OVERVIEW OF METHODS FOR PATIENT POSITIONING IN RADIOTHERAY USING POSITIONING PHANTOMS

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Abstract - In this article, we performed the daily check process of any VERO radiation device. We used different positioning method to position several phantoms and we checked their work functionality. Then we used pelvic phantom to check the accuracy of the registration algorithm in terms of using bony anatomy information or artificial markers positions as a reference for the registration process.

Index Terms - About four key words or phrases in alphabetical order, separated by commas.

I. INTRODUCTION

A. Immobilization

For modern radiotherapy, irradiation is mainly based on explicit plans from treatment planning system (TPS) and TPS optimizes treatment plans based on image data of related body regions, and that means patient positioning status in diagnostic imaging process should match the status during irradiation process, so to avoid dose mismatch. In clinical, immobilization and positioning are two widely-applied solutions to maintain the patient status during irradiation treatment. Patient immobilization devices are equipped almost in every radiation therapy department. These devices are designed to eliminate voluntary motions of patient during treatment, which can also ease patient's tense to some degree. Also, they can provide a reproducible pose before the treatment. During irradiation, immobilization devices can almost eliminate the effect of inter-fraction position offset by reproducing patient poses and position and reduce infra-fraction movement as much as possible. Organ motion like breathing and heart movement, can affect an organ position relative to beam source and thus reduce irradiation accuracy. So, immobilization is more a tradeoff between patient acceptance and demand for accuracy [1]. For head, neck or brain treatment, patients are mostly immobilized by means of plastic mask system, which turns malleable after being heated and solid when cooling down. In former stage like treatment planning, an exclusive mask is heated to" record" the head contour and then this" recorded" contour can be reproduced in following treatment stages. For treatment of lower areas, immobilizing pelvis or sacrum is typically employed and a variety of devices are now available.

B. Patient Positioning

Immobilization equipment providing a reproducible and stable pose, positioning is then performed to match the immobilized position to the beam isocenter, which ensures dose distribution defined by treatment plans to be most possibly received by human body. Typical positioning modalities include laser, kV X-ray imaging, IR camera, cone beam CT (CBCT) and electronic portal imaging device (EPID), which will be tested and compared in detail in following part. Before or during irradiation, physicists register patient position according to the isocenter defined by treatment plans, which can be realized by automatic or manual image registration. In clinical, positioning modalities are often assisted by implanted or surface markers, which can be used as reference for image registration and thus increases the accuracy of the positioning process [4, 5].

However, all positioning methods mentioned above or to be discussed are based on the assumption that only rigid translation occurs between treatments. Deformation is considered as one main obstacle for patient positioning methods.

A. Clinical Daily Check

Regular quality check is necessary to maintain the machine accuracy and the treatment accuracy. Though there exist variation in the quality assurance (QA) of the LINAC, AAPM TG- 40 [3] is a broadly consistent publication which is published is 1994. With the advance of new targeting component like MLC and the emergence of new treatments options like tomotherapy, old standards are not that appropriate, so TG-142[2] is published in 2009 which contains explicit quality control of the LINAC.

II. MATERIALS AND METHODS

A. Daily Check Steps

Daily check procedure of ExacTrac includes four main steps: trail irradiation, isocenter check, IR camera verification and gimbals check [6, 7, 8].

B. Trail Irradiation

Trail irradiation is performed every day before all treatments in order to assure dose accuracy. In this

check procedure, electronic dosimeter (Fig.1) is chosen to measure the dose irradiated.



Fig.1. Electronic dosimeter

C. Isocenter Check

LINAC device can contain several isocenter related to each positioning method. We perform comparison between them, these comparisons are conducted for isocenter calibration. Laser and kV x-ray laser positioning is the easiest method to perform patient positioning. We used the ISO Cube phantom as shown in Fig.2, which is designed specifically for daily system checks, to correct the isocenter shift. Laser and MV x-ray we compare the isocenter of EPID (MV x-ray imaging system) and laser system using the same phantom (ISO cube). The center of EPID image of phantom is compared to laser isocenter to calculate offset.

D. Infrared (IR) Camera Verification

We check the precision of IR camera by comparing it with isocenter of laser system. We locate the specifically-designed markers phantom (Fig.3a) on the couch and position it correctly to the red laser. The markers can be detected by IR camera, and we calculate the shift according to the markers position detected in the field of view of IR camera.

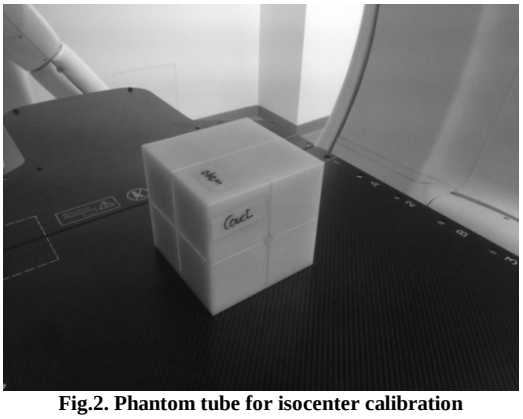


Fig.2. Phantom tube for isocenter calibration

E. Gimbals Check

Orthogonal gimbals hold the lilac-MLC assembly allowing real-time moving tumor tracking. This check determines the geometric accuracy of the tracking using sheet contains two squares to check if the field projection is within the bigger square when the gimbals moving as shown in Fig.3b.

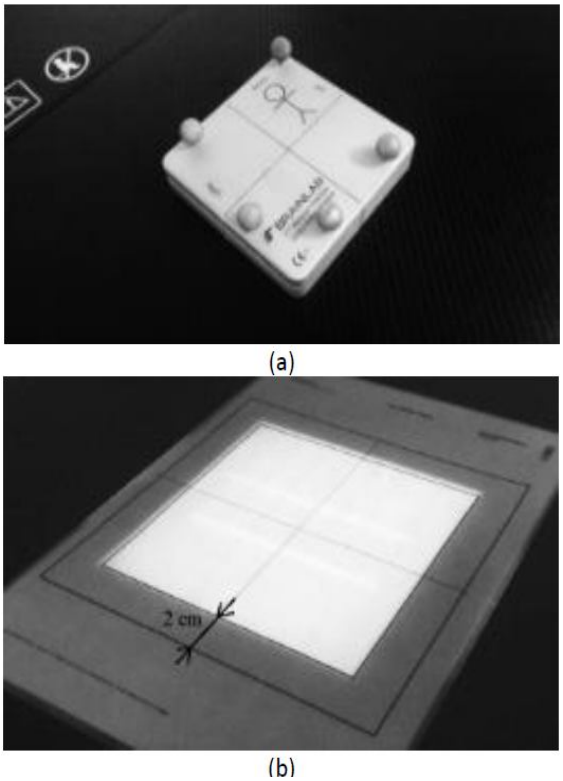


Fig.3. Phantoms: (a) for IR camera verification; (b) for check the Gimbals

F. ExacTrac

ExacTrac is an in-room x-ray based monitoring system that detects intra-fraction tumor motion during treatment delivery, regardless of the couch angle or gantry position. Instantaneous x-ray imaging with proprietary 6D fusion provides fast and highly accurate positioning information and reduces the possibility of geographical miss due to patient motion or internal anatomical shifts.

For this test, ExacTrac stereoscopic X-ray-DRR auto fusion software is used for image registration and offset calculation.

G. IR Camera

ExacTrac infrared (IR) tracking system is a special camera system attached to LINAC that can track the movement of reflective markers. For our LINAC system the IR camera is installed on the ceiling of the therapy room [9, 10].

IR tracking system is typically used for respiratory movement tracking in simulation or treatment stages. Reflective markers are placed on patient's abdomen when simulation and in treatment same reflective markers are placed at the same position, then IR camera can track the movement of markers and movement of markers is converted to movement of abdomen.

H. Cone Beam CT

Cone beam CT (CBCT) is an improvement of fan-beam CT or parallel-beam CT that x-ray is divergent to a cone, so that multiple slices can be acquired with one single scan. Fast scanning of multiple slices is needed for image guiding radiotherapy, which is the main reason that CBCT is widely combined with LINAC device. CBCT is used for positioning the patient based on the anatomical information.

I. MV X-ray

MV x-ray device, which is more often called electronic portal imaging device (EPID), is often applied during treatment to verify patient set-up with respect to beam source. MV x- ray detector is placed on the opposite side of beam source.

Image quality of MV x-ray is not as good as kV x-ray image, but online portal imaging provides first-hand positioning information during treatment and by comparing portal image with reference image, physicists can get a quick decision about the treatment set-up.

III. RESULT AND ANALYSIS

A. Trail Irradiation

In this check, we aim to prove that the start dose is still the same after delivering it several times or with small variations. The reason for that is to prove that there is no excessive dose delivered to the patient during real treatment. This experiment setting is applying 100MU to solid water phantom, with field size of 10 by 10 cm, and positioning the phantom to the red laser, using dosimeter for the dose measurement. We performed this experiment two times, in first measurement, the recorded dose value is 0.897 Gy and in second try the value 0.898 Gy.

The required value should be 1 Gy. We performed this check two times to check the stability of the machine. So, we noticed that the both values are relatively equal to reference value and the deviation between the both values are small and we can say that the check is satisfying the requirement and we can move to the second check.

B. Isocenter Check

This check uses KV X-ray images to position the cube correctly. The ISO Cube contains a unique center point. The cube is positioned to the isocenter of the machine (the red laser) as shown in Fig.2. Two X-ray images of cube are taken as shown in Fig.4, and the system gives us the calculated center of the cube. Then the system compares the both previous values and return the isocenter deviation as shown in Fig.4. LAT, LNG and VRT correspond to X, Y and Z direction.

The isocenter deviation in our experiment is 0.3 mm in lateral direction and -0.3mm in vertical direction. The deviation value is between laser isocenter (blue lines) and the cube ball isocenter (yellow lines) from MV image as shown in Fig.7.

The two x-ray images are taken at 45 degree, so we see the cube from its corners. The correction is performed by moving the x-ray tube to correct the deviation (automatic correction) as shown in Fig. 8 all the deviation value is zero after the correction (moving the x-ray tube).

C. MLCs Check

We performed a check using EPID MV x-ray images for leave accuracy check using 10 by 15 cm field size as shown in Fig.9.

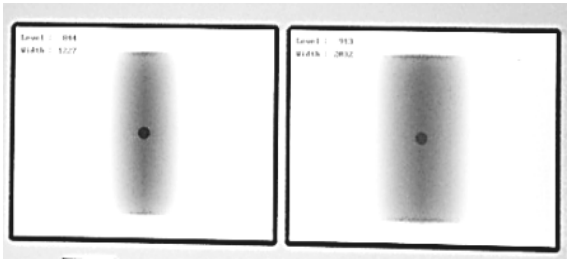


Fig.4. CT image of cube and measured isocenter deviation

Gantry sag is a well-known issue in radiation therapy that involves the use of LINAC gantry rotation to deliver radiation to the patient. The gravity of several tons of radiation-generating and shielding materials inside the gantry causes the gantry rotation to deviate from the ideal trajectory, which is a perfect circle about the rotation axis. This non-ideal gantry rotation, combined with other linac imperfections such as collimator misalignment, leads to the “wobble” of the radiation field centers (RFCs) around the radiation isocenter and thus compromises the spatial accuracy of radiation treatments.

D. IR Camera Verification

In this experiment, we used the IR markers phantom as shown in Fig. 3a. IR cameras identifies the markers position and compare it with the laser positions if the phantom is in the wrong position the screen shows failure sign to indicate that the phantom is not in the correct position.

After correcting the phantom position, the screen shows a passing sign that is the phantom is in the correct position.

E. Pelvic Phantom Positioning

We used pelvic phantom with external IR markers and internal markers to evaluated the positioning process. In Fig.5, we can see the phantom used in the experiment and we can notice the external IR markers. In Fig.6, we see that the phantom is not in the correct position based on the external IR markers screen. We noticed the two red flags, which indicate the wrong position.

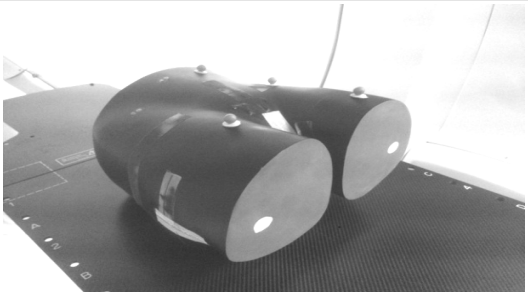


Fig.5. The Pelvic phantom with external IR markers

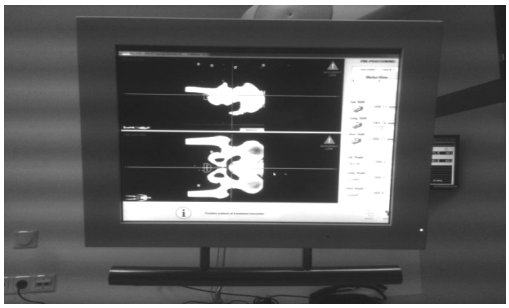


Fig.6. This screen shows the DRR images of the phantom and indicates to the positioning state. In this figure, the red flags indicate to wrong positioning

In treatment indications where there is difficulty visualizing the tumor or the need to compensate the tumor motion due to respiration or random motion, fiducial markers may be implanted prior to treatment. ExacTrac offers a simple, automated approach to visualize, detect and register implanted markers using a proprietary software solution and 6D fusion. In Fig.7, we see the implanted markers in the registration step between the green crosses and the blue ones. the automatic registration is offered based on the bony anatomy or implanted markers. We registered the phantom images several times based on the bony anatomy and based on the anatomic markers. We repeated this experiment for the same x-ray images five times to obtain the accuracy of the bony anatomy registration algorithm and the mean and the standard deviation values. We applied the bony anatomy registration algorithm on five different sets of images are taken at 315 degree of the gantry and the mean and the standard deviation. At the same time, we applied marker-based registration for the same five x-ray data sets and same angle, and the mean and the standard deviation.

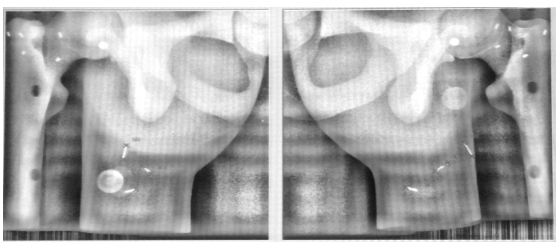


Fig.7. Implanted marker support for the registration process

F. Automatic Table Position Correction

In this experiment, we checked the automatic correction of the table, therefore we shift the phantom position by shifting the table position. Then we pressed the automatic correction button and we noticed that we obtained the same position as it is before we shifted the phantom.

G. Accuracy Comparison

In this section, we compared mean values and standard deviations of all experiment as shown in Table I. We can see from the tables that in lateral direction, registration with markers is superior to Bony methods, while in longitudinal and vertical direction two methods present similar precision.

After changing gantry angle from 315 degrees to 288 degrees, we noticed higher standard deviation in longitudinal direction, but the same standard deviation is for lateral and vertical direction.

We can see from Table II that Bony method performance is more stable than implanted markers method in all the three directions, and after changing gantry angle, the standard deviation of both methods increases, which indicates more instability is introduced.

H. Influence of Deformation

In this article, all positioning techniques we talked about above are based on the assumption that no deformation occurs between treatment planning and treatment, but such deformation can actually happen, because of either weight loss or physiological difference (bladder full or empty). When deformation of target region happens, auto-positioning program will never reach an acceptable position, so physicists have to rely on manual positioning to identify region of tumor before irradiation, which is dangerous sometimes. To deal with the influence of deformation, we think repeated treatment planning and shortening time between treatment planning and treatment can help, also treatment cycle should be shortened when treatment quality can be guaranteed. In each fraction, x-ray image of target region should be documented for evaluation of tissue deformation and patient should retain physiological status during each fraction.

CONCLUSION

In this article, we compared laser, kV x-ray imaging, CBCT and IR camera for a phantom positioning and evaluated their performance relatively. We conclude that among all positioning techniques, kV x-ray with implanted markers presents highest positioning accuracy, which conforms to clinical routine. Bony registration (auto) shows good accuracy but also more uncertainty and is more time-consuming. CBCT shows less accuracy than kV x-ray imaging but is superior for longitudinal deviation. Manual correction is both time-consuming and inaccurate, which is unpractical.

REFERENCES

[1] C. Bert. Localization lecture slides. WS 2016/17: Introduction to medical physics in radiation therapy, p. 6, 2016.

[2] E. E. Klein, J. Hanley, J. Bayouth, F.-F. Yin, W. Simon,S. Dresser, C. Serago, F. Aguirre, L. Ma, B. Arjomandy, et al. Task group 142 report: quality assurance of medical accelerators, Medical physics, pp. 4197–4212, 2009.

[3] G. J. Kutcher, L. Coia, M. Gillin, W. F. Hanson, S. Leibel, R. J. Morton, J. R. Palta, J. A. Purdy, L. E. Reinstein, G. K. Svensson, et al. Comprehensive qa for radiation oncology: report of aapm radiation therapy committee task group 40, Medical physics, pp. 581–618, 1994.

[4] S. D. Kapila, Cone Beam Computed Tomography in Orthodontics: Indications, Insights, and Innovations, John Wiley & Sons, pp. 321-322, 2014.

[5] T. Aziz, Cone-beam Computed Tomography Analysis of Nasal Septum Changes Caused by Rapid Maxillary Expansion in Adolescent Patients with Mild to Moderate Septal Deviation, pp. 34-37, 2015.

[6] A. Gorgulho, N. Agazaryan, B. Slotman, M. Selch, A. J. Burwick, R. Schul. Springer Science & Business Media, pp. 27-28, 2011.

[7] M. Maqbool. An Introduction to Medical Physics, Springer, p. 149, 2017.

[8] R. D. Timmerman, L. Xing. Image-guided and Adaptive Radiation Therapy, Lippincott Williams & Wilkins, p. 303, 2009.

[9] C. Meola. Infrared Thermography Recent Advances and Future Trends, Bentham Science Publishers, p. 210, 2012.

[10] A. Li. Adaptive Radiation Therapy, CRC Press, p. 240, 2011.

Table I. The comparison between all the mean values of all experiments

Mean	LAT	LAT/degree	LNG	LNG/degree	VRT	VRT/degree
Same X-ray image/Bony	-1.692	0.156	-0.354	-0.488	-0.434	0.058
X-ray/Markers (315 degree)	-0.124	-0.462	-0.456	-1.528	-0.74	-1.046
X-ray/Bony (315 degree)	-1.72	0.304	-0.342	-0.452	-0.476	0.068
X-ray/Markers (288 degree)	0.176	-0.38	-0.784	-1.734	-0.944	-1.134
X-ray/Bony (288 degree)	-1.532	0.076	-0.518	-0.544	-0.394	0.07
CBCT	-2.058	0.324	-1.02	0.474	0.276	-0.002

Table II. The comparison between all standard deviation values of all experiments

Standard deviation	LAT	LAT/degree	LNG	LNG/degree	VRT	VRT/degree
Same X-ray image/Bony	0.126	0.297	0.073	0.063	0.068	0.039
X-ray/Markers (315 degree)	0.076	0.010	0.702	0.088	0.027	0.019
X-ray/Bony (315 degree)	0.050	0.070	0.066	0.056	0.023	0.010
X-ray/Markers (288 degree)	0.143	0.055	0.051	0.123	0.034	0.121
X-ray/Bony (288 degree)	0.092	0.115	0.074	0.116	0.281	0.076
CBCT	0.108	0.352	0.408	0.561	0.265	0.047

★★★