Development of Video Image-Guided Setup (VIGS) System for Tomotherapy: Preliminary Study

Jin Sung Kim*, Sang Gyu Ju*, Chae Seon Hong*, Jaewon Jeong†, Kihong Son*, Jung Suk Shin*, Eunheak Shin*, Sung Hwan Ahn*, Youngyih Han*, Doo Ho Choi*

*Department of Radiation Oncology, Samsung Medical Center, Sungkyunkwan University School of Medicine, †Department of Research & Development, Infinitt Healthcare Co., Ltd., Seoul, Korea

At present, megavoltage computed tomography (MVCT) is the only method used to correct the position of tomotherapy patients. MVCT produces extra radiation, in addition to the radiation used for treatment, and repositioning also takes up much of the total treatment time. To address these issues, we suggest the use of a video image-guided setup (VIGS) system for correcting the position of tomotherapy patients. We developed an in-house program to correct the exact position of patients using two orthogonal images obtained from two video cameras installed at 90º and fastened inside the tomotherapy gantry. The system is programmed to make automatic registration possible with the use of edge detection of the user-defined region of interest (ROI). A head-and-neck patient is then simulated using a humanoid phantom. After taking the computed tomography (CT) image, tomotherapy planning is performed. To mimic a clinical treatment course, we used an immobilization device to position the phantom on the tomotherapy couch and, using MVCT, corrected its position to match the one captured when the treatment was planned. Video images of the corrected position were used as reference images for the VIGS system. First, the position was repeatedly corrected 10 times using MVCT, and based on the saved reference video image, the patient position was then corrected 10 times using the VIGS method. Thereafter, the results of the two correction methods were compared. The results demonstrated that patient positioning using a video-imaging method (41.7±11.2 seconds) significantly reduces the overall time of the MVCT method (420±6 seconds) ($p<0.05$). However, there was no meaningful difference in accuracy between the two methods (x=0.11 mm, y=0.27 mm, z=0.58 mm, $p>0.05$). Because VIGS provides a more accurate result and reduces the required time, compared with the MVCT method, it is expected to manage the overall tomotherapy treatment process more efficiently.

Key Words: Tomotherapy, Image guidance, Patient positioning

INTRODUCTION

The objective of radiotherapy is to deliver a therapeutic dose to a well-defined target while minimizing the dose to the surrounding normal tissue and critical organs. This requires optimization of the conformity of the prescribed dose to the planned target volume (PTV), dose homogeneity within the PTV, and a minimal dose to the surrounding normal tissue and critical organs.[1)]

Tomotherapy is a desirable treatment method to perform megavoltage computed tomography (MVCT) image acquisition as good image-guided radiation therapy (IGRT) and intensity-modulated radiation therapy (IMRT) simultaneously.[2,3)] In particular, this machine helps reduce the interference of normal tissue due to its excellent dose intensity using helical beam delivery. In addition, setup accuracy can be maintained within 2 mm using MVCT image acquisition. Additionally, MVCT can correct artifacts from general computed tomography (CT) images of high-density substances using MVCT. Adaptive ther-

This work was supported by the Technology Innovation Program, 10040362, Development of an integrated management solution for radiation therapy funded by the Ministry of Knowledge Economy (MKE, Korea).

Submitted March, 26, 2013, Accepted June, 12, 2013

Corresponding Author: Sang Gyu Ju, Department of Radiation Oncology, Samsung Medical Center, 50, Ilwong-dong, Gangnam-gu, Seoul 135-710, Korea
Tel: 02)3410-2617, Fax: 02)3410-2619
E-mail: sg.ju@samsung.com

apy based on MVCT is also possible.

However, the advantages of tomography are accompanied by the many disadvantages associated with daily setup verification using MVCT scans. There is a possibility that 2～3 cGy of unnecessary radiation could arise every day, and the CT scanning time and setup time can delay the overall treatment time. In practice, more than one-third of the entire treatment time is devoted to image scanning and MVCT setup. Unfortunately, the speed at which changes to tumor size can be detected is still under debate; some studies have reported that the changes are not large enough to warrant daily observation.[3,4)]

A setup verification system, using video images, has received much attention from some researchers due to advantages including fast processing speed, simple system implementation ability, accurate processing ability, lack of additional radiation exposure, and so on.[4-10)] These studies have been developed to achieve more-accurate results using three-dimensional information on patients' body surfaces. Recently, two new commercialized patient-position management systems (Sentinel™, C-RAD, Sweden, and AlignRT®, Visionrt, UK) that do not produce additional radiation have been introduced for this purpose. These researchers have contributed to validating the setup accuracy using video images. However, tomotherapy cannot use the current research results that were derived using an external device due to the gantry size limitation (bore 85 cm). Therefore, in this study, we designed a Video Image-Guided Setup (VIGS) system, which has the ability to perform the setup verification, by mounting the video camera (2 mega pixel resolution, Lifecam NX-8000, Microsoft, USA) inside the tomotherapy gantry. We evaluated the accuracy and usefulness of the VIGS system via a phantom study.

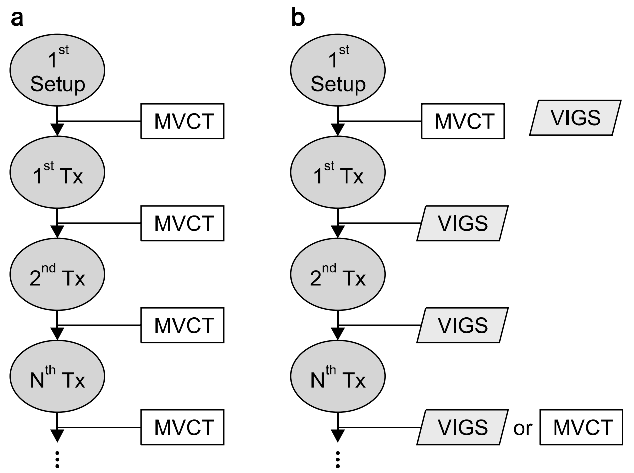

Fig. 1. Comparison of treatment process using (a) MVCT and (b) VIGS (Video Image-Guided Setup). The treatment process is shown for the typical patient using the first video image obtained after the MVCT correction as a reference image.

MATERIALS AND METHODS

The proposed treatment scenario is shown in Fig. 1. On the first day of treatment, after correcting the patient's setup using the MVCT scan, we captured and stored reference video image using an orthogonal video camera built into the gantry. On the second day, an orthogonal video camera image of the patient was taken after complete patient setup using a laser system in same treatment position and was compared with the

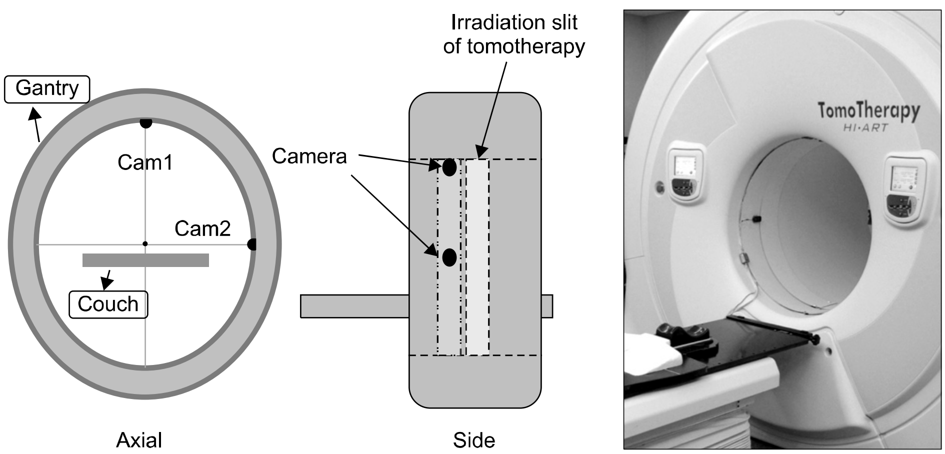

Fig. 2. In the closed-tomotherapy gantry, two cameras that meet at right angles are installed to take the patient's orthogonal image. It is important to install the cameras so that they do not block the slit through which radiation is emitted.

reference image obtained on the first day to evaluate the setup error. VIGS is expected to result in a more efficient process because it can promptly correct patient positioning without additional radiation exposure within short time. By contrast, MVCT delivers additional radiation each time. If required, MVCT can be used to correct the patient position instead of VIGS. This method was used to correct the patient position, and the accuracy of the camera image (reference image) was reevaluated using an MVCT scan once a week or once every two weeks.

Fig. 2 describes the VIGS system structure, in which a band was inserted inside the tomotherapy gantry to install two orthogonal video cameras, and the cameras were then connected to the treatment control room with two orthogonal video images to find positioning information with the in-house MATLAB program.

1. Camera calibration

Before measuring the daily setup accuracy, it was necessary to correct the camera movement or rotation. The camera calibration is basically 2D calibration for each camera angle and performed before daily treatment. We calibrate the camera position and actual distance per pixel of acquired image using fixed patterns on the couch and the gantry ring of the tomotherapy machine. The empty couch image (anterior-posterior image) with 4 holes is acquired with the camera 1 on Fig. 2 and in-house made fixed pattern on gantry ring image is also capture with the camera 2 on Fig. 2. Our calibration program automatically detects the each hole in two orthogonal planes using the canny edge detection (Fig. 3). After position and distance detection between holes, the program also calculates the spatial transformation between original image and each calibration image and defines the number of pixels on the distance in millimeters per pixel for the correction. And camera zoom, focus, and brightness were adjusted manually after the camera position was set. Automatic adjustments of these parameters can result in inaccurate patient motion detection via the image difference algorithm because this algorithm would continuously adjust the image capturing conditions during analysis and these adjustments could be mistakenly detected as patient motion.

2. Registration algorithm

After taking an MVCT image of the first treatment, we obtained the final two reference orthogonal images and two orthogonal images taken before every treatment session. The automatic registration was then performed for pattern matching

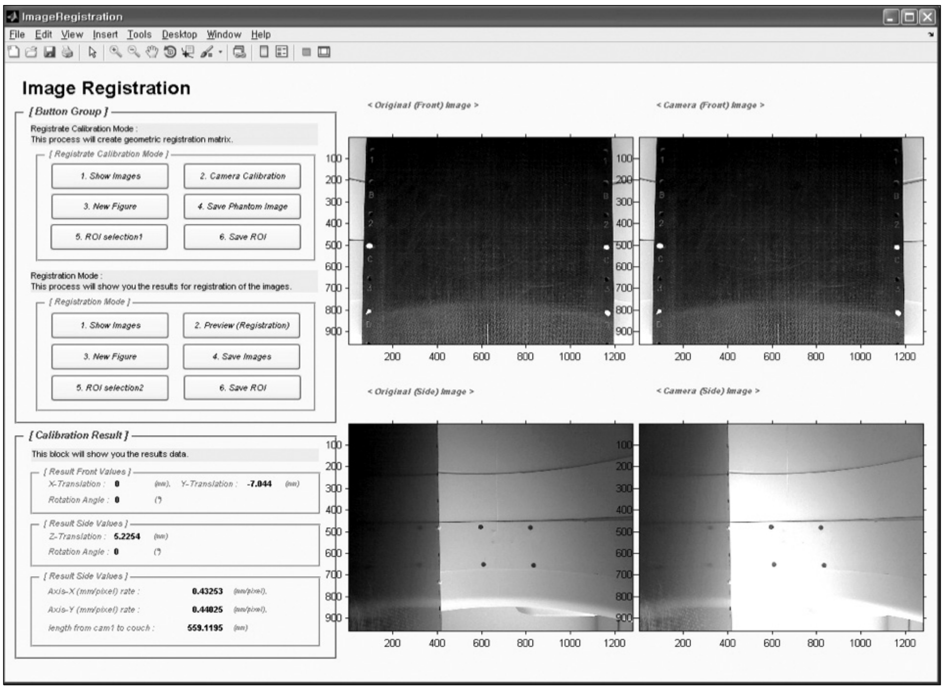

Fig. 3. The GUI program for the camera calibration. The empty couch image (anterior-posterior image) with 4 holes is acquired with the camera 1 (on Fig. 2) and in-house made fixed pattern on gantry ring image is also capture with the camera 2 (on Fig. 2). With pre-known distance between holes, the calibration program calculates the spatial transformation between original image and each calibration image and defines the number of pixels on the distance in millimeters per pixel for the correction.

using region-of-interest (ROI) images. When using the template-matching method, we selected the coordinate points with the largest normalized cross-correlation value of the two images, and the cross-correlation value formula was as follows.

$$\gamma(u,v)=\frac{\Sigma_{x,y}[f(x,y)-\overline{f}_{u,p}][t(x-u,y-v)-\overline{t}]}{\left\{\Sigma_{x,y}[f(x,y)-\overline{f}_{u,p}]^2\,\Sigma_{x,y}[t(x-u,y-v)-\overline{t}]^2\right\}}$$

f – original input image, t – template image, (u,v) – index

Although a variety of algorithms have been proposed for analyzing image-intensity variations, including statistical, difference and curve-fitting methods, we used the Canny edge detection method because it is considered an optimal edge detector for step edges corrupted by white noise. Although this image-correlation factor was very simple, it worked well in most patients. Additionally, we used Gaussian filtering and Laplacian filtering before Canny edge detection to increase the matching rate.

In addition to fully automatic registration, we added a function for users to manually adjust for patient positioning.

3. Phantom study

To mimic the general tomotherapy treatment process, a humanoid phantom (Rando110, Alderson Associates, NY, USA) was immobilized in a vacuum cushion with a thermoplastic head/shoulder mask, simulating a head-and-neck patient. The treatment plan was devised after the initial CT scan. Assuming there would be 10 treatment sessions, the setup was verified on the first day after MVCT scanning of the phantom; the phantom was moved to the treatment position, and two orthogonal video camera images were taken and saved as reference images.

Assuming the second day as the phantom treatment day, we reset for MVCT scanning with pre-defined shifts (Y (superior-inferior direction)=1.0 cm and Z (anterio-posterior direction)=1.0 cm) and orthogonal setup imaging, measured the verification error, repeated the same procedure assuming there would be a total of 10 sessions of treatment, and used an automatic matching method to eliminate the subjective opinions of the observers.

As seen in Fig. 4, we used an in-house program to obtain and compare the reference image and the treatment image. Our algorithm was implemented using the Matlab (The MathWorks Inc., Natick, MA, USA) programming environment with a PC (Intel Core2 Quad CPU at 2.66 GHz/processor, 8.0 GB RAM, 64-bit operating system).

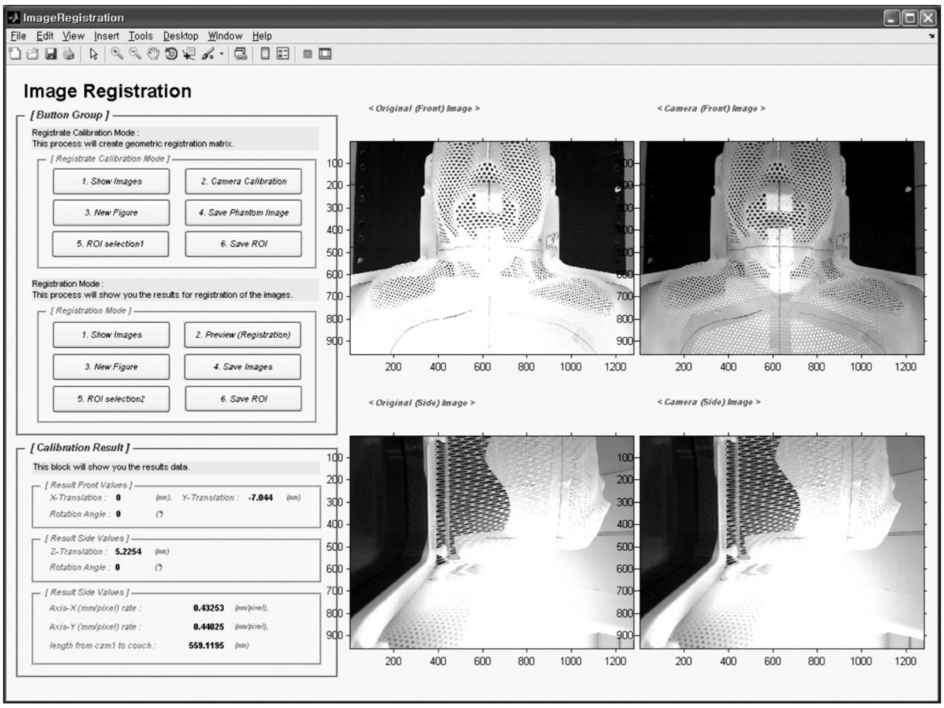

Fig. 4. The GUI program that corrects the patient position using two orthogonal video images. Fully automatic registration and a manual procedure are available. Both registration procedures were programmed using Matlab.

Table 1. Position differences between MVCT and VISG for 10 treatment fractions.

Variable	Lateral (x) (mm)	Longitudinal (y) (mm)	Vertical (z) (mm)	Vector (mm)
Median	0.11	0.27	0.58	−0.11
Range	−1.00∼0.90	−0.81∼1.33	−1.28∼1.43	−1.08∼0.87
p-value	0.76	0.09	0.15	0.24

We evaluated any significant difference in positioning results from the MVCT and VIGS systems by statistical analysis using a Wilcoxon signed-rank test (SPSS statistics version 19, IBM, USA).

RESULTS

The effectiveness of the proposed method was evaluated based on a simulation study using a humanoid phantom. No significant registration errors were observed for a given range of translations in the x, y, and z directions. When we assessed two sets of orthogonal images of the humanoid phantom using the VIGS system, we found that the video camera image quality was superior for image analysis when compared with the MVCT images.

Table 1 shows the positioning differences between the full 3D method using MVCT and the proposed 2D method using video camera images. The median differences were approximately 0.11, 0.27, and 0.58 mm in the lateral, longitudinal, and vertical couch directions, respectively. The median 3D vector magnitude difference was −0.11 cm. The Wilcoxon signed-rank test also demonstrated that the MVCT and VIGS positioning methods did not significantly different ($p>0.05$). The average time using VIGS system for a single registration was 41.7±11.2 seconds and it's 10 times faster than the original MVCT process (420±6 seconds). The time consumed for the patient-positioning process averaged seven minutes for MVCT and one minute for VIGS, which was significantly reduced ($p<0.05$).

DISCUSSION

The major limitations of the current MVCT system, however, often hinder its full use in clinical practice. One of these limitations is that the radiation dose and time for acquiring one MVCT image can range from 2 to 9 cGy and 6∼7 minutes for optimal image.[11,12] This dose level is generally delivered to an area much larger than the intended treatment area. Therefore, daily imaging can be impractical for those patients who might be at a high risk of developing second malignancies. The Video Image–Guided Setup (VIGS) system used in this study has a huge advantage in that it does not result in irradiation.

The two orthogonal video camera images provided an alternative 3D imaging technique that aims to resolve the limitations of MVCT in clinical practice. In this preliminary study, we found minimal differences between video image–based and MVCT-based patient positioning using bony anatomy. This clinical study is the first to demonstrate that video images can be used for patient positioning, with accuracy equivalent to that of MVCT for routine tomotherapy treatment processes. However, instead of using a video image–based positioning system during the entire course of treatment, we believe that alternating with MVCT for a reasonable range of use would be more efficient for treatment.

Our 1st registration of VIGS was performed with MVCT of normal 1st H&N treatment procedure with immobilization device. After physician's final confirmation with MVCT for the treatment, the orthogonal reference camera images were acquired for next treatment fractions. If some other obstruction devices were presented in that reference images, our VIGS system cannot perform registration process to correct patient position with captured images. We need to exclude those patients who have another device except the immobilization mask with H&N region.

Typically, patients' internal organs move, or over time, there can be some changes on the body's surface. The use of a humanoid phantom in our study, which did not result in any changes over time, to measure the accuracy of the patient-positioning system needs to be improved further. However, we believe that our study covered enough basic principles to validate the system.

There are still some limitations with the immobilization device using MVCT or other imaging techniques. Since we always re-take CT simulation after 18 fractions for reduced field treatment for H&N patients using tomotherapy, we can moderate the possibility to move or shrink under the immobilization device. And if we found over-tolerance difference between our immobilization device and patient surface during patient setup, we have our protocol to make another immobilization device for the changed device or surface. Our H&N patient tomotherapy treatment is performed after confirming the realistic treatment conditions with patient in the immobilization device. Since the MVCT or any other localization imaging techniques cannot overcome that setup error, the immobilization device and other setups are important to the both systems (MVCT and VIGS) and also treatment.

It typically takes 20∼30 minutes for tomotherapy treatment, and more than 30% to 40% of that time is spent checking patient positioning with MVCT. This is time consuming and obviously inefficient in busy clinic. Our study showed that the time to acquire images of a patient's location could be significantly 10 times reduced, which can, in turn, reduce the overall treatment time and thus help patients comfortably. It is also expected to help in operating the machine more efficiently.

Our video image-based positioning system reduces the setup time and allows continuous monitoring of patient movement. The current system has been designed and is being used to monitor patient movements during the entire process.[13] Furthermore, we believe we can study the monitoring of a patient's respiratory signals using a camera attached to patient's lateral gantry and an institutional review board approval for our patients is on the way with these results of the feasibility test.

However, there were some minor errors because the function to control the current couch's movement was not integrated. Therefore, in the future, if we develop an automatic system by integrating it with tomotherapy, it can be used for patient data with couch movements.

CONCLUSION

This study evaluated the accuracy of an automatic patient-positioning system, based on the image correlation of two video images as a new technique for 3D imaging-guided patient positioning for tomotherapy. Its performance in patient positioning using automatic registration was comparable to that of the MVCT technique, with a significant reduction in total treatment time and dose. Additional study of video camera imaging in other anatomic sites and of using soft tissue for patient positioning compared with the MVCT technique is needed to demonstrate its efficacy as a potential tool for daily 3D target localization for tomotherapy.

REFERENCES

1. **Chavaudra J, Bridier A**: Definition of volumes in external radiotherapy: ICRU reports 50 and 62. Cancer Radiother 5(5): 472-478 (2001)
2. **Mackie TR, Holmes T, Swerdloff S, et al**: Tomotherapy: a new concept for the delivery of dynamic conformal radiotherapy. Med Phys 20(6):1709-1719 (1993)
3. **Mackie TR, Kapatoes J, Ruchala K, et al**: Image guidance for precise conformal radiotherapy. Int J Radiat Oncol Biol Phys 56(1):89-105 (2003)
4. **Milliken BD, Rubin SJ, Hamilton RJ, Johnson LS, Chen GT**: Performance of a video-image-subtraction-based patient positioning system. Int J Radiat Oncol Biol Phys 38(4):855-866 (1997)
5. **Schoffel PJ, Harms W, Sroka-Perez G, Schlegel W, Karger CP**: Accuracy of a commercial optical 3D surface imaging system for realignment of patients for radiotherapy of the thorax. Phys Med Biol 52(13):3949-3963 (2007)
6. **Tao S, Wu A, Wu Y, Chen Y, Zhang J**: Patient set-up in radiotherapy with video-based positioning system. Clin Oncol (R Coll Radiol) 18(4):363-366 (2006)
7. **Yan Y, Song Y, Boyer AL**: An investigation of a video-based patient repositioning technique. Int J Radiat Oncol Biol Phys 54(2):606-614 (2002)
8. **Johnson LS, Milliken BD, Hadley SW, Pelizzari CA, Haraf DJ, Chen GT**: Initial clinical experience with a video-based patient positioning system. Int J Radiat Oncol Biol Phys 45(1):205-213 (1999)
9. **MacKay RI, Graham PA, Logue JP, Moore CJ**: Patient positioning using detailed three-dimensional surface data for patients undergoing conformal radiation therapy for carcinoma of the prostate: a feasibility study. Int J Radiat Oncol Biol Phys 49(1):225-230 (2001)
10. **Cervino LI, Pawlicki T, Lawson JD, Jiang SB**: Frame-less and mask-less cranial stereotactic radiosurgery: a feasibility study. Phys Med Biol 55(7):1863-1873 (2010)
11. **Xu SP, Xie CB, Ju ZJ, et al**: Measurement and analysis of the imaging dose with megavoltage computed tomography for helical tomotherapy. Ai Zheng 28(8):886-889 (2009)
12. **Beldjoudi G, Yartsev S, Bauman G, Battista J, Van Dyk J**: Schedule for CT image guidance in treating prostate cancer with helical tomotherapy. Br J Radiol 83(987):241-251 (2010)
13. **Ju SG, Huh W, Hong CS, et al**: Development of a video-guided real-time patient motion monitoring system. Med Phys 39(5):2396-2404 (2012)

단층치료용 비디오 영상기반 셋업 장치의 개발: 예비연구

*성균관대학교 의과대학 삼성서울병원 방사선종양학교실, †인피니트 헬스케어 연구개발부

김진성*·주상규*·홍채선*·정재원†·손기홍*
신정석*·신은혁*·안성환*·한영이*·최두호*

초고압 전산화단층촬영(megavoltage computed tomography, MVCT)이 단층치료(Tomotherapy) 환자의 치료 자세 교정 방법으로 사용되고 있다. MVCT는 부가적인 방사선 피폭뿐만 아니라 전체 치료 시간이 길어지는 단점을 가지고 있다. 이러한 문제점 해결을 위해 비디오 영상기반 환자 치료 자세 교정 시스템(video image-guided setup system, VIGS)을 개발했다. 단층치료 장치내 갠트리에 직각으로 2대의 비디오 카메라를 장착하고 이로부터 얻은 영상을 이용하여 환자의 자세 오차를 측정하는 프로그램을 자체 개발했다. 개발된 시스템은 사용자에 의해 정의된 관심 영역에서의 에지 검출(edge detection) 결과를 기반으로 자동 정합을 통해 자세 오차를 찾도록 고안되었다. 두경부 환자를 묘사하기 위해 휴먼 팬톰을 이용하여 컴퓨터 단층 치료계획 영상을 획득한 후 전산화 치료계획을 수행했다. 실제 치료 상태를 재현하기 위해 고정 용구를 이용하여 팬톰을 고정했으며 전산화치료계획 결과로 부터 팬톰 자세 검증을 위한 기준 MVCT 영상을 획득했다. 팬톰을 치료 위치에 위치시킨 후 MVCT 영상을 얻고 이를 기준 MVCT영상과 비교하여 치료계획시와 동일환 자세가 되도록 위치를 교정했다. 교정된 자세에서 VGIS를 이용하여 기준 비디오 영상을 획득했다. 10회 걸쳐 MVCT 영상을 이용한 자세 교정과 VIGS를 이용한 비디오 영상기반 자세 교정을 각각 수행하여 두 방법간의 교정 값 차이(상관 분석)와 분석 시간을 비교했다. 팬톰 위치 교정 시간은 VIGS 시스템(41.7±11.2 seconds)이 MVCT 방법(420±6 seconds)에 비해 현저히 적게 조사됐다($p<0.05$). 하지만 두 방법간의 위치 오차 분석 결과 통계적으로 유의한 차이는 보이지 않았다($x=0.11$ mm, $y=0.27$ mm, $z=0.58$ mm, $p>0.05$). VIGS시스템이 짧은 시간에 정확한 위치 오차 감지 능력을 보여 이의 개발이 단층치료의 절차를 효율적으로 개선하는데 효과적일 것으로 생각된다.

중심단어: 단층치료, 영상유도, 환자위치잡이