International Journal of Applied Research 2018; 4(3): 384-391

ISSN Print: 2394-7500
ISSN Online: 2394-5869
Impact Factor: 5.2
IJAR 2018; 4(3): 384-391
www.allresearchjournal.com
Received: 26-01-2018
Accepted: 27-02-2018

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Clinical feasibility of dual tube floor based kilo voltage X-ray localization system for image guided radiation therapy

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Abstract
In the treatment of cancer radiotherapy plays an important role and nearly 70% of all patients with solid tumors require radiation at some point of their treatment. Radiotherapy is effective when delivered accurately as only then will the treatment be successful in eliminating the tumor but also reduce side effects resulting from the normal tissue toxicity. Recent technological advances have helped in developing precision based machines and, the Image guided radiation therapy (IGRT) that uses frequent imaging during a course of radiation therapy improves the accuracy of the delivery of treatment. In this study an attempt is made to quantitatively analyse the patient positioning errors, target localisation, treatment verification and monitoring with the 2D –2D fusion using the Brain Lab Exac-Trac system in head and neck sites and pelvic sites. The analysis was done for definitive radiotherapy using IMRT and 3 dimensional conformal radiations.

Keywords: Cancer radiotherapy, Image guided radiation therapy (IGRT), patient positioning errors, target localisation, treatment verification, Brain Lab Exac-Trac system

1. Introduction

In the treatment of cancer, the accurate delivery of radiation is essential as this will not only enhance the tumour cell kill but also prevent the deleterious side effects resulting from the normal tissue toxicity [1-2]. Recent technological advances have helped in developing precision based machines and, the Image guided radiation therapy (IGRT) that uses frequent imaging during a course of radiation therapy improves the accuracy of the delivery of treatment [1-2]. Unlike in conventional apparatus, the IGRT machines are equipped with imaging technology that help the physician to figure the tumour immediately before or even during the time of radiation treatment when the patient is positioned on the treatment table [3]. Using specialized computer software, these images are then compared to the images taken during simulation and any necessary adjustments are then made to the patient's position and/or radiation beams to facilitate precise target radiation to the tumor and avoid healthy surrounding tissue. IGRT is extremely useful in treating tumours in areas of the body that are prone to movement, such as the lungs (affected by breathing) and the prostate gland, as well tumours located close to critical radiosensitive organs and tissues [3].

Due to its precision and associated sophistication, IGRT needs image guidance methodology that will assist in the accurate target localization and avoidance of bordering organs at risk [1-2]. In this regard, intensity modulated radiation therapy (IMRT), a planning procedure, is vital in assessing the precise localisation of the target, its irradiation and avoidance of the bordering normal tissue. A number of imaging modalities like the ultrasound based localisation systems [1-2], flat panel two-dimensional (2D) kilo voltage or megavoltage X-ray imaging systems, [3-4] and three-dimensional (3D) kilo voltage or megavoltage IGRT systems such as cone beam computed tomography (CT) [5] have been developed [1-3] and are in use in clinics.

The Exac-Trac system (Brain Lab, Germany) is a kilo voltage, X-ray based 2D to 3D image fusion guided target localisation [7, 8] for accurate patient positioning. When compared with the other kilo voltage IGRT systems, the Exac-Trac system has some unique configuration.

It comprises of two X-ray tubes and corresponding detector panels in fixed position, projections from two X-ray tubes placed on the floor in oblique directions that are non orthogonal to one another with source to isocenter and source to detector distance that are relatively large (2.2m and 3.62 m respectively).

The purpose of the present study is to quantitatively analyse the patient positioning errors, target localisation, treatment verification and monitoring with the 2D-2D fusion using the Brain Lab Exac-Trac system in head and neck sites and pelvic sites. The analysis was done for definitive radiotherapy using IMRT and 3 dimensional conformal radiation. The 6D fusion (2D-3D) which calculates the rotational deviation was not evaluated as our system at present is equipped with only 2D-2D fusion. This system was the first to be installed in India and hence the initial 2D-2D fusion was purchased with the 2D-3D being planned subsequently. The projections from two X-ray tubes placed on the floor in oblique directions that are non orthogonal to one another with source to isocenter and source to detector distance that are relatively large (2.2m and 3.62 m respectively).

The purpose of the present study is to quantitatively analyse the patient positioning errors, target localisation, treatment verification and monitoring with the 2D-2D fusion using the Brain Lab Exac-Trac system in head and neck sites and pelvic sites. The analysis was done for definitive radiotherapy using IMRT and 3 dimensional conformal radiation. The 6D fusion (2D-3D) which calculates the rotational deviation was not evaluated as our system at present is equipped with only 2D-2D fusion. This system was the first to be installed in India and hence the initial 2D-2D fusion was purchased with the 2D-3D being planned subsequently.

Materials and methods

The Exac-Trac IGRT system consisting of two floor-mounted kilo voltage X-ray tubes that project obliquely from lateral to medial, posterior to anterior and superior to inferior onto two corresponding flat panel detectors mounted on the ceiling and an infrared external marker monitoring subsystem (Fig.1). It also has an in room digital camera to monitor patient position during treatment. The infrared subsystem is used to perform initial patient set up according to external skin markers and to control the patient and couch positions with superior accuracy once position deviation is determined by image fusion. In the Exac-Trac system the X-ray tubes and the flat panel detectors are in fixed position but the isocenter is not a physically fixed point, rather it is determined by software during each daily calibration. The treatment room laser is used as the reference to correlate the IGRT isocenter with the linac isocenter.

The isocenter calibration requires a two step procedure. The first step is to use an isocenter calibration phantom (Fig.2) to calibrate the isocenter of the infrared subsystem to the isocenter of the linac. The isocenter calibration phantom has five fixed infrared markers and an isocenter defined by three orthogonal lines. The room laser is used to position the phantom in the linac isocenter. The two infrared cameras read the positions of the markers and hence calibrate the coordinates of the infrared system to those of the linac according to known geometric relationship between the infrared markers and the isocenter.

In the second step, an X-ray calibration phantom (Fig.3a &3b) with multiple external infrared markers and internal radiopaque markers is used to calibrate the isocenter of the X-ray system to the isocenter of the infrared subsystem. The infrared markers and the cameras are used to align the phantom to the isocenter of the infrared subsystem. Two radiographic images are then acquired and the positions of the radiopaque markers are automatically identified. The isocenter of the x-ray system is hence calibrated according to known geometric relationships. This isocenter calibration is done as part of daily quality assurance. The patients who were planned for definitive radiotherapy using IMRT or 3DCRT for head and neck malignancies and pelvis sites were evaluated in this study. The following steps were undertaken for all the patients:

1. Mould room for immobilisation with aquaplast or vacolac. Laser in mould room is used for proper positioning.
2. Planning CT acquired with 5 infrared markers placed in the treatment region over the mould.
3. Planning completed on Eclipse and data transferred to IGRT system placed in linac treatment console area.
4. Patient set up using IR markers and CT coordinates to planned isocenter position.

Two X-ray images from the pair of the flat panel are acquired and fused with DRR images by the 3D fusion software. The isocenter deviation in X, Y, Z direction is displayed on the monitor using either the couch auto correction or with the technologist going inside the linac room to apply the correction. A second pair of X-ray images is taken after the correction of the isocenter deviation. 2D - 2D fusion is repeated and if it is within 2 mm, it is accepted by the system with OK signal being displayed. The 2 mm tolerance is decided by the user and entered accordingly.

Results

The isocenter deviation of head and neck cancers in lateral (X) had a mean value of 1.55 mm with 95% CI. The maximum deviation was 27.08 mm with SD of 0.12. After correction the mean value was 0.31 mm and maximum was 1.85 mm with SD of .02mm. The values for isocenter shift in longitudinal(y) and vertical (z) and the corresponding values after the corrections are given in table1. The isocenter deviation pre and post corrections for abdominal malignancies are enlisted in table 1. The mean post correction accuracy was 0.31 mm, 0.42 mm and 0.39 mm in lateral, longitudinal and vertical directions in head and neck malignancies. In abdominal malignancy the post correction accuracy of isocenter was 0.35 mm, 0.36 mm and 0.42 mm in the lateral, longitudinal and vertical directions respectively. A total of 858 values were analysed and the post correction isocenter mean deviation was below the tolerance limit of 2 mm. In the first week of treatment the patients who had post correction values of more than 2 mm were the ones who had the maximum isocenter deviation pre correction. The mean time taken for the IGRT procedure was about seven minutes. The radiation technologist was responsible for the completion of the procedure.

Discussion: The Exac-Trac IGRT system uses multiple and integrated image modalities to achieve desired localisation accuracy. It is an integration of two subsystems: (1) an infrared based optical positioning system for initial patient setup and precise control of couch movement, and (2) a radiographic kV x-ray imaging system for position verification based on the internal anatomy or implanted markers.

Weiss *et al* [8] evaluated the localisation accuracy of the infrared body marker based Exac-Trac system (without the x-ray component) in patients treated for gynaecological carcinomas and compared it with patient positioned using the conventional room laser system. They found that there is no significant difference between the Exac-Trac system and room laser system. Hence it is a faster and automatic tool for initial patient set up. The external marker and infrared camera based Exac-Trac system could achieve excellent localisation accuracy for the rigid object that has fixed relation between external marker and internal target [8]. In the present study we evaluated the isocenter deviation after 3D fusion to be 0.31 mm, 0.42mm and 0.39 mm in lateral, longitudinal and vertical directions for head and neck malignancy which is comparable to a study conducted by Yin *et al* on twenty five patients for spinal region. This result is consistent with the accuracy demonstrated in phantom studies [8, 9]. The isocenter localisation by the Exac-Trac system is based on the Linac isocenter and hence the inconsistency of the linac isocenter was not taken into account in this study.

Materials and methods

The Exac-Trac based IGRT can be used with accuracy when the bony structure has fixed relation with the internal structure. It also provides for precise patient and couch positions. However in 3D fusion rotational errors are not accounted for hence a 6D fusion is required to correct angular difference between X-ay images and DRRs. The Exac-Trac X-ray 6D system uses kV x-ray to obtain the localisation images with high spatial and contrast resolutions. The 6D fusion algorithm provides optimal match between the 2D localisation images and the 3D CT simulation images.

The infrared based Exac-Trac systems provide precise control of patient position and make the accurate on-line adjustment of the patient possible. The Exac-Trac system is in fixed position so that its isocenter is fixed and consistent with the linac isocenter defined by the room laser system[8]. Hence this makes it an excellent IGRT system for targets that have fixed relationship to rigid bony structures. The operation of the system is simple, fast and most importantly it can be done by the technologist without the presence of the radiation oncologist which saves time. The cost compared to cone beam CT is less and the radiation delivered to the patient is negligible compared to cone beam CT and 2D MV portal images [9].

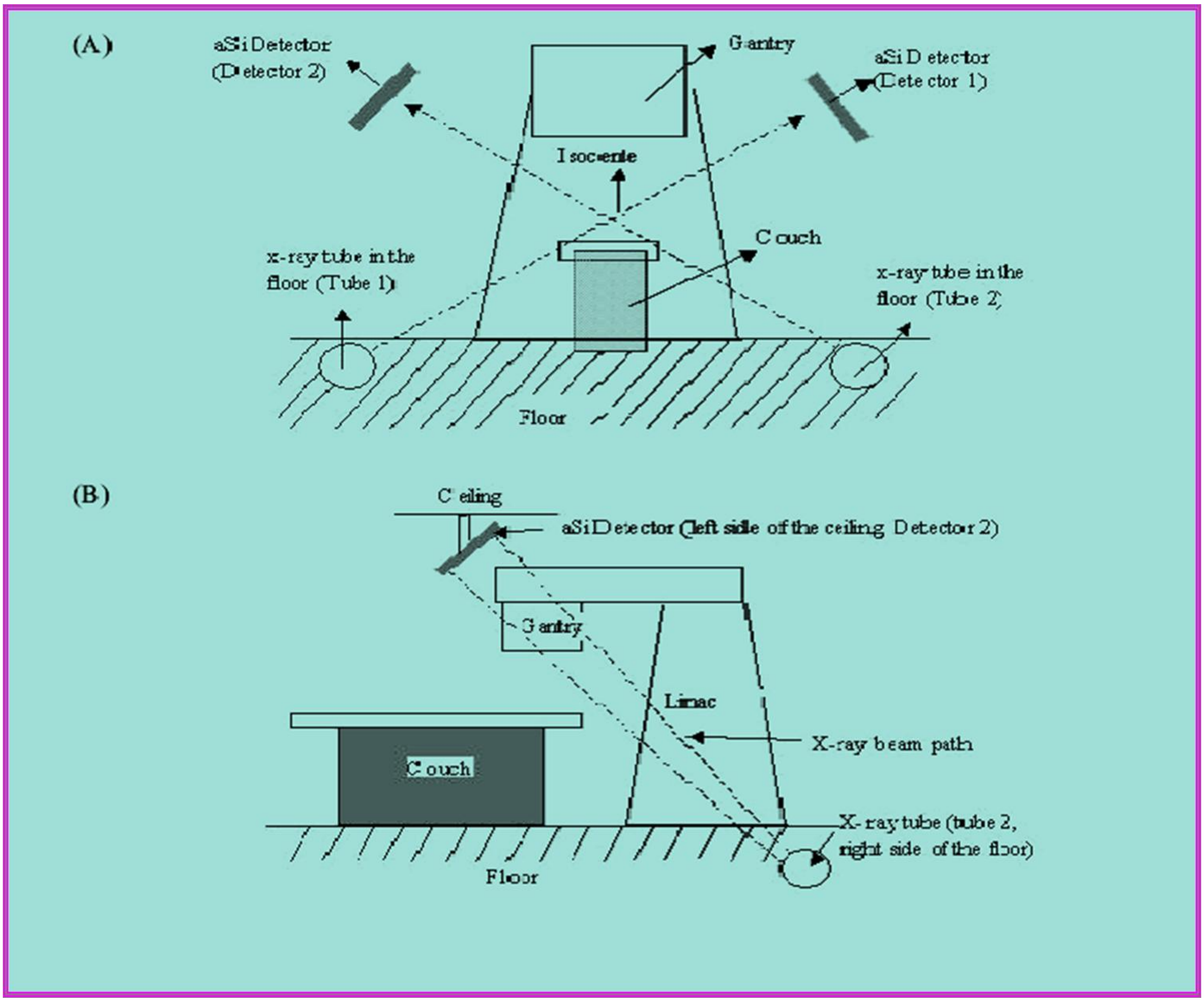

Fig 1: Schematic of the two X-ray systems in treatment room(a) Frontal View (b) Side View**.**

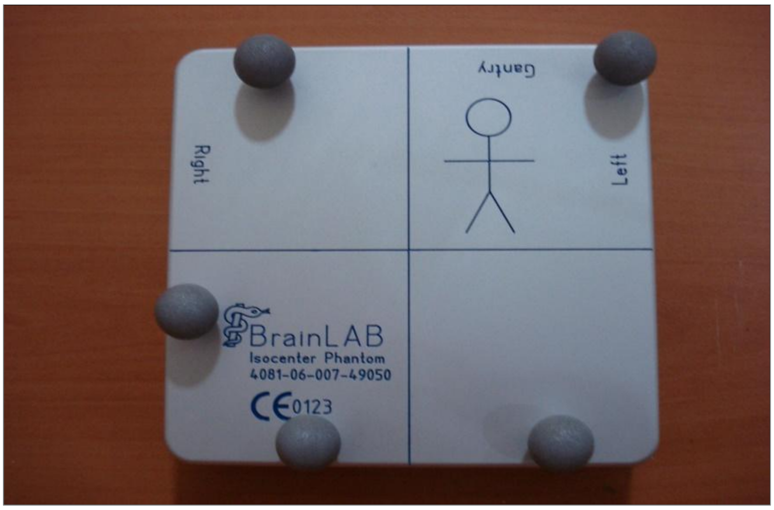

Fig 2: An isocenter calibration phantom to calibrate the isocenter of the infrared subsystem to the isocenter of the linac.

Fig 3a: an X-ray Calibration Phantom for daily isocenter calibration to ensure that the isocenter of IGRT system is consistent with the laser system.

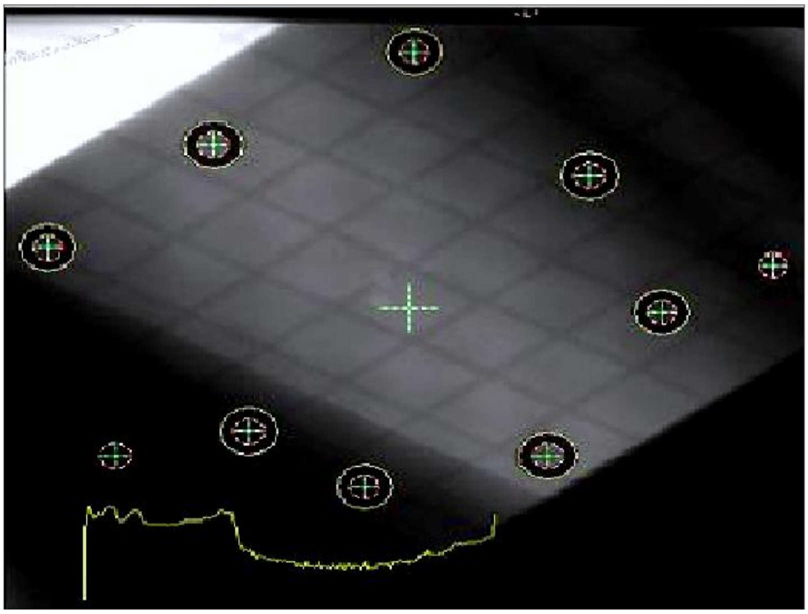

Fig 3b: an X-ray image of the Calibration Phantom for daily isocenter calibration to ensure that the isocenter of IGRT system is consistent with the laser system.

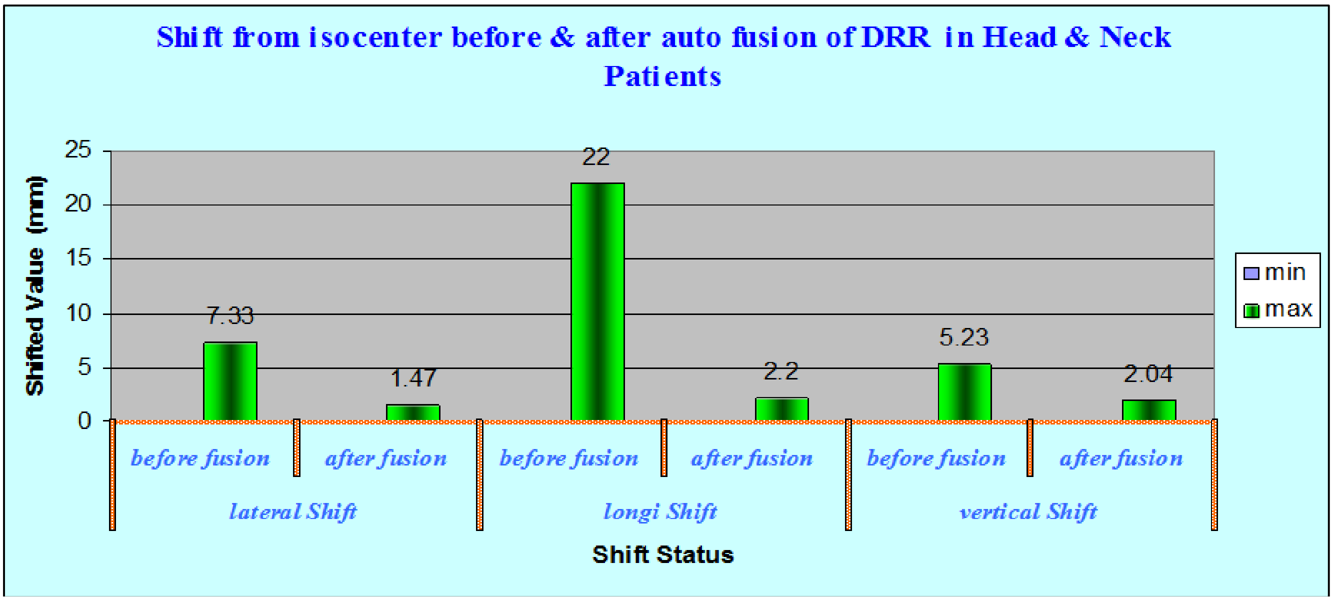

Fig. 4

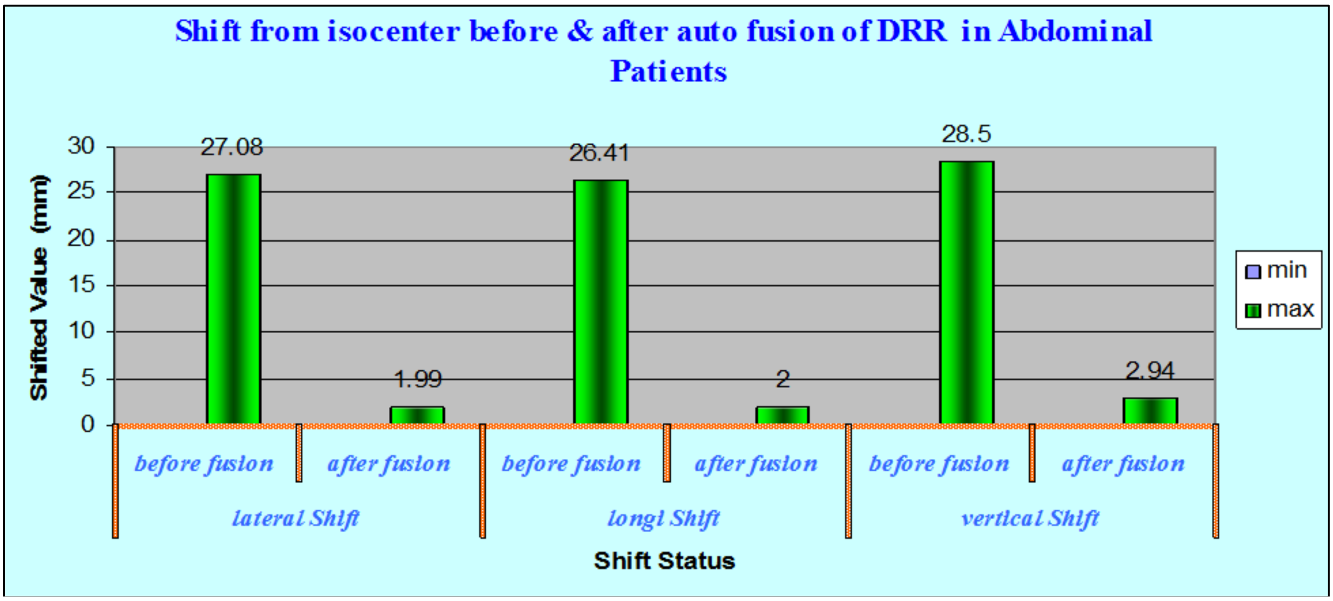

Fig. 5

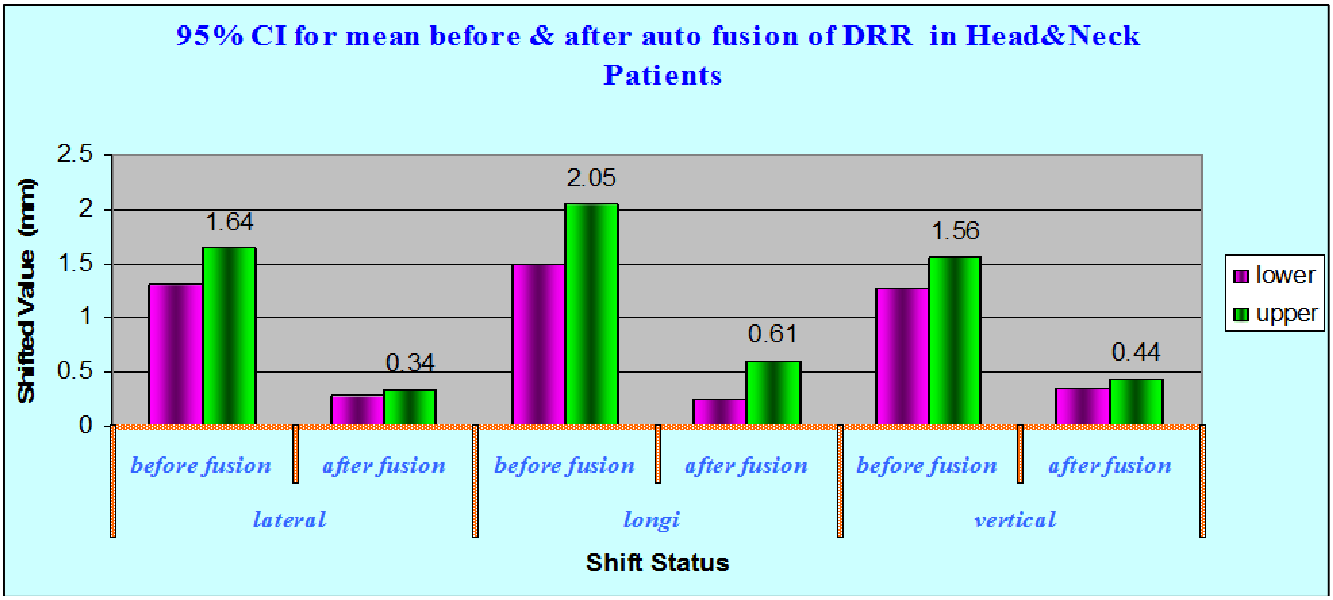

Fig. 6

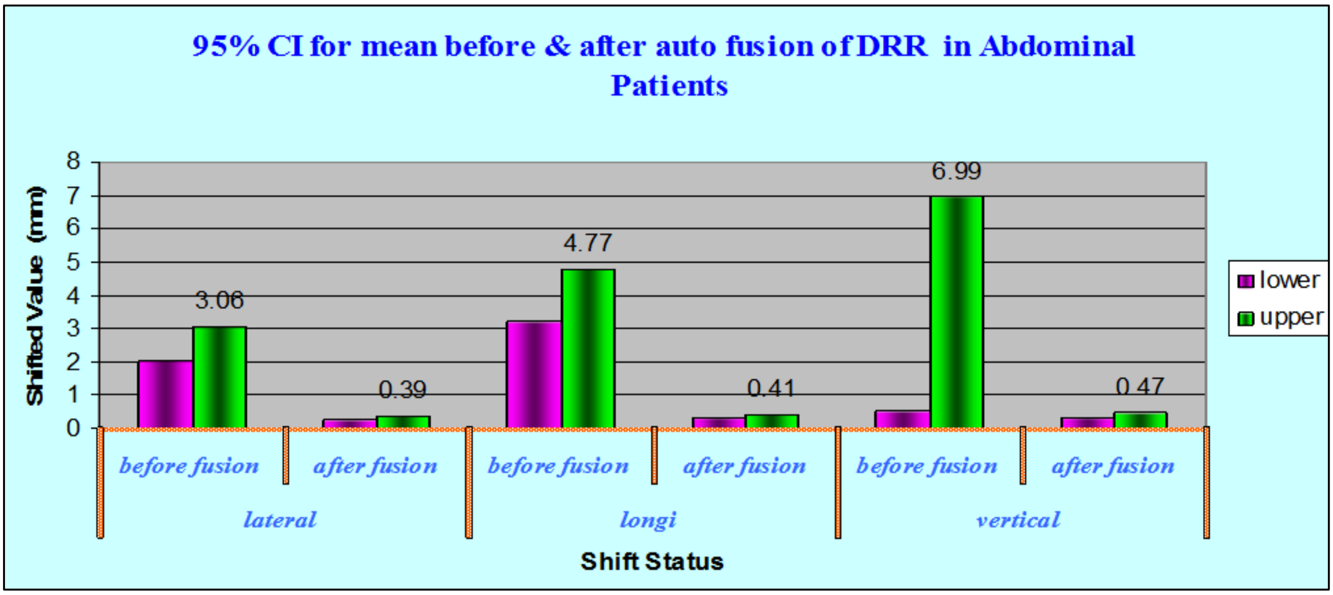

Fig. 7

Figures 4-7: shows the pre-correction and post correction values for isocenter deviation in IMRT and 3DCRT cases

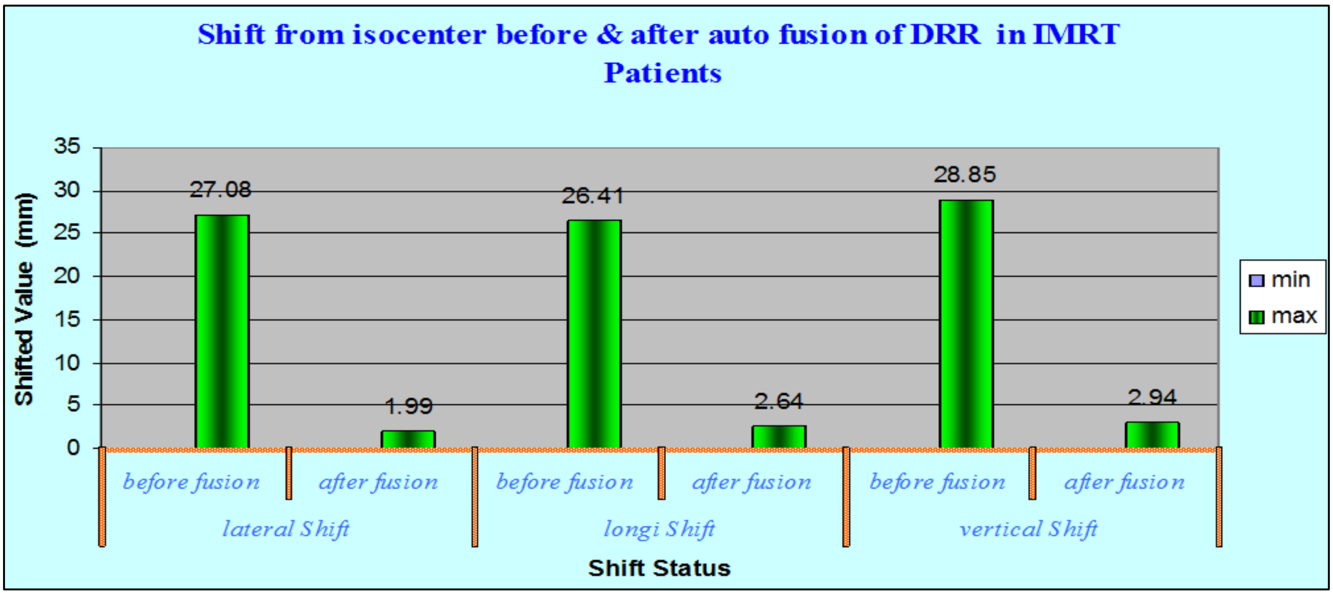

Fig. 8

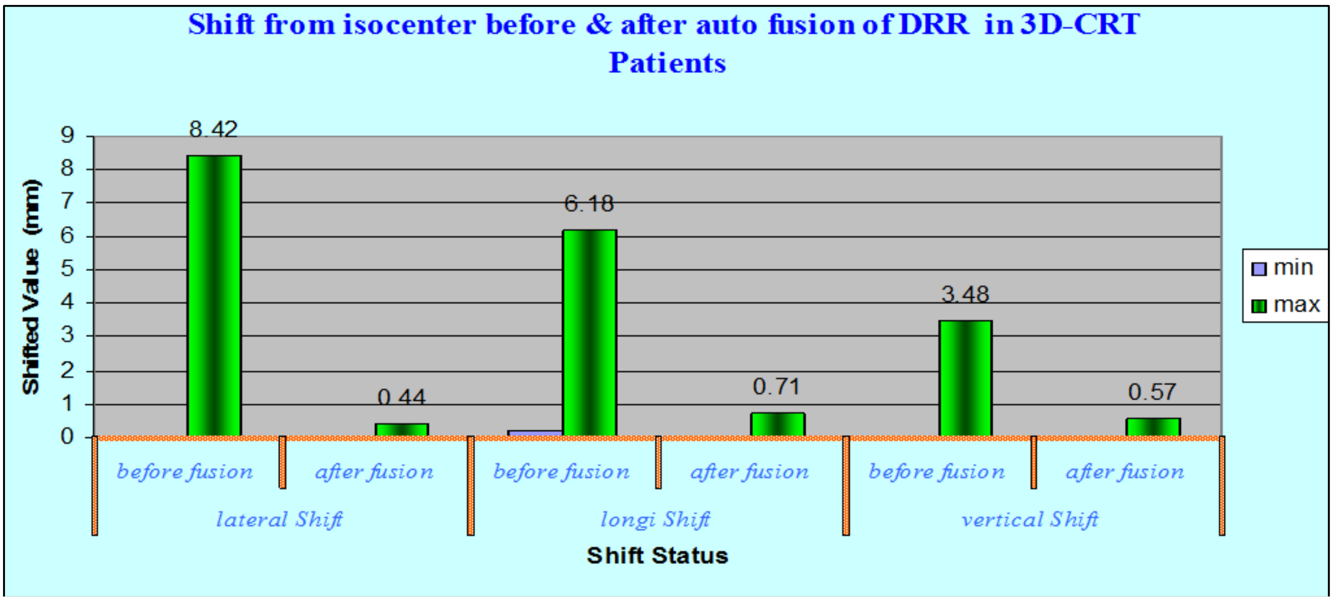

Fig. 9

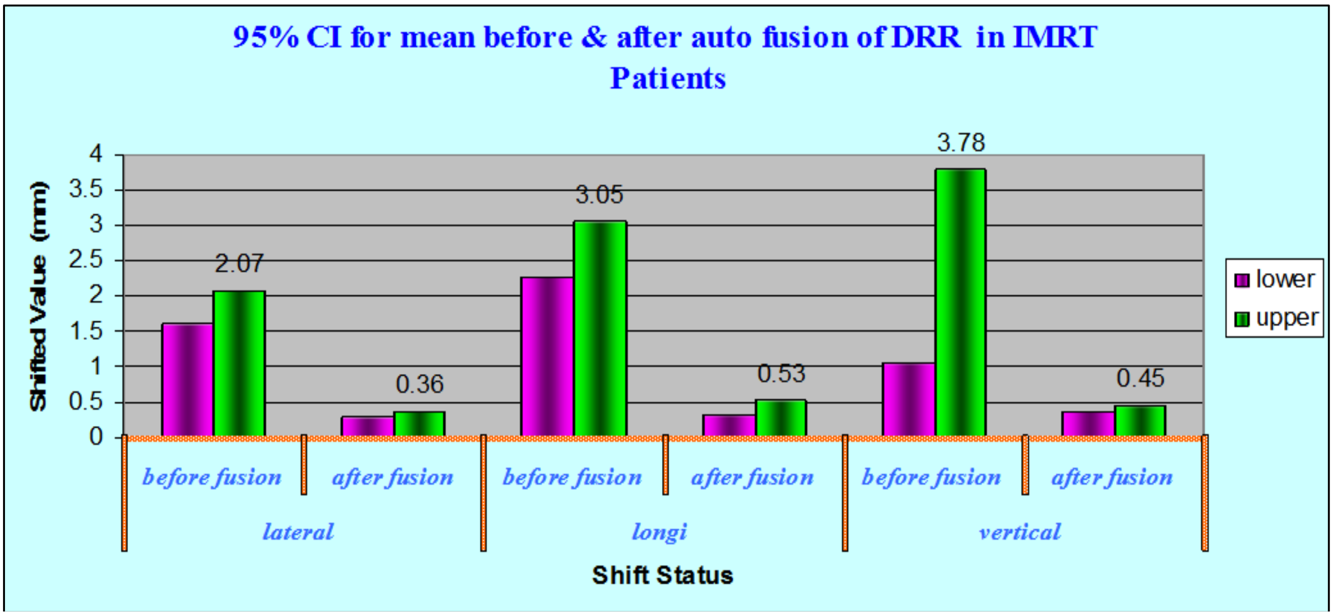

Fig. 10

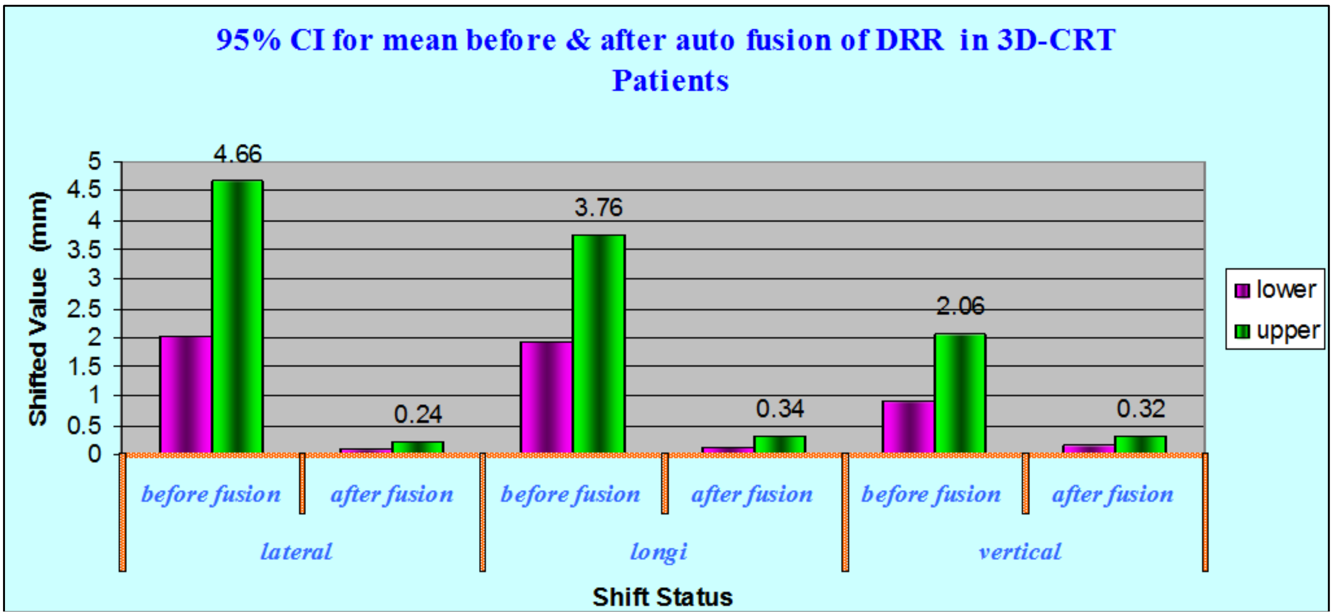

Fig. 11

Fig. 8-11: shows the pre-correction and post correction values for isocenter deviation in IMRT and 3DCRT cases

Table 1: This table represents the shift from isocenter before & after auto fusion of DRR, X-ray images in Head & Neck, Abdominal patients

Patient group	Shift from isocenter		Mean	95% CI		Min	Max	Sd.error
				Lower	Upper			
HEAD & NECK (n= 332)	Lateral (x)	Before	1.55±2.19	1.31	1.79	0.01	27.08	0.12
		After	0.31±0.27	0.28	0.34	0.00	1.85	0.02
	Longitudinal (y)	Before	1.50±2.08	1.27	1.72	0.00	26.41	0.11
		After	0.42±1.25	0.29	0.56	0.00	2.200	0.07
	Vertical (z)	Before	1.66±1.79	1.46	1.86	0.02	24.40	0.10
		After	0.39±0.40	0.35	0.44	0.00	2.04	0.02
ABDOMEN (n=97)	Lateral (x)	Before	3.13±2.88	2.56	3.72	0.01	13.04	0.29
		After	0.35±0.38	0.27	0.42	0.00	1.99	0.04
	Longitudinal (y)	Before	6.68±5.69	5.53	7.82	0.05	23.78	0.58
		After	0.36±0.31	0.29	0.42	0.00	1.55	0.03
	Vertical (z)	Before	4.78±1.79	-1.02	10.59	0.02	10.88	2.92
		After	0.42±0.45	0.33	0.51	0.00	2.94	0.05

Table 2: This table shows the pre-correction and post correction values for isocenter deviation in IMRT and 3DCRT cases.

Patient group	Shift from isocenter		Mean	95% CI for mean		Min	Max	Sd.error
				Lower	Upper			
IMRT (n = 409)	Lateral (x)	Before	1.84±2.41	1.61	2.07	0.01	27.08	0.12
		After	0.33±0.31	0.30	0.36	0.00	1.99	0.31
	Longitudinal (y)	Before	2.66±3.99	2.27	3.05	0.00	26.41	0.20
		After	0.42±1.13	0.31	0.53	0.00	2.64	0.20
	Vertical (z)	Before	2.41±14.13	1.04	3.78	0.02	28.85	0.69
		After	0.41±0.41	0.37	0.45	0.00	2.94	0.02
3DCRT (n=20)	Lateral (x)	Before	3.34±2.81	2.03	4.66	0.05	8.42	0.63
		After	0.18±0.14	0.11	0.24	0.00	0.44	0.03
	Longitudinal (y)	Before	2.85±1.96	1.92	3.76	0.22	6.18	0.44
		After	0.23±0.23	0.12	0.34	0.00	0.71	0.05
	Vertical (z)	Before	1.50±1.21	0.93	2.06	0.02	3.48	0.27
		After	0.24±0.18	0.15	0.32	0.00	0.57	0.04

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