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Original Article

An assessment of the accuracy of tattoo marks in aligning treatment fields for pelvic radiotherapy

J. Mowbray* and D. E. Bonnett**

*Radiotherapy Department, **Department of Medical Physics, University Hospitals of Leicester, Leicester Royal Infirmary, Leicester, UK

Abstract

Electronic portal imaging (EPI) has been used in the assessment of the accuracy of radiotherapy treatments in the pelvis. The daily reproducibility of any treatment is primarily dependent on the effectiveness of the set-up method. Treatments of radical planned volumes within the pelvis are subject to field placement errors (FPE) which could potentially compromise the successful outcome of radiotherapy treatment. Increasing use of shaped treatment fields to limit the dose delivered to surrounding normal tissues has prompted a more detailed examination of set-up methods.

Within the radiotherapy department at the Leicester Royal Infirmary it was noted that tattooed marks on the anterior or posterior and the lateral skin surface, marked at simulation, could not always be aligned for daily radiotherapy treatment.

An assessment of the relative merit of the anterior/posterior or the lateral tattoos in determining the isocentre position in the superior-inferior (cranio-caudal) plane is presented. This study showed that changes in the use of tattoo marks during set-up would have reduced the incidence of FPE >5 mm for a small sample group of patients. Implementation of changes in clinical practice, or research using a larger sample group is now needed to verify any improvement in accuracy using a modified treatment set-up technique.

Keywords

Pelvic radiotherapy; tattoo marks; patient alignment; electronic portal imaging

INTRODUCTION

Radiotherapy treatments are subject to field placement errors (FPE) which could potentially compromise the successful outcome of treatment. The increased use of shaped treatment fields to limit the dose delivered to surrounding normal tissues has prompted a more detailed examination of set-up methods using electronic portal imaging (EPI).[1,2] EPI is a useful tool in quantifying the effectiveness of current treatment set-up techniques. The visualisation of the treatment field highlights the importance of set-up method, and radiographers treating patients can quickly see the effect of improvement in treatment accuracy. By concentrating on specific FPEs the overall accuracy of treatment delivery can be improved systematically with the full co-operation of the staff delivering the treatments. Such improvements will allow the implementation of conformal radiotherapy treatments, and improve the overall accuracy of all radiotherapy treatments delivered. Portal imaging can be used for the immediate detection of gross error by visual comparison with X-rays taken at treatment verification.[3] It can also be used to quantify the magnitude and direction of

Correspondence to: J. Mowbray HDCR(T), FETC, Radiotherapy Department, Derby Royal Infirmary, London Road, Derby DE1 2QY

any error by use of image registration or template matching methods.[4] The results of any measurements may then be used to modify treatment delivery by adjusting the set-up parameters to make effective changes in the alignment of the isocentre relative to the external surface markings used to determine its position.

These decision making processes are readily applied to individual patients, but the use of EPI is also relevant in determining the accuracy of treatment delivery for groups of patients using specified treatment techniques and set-up methods.[5–7] Used in this way, audit of the set-up method can be carried out and the overall accuracy for all patients using a set-up method may be assessed, together with its suitability to the treatment situation.

Radiotherapy treatments within the pelvic region were highlighted as a priority since this is currently the site for clinical trials into beam conformation in order to reduce the normal tissue complication probability (NTCP), and dose escalation in order to decrease the local disease relapse rate. The emphasis has been placed on examination of specific disease sites within the pelvis, but at the Leicester Royal Infirmary it was felt that the accuracy of all radiotherapy treatments delivered with radical intent in the pelvis should be examined.

Such examination should aim to assess the suitability of the existing set-up technique to more conformal treatment methods with the aim of reducing all FPEs for the pelvis to <5 mm. The purpose of this paper is to report an investigation into the degree of accuracy achievable in the superior-inferior plane only using one such technique currently in use at the Leicester Royal Infirmary.

PRELIMINARY STUDY OF SET-UP TECHNIQUE

In the radiotherapy department at the Leicester Royal Infirmary radical planned volumes within the pelvis are treated using 3 or 4 field isocentric treatment techniques. These include tumour sites in the prostate, bladder, cervix, endometrium, vagina and rectum. Patients were positioned predominantly supine, with those for treatment to the rectum being prone. Simple head support sponges and no immobilisation was used and all patients were treated daily. The treatment and planning process for patients in this group utilises a diagnostic CT scanner, radiotherapy simulator (Varian Ximatron CX) with an Osiris™ optical patient outlining system, treatment planning system (Helax TMS), and Elekta SLi linear accelerator with networked Helax VISIR record and verify system and Theraview™ electronic portal imaging device. Treatments were planned using the simulator, Osiris™ and Helax TMS to produce a two-dimensional plan through the isocentre; or using data from the CT scanner to generate a three-dimensional treatment plan. The patients skin was marked at localisation with three tattoo points, one on the anterior or posterior skin surface and two on the opposing lateral skin surfaces. These were then used to align the patient using the laser positioning lights in the scanner, simulator and treatment rooms. The position of the isocentre for verification and treatment was defined using reference movements from these tattoos. The aim was to align all three tattoos at each stage of radiotherapy planning and treatment. Lateral tattoos were always aligned with one another. However on some occasions it was not possible to align the anterior/posterior tattoo with the laterals. Reference movements from the anterior or posterior tattoo determined the position of the isocentre in the superior-inferior and right-left planes.

EPI was used to assess the accuracy in placement of the treatment fields at weekly intervals during radiotherapy treatments. Two orthogonal views of the treatment were taken during normal treatment delivery, for comparison with reference simulator verification images. The simulator verification films were digitised into the imaging system using a Vidar™ image scanner. The Theraview™ imaging software was then used to delineate the treatment field centre and borders, with the user defining an anatomical template identifying the fixed bony structures to be used for registration to the on-line treatment image. Results of this image registration process were expressed in terms of shift of the field centre in the transverse and longitudinal directions for each image viewed.

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A preliminary study of the accuracy of current treatment set-up techniques within the radiotherapy department at the Leicester Royal Infirmary using EPI reviewed 44 patients. One image from each patient was studied which was taken during his or her first treatment week. In this way it was possible to exclude any changes that had been made to patient position following image review. Of the 44 images 13.6% had field placement errors (FPE) $\geq$ 5 mm in the transverse direction (i.e. right to left) and 25% FPE $\geq$ 5 mm in the longitudinal direction (i.e. superior-inferior direction). Some of these errors were very large as shown in the Table 1. Examination of the distribution of shifts in the longitudinal direction for these fields shows a normal distribution with an average value of 1.3 mm in the inferior direction. Figure 1 shows the distribution of longitudinal FPE (as an absolute value) for this group of patients. It was noted that the shift could be reduced by re-verification and changes in the reference movements, but rarely eliminated using the existing set-up technique.

Some investigators recommend that the first treatment is not used to assess the FPE as it is unreliable in indicating the patient position due to the additional tensions present on this occasion,[21] however other investigators did not find such trends.[1] Examination of the initial audit results showed that the distribution of FPE shifts in the superior-inferior direction was similar for the images reviewed in the first week (mean value 1.3, SD 5.6, n=44), to that achieved if all results were reviewed (mean value 1.5, SD 5.0, n=69). As the number of images for each patient reviewed varied, and some treatments may have been altered based on the results of image review, it was decided to review only one image per patient, and that the most representative would be the first.

It is generally accepted that significant variation exists in clinical practice between radiotherapy centres within the UK. One element of this variation was in how tattoo marks were interpreted to set up pelvic treatment. The literature revealed evidence to indicate the methodology to determine the isocentre in the antero-posterior plane, but no evidence of a preferred process to achieve

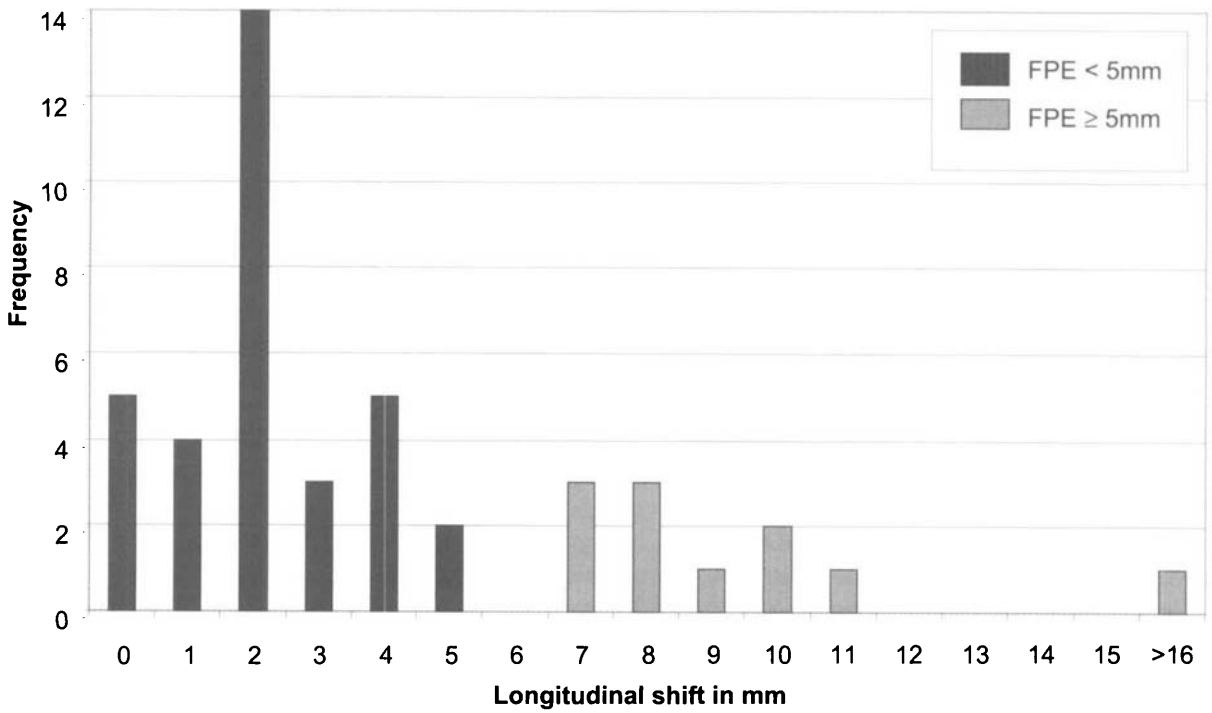

Figure 1. Frequency of field placement errors in the superior-inferior direction for planned pelvic volumes using original technique (absolute values).

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Table 1. EPI results: preliminary audit of FPE for anterior or posterior treatment fields (gantry 0°) using absolute values.

	Max	Mean	Standard deviation
Transverse	8.5 mm	2.77 mm	1.95
Longitudinal	24.5 mm	3.63 mm	4.45

precision in the superior-inferior plane.[5,8,9] It is generally recommended that detailed examination of local practise is undertaken to monitor accuracy. The hypothesis was postulated that the position of the lateral tattoos would be less subject to alteration in determining the superior-inferior location of the isocentre as opposed to a single tattoo mark on the anterior or posterior skin surface. It was proposed that the lateral tattoos represented two points in line with the approximate position of the isocentre, and as such were less subject to movement than the anterior or posterior skin surface. The degree of accuracy achievable in the superior-inferior plane only using lateral versus anterior/posterior tattoo marks is investigated.

METHOD

The sample patient group consisted of all patients with treatment plans to pelvic lesions being treated with radical intent on one linear accelerator. This data was collected during one randomly chosen working day on one treatment machine to ensure consistency of data collection. In the treatment room each patient was set up using the existing technique. Where the anterior/posterior tattoo (point B*) could not be aligned with the plane containing the lateral tattoos (plane B) the distance between these two was measured, and it was noted if point B* was inferior or superior to plane B (Fig. 2). Electronic portal images were acquired for each patient during the normal treatment beam exposure, thus requiring no additional dose to the patient. These images were reviewed retrospectively along with the measurements of anterior/posterior to lateral tattoo shift relating to them. In order to assess the accuracy of patient positioning all FPEs on the anterior or posterior portal image (gantry 0° view) were measured using the Theraview™ Target Check software. By using these measurements the actual FPE of the treatment field could be compared with the calcu-

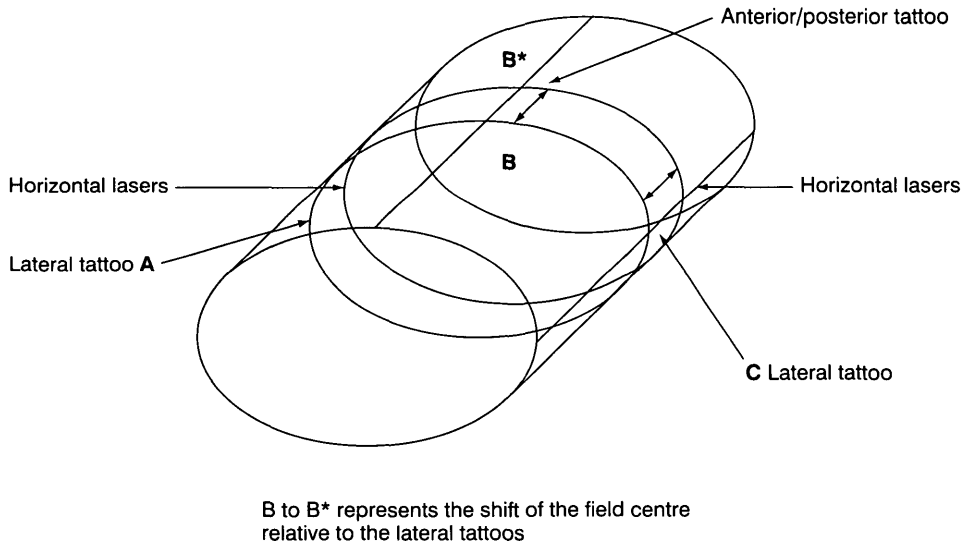

Figure 2. Relative positions of pelvic tattoos.

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lated FPE that would have resulted if the lateral tattoos had been used for superior-inferior isocentre positioning. This was achieved by measuring the FPE using the EPI in the superior-inferior direction. This measurement would then be recorded, and the measured difference in tattoo position used to calculate the shift that would have resulted if the lateral tattoos had been used to position the isocentre in this direction.

RESULTS

Sixteen patients were treated in the sample group. Three of the patients were already being positioned using lateral tattoos due to problems relating to skin creases and folds so were excluded from the data analysis. Of the remaining thirteen patients six patients would have shown improvement of the field position had the lateral tattoos been used. Five patients would have had their treatment fields placed further from the planned position had the lateral tattoos been used (Table 2), and two had no measured shift between the three tattoos. Analysis of the FPE data for the sample group was examined using paired student's t-Test. There was no significant difference in using two different methods of isocentre location ($p=0.252$) as shown in Figure 3. Analysis of the FPE data considering the distance from the isocentre, independent of direction in the superior-inferior plane, was used to detect differences of a magnitude that exceeded what was clinically achievable. Using the anterior/posterior tattoo to position the isocentre in the SI plane resulted in a mean displacement of 5.1 mm from the planned position, whereas use of the lateral tattoos would have resulted in a mean field displacement of 4.3 mm. Thus use of the lateral tattoos in all cases would result in an overall improvement of 0.8 mm in field displacement. If FPEs $\geq$5 mm are considered the current technique produced 7 errors (54%) of this magnitude, whereas use of the lateral tattoos would have reduced this to 3 (23%). To establish the effectiveness of this change a larger study would have to be undertaken. The reduction in FPE $\geq$5 mm in the sample group was considered to be of clinical significance and led to a change in practice in the treatment of planned isocentric volumes in the pelvic region. To assess the result of this change further collection of data using the Theraview™ Target Check software alone was undertaken.

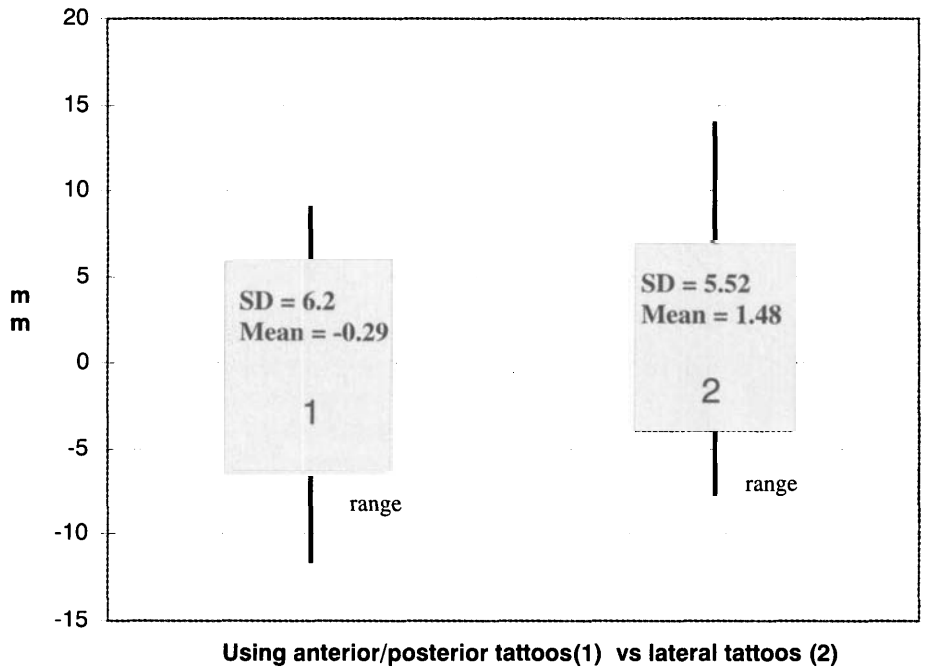

Figure 3. Distribution of FPE values for two methods of isocentre location in the superior-inferior plane.

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Table 2. Change in FPE that would have resulted from use of lateral tattoos for superior-inferior alignment of the isocentre as opposed to existing set-up technique (as calculated from the EPI result and tattoo shift).

Measured decrease in FPE on individual patients	Measured increase in FPE on individual patients
1.0	2.0
2.8	2.0
3.0	2.8
4.6	3.0
4.7	4.9
11.0	
4.5 mm (mean)	2.3 mm (mean)

Subsequent changes in technique to implement use of lateral tattoos to define isocentre location in the superior-inferior direction allowed re-audit of a similar patient group to the initial audit. By applying unpaired student's t-Test using a 95% confidence interval, and excluding one outlying value of >20 mm from each audit group, no statistically significant difference was shown between the two groups ($p=0.054$). Similar results were found when analysing the data including the outlying values ($p=0.14$). There was no significant change in the mean FPE between the two groups, but FPEs ≥5 mm were reduced from 25% to 12% (Fig. 4).

DISCUSSION

Although the ability to delineate accurately the volume to be treated has improved considerably over the last 15–20 years the ability of treatment systems to deliver treatment to that area precisely on a daily basis has been questioned.[1,10–12] In addition it is increasingly evident that society is becoming less tolerant of symptomatic late tissue changes in non-target tissues, when technical means to exclude such tissue from the treatment volume are available.[13] Increased availability of new technology will increase the likelihood that conformal methods are chosen and will have an impact on the proportion of complex radiotherapy treatments undertaken as part of the normal daily workload.

All tattoos are subject to movement due to the skin and its interdependence on the posture and position of the patient and the influence of physical and physiological factors on the patient's body. EPI image registration is based on the measurement of FPE using the bony anatomy visible within and in the vicinity of the treatment area. The accuracy of EPI is dependent on the relationship between the bony anatomy and the skin marks, and the relationship between the bony

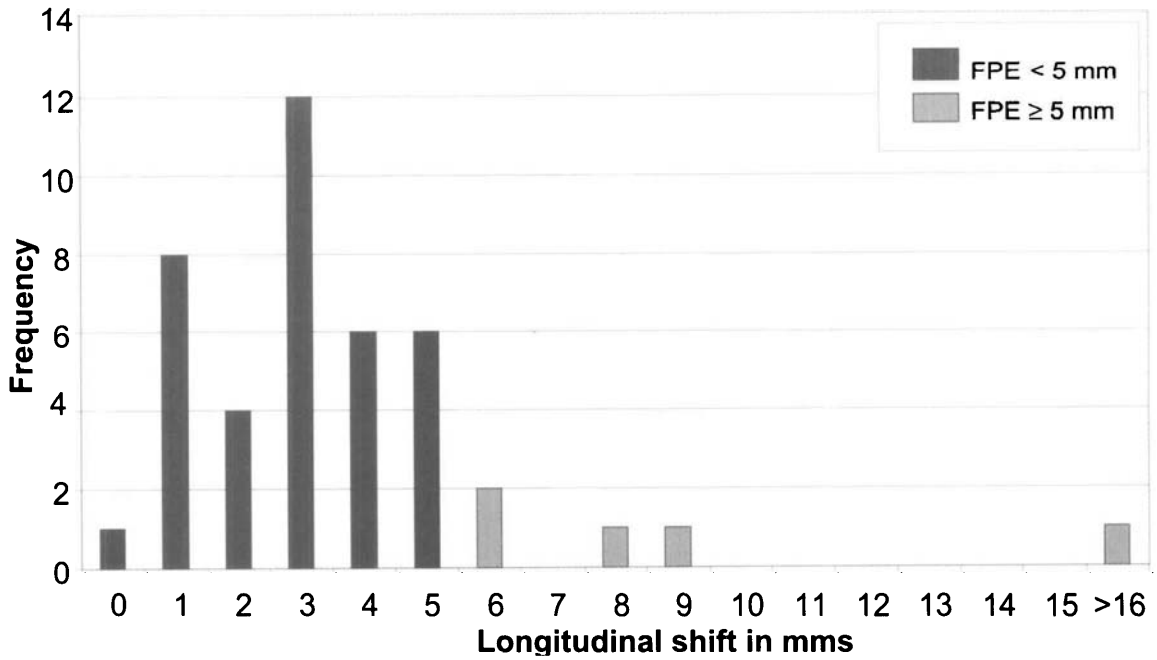

Figure 4. Frequency of field placement errors in the superior-inferior direction for planned pelvic volumes using modified technique (absolute values)

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anatomy and the soft tissue structures including the target volume, being as stable as possible during the treatment course. It is recognised that the internal soft tissue organs will be subject to positional changes during any radiotherapy treatment course.[14–20] In addition to these variations problems in seeing the skin marks due to equipment design, room lighting and patient related issues such as skin condition, colour and folds, may lead to random or systematic errors in positioning treatment fields leading to FPE in any direction. Previous study at the Leicester Royal Infirmary had shown that errors in the right left direction could be improved by use of the couch scales rather than rulers, and tattoos rather than pen marks. However, such changes had not influenced the range or magnitude of FPEs in the superior-inferior direction.

The mean, range and standard deviation were calculated using one dimensional vector changes for the initial audit group (Table 1), but the clinical significance is better represented by examination of shifts that would have been deemed clinically unacceptable. This may vary between sites with conformal prostate studies aiming for 3 mm maximum whereas FPEs of up to 10 mm may be accepted for larger treatment volumes. To assess the clinical significance of the results a threshold of 5 mm was chosen. This was considered to be clinically achievable, and an error of less than this value was considered to be acceptable.[1]

The initial audit showed that there were some relatively large FPEs arising from use of the current technique. This initial audit provided a baseline for further investigations. One possible improvement would be the use of lateral tattoos as well as the anterior/posterior in setting the isocentre. By measuring the relationship between the lateral tattoos (which were aligned with one another) and the anterior/posterior tattoo it was possible to assess if there was any correlation between alignment and FPE. A small study of 13 patients indicated that although overall differences were not significant, there was an indication that the larger FPEs ($\geq$ 5 mm) could be reduced.

It is important to note that in the ideal situation all three tattoos used for patient positioning should be in line. Written guidelines to establish the tolerance value for differences in alignment of these tattoos should be produced. Large misalignments could indicate a change in the patient position and would result in differences in the direction of FPE between treatment fields. Changes in clinical practice to tattooing the lateral skin surface markings at verification would further eliminate the need for movement in the superior-inferior direction in most cases. It is noted that there is more opportunity for human error when reference movements are undertaken from skin markers. If these reference movements can be reduced it is believed that the error rate will decrease. Further examination of the FPE results from lateral views of the pelvis should also be undertaken to establish any trends in antero-posterior field placement, as this has been identified as being the most likely parameter to show systematic differences from planning to treatment.[5–7]

CONCLUSION

As a result of this study current practice at Leicester Royal Infirmary changed to the use of lateral tattoos to define the position of the isocentre in the superior-inferior plane as opposed to a single tattoo on the anterior or posterior skin surface. The isocentre position is now tattooed at verification, as opposed to localisation, to minimise reference movements. All FPEs identified by EPI review are used to adjust radiotherapy treatment delivery according to written protocol guidelines.

It was recognised that the protocol for frequency of image acquisition required amendment in order to differentiate between random and systematic error. This would allow the correction of individual treatment parameters once more confidence in the overall treatment technique was established.

Further study is required to determine if the treatment accuracy achieved using current techniques is adequate to allow implementation of conformal therapy within the pelvis. It should also examine if a change in the size of margin allowed for patient movement and set-up error at the treatment planning stage is possible. Such study should measure the magnitude of FPE in discrete directions, and differentiate between systematic and random errors.

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