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Measurement of the immobilisation efficacy of a head fixation system

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Background: In order to assign appropriate planning target volume (PTV) margins, each centre should measure the patient positioning deviations for their set-up techniques. At the Royal Marsden Hospital, UK, a conformal shell (cast) system is used when a stereotactic frame is not suitable. In this paper, we report on a series of measurements with the aim of obtaining the systematic and random components of positioning error when using the above-mentioned shell system. ***Materials and Methods:*** The verification protocol was based on orthogonal pairs of anterior-posterior and lateral electronic portal images (EPIs) used to check the isocentre position. The isocentre verification results of paediatric patients were analysed. A practical 'off-line' patient set-up correction strategy had been used with the aim of reducing systematic errors. The verification protocol involved EPI acquisition on the first three fractions and then on a weekly basis. Additional images were taken if an isocentre movement was applied based on a 3 mm tolerance for a consistent 1D discrepancy. ***Results:*** Four patients required isocentre corrections ranging between 2 mm and 4 mm. Following the off-line corrections, the residual systematic errors in each direction were within 0.5 mm while the 1D random variation was about 1.0 mm. ***Conclusion:*** The head fixation system in conjunction with the correction strategy successfully kept the random and systematic positioning errors within an acceptable level well within the 3 mm tolerance. The measured components of positioning error can be used to define appropriate PTV margins. ***Iran. J. Radiat. Res., 2006; 4 (1): 1-6***

Keywords: *Treatment verification, patient immobilisation, head fixation devices, electronic portal imaging, patient positioning correction, brain radiotherapy.*

INTRODUCTION

Image-based, on-treatment verification is increasingly becoming an indispensable aspect of modern radiotherapy. Portal imaging has been the most widely used method of on-treatment verification for many years [1, 2]. Portal imaging uses the beam of the treatment machine itself to get an image of the patient exactly in the treatment position, in order to verify the patient/target position or to correct patient set-up errors.

Conventionally, port films were used for patient positioning verification purposes. Port films, however, had several limitations including the need for a film processor, time needed to process the film and relatively poor image quality. Further, unless port films were digitised, digital image enhancement cannot be used and it is also difficult to obtain accurate quantitative information on the patient's position. To overcome the majority of these problems, electronic portal imaging devices (EPIDs) were developed. Since their commercial introduction in the late 1980s, the use of EPIDs has become increasingly widespread. A relatively recent review of EPIDs is given by Antonuk [2].

EPIDs provide useful patient positioning information that is required when deciding on the margin to be added to the clinical target volume (CTV) to obtain the planning target volume (PTV) [3, 4]. Patient positioning errors have two components: a systematic component resulting in the same deviation in the same direction for every imaged fraction and a random component that changes from day to day.

Benign or low-grade childhood brain tumours are normally treated at the Royal Marsden Hospital, UK, with the patient immobilised in a stereotactic frame [5, 6]. However, a conformal shell system is used when a stereotactic frame is not suitable [5].

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In this paper, we report on the reproducibility of patient set-up with the shell, based on orthogonal pairs of anterior-posterior (AP) and lateral electronic portal images (EPIs) used to verify the isocentre position.

The aim of this work was to obtain the systematic and random components of positioning error. The ultimate goal is to obtain a margin, relevant to our patient set-up technique, for adding to the CTV in order to define the PTV.

MATERIALS AND METHODS

Figure 1 shows the conformal shell system comprising a vacuum-formed, clear plastic shell (cast) which extends below the chin to reduce cranio-caudal tilt and a personalised VacFix®bag formed at the mould room session, which extends under the head, neck and upper body. This shell system can be used in conjunction with general anaesthetic (for patients who require them) or for patients who cannot tolerate a stereotactic frame.

The EPIs were acquired and checked using a Cablon Theraview®system (figure 2). This



Figure 2. The Cablon Theraview EPID attached to an Elekta SL15 linear accelerator.

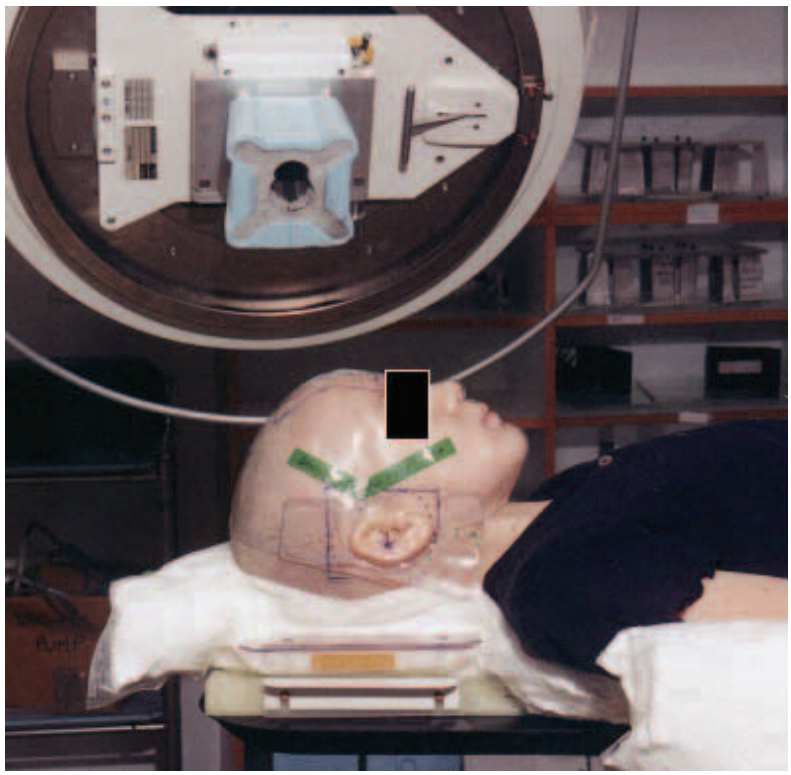

Figure 1. A patient immobilised in the conformal shell system. Also shown is the high-precision, in-house blocking system attached to the head of a linear accelerator.

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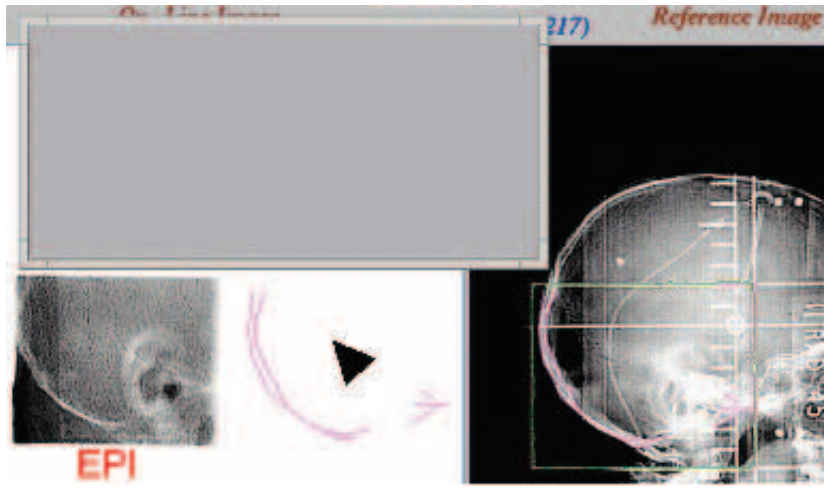
EPID uses a metal-plate-and-phosphor-screen detector, the optical image formed by which is viewed by a camera and lens combination through a 45 degree planar mirror [2].

Figure 3 shows the process of isocentre verification in the case of a right-lateral EPI. In addition to the 1D deviation in each direction, the resultant 2D error in that image is also calculated. At the Royal Marsden Hospital, portal images are checked by the treatment radiographers (therapy technologists) with a review by clinicians at a weekly audit meeting.

The isocentre verification results of fourteen paediatric patients were analysed. Their ages varied between 1 and 16 years old (median = 8, mean = 9, standard deviation = 5). All patients had 30 treatment fractions. The verification protocol involved EPI acquisition on the first three fractions and then on a weekly basis. Additional images were taken if an isocentre movement was applied based on a 3 mm tolerance for a consistent 1D discrepancy. EPIs were acquired on 8-12 fractions.

The EPIs were checked against digitally reconstructed radiographs (DRRs) directly or



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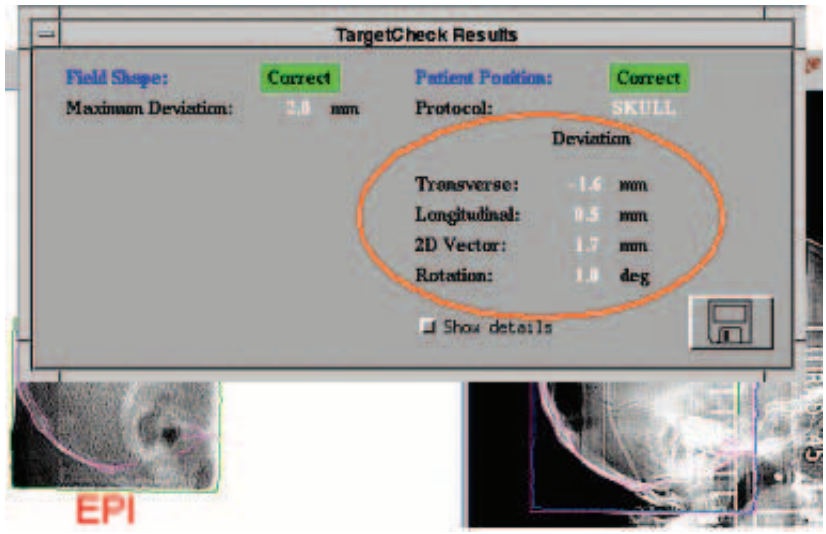

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Figure 3. The isocentre verification process using the Theraview software following the user definition of the isocentre position on the reference image. (a) Drawing the anatomical template and dragging it onto the EPI. (b) Matching the anatomical template to the corresponding bony structures in the EPI and the resulting field displacement values computed by the system.

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versus digitised simulator films, which in turn had been compared with DRRs to remove any systematic errors occurring at simulation. The data presented here includes corrections for systematic differences between DRRs and simulator films.

The data was analysed in three ways:

1) The actual treatment verification history including any isocentre corrections gave the *overall error*, i.e., a measure of the remaining discrepancy from DRR having made corrections for out-of-tolerance errors.
2) Deviations about the mean position at each isocentre location gave the *random error*, a measure of the efficacy of the immobilisation system and the consistency of the treatment machine set-up parameters through a course of radiotherapy.
3) Considering the mean of the positions (as opposed to the magnitudes) of the set-up discrepancies relative to DRRs gave the *systematic error*, i.e., a residual transfer error.

Deviations in 3D were calculated using an average of the cranio-caudal distances from the two beams in conjunction with each AP and left-right value. The quoted plus-or-minus figures are 95% confidence intervals.

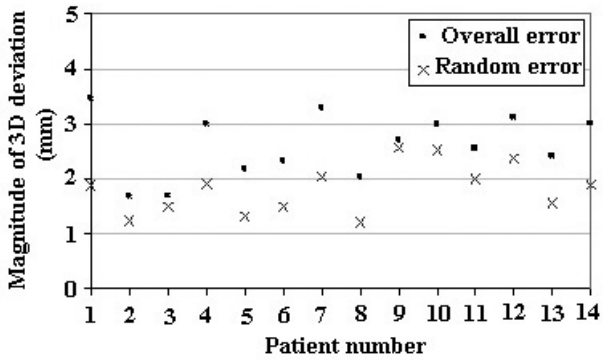

Figure 4. Mean 3D overall and random errors for individual patients shown in chronological order.

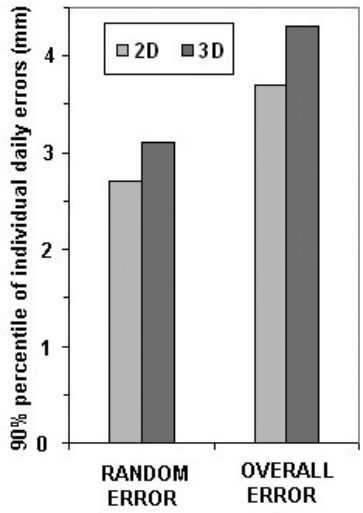

Figure 5. The 90% percentiles of the individual daily 2D and 3D deviations for random and overall errors.

RESULTS

Individual patients

We first present the results for individual patients. Four out of the fourteen patients (29%) required isocentre corrections, which ranged between 2 mm and 4 mm.

Absolute magnitudes of deviations in 3D for individual patients are shown in figure 4 for both overall and random errors. It can be seen that the mean 3D overall errors for individual patients were within 3.5 mm.

Figure 5 shows the 90% percentiles of all of the individual daily deviations, the values for 2D random and overall errors being 2.7 mm and 3.7 mm respectively. The corresponding 3D 90% percentiles were 3.1 mm and 4.3 mm respectively.

Patient averages

We next present the results averaged over all patients. The mean 1D random error along each principal axis ranged between 0.9 mm and 1.1 mm.

The resulting mean 2D and 3D random errors were 1.6±0.2 mm and 1.8±0.2 mm respectively while the overall errors in 2D and 3D were 2.2±0.2 mm and 2.6±0.2 mm respectively (figure 6).

The 90% percentiles of the random component of individual 2D and 3D daily results were 2.7 mm and 3.1 mm respectively.

The residual 1D systematic errors in the AP, left-right and cranio-caudal directions were <0.1 mm, 0.5 mm and 0.3 mm, respectively.

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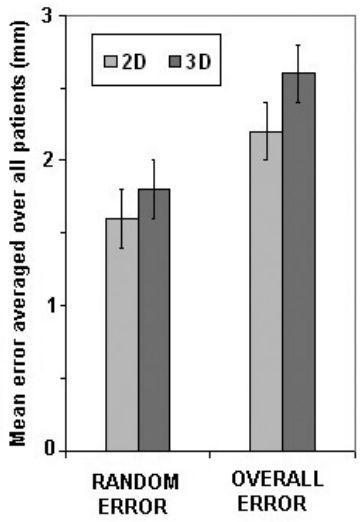

Figure 6. Mean 2D and 3D random and overall errors averaged over all patients.

DISCUSSION

We have adopted a patient positioning verification protocol, which checks the position of the isocentre with respect to bony anatomy visible in orthogonal pairs of AP and lateral verification fields. We do not use the actual treatment fields to verify the patient's position for two reasons: (1) The treatment fields for benign and low-grade brain tumours are small and often do not contain much anatomical information, and (2) the treatment beams are usually non-coplanar and approach from oblique angles, which means that any 1D or 2D deviation derived from such images will be difficult to correct for using the movements possible with radiotherapy treatment couches. We, however, check the shapes and sizes of all treatment fields by comparing their light fields against beam's eye view printouts and taking an EPI during the first treatment fraction.

We use an 'off-line' set-up correction strategy, which tries to reduce systematic errors only. Reducing systematic errors has a major influence on the CTV-to-PTV margin required [3, 4]. In the off-line method, the patient is imaged but the treatment is delivered before analysing the images, which is performed after the patient, has gone. The main alternative would have been an 'on-line' strategy, which tries to reduce both systematic and random errors. The on-line method is more time-consuming and difficult to implement in practice as it requires daily imaging and position correction before delivering each treatment.

Our off-line correction strategy was shown here to reduce the systematic error to within 0.5 mm, which is acceptable. Possible sources of systematic errors may be patient-related (e.g., change in weight, length of hair, thickness of clothing) or hardware-related (e.g., differences in the set-up of the immobilisation system between CT/simulator and treatment units).

Following this off-line correction strategy, the random variations of about 1.0 mm in each direction were shown to be larger that the residual systematic errors. However, the impact of random errors on dose distribution (and therefore probably treatment outcome) is smaller than that of systematic errors [3, 4] because a random deviation on one fraction may compensate for the random error from the previous day to some extent.

The mean 2D random error and 90% percentile were within 0.2 mm of those measured on treatment field images for a previous group of patients treated in the shell [5], showing consistency with time.

This study is as an audit of our paediatric patients' set-up variability and the immobilisation efficacy of our head fixation system. Both simulator images and DRRs were used as reference images for comparison with EPIs because the two types of images had previously been studied and found to produce similar results [7].

In order to assign appropriate CTV-to-PTV margins, each centre should measure the patient positioning deviations for their set-up techniques. This paper demonstrated the methodology and presented the results of such a set of measurements. The measured components of positioning error can be used to define appropriate PTV margins.

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