Journal of Medical and Bioengineering Vol. 4, No. 6, December 2015

Comparing Setup Errors of CBCT Guidance System and Optical Positioning System Using Phantom Experiments

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***Abstract*—Objective: To compare the clinical positioning error of patient setup between the cone beams computed tomography (CBCT) guidance with Optical Positioning System (OPS), and to evaluate the OPS based on our proposed approach of patient positioning. Materials and Methods: A phantom was used. We measured setup errors in left-to-right (LR) and anterior-to-posterior (AP) directions by vernier caliper on a graph paper on Varian Linear accelerator, and then we shifted the couch height to make the source-to-surface distance (SSD)=100cm and recorded the height change which was displayed on monitor screen as the setup error in inferior-to-superior (IS) direction. Results: Average(Avg) setup errors for the CBCT guidance system were 0.42mm, 0.50mm,and0.66mm in LR, IS and AP directions, respectively; the SD of it were 0.24mm, 0.00mm and 0.52mm in LR, IS and AP directions, respectively. The OPS has an Avg setup error of 0.28mm, 0.40mm and 0.30mm in LR, IS and AP directions and SD of 0.08mm, 0.10mm and 0.07mm in LR, IS and AP directions, respectively. Conclusion: We demonstrated that OPS shows a comparable, fast and efficient positioning method compared to CBCT guidance system, and lives up to the actual need and will have a wide use in clinical application.**

***Index Terms*—radiotherapy, CBCT guidance system, optical positioning system.**

I. INTRODUCTION

Radiotherapy aims to provide higher dose to the tumor area than to the tumor area than to the surrounding normal tissues. It has the advantages of increasing tumor cure rate, improving the radiate sensibility of the tissue, and decreasing the damage of normal tissue. However the normal tissue around the tumor has considerable low tolerance level to radiation. As a result, in order to acquire a better tumor control probability (TCP), an accurate positioning is of paramount importance to radiation treatment. Besides, positioning accuracy is a significant factor for drawing the plan target volume (PTV)[1]-[3].

With the development of "precise radiotherapy", positioning guidance techniques, such as CBCT guidance system and optical guidance system, have received more attention and have already widely used in clinical.

The CBCT guidance system is a medical image acquisition technique. The whole operation process is as follows. First, the X-ray tube rotates a circle by targeting the patient as the pivot. At the meantime, the flat panel detector, located in the tube side, collected the projection data [4]. When reconstructing those data, we receive the current position layer of CBCT images. At last, the image registration between CT and CBCT reveals the set-up errors, which will be corrected on line. After all these steps, we achieve the precise placement of the patients [5] [6].

The Optical Positioning System (OPS), developed by Nanjing University, achieves precise set-ups through real-time tracking of the tumor. OPS leads tumor to the center of the accelerators precisely by tracking the infrared positioning balls on the patients' faces or bodies. At the same time, with the help of three-dimensional radiotherapy planning system, OPS can maximally kill the tumor and protect the normal tissues, and then realize the value of precise radiotherapy [7] [8].

As above, we reported two commonly used methods of positioning guidance systems. However, due to different technical principles, the applications of the two methods in practice clinical practices are also different. Therefore, the present paper will conduct a comparative study to explore the positioning error between CBCT guidance system and OPS guidance system.

II. MATERIALS AND MATHODS

A. Experimental Phantom

A phantom regarded as a virtual patient was positioned on the treatment couch (Fig. 1(a)). Firstly, we fixed a metallic sphere (Fig. 1 (b)), which diameter is 1mm,

Manuscript received July 20, 2014; revised December 2, 2014.

doi: 10.12720/jomb.4.6.484-487

inside the phantom as tumor. Then a graphing paper was put under the metallic sphere to calculate deviation position. Secondly, six IR sensitive markers were attached to the surface of the phantom. The real-time locations of the six IR sensitive markers, which were fixed on the phantom, can help OPS monitor the planned isocenter motion.

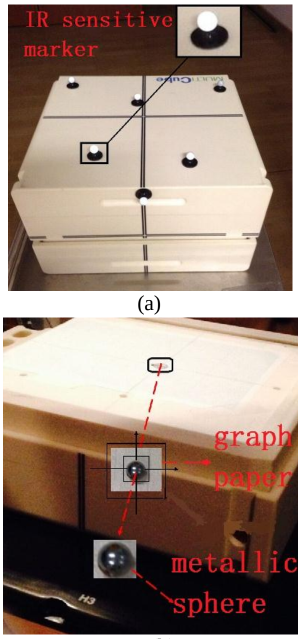

Figure 1. (a) The phantom that was implemented as a virtual patient. (b) The metallic sphere in the middle layer is the planned isocenter.

B. *Optical Positioning System*

Superior to other positioning systems in accuracy, OPS has become the most widely use positioning system in the field of image guidance [9].

The Optical Positioning System consists of two components: an optical tracking system (from Northern Digital Inc.) (as shown Fig. 2) used to detect IR sensitive markers, and a software used to compute the distance between the treatment machine isocenter and the planned isocenter.

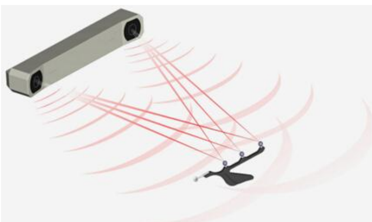

Figure 2. The operating principle of optical tracking system

The infrared light released by the infrared ray led occupied all the detection area. The marked balls, lobulated in the detection area, reflected light to the two location sensors. According to the images formed between the two location sensors, we could calculate the coordinates of the three dimensional spaces [10].

The workflow chart of ops-guidance patient position is presented in Fig. 3.

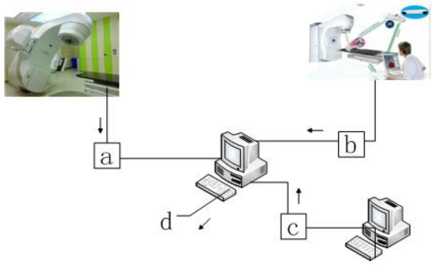

Figure 3. The operation procedures of OPS wherein (a)in-house software read the machine isocenter; (b)OPS tracked 6 markers positioning data; (c) treatment plan; and (d) positioning errors in three directions.

C. *Plan and Transform*

Once IR markers were attached to phantom, a 3mm thick CT scan would be operated on it. The CT images were used to complete CT simulation and to design treatment plan by Varian treatment planning system.

D. *Setup Verification*

CBCT guidance system

We aligned the phantom on the Varian couch in accordance with positions when it underwent CT scan, then setup registration frame and underwent CBCT scan. After acquiring CBCT images, we matched planning CT images with CBCT images by the method of bone anatomy [11] [12]. After image registration, linear errors along three axes(LR: left to right, IS: inferior to superior, AP: anterior to posterior)is computed and sent to the dialog box by in-house software [13]. Radiotherapists adjust treatment couch to the real-time setup errors.

OPS guidance system

Importing treatment planning to OPS and draw the six markers of CT images. Then the system calculated the relationship between the markers and the target, and then generated positioning planning. Finally, compare the degree of conformity between isocenter and lesion position when in the actual treatment. Meanwhile, setup errors, entering into the database, were showed on the monitor [14].

Measurement of setup errors

Therapist aligned the phantom and opened it. The aim was to let the infrared light irradiate on the coordinate papers inside the phantom. After that use Vernier gauge to measure the differences between the centers of light field and the actual tumor from two directions –LR and AP respectively, and then kept records. What we got here was Δ x and Δ z. Besides we shifted the couch height to make the source-to-surface distance (SSD) equal to 100cm and then we got the height change Δ y in inferior-to-superior (IS) direction. The data was displayed on a monitor screen.

III. Results

The statistics of 20 databases were shown in Table I. It summarizes the setup errors of the two methods. The setup errors of CBCT guidance system in three directions were all about 0.5mm, while the deviations of OPS were 0.3mm. However, the deviation in one direction of CBCT guidance system reached up to 1.5mm. Comparatively, the deviation of OPS was just about 0.5mm.

The Avg and SD of setup errors were shown in Fig. 4.

TABLE I. SETUP ERRORS AND DIFFERENCES BETWEEN CBCT GUIDANCE SYSTEM AND OPS.

Setup errors (mm)	CBCT guidance			OPS guidance		
	Avg (mm)	SD (mm)	MAX (mm)	Avg (mm)	SD (mm)	MAX (mm)
LR/Δ x	0.42	0.24	0.80	0.28	0.08	0.40
IS/Δ y	0.50	0.00	0.50	0.40	0.10	0.50
AP/Δ z	0.66	0.52	1.50	0.30	0.07	0.40

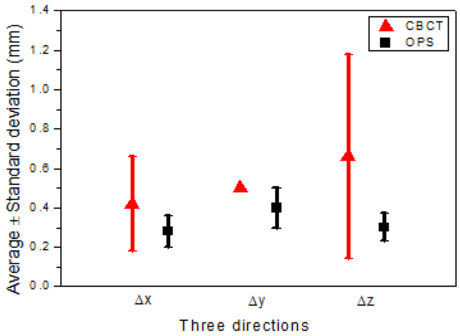

Figure 4. A plot of the Avg and standard deviation (SD) of the setup error

IV. DISCUSSIONS

The accuracy of patient positioning and the reduction of daily repositioning errors are of great importance to radiotherapy; as Table I shown, the Avg setup errors of CBCT and OPS in three directions are less than 1.0mm, which meets the clinical demand. But the setup errors of CBCT guidance system are less than that of OPS. Besides although the standard deviate of setup error of CBCT guidance system in IS direction is 0 mm, it showed a very perfect stability. But in LR and AP directions, the errors were 0.24mm and 0.52mm, which are less than that of OPS in the same directions. The errors of OPS were 0.08 and 0.07mm. From the results we can see, the setup stability of OPS is better than CBCT guidance system. It is because during the process of image registration of CBCT images and CT images, the matched images are related to the voxel size of the image [15]. and it also relies on how the operator of the accelerator justifies the two images. The generalization of the Avg and standard deviate of setup error was shown in fig. 4. In general, it revealed that the number of setup errors of CBCT guidance system were more than that of OPS's in most cases.

According to the above analysis, it can be concluded that there is a significant correlation between the positioning error and the application process of CBCT image registration adjusted by operators [16].

Finally, it should be noted that, according to the comparison of performance between the two patient-techniques, the operation process of CBCT is relatively complex. In order to acquire precisely patient-positioning, even experience radiotherapist also need to take 5min -10 min to align patients [17], [18]. This process may add patients' pain and uncomfortableness. However, OPS can save many manual operations, and only require thirty seconds to acquire accurate patient-positioning. The reason is that OPS operate very simply. Most steps are finished automatically except drawing the markers which are completed by hands. As demonstrated above, radiotherapist can receive localization feedback to locate target because OPS can monitor the real-time positions of the planned isocenter and the machine isocenter by putting them in the same coordinate system [19], [20], namely the infrared coordinate system. The only thing that matters here is whether the six IR sensitive markers can be monitors by OPS. During this process, the accuracy of the markers' positions is of no concern, OPS will be changed as soon as the positions of the markers are shifted [21].

In summary, OPS improve the accuracy, reproducibility and survive rate of patient positioning, and meanwhile reduceenne daily repositioning errors. In a word, it provides quality assurance for radiotherapy.

V. CONCLUSIONS

We compared OPS and CBCT guidance system by using phantoms. In the research, this two positioning methods have achieved higher setup accuracy than conventional methods. But in terms of accuracy and stability, OPS are superior to CBCT guidance system. Compared with CBCT, OPS are more convenient, efficient, and suitable for clinical practices. Infrared system improves the shortcomings of CBCT guidance system such as time-consuming. Therefore, OPS are a top choice method for patient positioning due to its high accuracy and efficiency, which may replace CBCT one day.

ACKNOWLEDGMENT

This work is supported by the National Nature Science Foundation of China (81371638), Fundamental Research Funds for the Central Universities (1106021034), Jiangsu Provincial Nature Science Foundation of China (BE2012158, BK2011393 and BY2012186).

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