Technical Note

Simultaneous Measurement of *In vivo* and Transit Mid-Plane Doses with Ionization Chambers in Gynecological Malignancy Patients Undergoing Three-Dimensional Conformal Radiotherapy

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Abstract

Purpose: The aim of this study is to estimate delivered radiation doses inside planning tumor volume (PTV) using the *in vivo* (mid-plane dose) measurement and transit measurement methods in gynecological malignancy patients undergoing three-dimensional conformal radiotherapy (3DCRT) using calibrated ionization chambers. **Materials and Methods:** Six patients with histopathologically proven carcinoma of the cervix or endometrium were planned with four-field 3DCRT to the pelvic site. Isocenter was at the geometric mid-plane of PTV with a dose prescription of 50 Gy in 25 fractions. Clinical mid-plane dose ($D_{iso,\ Transit}$) estimates were done in one method (transit) using the FC-65 positioned at electronic portal imaging device level. In another method, a repeat computerized tomography scan was performed (at the 11th fraction) using CC-13 having a protective cap in the vaginal cavity for *in vivo* measurements ($D_{in\ vivo}$). Simultaneous measurements were performed with the two chambers from the 11th fraction onward at least 3–4 times during the remaining course of treatment. **Results:** The agreement of mean doses from these two described methods and treatment planning system reference doses was in the range of −4.4 ± 1.1% (minimum) to −0.3 ± 2.0% (maximum) and −4.0 ± 1.7% (minimum) to 1.9 ± 2.4% for $D_{in\ vivo}$ *and* $D_{iso,\ Transit}$, respectively, which are an acceptable range of daily radiation dose delivery. **Conclusion:** The fundamental importance of this study lies in simultaneous validation of delivered dose in real time with two methods. A study in this small number of patients has given the confidence to apply transit measurements for quality assurance on a routine basis as an accepted clinical dosimetry for the selected patients.

Keywords: *In vivo dosimetry,* quality assurance, real-time dose estimate, transit dosimetry

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Introduction

In vivo dosimetry in external-beam radiotherapy plays a vital role in ensuring the delivery of prescribed dose to the patient at the treatment site. In the individual departments, regular quality assurance (QA) checks such as beam output and quality, isocenter, field congruence, and reproducibility in treatment executions are performed in the treatment machines on a routine basis. Apart from these, however, errors are known to occur during the course of treatment (both inter- and intra-treatments) (e.g., setup positions, source to the skin distance, and morphological changes resulting in variations in patient contour), necessitating the implementation of *in vivo* dosimetry.[1]

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An effective way of checking the status of the entire dosimetric procedures, starting from the performance of the treatment machine to accurate positioning of the patient, is to make absorbed dose measurements in the patient and when possible, in body cavities. Several studies have demonstrated

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quantification of mid-plane dose during real-time treatment deliveries (e.g., entrance, exit and transit dose measurements) with different detectors (e.g., thermoluminescence detectors, diodes, metal–oxide–semiconductor field-effect transistor, ionization chambers, chemical dosimetry, and/or electronic portal imaging device [EPID]).[2-5] Ionization chambers have always been the gold standard for reference dosimetry in radiation therapy; several documents, textbook chapters, and clinical studies have demonstrated their important role in *in vivo* dosimetry in patients treated by megavoltage radiotherapy with different techniques, for example, parallel-opposed three-dimensional conformal radiotherapy (3DCRT) and intensity-modulated radiotherapy (IMRT).[6-12]

Typically, these chambers are placed in a central region of a phantom or in a region corresponding to the uniform high-dose area, which is then irradiated by all of the treatment beams. Ionization chambers are limited by the fact that they can only report dose to a point or averaged over a small area. In some of the studies, the *in vivo* dose was measured by inserting an ionization chamber directly into the natural body cavity (e.g., esophagus, rectum, or vagina) with a protective cap which comes in the region of the treatment portals.[13-16] The temperature of the cavity (which is the surrogate of the body temperature) where the chamber is placed is taken into account for temperature correction factor that needs to be applied to the charge collected by the chamber. The dose is then calculated by application of all chamber-related correction factors (e.g., calibration factor, temperature, pressure, and beam quality) to the collected charge. The estimated dose is compared to the planned dose by the computerized treatment planning system (TPS). Few studies described methods to assess *in vivo* mid-plane dose in patients through transit signal measured by an ionization chamber positioned at the EPID level while actual treatment is going on.[3,13,14,16-19]

Angelo Piermattei *et al*.[18] reported the results of the application of a practical method to determine the *in vivo* dose at the isocenter point of the brain, thorax, and pelvic treatments using a transit signal "S_t" (X-ray beam transmitted through the patient) measured with an ionization chamber which is positioned at the EPID level. By this method, the disadvantages associated with the use of solid-state detectors positioned on the patient and their positioning time are minimized. Simultaneous measurements of *in vivo* and mid-plane dose through transit method were performed using two ionization chambers, one placed intraluminally in patients who are undergoing esophagus treatment and the other one kept at a transit level, which was reported in the literature.[13] A method was described to estimate mid-plane dose by measuring transit signal ($D_{iso\text{-}transit}$) in pelvic and thorax patients which was correlated with TPS-calculated values.[3,20] In these studies, simultaneous measurements of *in vivo* and mid-plane dose were also carried out on pelvic and thorax phantoms using two ionization chambers, one kept at the mid-plane level and the another one at EPID level which were compared with the TPS-calculated values. In such new treatment plans in the department, there is a need for documentation of daily dose delivered to the planning target volume (PTV). To confirm delivered doses in a protocol group of pelvic radiotherapy, we need to standardize a method and we investigated simultaneous measurement with *in vivo* and transit dosimetry.

Materials and Methods

Subjects of study

A medical linear accelerator (Model: Compact, Elekta Ltd, Crawley, UK) with 6 MV photons, equipped with motorized wedge, 40 pairs multileaf collimator (MLCi2) having leaf thickness of 1 cm at 100 cm isocenter, and camera-based portal imaging was used for 3DCRT treatments. The machine was calibrated to deliver 1cGy/MU with a dose rate of 350MU/min under the calibration conditions stated in the International Atomic Energy Agency (IAEA) dosimetry code of practice (TRS-398).[21] In this study, online *in vivo* mid-plane dose estimates are made using two calibrated ionization chambers (Models: CC13 and FC65, IBA Dosimetry, Germany) simultaneously in patients with gynecological malignancy (endometrium and cervix), who have received the 3DCRT course schedule. Both the chambers are connected to dual-channel electrometer (Dose2, IBA Dosimetry, Germany) for charge collection, and the absolute dose measurements are arrived in a water phantom using TRS-398 protocol and the doses accepted within 0.2%. Estimates of online *in vivo* mid-plane doses were correlated with the TPS-calculated values at reference point inside the PTV. We got approval from a small number of gynecological malignant patients from institutional ethics committee (approval letter number: IEC KMC MLR 11-14/224) to conduct this *in vivo* dosimetric study. Six patients had participated in this study. After the explanation of the nature of procedure, informed consent was obtained from all patients before the treatment process began.

Treatment planning (immobilization, simulation, and contouring)

All patients were immobilized in the supine treatment position using "Vacloc" device keeping their hands above the head; institution-specific bladder and rectal protocol was followed during simulation and treatment. Transverse images of 5 mm slice thickness acquired from computerized tomography (CT) scanner (Wipro GE, Model: High Speed) were exported to a contouring station (Focal Sim, M/s Elekta Ltd., Crawley, UK) for the generation of the clinical target volume (CTV) and marking organs at risk (OAR). A 5 mm margin was created around the CTV which forms PTV, to account for inter-fractional and geometric positional uncertainties. The contoured image data set was exported to the TPS (CMS XiO®, version 5.0, Elekta Ltd, Crawley, UK) for dose calculations using a superposition algorithm.

Four-field box technique treatment plans were used in all patients with beams directed through gantry angles of 0°, 90°, 180°, and 270°. The isocenter of all beams coincides with the intersecting point of anterior–posterior and lateral portals,

along with the central axis corresponding to the center of PTV. The generated 3DCRT treatment plan with MLC covers PTV along with an additional margin of 5 mm. Depending on the requirement, either field-in-field (subfields) and/or wedge technique was used, for better homogeneity of the dose around the target region. A dose prescription of 50 Gy in 25 fractions (at 2.0 Gy per fraction) was normalized to 100% isodose line covered to PTV. It was ensured that the dose at the isocenter (i.e., $D_{iso,\ TPS}$) is identical to the homogeneous prescribed dose in 3DCRT plan. This "template" treatment plan was saved to locate the detector location *in vivo*, in future fractions. Plan evaluation, approval, scheduling, and patient treatment verification before the execution of the first fraction were carried out in a similar way as followed by Putha *et al*.[3]

Dosimetric measurements

Transit dose estimates

At the EPID level, a 0.65 cc ionization chamber (Model FC65-G from IBA Dosimetry, Germany) with vendor provided acrylic buildup cap (for 6 MV photon beam) of thickness 3.0 cm diameter was placed on the mounting assembly along the central axis. Source to chamber center distance was maintained approximately 1.463 m. The chamber was connected to the channel 1 of Dose2 electrometer for the measurement of transit signals for all conformal fields during "real-time" treatment for all patients. The mid-plane dose at isocenter by transit signal (i.e., $D_{iso,\ Transit}$) was calculated using the method described by Putha *et al*.[3] and was compared with the values of "$D_{iso,\ TPS}$" of all the respective patients' conformal fields.

Transit and in vivo dose estimates

After 10 fractions were done, a repeat CT scan was performed in all patients by placing a CC13 ionization chamber (which is covered with a custom made acrylic cylindrical cap, extending to the stem level) in the vaginal cavity without changing immobilization device and patient orientation. In addition, a removable latex rubber sleeve is used to overcome the risk of fluid intrusion into the cap. As per the technical manual of CC13 ion chamber, the outer electrode is at earth potential along with the cable. Therefore, along with a rubber sleeve, it was confirmed that there is no risk to the patient during the collection of signals in nano Coulombs (nC). In this way, *in vivo* detector positioning was performed in all patients after 10 fractions. Three fiducial markers (one marker representing the anterior entry beam and the other two at left and right lateral sides indicating lateral beam entry) were placed along the patient's ongoing transverse iso-center plane. Repeat serial CT images were imported to the contouring station for chamber localization and exported them to TPS for dose calculations. Confirmation of CTV and treatment area has been reconfirmed by the radiation oncologist using the first collection of CT images in the repeat CT images. The point of calculation corresponds to the point of intersection of all three "fiducial" markers (visualized on the repeated transverse CT slice). Chamber location was ensured in all conformal treatment portals. The mean dose of the chamber (i.e., $D_{in\ vivo,\ TPS}$) to the location of the sensitive volume is noted from the dose–volume histogram of TPS.

At the 11th fraction of the treatment, *in vivo* detector was positioned into the vaginal cavity of the patient for real-time *in vivo* dose measurements. The temperature of the patient's body is recorded. Verification of patient's treatment setup under Linac was checked with camera-based EPID (iViewC). A 3 mm margin of translational (x, y, and z) errors was permitted and appropriate couch changes were applied as needed. Once the treatment setup is verified, the transit stand is fixed at the level of EPID. The fixation of the stand (with FC65 ionization chamber in transit position) at the level of EPID of the Linac is well explained in our earlier work by Putha *et al*.[3]

Both the chambers (i.e., FC65 [*transit*] and CC13 [*in vivo*]) were connected to the Dose2 electrometer in channel 1 and 2, respectively. The scheduled treatment plan was executed on the patient. With this measurement setup, chamber readings in nano Coulombs were recorded simultaneously during real-time treatment delivery. The readings of the detector (CC13) are converted to absorbed dose by incorporating necessary correction factors (calibration factor, body temperature, pressure, polarity, beam quality, and saturation) at chamber location, designated as *in vivo* dose (i.e., "$D_{in\ vivo}$"). The chamber reading obtained from FC65 (transit signal) is used to estimate the mid-plane dose at isocenter (i.e., $D_{iso,\ Transit}$) using the method described by Putha *et al*.[3] This procedure was repeated at least 3–4 times with a gap of 3–4 fractions during the remaining course of treatment. The measured value of *in vivo* dose, i.e., $D_{in\ vivo}$, is correlated with the value obtained from TPS i.e., $D_{in\text{-}vivo,\ TPS}$. Figure 1 shows the position of CC13 ionization chamber with contour inside the patient's body in transverse, coronal, and sagittal sections of CMS XiO TPS. The Figure 2a and 2b shows the anterior conformal RT field in a patient (in supine position) with Coronal and Transverse planes where the estimates of mid-plane dose through transit signal with FC65

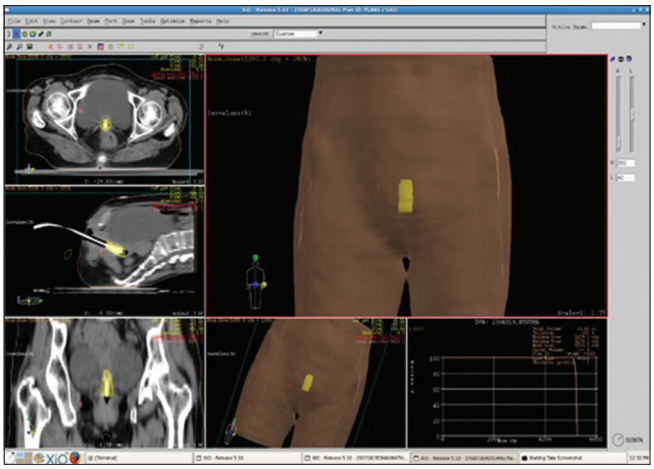

Figure 1: Position of CC13 ionization chamber with contour inside the patient's body in transverse, coronal, and sagittal sections of CMS XiO TPS

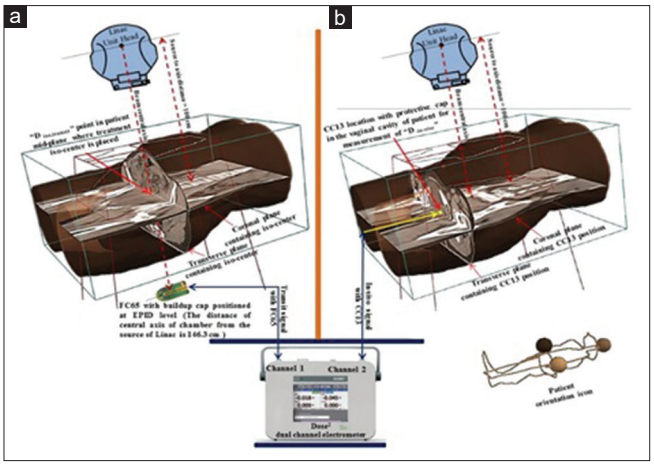

Figure 2: (a and b) Represents the perspective views of anterior field of three-dimensional conformal radiotherapy treatment to the pelvic site of a patient under linac, showing the transverse and coronal planes containing (a) the treatment isocenter for estimation of transit mid-plane dose ($D_{iso,\ transit}$) through transit signal obtained from FC65 chamber with buildup cap, which was kept at EPID level, and (b) the location of CC13 chamber (with protective cap) in vaginal cavity for measurement of "$D_{in\ vivo}$". Both the measurements were done simultaneously with chambers during real-time treatment delivery, for all four conformal fields (0°, 90°, 180°, and 270°) on at least 3–5 occasions (after having taken the repeat computerized tomography) during the course of treatment. Chambers' signals were measured with "Dose^2" dual channel electrometer. The lower right side of the figure represents the patient orientation icon for treatment

(i.e., *Diso*, Transit) and *in vivo* dose measurement with CC13 (i.e., *Din vivo*), respectively, by dual-channel electrometer is obtained.

Results

Table 1 outlines the TPS reference doses correlated to the measured doses by the both (*in vivo* [$D_{in\ vivo}$] and transit [$D_{iso,\ Transit}$]) methods. Last four columns compare the agreement of delivered dose, confirmed by these two methods. In Figure 3a-d, the percentage deviations of measured *in vivo* and estimated mid-plane dose through transit signal as against TPS planned dose for 6 patients can be seen. The variations in *in vivo* measurements from these two described methods differed with TPS doses with a mean deviation in the range −4.4 ± 1.1% (min) to −0.3 ± 2.0% (max) and −4.0 ± 1.7% (min) to 1.9 ± 2.4% (max) for $D_{in\ vivo}$ and $D_{iso,\ Transit}$, respectively. Transit dose estimates appear to give more nearer estimates than *in situ* doses, as not much variation due to tissue involuntary motion encountered with dosimeter placed outside.

Discussion

It is easier to implement the *in vivo* dosimetry in sites with regular body contours such as the pelvis and for simple techniques not involving high-dose gradients. In a coordinated research project initiated by IAEA, the importance of exit/transit dosimetry is was highlighted, though the entrance dose measurements detect most of the human errors in treatment setup and error in the treatment equipment, but they could not account for inaccuracies taking place owing to morphological changes in the patients.[1]

Srinivas *et al*.[4,16] studied the *in vivo* dose measurements in the vaginal cavity by inserting the different detectors. An ion chamber (0.6 cc Farmer type with protective cap) in 12 cervical carcinoma patients undergoing 3DCRT[16] treatment to the pelvic site demonstrated good agreement between planned vs prescribed dose which was within 3%.

Wertz *et al*.[14] showed the feasibility to verify the actual dose measured with a small ionization chamber directly inserted in the rectum of eight patients, during the treatment for prostate with IMRT technique, and compared with TPS calculated values. In one patient, undergoing full pelvic treatment, the dose measurements in a homogeneous high-dose area resulted in a very small dose deviation between the measured and calculated doses. The mean deviation (± standard deviation) of 0.1% ± 2.1% relative to isocenter was reported in their study.

Goldenberg *et al*.[13] has compared the *in vivo* dose (in the esophageal region) measured with an ionization chamber (the signal was corrected with the temperature of the body) with transit dose in the same patients and found it to be within 3%. In a clinical application of *in vivo* dosimetry system used for transmission dosimetry, applied on 11 patients who were treated for the pelvic site, with and without bone correction done in TPS,[22] the mean errors were between −5.20% and +2.20% for anteroposterior–posteranterior without bone correction and between −0.62% and +3.32% with bone correction. For lateral fields, the 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 the transmission method is a useful form of *in vivo* dosimetry because of non-invasiveness 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 in-homogeneity corrections in TPS.

In two recent publications, dealing with 24 pelvic[16] and 13 thorax[20] patients undergoing 3DCRT, the role of transit dosimetry was highlighted in estimating the mid-plane doses using ionization chamber kept at EPID level. The percentage deviation in estimated doses against TPS values was −1.37% ± 2.03 and −0.73% ± 2.09, respectively. They also conducted simultaneous measurements with two ionization chambers (one kept at the mid-plane level and other one kept at EPID level) on locally fabricated pelvic and thorax phantoms: Measured/estimated values correlated well with TPS values. The mean percentage deviation of $D_{iso,\ Transit}$ with $D_{iso,\ TPS}$ and $D_{iso,\ mid}$ combined from all fields treated was 0.9 and 0.4% 2.7 and −2.6%, with the pelvic and thorax phantom, respectively.

In this study, we have reported only six patients' data. Our earlier work[16] brought out the efficacy of on-line collection of

Table 1: Comparison of estimated transit mid-plane and in-vivo doses for treatment planning system reference dose

Patient ID	Measurement number	Fraction number	*In-vivo* method		Transit method		% Deviation			
							In-vivo method		Transit method	
			$D_{in\text{-}vivo,\ TPS}$ in cGy	$D_{in\text{-}vivo}$ in cGy	$D_{iso,\ TPS}$ in cGy	$D_{iso,\ Transit}$ in cGy	$D_{in\text{-}vivo}$ *versus* $D_{in\text{-}vivo}$, TPS	Mean±SD	$D_{iso,\ Transit}$ *versus* $D_{iso,\ TPS}$	Mean±SD
278/18	1	18	136.6	140.8	145.5	143.9	−3.1	−2.6±0.6	1.1	0.2±1.2
	2	21		139.2		144.7	−1.8		0.6	
	3	23		140.6		147.4	−2.8		−1.2	
286/18	1	11	203.4	200.9	203.6	201.0	1.3	−2.2±2.5	1.3	0.1±0.9
	2	14		208.8		203.1	−2.6		0.3	
	3	16		212.9		204.7	−4.4		−0.5	
	4	22		209.9		204.7	−3.1		−0.5	
292/18	1	11	207.0	204.9	202.0	192.4	1.0	−0.3±2.0	5.0	1.9±2.4
	2	14		203.8		196.9	1.6		2.6	
	3	17		212.7		203.4	−2.7		−0.7	
	4	21		209.5		200.3	−1.2		0.8	
312/18	1	6	200.9	-	204.1	204.5	-	−2.0±1.2	−0.2	−1.8±2.0
	2	8		-		204.9	-		−0.4	
	3	11		203.1		206.0	−1.1		−0.9	
	4	16		202.4		204.5	−0.8		−0.2	
	5	20		206.6		214.1	−2.8		−4.7	
	6	23		207.7		207.0	−3.3		−1.4	
334/18	1	3	208.8	-	204.8	210.6	-	−1.5±1.4	−2.7	-4.0±1.7
	2	5		-		210.4	-		−2.7	
	3	8		-		208.7	-		−1.9	
	4	13		209.9		209.2	−0.5		−2.1	
	5	18		215.4		214.6	−3.1		−4.6	
	6	22		210.5		216.5	−0.8		−5.4	
348/18	1	3	151.1		163.1	164.2	-	−4.4±1.1	−0.6	−1.7±1.1
	2	5				168.0	-		−2.9	
	3	8				167.1	-		−2.4	
	4	12		158.1		166.8	−4.4		−2.2	
	5	15		160.7		167.7	−6.0*		−2.7	
	6	18		157.0		164.2	−3.8		−0.6	
	7	21		156.7		164.0	−3.6		−0.5	

*Slightly excess deviation was due to setup error in lateral fields. Following are the abbreviations used in the table: "$D_{in\text{-}vivo}$"=Dose (in cGy) measured through CC13 chamber while actual 3DCRT treatment is going on, "$D_{in\text{-}vivo}$, TPS"=Mean dose (in cGy) to the chamber volume obtained from DVH of 3DCRT plan of particular patient from TPS, "$D_{iso\text{-}Transit}$"=Estimated dose (in cGy) at iso-center through transit signal obtained from FC65 chamber while actual 3DCRT treatment is going on, "$D_{iso,\ TPS}$"=Dose (in cGy) calculated by TPS at isocenter. SD: Standard deviation, DVH: Dose-volume histogram

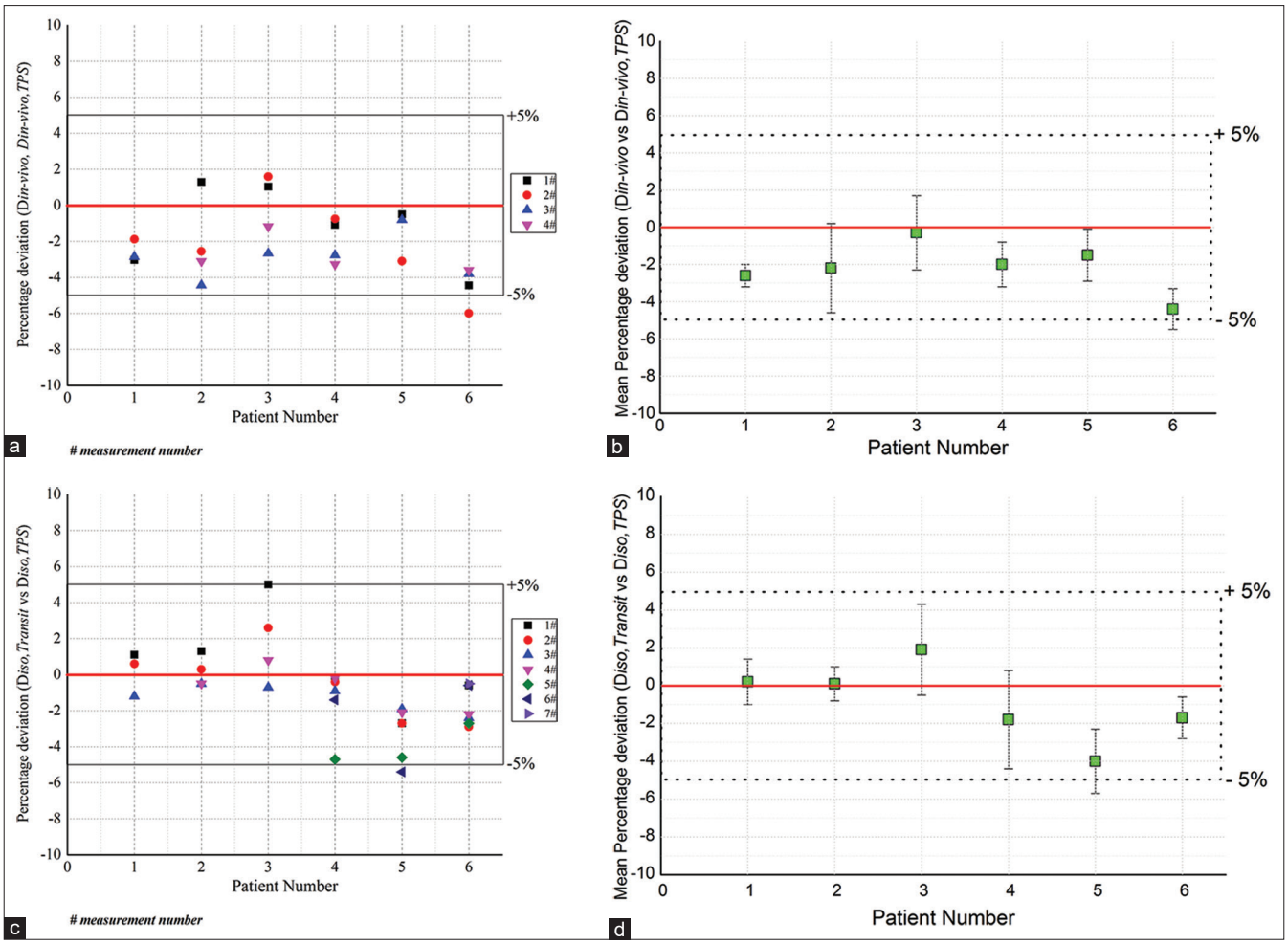

Figure 3: (a) Percentage deviation $D_{in\ vivo}$ vs $D_{in\ vivo,\ TPS}$ of six patients taken through *in vivo* measurements. (b) Mean percentage deviation of $D_{in\ vivo}$ vs $D_{in\ vivo,\ TPS}$ of six patients taken through *in vivo* measurements. (c) Percentage deviation $D_{iso\text{-}Transit}$ *vs* $D_{iso,\ TPS}$ of six patients taken through transit signal. (d) Mean percentage deviation of $D_{iso\text{-}Transit}$ *vs* $D_{iso,\ TPS}$ of six patients taken through transit signal measurements

signal during the actual treatment delivery. In our department, we treat more number of cancer cervix patients with radical treatment plans. As we knew the accuracy of our method, we wanted to correlate to *in vivo* dose estimates in the PTV region. Therefore, our physician co-authors felt that six patients are a sufficient number to validate the accuracy of this method. A beam therapy dosimeter based on "ion chamber measurement" gives more confidence to the inference. The measurement of *in vivo* dose and estimation of mid-plane dose simultaneously by means of two ionization chambers may be possible in busy departments as a QA measure at least in protocol patients.

Conclusion

The efficacy of this transit dose estimation method is simultaneous validation of the delivered dose in real time. This will enable any corrective actions (if any) that may be applied during subsequent fraction of radiotherapy. Our presentation correlated the confidence limit on the transit dosimetry, with a simultaneous estimate of true dose "*in situ*" of the tumor. The transit dosimetry method can be routinely applied in clinical dosimetry because the present work has validated the estimated patient dose "*in situ*" simultaneously with "transit method with dosimeter outside." As the patient does not have any detector, there is no inconvenience to the patients.

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Conflicts of interest

There are no conflicts of interest.

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