Comparison of image registration performed with MV cone beam CT and CT on rails and Syngo™ Adaptive Targeting software

Sylwia ZIELIŃSKA-DĄBROWSKA, Paweł F. KUKOŁOWICZ, Piotr CZEBEK-SZEBEK

Received: 1.06.2009
Accepted: 13.08.2009
Subject: original article

Holycross Cancer Center, Medical Physics Department

Address for correspondence:
Dr Sylwia Zielińska-Dąbrowska
Zakład Fizyki Medycznej
Świętokrzyskie Centrum Onkologi
Artwińskiego 3
25-734 Kielce
e-mail: sylwiada@onkol.kielce.pl

ABSTRACT

BACKGROUND: Minimization of geometric errors in treatment delivery is essential in modern conformal and intensity-modulated techniques.

AIM: In this paper two Siemens systems, MVision megavoltage cone beam CT, and CTVision (CT on rails), are compared.

MATERIAL AND METHODS: The reproducibility and uncertainty of the image registration procedure performed with Adaptive Targeting (AT) software were evaluated. Both systems were evaluated by means of simulating the clinical situation with an anthropomorphic phantom in three anatomical sites: head & neck, thorax and pelvis.

RESULTS: The results for two methods of image registration, manual and automatic, were evaluated separately. The manual procedure was used by two users, more and less experienced.

CONCLUSIONS: The MVision system and CTVision and the Therapist Adaptive software ensure image registration with the uncertainty of about 2.0 mm (2 standard deviations). In the case of the automatic registration method better reproducibility of image registration was obtained for MVision. For CTVision the necessity of manual identification of the machine isocentre made the registration less reproducible. In the case of MVision, the automatic method was more reproducible than the manual one (smaller dispersion of results). In the case of CTVision, similar results were obtained for both registration methods. In the case of manual registration slightly better reproducibility for CT data acquired at 2 mm slice thickness and 2 mm slice separation than for data acquired at 5 mm slice thickness and 5 mm slice separation were obtained. Similar results of manual registration performed by more and less experienced users were obtained.

KEY WORDS: cone-beam CT, CT on rails, accuracy of image registration

BACKGROUND

In conformal radiotherapy, the precision of patient set-up is of utmost importance[1, 2]. Very precise patient set-up allows for decrease of the set-up margin and minimizes the damage to normal tissues. The 2D electronic portal imaging systems were used for years as the gold standard for verification of the patient set-up [3, 4, 5, 6]. In the last few years, 3D imaging techniques which enable verification of the patient set-up immediately before treatment have become more widely available in clinical practice. Several systems are now in use including: the "CT on rails" (CTonR) system, the kilovoltage cone-beam CT system, and the megavoltage cone-beam CT (MVCBCT) system [7–11]. In addition, helical tomotherapy and systems that utilize two ceiling-mounted kilovoltage sources and two floor-mounted amorphous silicon flat-panel detectors are also used [12–15].

In 2006 two systems, CTVision and MVision, were installed in the Holycross Cancer Centre with a Siemens ONCOR Avant-Garde accelerator. The details on these systems are published elsewhere [8, 16, 17]. Both systems enable on-line registration of images, a planning CT, and a treatment CT obtained with either the CT on rails or the megavoltage cone-beam CT. In general, the registration of planning and treatment images can be performed with different computer applications. In our hospital, the registration procedure is performed with the Adaptive Targeting of the Syngo™ workspace (Siemens), which enables automatic and manual overlaying of images. The reproducibility and uncertainty of the registration procedure depend on at least three factors: the mechanical uncertainty of the system, the uncertainty of the image registration procedure, and in the case of manual registration, the skills of the operator. The reliability of registration also depends on the quality of images.

AIM

The aim of this work was to compare both systems in terms of the: 1) reproducibility, 2) uncertainty and 3) time needed for image registration. We were also interested in how the results of image registration depend on the experience of the user. The evaluation was performed by simulating the clinical situation for patients treated in three anatomical sites: head & neck (H&N), thorax and pelvis.

MATERIAL AND METHODS

Planning image data acquisition

All experiments were carried out with an anthropomorphic phantom (Alderson Phantom). For each experiment, a planning kV CT scan with large bore Somatom Sensation Open (Siemens) was made. The phantom was always aligned with the laser system and with the three radiopaque markers placed on the anterior, left, and right surfaces of the phantom.

The radiopaque markers were made in the form of small crosses. They were made from zinc wire. The diameter of the wire was 0.7 mm. The planning CT scans were made in three anatomical sites: in the head and neck, in the thorax and in the pelvis. The CT was acquired at slice thickness of 5 mm and slice separation of 5 mm in a region volume larger by at least 3 cm in superior and inferior directions than the treated volume. In order to evaluate the influence of the CT information density on the reproducibility and uncertainty of the matching procedure, the phantom was scanned additionally in the thorax region at slice thickness of 2 mm and slice separation of 2 mm. The 512 x 512 pixel matrix was always used for the reconstruction.

Treatment planning

The images were sent to a virtual simulation station (Syngo™ Dosimetrist) and simple treatment plans were prepared. In the H&N region, two opposed lateral fields of 15 x 15 cm^2 were used. The isocentre was placed at the level of the skull base. In the thorax region, two opposed AP–PA fields of 15 x 15 cm^2 were used to simulate the initial phase of lung cancer treatment. The isocentre was placed proximal to the parenchyma of the right lung at TH5 level. In the pelvis region, the rectangular box technique with AP–PA fields of 15 x 15 cm^2 and lateral fields of 8 x 15 cm^2 was used. The isocentre was placed at the level of the acetabulum. Then, the treatment plans were sent to Syngo™ Therapist, the application controlling the accelerator with the Adaptive Targeting module.

MV cone-beam CT and CT on rails studies

The theoretical analysis of the procedure of image registration shows that the result of image registration should not depend on the initial position of the phantom. For manual mode of registration and for CTonR this assumption is obvious. In this mode the user always moves the treatment set of images from its initial position (the images are grabbed with a mouse and moved by the operator) and tries to find the best matching of both sets of images. Therefore, after any shift of images made by the operator the initial position of both sets of images is lost.

For CTonR the initial position of the phantom is not kept constant due to rotation and movement of the phantom. In automatic mode the registration is performed with the MMI technique which should not depend on the initial position of registered objects. To confirm this theoretical conclusion the following experiment was performed. After set-up of the phantom in the treatment position the MV cone-beam CT was performed without changing the position of the phantom with respect to the isocentre. Next the phantom

Table 1. Results of image registration for different phantom shifts

		MVCBCT (mm)		
		Auto Mean ± SD	Auto Mean ± SD	Auto Mean ± SD
Expected Shift		0 mm	4 mm	8 mm
Thorax	Lat	0.5 ± 0.9	4.1 ± 0.7	8.5 ± 0.8
	Long	0.8 ± 1.3	5.8 ± 0.9	9.0 ± 1.7
	Vert	1.1 ± 1.1	4.4 ± 1.0	8.5 ± 1.0

was shifted from its initial position of minus 4 and minus 8 mm along each direction and again the MV cone-beam CT was performed. The whole procedure was repeated 10 times altogether. After each examination the image registration was made and the displacement was measured. The expected displacements should be (+0 mm, +0 mm, +0 mm), (+4 mm, +4 mm, +4 mm) and (+8 mm, +8 mm, +8 mm) respectively. In Table 1 the results of this experiment are shown. The results confirmed the assumption that the image registration does not depend on the initial position of the phantom. Therefore in all other experiments the phantom was placed in the treatment position on the treatment couch as precisely as possible and was not moved from this position (the expected shift was always zero).

In the next experiment after placing the phantom in the treatment position the MV cone-beam CT and registration with CTonR was repeated 10 times without changing the position of the phantom with respect to the isocentre. The cone-beam images were reconstructed from a set of 200 planar projections acquired in 1° steps around the phantom. In total 8 MU was delivered. The reconstructed cone-beam volume was a cylinder of 27.4 cm in height and 27.4 cm in diameter. The doses at the centres of the H&N, thorax and pelvis were 8 cGy, 7 cGy and 8 cGy respectively [18].

After finishing the experiments for MVision the couch was rotated to 180° degrees and moved towards the CT gantry (the initial position of the phantom was not changed). The CT scanning was performed by moving the CT gantry on a pair of horizontal rails. The CT scanning was repeated 10 times without changing the position of the table which was obtained after rotation of the table. The CT acquisition protocol used for treatment scanning was identical to the protocol used for planning. The image data stored in the computer running the CTonR were sent to the Syngo™ Therapist station for image registration.

In another experiment the phantom was aligned on the treatment couch and one image acquisition with either MVision or CTVision was performed. After completing the acquisition the phantom was taken out of the table. These three steps, 1) alignment of the phantom on the table, 2) acquisition of images and 3) taking the phantom out of the table, were repeated 10 times. In total 10 image data sets were obtained.

Additionally the experiment was performed for the thorax region with the planning data scanned with 2 mm slice thickness and 2 mm interval. In this case, for the CT on rails the treatment scanning was made with 2 mm slice thickness and interval. The time needed to perform each single procedure was measured.

Image registration

Each set of images acquired with either the MVCBCT or the CT on rails was registered to the appropriate set of CT planning images. There were available two methods of registration: the manual and the automatic one. The manual registration was performed by two users independently, more and less experienced.

In the case of automatic registration, the only thing the operator does is to start the process of registration and after completing it to accept or reject the result. The AT application usually needs less than 10 seconds to perform the automatic registration. In the automatic method, the images were registered using a maximization of mutual information algorithm (MMI algorithm) [19, 20]. In the current software version the rotations have been disabled (Version 2.0.125). Before the result of registration is accepted the user might go through overlaid images presented in three views: the coronal, sagittal, and frontal one. The system can display each set of images, the planning and the treatment ones, with different colour schemes.

The transparency levels can be adjusted, which helps the user in evaluating the quality of image matching. If the result is not accepted the matching may be corrected manually. In the manual mode, the registration process consisted of a series of rigid-body translations. For both methods the results of registration were presented to the user in the coronal, the sagittal and the frontal subwindow (see Figure 1 and Figure 2) in terms of shifts along the vertical, longitudinal and lateral axis of the treatment couch. The shifts describe the required shifts to place the phantom in the planning position.

The table offset is defined by the vector which joins the planning isocentre and the isocentre of the accelerator. In the case of MVision the isocentre of the accelerator is identified by the centre of rotation of the gantry. The position of the centre of rotation is measured every three months according to the procedure recommended by the vendor with a specialized geometric phantom. The description of the geometric calibration can be found in the paper published by Pouliot et al. [10]. For MVision, before the registration procedure is started, it is assumed that the planning isocentre lies at the isocentre of the accelerator. The user does not need to identify the planning isocentre. The process of identification is fully automatic. This is not the case for the CTVision. In the case of CTVision, before the start of data acquisition, the table has to be rotated and shifted. The position of the CT gantry with respect to the accelerator isocentre is known with the accuracy of not better than 3 mm.

Therefore the position of the accelerator isocentre within CT images cannot be defined automatically with sufficient certainty. The planning isocentre has to be defined by the user manually with the help of fiducial markers. Before the CT scanning three fiducial radiopaque markers were attached to the surface of the phantom (two lateral and one frontal) at the places indicated by the accelerator laser system pointing to the planning isocentre.

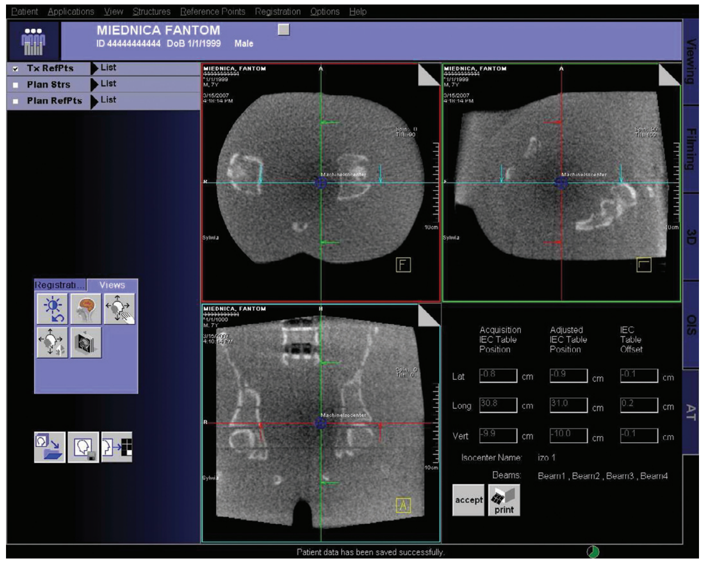

Fig. 1. Main screen of the Adaptive Targeting software – Siemens Coherence Therapist Workspace. In the application, three views are presented to the user: the coronal, the sagittal and the frontal one. In the bottom right corner, the results of registration are provided. The images obtained with MVision are presented

Fig. 2. The images obtained with CTonR are presented

After scanning, the operator based on the position of the fiducial markers with the help of the two perpendicular lines pointed to the treatment isocentre of the phantom. The table offsets were always given in millimetres as integer values.

In order to evaluate the influence of operator skill and how individual decisions influence the result, the manual registration procedure was performed by two users. The first one (SZD) had used the application for more than 6 months. The second one was a young medical physicist (PCS) who was trained in using the application for less than 1 month. For the first experiment, in the case of the automatic method of registration, the results describe the reproducibility of the MMI algorithm.

Presentation of the results

The results are presented in terms of the standard deviation and the mean displacement. Let us assume that for the k-th registration the shift needed to set up the phantom in the correct position along the lateral direction is Latk (lateral table offset). The standard deviation and the mean displacements are given with the formulas:

$$SD_{Lat} = \sqrt[2]{\frac{\sum_{k=1}^{10}(Lat_k - \overline{Lat})^2}{9}}, \quad (1)$$

where

$$\overline{Lat} = \frac{\sum_{k=1}^{10} Lat_k}{10} \quad (2)$$

Similar formulas were used for longitudinal and vertical directions. The standard deviation represented the reproducibility of the procedure. In the literature this value is known as the random error for a single patient [19]. For the last two experiments, apart from the reproducibility given with formula (1), also the mean displacement given with formula (2) was used. The mean shift represented the uncertainty of the phantom positioning and is known in the literature as the systematic error for a single patient [21]. Results are given separately for both users, for each location, and separately for the manual and automatic registration procedure.

RESULTS

Results of image registration for different phantom shifts (nominal shift 0 mm, 4 mm, 8 mm) for the thorax are given in Table 1. Results of the first experiment (for single set-up of the phantom and 10 MVCBCT acquisitions – Table 2) and second experiment (for single set-up of the phantom and 10 CTonR acquisitions – Table 3) are given in terms of the standard deviation of displacement received along each axis, i.e. along the lateral, longitudinal, and vertical axes.

The MVCBCT acquisitions for single set-up of the phantom are presented in Table 2. The standard deviation was not larger than 0.5 mm for automatic registration. Higher standard deviations were obtained for the manual registration. In five cases, the standard deviation was smaller than or equal to 0.5 mm. In five cases the standard deviation was 1 mm or larger.

The CTonR acquisitions for single set-up of the phantom are presented in Table 3. The standard deviation was not larger than 0.7 mm for automatic registration. In four cases, the standard deviation was smaller than or equal to 0.5 mm. For the manual registration the standard deviation was smaller than or equal to 0.5 mm in five cases. In four cases the standard deviation was 1 mm or larger.

For the third (10 MVCBCT, the phantom was set up before each image – Table 4) and fourth (10 CTonR, the phantom was set up before each image – Table 5) experiment results are given in terms of the mean and standard deviation values of displacement along each axis, i.e. along lateral, longitudinal, and vertical axes. Results are given separately for each location, and separately for the manual and automatic registration procedure. In the first and second experiment the standard deviation reflects the reproducibility of the registration procedure. In the third and fourth experiments the standard deviation reflects both the reproducibility of the registration procedure and the differences in positioning of the phantom on the couch. In these experiments the mean value reflects the accuracy of the phantom set-up.

A comparison of reproducibility of image registration for the CT planning study performed with 2 mm and 5 mm step and slice thickness for MVCBCT and CT on rails is pro-

Table 2. Results of the first experiment (single set-up of the phantom and 10 MVCBCT acquisitions)

		Auto SD (mm)	Manual I SD (mm)	Manual II SD (mm)
H&N	Lat	0.0	0.5	0.3
	Long	0.5	0.8	0.5
	Vert	0.2	0.7	0.8
Thorax	Lat	0.25	1.6	0.5
	Long	0.0	1.3	0.6
	Vert	0.0	1.1	0.7
Pelvis	Lat	0.0	0.7	0.7
	Long	0.5	0.3	1.0
	Vert	0.0	1.0	0.9

Table 3. Results of the second experiment (single set-up of the phantom and 10 CTonR acquisitions)

		Auto SD (mm)	Manual I SD (mm)	Manual II SD (mm)
H&N	Lat	0.25	0.5	0.5
	Long	0.75	0.9	0.8
	Vert	0.50	0.9	0.7
Thorax	Lat	0.45	1.2	0.5
	Long	0.70	1.4	0.9
	Vert	0.50	0.8	0.8
Pelvis	Lat	0.65	0.7	0.5
	Long	0.70	1.1	0.5
	Vert	0.75	1.1	0.6

vided in Table 6 and Table 7 respectively. The comparison did not reveal large differences between the data obtained with 2 mm and 5 mm step.

DISCUSSION

In the experiments the anthropomorphic phantom was set up on the treatment couch once the reproducibility of the registration procedure, performed either automatically or manually, was evaluated. In each single case the manual registration was carried out by two users, one more experienced and one less experienced. For MVision the image registration was robust for location and for direction (see Table 2). For automatic registration, the standard deviation was not larger than 0.5 mm. The results show that the automatic registration is very reproducible. Higher standard deviations were obtained for the manual registration. Only in 2 cases was the standard deviation smaller than 0.5 mm. In four other cases the results were very close to 0.5 mm. In five cases the standard deviation was 1 mm or larger. The mean values of the SD calculated for all locations and directions were 0.2 mm and 0.8 mm for automatic and manual registration respectively.

For CTVision, there was no difference between the automatic and manual procedure (see Table 3). The mean values of the SD were 0.7 mm and 0.8 mm respectively. For the automatic procedure, in only two cases were standard deviations smaller than 0.5 mm. The

Table 4. Results for the third experiment (10 MVCBCT, the phantom was set up before each image acquisition)

		Auto Mean ± SD (mm)	Manual I Mean ± SD (mm)	Manual II Mean ± SD (mm)
H&N	Lat	0.4 ± 0.5	0.8 ± 0.9	0.2 ± 0.4
	Long	–2.0 ± 0.0	–1.8 ± 0.6	–2.2 ± 0.6
	Vert	–0.5 ± 0.5	–1.0 ± 0.7	–0.7 ± 0.7
Thorax	Lat	–2.5 ± 0.9	–0.9 ± 0.7	–0.9 ± 1.2
	Long	–1.1 ± 0.5	1.2 ± 0.8	–0.6 ± 1.3
	Vert	1.1 ± 1.1	–0.8 ± 1.2	–1.9 ± 1.0
Pelvis	Lat	–1.0 ± 0.3	1.0 ± 0.8	0.9 ± 0.6
	Long	1.7 ± 0.5	0.9 ± 0.7	1.5 ± 0.5
	Vert	–1.8 ± 0.4	–2.2 ± 0.6	–2.3 ± 0.5

Table 5. Results for the third experiment (10 CTonR, the phantom was set up before each image acquisition)

		Auto Mean ± SD (mm)	Manual I Mean ± SD (mm)	Manual II Mean ± SD (mm)
H&N	Lat	0.8 ± 0.6	0.7 ± 0.7	0.4 ± 0.5
	Long	–1.3 ± 0.6	–1.1 ± 1.0	–2.2 ± 0.8
	Vert	0.6 ± 0.5	0.7 ± 0.5	0.4 ± 0.8
Thorax	Lat	–1.1 ± 0.9	–0.7 ± 1.2	–0.5 ± 0.5
	Long	1.7 ± 0.6	1.5 ± 1.4	1.7 ± 1.3
	Vert	–1.7 ± 0.5	–1.5 ± 1.2	–2.3 ± 0.7
Pelvis	Lat	–1.7 ± 0.7	–0.3 ± 1.3	–1.8 ± 0.8
	Long	1.4 ± 1.3	1.0 ± 1.9	2.1 ± 1.8
	Vert	–1.0 ± 0.7	–0.8 ± 0.8	–1.0 ± 0.9

main reason for having larger SDs for the CT on rails than for MVision, and for the automatic method, was the necessity of manual identification of the isocentre with the help of fiducial markers. In the case of MVision the planning isocentre was identified automatically. The position of the isocentre is identified with the centre of rotation of the gantry. For CTVision the isocentre was identified with the help of three radiopaque crosses. These zinc crosses were seen in the image as a circle of almost 5 mm diameter. This caused identification of the isocentre to be less reproducible. For CTVision to improve the reproducibility of image registration a more precise procedure of identification of the isocentre should be established.

All experiments were carried out with an anthropomorphic phantom which is constructed from homogeneous material imitating soft tissue. Therefore, in all experiments, the procedure of manual registration of either MV or kV images was mostly based on bony anatomical structures. In a real clinical situation, one may expect that soft tissues would influence the registration procedure, which on one hand would favour CTVision over MVision and on the other hand would make the registration result more difficult. Internal organ movements, changes of the external contour of the

Table 6. Comparison of reproducibility of image registration for CT planning study performed with 2 mm and 5 mm step and slice thickness for MVCBCT

		MVCBCT (mm)			
Average value of results obtained by 2 observers		**Auto 2 mm SD**	**Auto 5 mm SD**	**Manual 2 mm SD**	**Manual 5 mm SD**
Thorax	Lat	0.65	0.00	0.70	0.95
	Long	1.50	0.35	0.65	1.25
	Vert	1.20	0.50	0.65	0.70

Table 7. Comparison of reproducibility of image registration for CT planning study performed with 2 mm and 5 mm step and slice thickness for CTonR

		CTonR (mm)			
		Auto 2 mm SD	**Auto 5 mm SD**	**Manual 2 mm SD**	**Manual 5 mm SD**
Thorax	Lat	0.75	0.75	1.00	0.65
	Long	0.80	0.60	0.65	1.35
	Vert	0.60	0.50	0.45	0.95

body and other factors would make the registration more complex.

The MMI registration procedure, applied for rigid bodies, works quite well. The MMI registration method is implemented as a global one, i.e. all the voxels take part in registration. The manual method of registration gives the user a chance to register images locally. The user may focus on the chosen part of the body, thus neglecting the rest of the image information. For local registration, usually soft tissue based, good quality of images is a crucial point. Therefore, in our opinion, for local registration the use of the MV images may be more difficult. The authors' experience with clinical application of the system for local soft tissue registration (mostly for prostate patients) revealed that such registration may be performed only off-line. The on-line registration procedure is too long to be clinically acceptable. All these facts should be kept in mind when interpreting the results obtained from the registration procedure in which a rigid body phantom was used. It should be emphasized that in the current version of Syngo™ AT application the local registration may be performed only manually.

In the next experiment, the anthropomorphic phantom was manually placed on the treatment couch 10 times and scanned after each set-up. Results are given in Tables 4 and 5. The experiment simulates a real clinical situation. No significant differences were obtained for automatic and manual registration methods for MVision and CTVision. For MVision, unexpectedly large differences between planned and treatment position of the phantom were obtained in each location in one of the three directions. For the H&N and longitudinal direction, the mean difference between planned and treatment position was close to 2 millimetres. For the thorax and lateral direction, and for the pelvis vertical direction, differences of almost 2 millimetres were obtained. Oliver Morin and coworkers stated that MVCBCT used with AT software has the potential to verify patient shift with sub-millimetre precision [11]. In their work the uncertainty of the system was measured with a phantom with three embedded gold seeds. In our opinion the uncertainty of the registration is larger. The first source of the systematic uncertainty is the geometric calibration of the system. In the calibration procedure, the geometric position of the isocentre is measured. According to vendor specification a misalignment of ±1 mm is accepted. An additional source of the systematic error comes from the fact that the result of registration is given in millimetres. It means that the uncertainty of the offset given by the system is in the range of ±0.5 mm. The last important component of the uncertainty is the random error made in the registration procedure. In the first experiment, it was found that for MVision for automatic and manual registration for single set-up two standard deviations were 0.4 mm and 1.6 mm respectively. For CTonR for automatic and manual registration methods the uncertainties given in terms of two standard deviations were 1.4 mm and 1.6 mm respectively. To summarize, the uncertainty of a single measurement for automatic and manual methods may reach the values of 1.5 mm and 2 mm respectively. Similar estimations of the uncertainty of the method for MVision and Syngo™ AT were obtained by Gayou and Miften. 19 In their opinion, the registration software is accurate within 2 mm in each direction. Wong 13 and coworkers evaluated total positional accuracy of CTVision to within 2 mm. The precision of the positioning of the phantom on the treatment couch is limited by the finite precision of the alignment of a laser system. In our department, the laser system is checked weekly and the action level is ±1.0 mm. Therefore if one accounts for the uncertainty of the registration and the uncertainty of the phantom set-up, it is likely that the difference between planned and actual position of the phantom is close to 2 mm.

The question how the reliability of manual registration depends on the experience of the user was also assessed in our paper. The results obtained in the third experiment showed that there was a rather small difference between the more and the less experienced user. For CTonR in two cases the difference between the mean value of displacement was larger than 1 mm (pelvis vertical and longitudinal). However, a slightly larger influence of user experience on the reliability of the manual registration procedure may be expected in real clinical situations. Due to changes of the shape and position of internal anatomical structures relative to each other, the matching might not be as easy as for the phantom. Moreover, in clinical situations, manual registration has to be done relatively fast, which also may affect the accuracy.

Another question raised in this work was how the reproducibility of the procedure depends on the CT planning slice thickness and separation (see Table 6 and Table 7). For MVision (Table 6), and if the automatic procedure was applied, the reproducibility was worse for the CT data collected at 2 mm thickness and 2 mm separation. For all directions the standard deviation for the 2 mm step is at least two times larger than for the 5 mm step. The authors cannot explain why the results for the 2 mm step are worse than for the 5 mm step. Answering this question requires more details on implementation of the MMI algorithm, which are not accessible for the users. In the case of manual registration the results for both planning CT data with 2 and 5 mm were similar. However, in our subjective opinion using the fine CT data made the registration easier. For CT on rails (Table 7) and if the automatic procedure was applied for both planning CT data with 2 mm and 5 mm steps, the reproducibility of the registration did not differ. Morin [11] and co-workers showed that a fine sequential 1 mm and 3 mm slice thickness gave a standard deviation of the difference between the applied shift and the measured shift of 0.4 mm and 0.9 mm respectively. In their paper there was no detailed information on the experiment, so it was difficult to compare the two values. The manual registration plays a very important role in local registration. Using fine CT seems to be advisable if local registration is planned.

In the case of CTVision, the mechanical accuracy of treatment couch positioning is important in the reliability of registration. The rotational accuracy of the table was evaluated by Uematsu [23] and co-workers to 0.5 mm and by Kuriyama [24] and co-workers to 0.4 mm. Such a small error in positioning of the table has negligible influence on the image registration. However, the necessity of table rotation and manual identification of the position of the isocentre makes the procedure longer.

CONCLUSION

In conclusion, both systems, MVision and CT-Vision, ensure reliable data acquisition for image registration based on bony anatomy with uncertainty of about 2 mm. The reproducibility of the registration performed with CTVision is deteriorated by the necessity of manual identification of the isocentre. The automatic image registration method implemented in the Adaptive Targeting Module of the Syngo™ workspace enables the reliable global registration of planned and treatment images. For CTVision there is no difference between the reproducibility of the procedure based on CT data acquired at 2 mm slice thickness and 2 mm slice separation and 5 mm slice thickness and 5 mm slice separation. For MVision and automatic procedure better reproducibility was obtained for the CT data acquired with the 5 mm protocol.

References

1. Hurkmans CW, Remeijer P, Lebesque JV, Mijnheer BJ: Set-up verification using portal imaging; review of current clinical practice. Radiother Oncol 2001; 58: 105–20
2. Craig T, Battista J, Moiseenko V, Van Dyk J: Considerations for the implementation of target volume protocols in radiation therapy. Int J Radiat Oncol Biol Phys 2001; 49: 241–50
3. Herman MG, Balter JM, Jaffray DA et al: Clinical use of electronic portal imaging: report of AAPM radiation therapy committee task group 58. Med Phys 2001; 28: 712–37
4. Dąbrowski A, Kukołowicz PF, Paczkowski N: Time trend of setup deviations during irradiation of patients with breast, prostate and gynecologic cancers. Rep Pract Oncol Radiother 2004; 9(S2): 291–1
5. Kukołowicz PF, Dąbrowski A, Gut P, Chmielewski L, Wieczorek A, Kędzierawski P: Evaluation of set-up deviations during the irradiation of patients suffering from breast cancer treated with two different techniques. Rep Pract Oncol Radiother 2004; 9(S2): 240
6. Milecki P, Nawrocki S, Malicki J, Stryczyńska G: Evaluation of an electronic portal imaging device (target view, GE) as a quality assurance tool. Rep Pract Oncol Radiother 2001; 6(4): 169–72
7. Kuriyama K, Onishin H, Sano et al: A new irradiation unit constructed of self-moving gantry-CT and linac. Int J Radiat Oncol Biol Phys 2003; 55(2): 428-35
8. Ma CM, Paskalev K: In-room CT techniques for image-guided radiation therapy. Med Dosim 2006; 31: 30–9
9. Jaffray D, Siewerdsen JH, Draka DG: Flat-panel cone-beam tomography for image-guided radiation therapy. Int J Radiat Oncol Biol Phys 2002; 53: 1337–49
10. Pouliot J, Aubin M, Verhey L et al: Low dose megavoltage CT cone beam reconstruction for patient alignment. Proceedings of the Seventh International Workshop on Electronic PortalImaging -EPI2K2; 2002 Jun; Vancouver, BC, Canada
11. Morin O, Gillis A, Chen J et al: Megavoltage Cone-Beam CT: System Description and Applications. Med Dos 2006; 31: 51–61
12. Simpson RG, Chen CT, Grubbs CM, Swindell W A: 4-MV CT scanner for radiation therapy: the prototype system. Med Phys 1982; 9: 574–9
13. Mackie TR Helical tomotherapy: Image-guided IMRT, Med. Phys. 2002; 29: 1332–1324
14. Yan H, Yin FF, Kim JH: A phantom study on the positioning accuracy of the Novalis Body system. Med Phys 2003; 30: 3052–60
15. Gibbs IC, Kamnerdsupaphon P, Ryu MR et al: Image-guided robotic radiosurgery for spinal metastases. Radiother Oncol 2007; 82: 185–90
16. Wong JR, Cheng CW, Grimm L, Uematsu M: Clinical implementation of the world's first Primatom, a combination of CT scanner and linear accelerator, for precise tumor targeting and treatment. Phys Med 2001;XVII: 271
17. Pouliot J, Bali-Hashemi A, Chen J: Low-Dose Megavoltage Cone-Beam CT for radiation therapy. Int J Radiat Oncol Biol Phys 2006; 61: 52–560
18. Morin O, Gillis A, Descovich M, Chen J et al: Patient dose considerations for routine megavoltage cone-beam CT imaging. Med Phys 2007; 35: 1819–27
19. Hill DLG, Batchelor PG, Holden M, Hawkes DJ: Medical image registration. Phys Med Biol 2001; 26: R1–R45
20. Pluim JPW, Maintz JBA, Viergever MA: Mutual Information Based Registration of Medical Images: A Survey. IEEE Trans Med Imaging 2003; 22(8): 986–1004
21. Byhardt RW, Cox J, Homburg A: Maximizing setup accuracy using portal images as applied to a conformal boost technique for prostatic cancer. Radiother Oncol 1992; 24: 261–27
22. Gayou A, Miften M: Commisioning and clinical implementation of mega-voltage cone beam CT system for treatment localization. Med Phys 2007; 34: 3183–92

23. Uematsu M, Fukui T, Shioda A et al: Dual computed tomography linear unit for stereotactic radiation therapy: A new approach without cranially fixated stereotactic frames. Int J Radiat Oncol Biol Phys 1996; 35(2): 587–92

24. Kuriyama KI, Onishi H, Sano N et al: A new irradiation unit constructed of self-moving gantry-CT and linac. Int J Radiat Oncol Biol Phys 2003; 55(2): 428–35