Evaluation of Positional Accuracy in Moving Tumors Using a CIRS Dynamic Phantom

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PURPOSE/OBJECTIVES

With the CIRS Dynamic Phantom (Computerized Imaging Reference Systems, Inc, Norfolk, VA), a lung target moves in the inferior/superior and left/right directions. In addition to the internal motion of the tumor mimicked by the CIRS phantom, a chest plate on the phantom (Fig. 2) simulates the anterior/posterior motion of a patient's chest wall. These are used to establish the motion tracking model for Synchrony. The tumor and the chest plate move in concert along a predetermined sinusoidal pattern (Fig. 4). Four fiducials are inserted around the target to allow translational and rotational tracking. A dose volume of the lesion is acquired during delivery using gafchromic film set orthogonally in a mini ball cube phantom (Fig. 3) insert.

Features tested with the use of this phantom include reliance of imaging for accuracy, X-ray techniques, varying image parameters, and effect of rotation with limited number of fiducial markers. Because the phantom is a perfect patient, external patient movements (i.e. leg movements, patient coughing, etc.) and fiducial migrations can be extracted from system errors commonly associated with treatment. This allows for a closer inspection of the previously mentioned features.

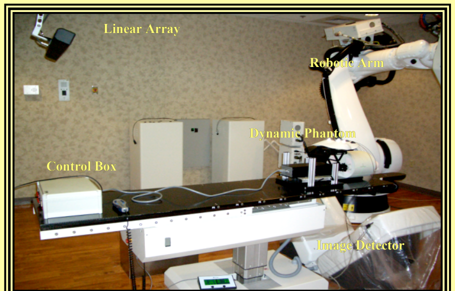

Fig. 1 CIRS Dynamic Phantom setup

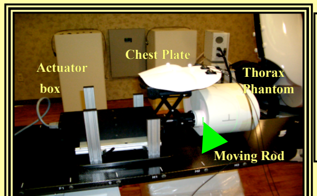

Fig. 2 Close up of Dynamic Phantom

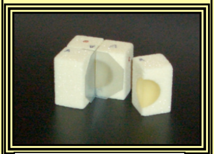

Fig. 3 Ball cube phantom with Gafchromic film

MATERIALS AND METHODS

The CIRS dynamic phantom, model 008, was scanned with 1.0mm slices on a GE HiSpeed 4 slice helical CT scanner. The dynamic phantom includes a thorax phantom, cylindrical moving rod with target insert (ball cube phantom), motion actuator, tracking device (chest plate), and control box (Fig.1 and Fig. 2). The phantom is 15 cm in length, but was modified for this experiment; an additional 5 cm slab was appended to the cranial end of the phantom. The target insert is a 3 x 3 cm^2 ball cube phantom with a 4.2 cc acrylic sphere (Fig. 3). The phantom, target, and rod are tissue equivalent, and the cube is lung equivalent (air). The extent of the preprogrammed sinusoidal patterns are as follows: SI motion is up to 40mm, AP motion is up to 7 mm via rotation, LR motion is up to 7 mm via rotation with cycle times between 4 and 7 seconds. Other types of patterns can be programmed as needed. There are 15 profiles with preprogrammed patterns with the 16th profile allowing for the option to manually program the pattern.

Seven treatments were delivered to the phantom. The treatment plans are summarized in Table 1. Table 1 includes the dose, isodose line (IDL), number of fractions delivered, collimator(s) used, number of nonzero beams, number of fiducials tracked during treatment, average time of each treatment, and experimental variables added to the phantom. Rotational corrections were either disabled or unavailable (see treatment 7 in Table 1) during treatment. For treatment 6, a wedge was placed under the phantom's left side to simulate patient misalignment or 5˚ roll. Approximately 12 hours after treatment, the gafchromic film was scanned using a reflective Epson Expression 1680 scanner with a resolution of 300 dpi, 16 bit grayscale and analyzed to determine the total targeting error with the use of End-2-End testing software (Fig. 6)

Table 1. Plan Summaries and Results

	Dose	IDL	# fx	Collim size	# nonzero beams	# fiducials tracked	Avg. Tx. Time (min)	Variable	Total Error (mm)
1	30	70	3	10, 20	69	3, 2	95		0.5839
2	30	70	3	10, 20	69	2	93		0.44852
3	30	80	3	20	34	4	77		0.74401
4	30	80	3	20	34	4	70		0.7628
5	30	70	3	15	68	4	90		0.70993
6	30	70	3	20	80	4	98	5º wedge	0.69578
7	30	70	1	15, 20	83	1	68		1.4005

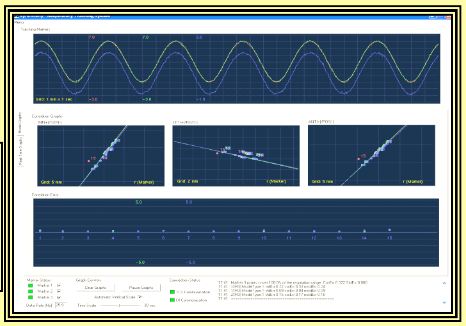

Fig. 4 Respiratory model of Dynamic Phantom during treatment

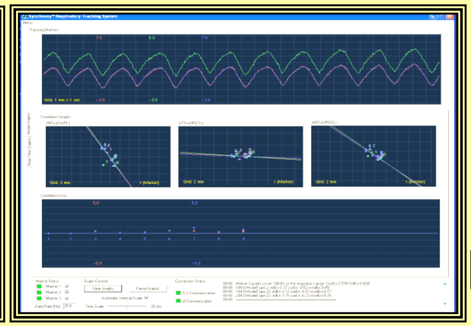

Fig. 5 Respiratory model of patient during treatment

RESULTS

The total targeting error reported by the software accounts for any error associated with imaging, treatment planning, the robot and/or linear accelerator, and the safety subsystem. The total error is the RMS value in mm of the left, superior, and anterior edges as compared to the actual distance from the respective edge to the center of the ball cube phantom. The results from the delivered treatments are shown in Table 1 in the last column. All the results show sub-millimeter accuracy except for treatment 7. Treatment 7 showed poor correlation errors (> 1.0 mm) during the first half of treatment, and then an error resulted in the plan being aborted. After the plan was recovered, the correlation error was once again below 1.0 mm.

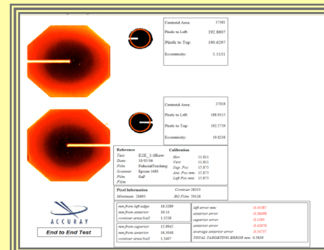

Fig. 6 End-2-End Result using first treatment plan

CONCLUSIONS

The CIRS Dynamic Phantom can mimic patient respiration with the use of a chest plate, and tumor motion with the use of the moving rod. In the past, Synchrony was tested using AP movement of the couch, but with the dynamic phantom, S/I and L/R movement of the tumor and A/P movement of the chest wall can determine positional accuracy that more closely reflects patient respiratory models (Fig.5). In fact, the average error, 0.76 +/- 0.33 mm (including the 1.4 mm outlier), is less than the 0.9 mm that Accuray had commissioned the Cyberknife unit in San Antonio. Further experiments into the effect of variables (e.g., physical positioning alterations, dosimetry changes) on the treatment plan and delivery need to be done to determine the positional consistency of tracking with Synchrony, and perhaps make clinical recommendations based on these measurements.

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