implemented in clinics since the detector is kept away from the patient during transit measurements for all gantry angles. This work is not limited to only four-field box technique but also applicable to parallel opposed, three-field or five-field techniques as well. There are no difficulties arising pertaining to the positioning, reproducibility, and calibration. Measurements can be repeated during several sessions giving the opportunity to build new strategies for the validation by statistical evaluation of the data. The described method is applicable only when isocenter is at the mid-plane, both anterio-posteriorly and laterally. In situations when this is not the case, this method is not applicable. As the

treatment planning algorithms have a few assumptions and extrapolations in dose calculations and display, our method will estimate the true path lengths encountered in the real patient, and therefore check the validity in delivered doses. This transmission method can quantify gross errors easily. We could estimate the dose to mid-point in the central axis with reasonable accuracy. However, this method is not a substitute to pretreatment quality assurance, but serves as an adjuvant dose verification, to track dose delivery and to catch gross errors which may be harmful for patients. This study also addresses a scientific problem where alternatives to EPID sophisticated dosimetry methods for transmission measurements are not available. With further work, this method may also be used to evaluate dose distribution variations throughout treatment fractions due to inter-fractional variability (weight loss, swelling) and help as a guide to adaptive radiotherapy.

Conflicts of interest
There are no conflicts of interest.

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Annexure

Table 1: Corrected transit signal (nC) readings for different field sizes and water thicknesses taken with ionization chamber in transit position keeping water phantom in isocentric condition under linac

Thickness (cm)	Field size (cm^2)				
	5	10	15	20	25
6	6.7694	7.0808	7.3314	7.5505	7.7664
8	6.1511	6.4776	6.7282	6.9745	7.2207
10	5.6011	5.9200	6.1728	6.4353	6.6837
12	5.0771	5.3819	5.6455	5.9135	6.1739
14	4.6204	4.9165	5.1866	5.4579	5.7269
16	4.2287	4.5195	4.7907	5.0641	5.3407
18	3.8759	4.1613	4.4381	4.7138	4.9993
20	3.5405	3.8194	4.0908	4.3665	4.6487
22	3.2192	3.4895	3.7543	4.0311	4.3046
24	2.9511	3.2149	3.4667	3.7315	3.9996
26	2.7205	2.9699	3.2193	3.4817	3.7203
28	2.4722	2.7222	2.9656	3.2182	3.4638
30	2.2689	2.5015	2.7401	2.9819	3.2112

Table 2: D$_{iso,TPS}$ (cGy) values for various field sizes and water thicknesses taken from treatment planning system with virtual water phantom

Thickness (cm)	Field size (cm^2)				
	5	10	15	20	25
6	95.9	101.0	103.8	105.5	107.0
8	91.6	97.6	100.7	102.7	104.2
10	88.4	94.8	98.2	100.4	102.1
12	85.0	91.3	95.5	97.8	99.6
14	81.5	88.8	92.7	95.2	97.2
16	78.1	85.6	89.9	92.5	94.5
18	74.9	82.6	87.0	89.7	91.9
20	71.6	79.5	84.0	86.9	89.2
22	68.5	76.4	81.0	84.2	86.6
24	65.5	73.4	78.1	81.4	83.9
26	62.7	70.5	75.4	78.7	81.3
28	60.0	67.6	72.7	76.2	78.7
30	57.4	65.0	70.0	73.4	76.2

Table 3: nC/cGy ratios for different field sizes and water thicknesses

Thickness (cm)	Field size (cm²)				
	5	10	15	20	25
6	0.0706	0.0701	0.0706	0.0716	0.0726
8	0.0672	0.0664	0.0668	0.0679	0.0693
10	0.0634	0.0624	0.0629	0.0641	0.0655
12	0.0597	0.0589	0.0591	0.0605	0.0620
14	0.0567	0.0554	0.0560	0.0573	0.0589
16	0.0541	0.0528	0.0533	0.0547	0.0565
18	0.0517	0.0504	0.0510	0.0526	0.0544
20	0.0494	0.0480	0.0487	0.0502	0.0521
22	0.0470	0.0457	0.0463	0.0479	0.0497
24	0.0451	0.0438	0.0444	0.0458	0.0477
26	0.0434	0.0421	0.0427	0.0442	0.0458
28	0.0412	0.0403	0.0408	0.0422	0.0440
30	0.0395	0.0385	0.0391	0.0406	0.0421

An example to estimate *in vivo* dose

To estimate the *in vivo* dose at isocenter ($D_{iso,transit}$) in cGy from the transit signal (in nanoColumbs, "nC") measured with ionization chamber in pelvic patient for one fraction and its comparison with $D_{iso,TPS}$

RT No: 421Y14

Date: October 28, 2014

Fraction: 03

Temperature: 22.0°C

Pressure: 1007.4 mb

K_{tp}: 1.0126

K_{tp}: Temperature and pressure correction factor, MU: Monitoring units

Table 4: Example of estimation of '*in vivo*' dose with transit signal and comparison with TPS calculated dose

A	B	C	D	E	F	G	H	I	J	K	L	M
Field	Gantry angle (°)	Couch factor	W_{ph} (cm)	Eq.sq (cm²)	MU's delivered	S_t (nC) measured	nC corrected	W_{eq} (cm)	nC/cGy ratio	$D_{iso,Transit}$ (cGy)	$D_{iso,TPS}$ (cGy)	Percentage deviation
Right lateral	270	1.000	28.0	12.5	71	1.901	1.924	29.2	0.0393	48.9	49.1	−0.4
Anterior	0	0.973	17.6	15.0	57	2.263	2.362	19.7	0.0492	48.0	50.0	−4.0
Left lateral	90	1.000	28.0	13.5	71	1.920	1.944	29.4	0.0394	49.4	49.8	−0.8
Posterior	180	0.973	17.6	15.0	57	2.283	2.383	19.4	0.0498	47.7	50.0	−4.6
Total										194.0	198.9	−2.5

W_{ph}: Physical thickness of patient along central axis, W_{eq}: Water equivalent thickness of patient along central axis, K_{tp}: Temperature and pressure correction factor, MU: Monitoring units, *Eq.Sq*: Equivalent square field

Table 5: Steps involved in estimation of '*in vivo*' dose at isocentre using transit signals

Step	Description
1	Transit signal in nC was measured with IC (in transit condition) for a field (given in column G) after delivering the planned MU's
2	The above measured transit signal was corrected with Ktp and couch correction factors (if applicable) (given column in H)
3	The water equivalent thickness (W_{eq}) for the corresponding equivalent square field versus the above corrected transit signal was taken from the table-1 (mentioned in the column I)
4	From the Table 3, nC/cGy ratio was picked up for the corresponding W_{eq} and equivalent square field size (mentioned in the column J)
5	The estimated *in vivo* dose at isocenter $D_{iso,Transit}$ (in cGy) was obtained by dividing the values of corrected nC reading (from column H) with the nC/cGy ratio (from the column J). This was mentioned in the column K
6	The percentage deviation of estimated dose (mentioned in the column K) was compared with the calculated one ($D_{iso,TPS}$) from c (mentioned in column L). This value was mentioned in the column M
7	Overall estimated dose and TPS calculated ones was compared and shown in the last row in the above table

MU: Monitoring units, TPS: Treatment planning system, IC: Ionization chamber, K_{tp}: Temperature and pressure correction factor, All columns (G, H, I , J, K, L, M) mentioned in this are to be referred from Table 4