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Comparison of three immobilisation systems for radiation therapy in head and neck cancer

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To the Editor,

The aim of immobilisation in radiotherapy is to secure the patient is in the same position at each

treatment fraction. This is required in order to deliver the planned radiation doses accurately. Several publications [1–10] have characterised the uncertainties

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in positioning of head and neck (H&N) cancer patients during a full course of radiotherapy and proposed various correction procedures in order to compensate for the uncertainties during treatment [11–14]. However, the rotational setup errors are often not taken in to account or reported.

In modern radiotherapy, narrow margins and high conformity are often used to lower normal tissue complication probability (NTCP) [15–17]. To secure that these margins do not impede good tumour control probability, image-guided radiotherapy (IGRT) is performed to eliminate the systematic setup error. Daily cone beam computed tomography (CBCT) scans are becoming increasingly common to ensure high accuracy of the delivered treatment [18–20]. From this, the translational systematic and random setup errors may be corrected at each fraction and therefore play a minor role in patient positioning. However, rotational setup errors are generally insufficiently corrected through table shifts. Rotational errors are particularly of concern in the head and neck region due to the close adjacency of organs at risk, such as the spinal cord and the clinical target volume. Furthermore, continuous setup errors may require repeated CBCT after repositioning (reCBCT) which adds to the workload and reduces efficiency in treatment throughput. Therefore, immobilisation remains important in modern radiotherapy. This study investigates the precision of three commercially available immobilisation systems by measuring the random and systematic setup errors for three equal groups of H&N cancer patients.

Materials

Three commercial H&N immobilisation systems were selected for testing. Each system was used for treatment of 14 H&N patients selected consecutively. The three systems were evaluated separately during a period of 12 months, one after the other to secure confident handling procedures by the treatment staff.

Each patient group consisted of 14 H&N patients referred for radical radiation treatment. The patients were scheduled for 66–68 Gy in 33 fractions over 5½–6½ weeks. One patient was changed to semi-curative treatment with 52 Gy in 13 fractions, also in 6½ weeks. Patients in each subgroup were enrolled in the study as fast as possible. Enrolment time was less than the time for a standard treatment course. The majority of patients in the clinic were fixated in the provided immobilisation equipment ensuring that the treatment staff used the provided system on a daily basis.

Most of the patients had stage IV disease from pharyngeal sites. The three patient groups were comparable with no statistical significant differences with

regard to age (median 65.5, 60.4, and 64.4 years for systems A, B, and C, respectively), gender, or stage.

The three systems tested were: A) Orfit AIO base plate, standard neck supports and a pre-cut five-point reinforced Efficast mask fixed to the base plate with L-shaped profiles, B) Q-Fix AccuFix Cantilever Board Featherline base plate with adjustable shoulder locks, Vacfix neck support and a U-Frame Aquaplast mask for the head, and C) Aquaplast mask covering the head and shoulders, fixed to a Vacfix cushion at eight points with velcro strips. System C was the clinical system in the department at the time of the investigation. The base plates of system A and B were supplied by the two vendors, while the masks were purchased by the hospital.

The immobilisation personnel and treatment staff received one day of training for each system, provided by the vendors' application specialists.

All planning CT scans were performed on a Philips Big Bore Brilliance CT scanner, and the dose plans were produced in Pinnacle. All patients received 5–7 field 'step-and-shoot' IMRT treatment plans delivered at two Elekta Synergy MLCi accelerators.

Daily CBCT was performed prior to each treatment fraction. The clinical registration was performed on the bony structures, typically including the vertebral bodies from C1 to C6, as well as on soft tissue registration of a volume surrounding the tumour. Unless large deviations were observed between these registrations, reposition of the treatment couch was based on the translational registration from the soft tissue match for each treatment fraction. In the current study, the registrations of the bony structures were used as proxy for the immobilisation quality since these registrations are influenced to a less extent by anatomical changes during the treatment course. All registrations were performed using the clinical CBCT registration system (XVI version 4.5 from Elekta AB), which is based on optimisation of the mutual information between the CT and CBCT images within specific volumes of interest translating and rotating the images as a solid object. Translational and rotational setup errors from the bony structures were extracted from the CBCT system with in-house developed software.

For rotational setup errors of more than 3°, reposition in the immobilisation equipment of the patient was performed (as per protocol) and a new CBCT scan was acquired (reCBCT). If a reCBCT was performed, the former scan was not included in the analysis. Also the frequency of reCBCT was evaluated.

Daily CBCT data were obtained with a few exceptions yielding a total of 1344 CBCT scans for analysis. Three percent of the CBCT scans were

missed out due to technical problems with either the accelerator or with the image acquisition.

The setup error were defined as in van Herk et al. [21] for translational systematic errors ($\Sigma_{\text{translation}}$) and translational random errors ($\sigma_{\text{translation}}$), and calculated from all 14 patients in each group with all 33 fractions from each patient. The rotational systematic errors (Σ_{rotation}) and rotational random errors (σ_{rotation}) were calculated in the same way.

For each immobilisation system, the CBCT scans were divided into groups of five fractions (1–5; 6–10; 11–15; 16–20; 21–25; 26–30 and 31–33). The groups were used to study temporal evaluation of the random errors during the treatment course.

Random and systematic errors are given as one standard deviation. The uncertainty for the systematic error is calculated through bootstrap over the patients included for the given immobilisation equipment. The reported random error is the mean of the patient-specific random errors, and the uncertainty is calculated as the standard error of the patient-specific random errors (standard deviation divided by square root of the number of patients).

Statistics was performed by Student's t-test (systematic errors) and Mann-Whitney U-test for non-parametric data (random errors). P-values less than 0.05 were considered statistically significant.

Results

Translational error

For all immobilisation systems, no clinical relevant time trends were observed in $\sigma_{\text{translation_frac}}$ during the treatment course (see Supplementary Figure 1, available online at <http://informahealthcare.com/doi/abs/10.3109/0284186X.2013.813966>).

The random setup errors ($\sigma_{\text{translation}}$) for system A were less than that of system B in all directions ($p < 0.02$). System A had significant less $\sigma_{\text{translation}}$ than C in the lateral direction ($p < 0.002$), but not longitudinally or vertically (Table I).

The systematic setup errors ($\Sigma_{\text{translation}}$) were similar for all systems in the lateral and vertical directions. However, in the longitudinal, $\Sigma_{\text{translation}}$

for system A were statistical significant smaller than for B and C ($p < 0.001$) (Table I).

Rotational error

For all immobilisation systems, no clinically relevant time trends were observed in $\sigma_{\text{rotation_frac}}$ during the treatment course (see Supplementary Figure 2, available online at <http://informahealthcare.com/doi/abs/10.3109/0284186X.2013.813966>).

Random rotational setup errors (σ_{rotation}) for A were less than that of B and C for all axes ($p < 0.02$) (Table II). System C had less σ_{rotation} than B for the vertical axis ($p < 0.001$). There was no statistical difference on rotational errors between B and C for the lateral and longitudinal axes.

Systematic rotational setup errors in (Σ_{rotation}) for system A were less than that of B for the lateral and longitudinal axes (Table II). In the vertical direction, Σ_{rotation} for system B is statistically significant larger than both A and C ($p < 0.02$).

The reCBCT frequencies due to rotational errors above 3° were 6.7%, 11.6%, and 12.5% for system A, B and C, respectively. System A had significantly lower reCBCT frequency compared to B and C.

Discussion

The precision of the immobilisation equipment reported in this study is in line with results from other publications (see Supplementary Tables I and II, available online at <http://informahealthcare.com/doi/abs/10.3109/0284186X.2013.813966>). By a simple inspection none of the tested systems in the current study seem to deviate significant from the calculated mean of the listed values in the tables, indicating that the handling and evaluation of the current tested system is similar to previous studies. However, from the tables it is also seen that variations in reported values exist between institutions, fixation equipment but also between the parts of the spine used for the registration within the individual study. The later variation makes it difficult to make firm comparisons between the qualities of fixation equipment validated in different studies. Due to

Table I. Translational random and systematic setup errors. Star (*) shows values statistically better than both other systems. All units given in mm.

System	$\sigma_{\text{translation}}$			$\Sigma_{\text{translation}}$		
	Lat.	Long.	Vert.	Lat.	Long.	Vert.
A	$0.9 \pm 0.1^*$	1.0 ± 0.1	1.3 ± 0.1	1.2 ± 0.2	$1.0 \pm 0.1^*$	1.9 ± 0.3
B	1.7 ± 0.2	2.4 ± 0.2	2.1 ± 0.3	1.1 ± 0.1	2.4 ± 0.4	2.6 ± 0.5
C	1.4 ± 0.1	1.2 ± 0.1	1.8 ± 0.3	1.3 ± 0.2	1.9 ± 0.2	2.5 ± 0.4

Table II. Rotational random and systematic setup errors. Star (*) shows values statistically better than both other systems. All units given in degrees.

System	σ_{rotation}			Σ_{rotation}		
	Lat.	Long.	Vert.	Lat.	Long.	Vert.
A	$0.7 \pm 0.1^*$	$0.8 \pm 0.04^*$	$0.5 \pm 0.04^*$	1.1 ± 0.3	1.0 ± 0.2	0.5 ± 0.2
B	1.2 ± 0.1	1.1 ± 0.1	1.3 ± 0.1	1.0 ± 0.2	1.3 ± 0.4	1.1 ± 0.2
C	1.1 ± 0.1	1.0 ± 0.1	0.8 ± 0.04	1.3 ± 0.2	1.0 ± 0.2	0.6 ± 0.2

the variation related to use of different registration volumes repositioning of the patient at each treatment fraction without deformation of the neck (e.g. flexion) is of concern and calls for high quality immobilisation equipment not only in relation to translations but also rotations. Deformable registration is not a standard clinical tool and no obvious way is available to compensate for any deformation. Thus, in the current study the evaluation was based on rigid registration which can directly be used clinically to correct the patient position. In contrast to previous studies (see Supplementary Tables I and II, available online at <http://informahealthcare.com/doi/abs/10.3109/0284186X.2013.813966>), the current study aimed at comparing three different immobilisation equipment systems within the same institution such that a direct comparison, with reduced bias from local handling and evaluation of the immobilisation equipment, is obtained.

The reCBCT frequency is closely related to σ_{rotation} and Σ_{rotation} , hence the risk of reCBCT will be higher with larger σ_{rotation} and Σ_{rotation} . In daily practice, the reduction of the number of reCBCTs by changing from system C to A is roughly two scans for a total treatment schedule of 33 fractions. This accounts for approximately 10–15 minutes per patient.

System A provides an opportunity for improved treatment precision. Tight margins are of utmost importance if future high precision treatment strategies should be applied such as dose painting of small tumour volumes, say of hypoxic regions. The success of such treatment techniques therefore rely on precise immobilisation.

In the current clinical setting, head and neck immobilisation system A shows a significantly higher precision than system B and C with respect to random errors in rotations for all three axes as well as for random errors in translations in the lateral direction compared with C, and lower than B in all translational directions. The vertical systematic translational error of A is more precise than both B and C. The systematic rotational error for the vertical axis of B is less precise than A and C. In addition, B and C required more frequent reCBCTs than A demonstrating superiority of positioning of head and neck patients during radiotherapy. System A is now implemented for H&N and brain tumours in the clinic and is also used for stereotactic radiosurgery.

Declaration of interest: The authors report no conflicts of interest. The authors alone are responsible for the content and writing of the paper.

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Supplementary material available online

Supplementary Figures 1–2

Supplementary Tables I–II