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Original Article

Set-up verification on a belly-board device using electronic portal imaging

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Abstract

Purpose: Quantification of set-up errors is necessary to assess the accuracy of patient positioning and define set-up margins. In this article, we describe the analysis of two different set-up verification and correction procedures in pelvic irradiation for rectal cancer patients treated on a belly-board device.

Methods: First, we conducted a retrospective study in ten patients. Skin marks were used for set-up and the position was verified and corrected at the start of treatment by portal imaging. Second, we analysed the implementation of a more rigorous verification and correction procedure in ten patients. The same set-up procedure was used, but verification was performed during the first three sessions and on a weekly basis thereafter. In both studies, systematic and random errors were linked with possible patient-related, treatment-unit-related and time-related factors.

Results: The pooled data showed a significant reduction in systematic and random error in favour of the second verification procedure ($p < 0.05$). This resulted in a reduction in the size of the safety margin of more than 3 mm in all directions. Time trends were significant in four patients in the first analysis and in three patients in the second analysis. In six patients in the first and seven patients in the second study, a significant correlation was found between the vertical couch movement and the antero-posterior set-up error. Analysis of patient-related factors demonstrated a relationship between the abdominal contour and rotational errors in both studies.

Conclusion: The results of these set-up analyses show that patient positioning on a belly-board device by laser alignment to skin marks is accurate and reproducible. However, in some patients we recommend the implementation of a fixed vertical couch position. The systematic error should be identified and corrected during the first fractions of treatment. Thereafter, verification should be performed at regular intervals to correct for possible time trends. Positioning of obese patients was found to be more prone to set-up errors and requires online position verification.

Keywords

Set-up verification; belly-board device; vertical couch position

INTRODUCTION

With modern radiotherapy techniques, we can achieve dose distributions that 'conform' highly to the target volume. This allows a higher dose

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to the malignant tissue without jeopardising the surrounding normal tissues. However, as conformal radiotherapy introduces dose gradients closer to the planning target volume (PTV), the risk of geographical misses is greater, potentially counteracting any benefit otherwise introduced. Therefore, an accurate definition of the safety margin (SM) around the clinical target volume (CTV) is mandatory. Moreover, a smaller SM could help avoid toxicities that previously prevented the adoption of dose escalation using conventional treatment modalities. This can be obtained only with an accurate verification and correction protocol.

An SM should include all variations and uncertainties in the position, size, shape and orientation of the tissues, the patient and the beams in relation to the common coordinate system.[1] Many authors have come up with protocols to determine an SM. A comprehensive overview of these is given by van Herk.[2]

The purpose of this study was to quantify the set-up errors in pelvic treatment for rectal cancer on a belly-board device with two different verification and correction procedures.

PATIENTS AND METHODS

Radiotherapy

All patients in this study were treated for rectal cancer with a three-field box technique and received a long course of radiotherapy to a total dose of 45–50.4 Gy in daily fractions of 1.8 Gy, 5 days a week. Patients were treated in the prone position on a belly-board device. This belly board is made of high-impact polystyrene (PI Medical Diagnostic Equipment B.V.) and contains a large aperture for the belly region and an adapted support for the symphysis and the upper legs. No other immobilisation device was used. During simulation, the isocentre was defined and marked on the patient's skin. The longitudinal position of the patient on the belly board was accepted when the horizontal strip inside the board was located at the upper level of the pubic symphysis. For reasons of reproducibility, the longitudinal isocentre position was noted on the treatment chart from the lateral ruler fixed to the belly board. This provided the same couch parameters in the longitudinal direction during the whole treatment, as the belly board is fixed to the couch.

After simulation, the patient was positioned on the computer tomography (CT) scan table by aligning the inline lateral and sagittal lasers to the skin marks. CT information was used for target volume delineation, treatment planning and construction of digitally reconstructed radiographs (DRRs) using the Eclipse treatment planning system (Varian Medical Systems). The CTV was defined as the gross tumour volume plus the areas at risk for microscopic tumour involvement.[3] The CTV was expanded to 1 cm to give the PTV.

During treatment, the patient was positioned by aligning the skin marks to the laser lines and to a fixed point on the lateral ruler on the belly board for the longitudinal positioning. After this set-up procedure, the vertical couch position was noted each day from the record-and-verify system and is defined as the distance from the isocentre to the table top (Varian Medical Systems). During treatment no special requirements were enforced for rectal filling or bladder filling.

Retrospective analysis

This analysis included ten patients in whom daily portal images (PIs) were taken during each session from both lateral fields and the posterior field. A total of 623 PIs were taken for all ten patients. At the start of treatment (day 1), the radiation oncologist verified the position using an offline qualitative comparison between the DRR and the PI. The action level for correction according to the clinical practice at that time was 5 mm. Rotational errors were not corrected. In accordance with the study design, subsequent PIs after the first fraction were not used to perform set-up corrections.

After completion of the treatment, all PIs – mean of 21 PIs per patient (min. 11; max. 25) – were analysed retrospectively by the same radiation oncologist using a semi-automatic matching procedure. This was carried out with a software program that uses semi-automatic

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Table 1. Mean (μ), systematic (Σ_{syst}) and random error (σ_{random}) for translational displacements and rotational errors

	AP (mm)	ML (mm)	CC (mm)	ROT_{SAG} (°)	ROT_{FRON} (°)
First analysis, $N = 10$					
μ	−2.3	−1.4	0.6	0.3	0.9
Σ_{syst}	3.5	2.8	2.8	1.2	1.5
σ_{random}	2.7	2.4	2.4	1.2	1.6
Second analysis, $N = 10$					
μ	−0.6	0.3	−0.4	−0.2	0.2
Σ_{syst}	2.2	1.7	1.6	0.5	0.7
σ_{random}	3.0	1.9	2.2	0.6	1.2

AP: antero-posterior; ML: medio-lateral; CC: cranio-caudal; ROT_{SAG}: rotational error around the sagittal axis; ROT_{FRON}: rotational error around the frontal axis.

alignment of anatomical structures in the DRR and the PI (Portal Vision Varian Medical Systems).[4] Results in the form of a numerical mismatch in the X and Y direction provided displacements in the medio-lateral (ML), cranio-caudal (CC) and antero-posterior (AP) directions. Rotational errors were calculated around the frontal (ML) and sagittal (AP) axis. For ML displacements, we used the X value of the posterior field (a negative value represented a shift to the left); for the CC displacements, the mean of the Y value in the two lateral fields (a negative value represented a caudal shift); and for the AP displacements, the mean of the X value in the left and the right fields (a negative value represented a posterior shift). The posterior field was not used for evaluation of the CC displacement, as rotation around the LR axis can alter the projection of the pelvic structures in the posterior field. This can cause difficulties in alignment of the anatomical structures. Clockwise rotations were displayed with a positive value.

All measurements (total of 623 PIs) were exported to an Excel file, and the mean error and the standard deviation (SD) of all errors for each patient and for the population of ten patients were calculated (Table 1). The systematic error for a patient is given by the mean (μ) of that patient's AP, ML or CC movement during treatment. For all ten patients the systematic variation was quantified by the SD of the individual systematic errors (Σ_{syst} or the distribution around the mean over all patients).[5–8] The day-to-day variation of the position can be calculated by subtracting the patient's systematic error (μ) from each daily displacement measurement. The SD of the patient's systematic error (μ) represents the random error of a patient. To calculate the random error for the total population (σ_{random}), we averaged the individual random errors.[5–8]

We also looked for possible time trends in the systematic errors during treatment. Therefore, the set-up errors were plotted against time from the start of irradiation for each of the directions analysed. The linear fit through these points (regression line) represents the trend of the set-up error with time. The slope of each linear curve or unstandardised regression coefficient was then tested for statistical significance at the 95% confidence interval. When a significant time trend was detected, we calculated the magnitude of displacement resulting from this time trend during the period of observation. Time trends have been described in patients treated for rectal cancer,[9] and different analysis methods for set-up accuracy might be necessary in these patients.

Prospective analysis: implementation of new verification and correction protocol

To achieve more accurate patient positioning, we implemented a more rigorous verification and correction procedure. During the first three sessions PIs were taken from both lateral fields and the posterior field and verified offline by the radiation oncologist. Here, the semi-automatic matching procedure was applied for verification during treatment. Translational and rotational errors were verified, but only the translational errors were corrected. An initial threshold of 7 mm was tolerated for correction of the position. After the first three fractions, the systematic error was calculated in each direction, with the action level for correction set to 3 mm. If a correction

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was necessary, additional PIs during the next two sessions were mandatory with a measured position error of $\leq$3 mm. After three fractions (or more if a correction was necessary), we verified the position once a week during the rest of the treatment and corrected the displacement when it exceeded 5 mm. Similar to the first study, all measurements (total of 269 PIs) were exported to Excel to calculate the systematic and random errors (Table 1).

To evaluate the benefit of the new protocol, we performed a pooled data analysis providing an overall mean and SD for all patient positions in both studies. Significance of the data sets was calculated using the Student's *t*-test for the mean and an *F*-test for the variances (SD). In addition, we defined an SM with the margin calculation described by van Herk et al. for both protocols (SM = $2.5\star\Sigma+0.7\star\sigma$).[10] As in the previous analysis, we looked for possible time-related shifts in translational errors.

Correlation of set-up error with patient-related and treatment-unit-related factors

Identification of patients at higher risk for set-up errors is important as they may benefit from additional set-up measurements or margin. Therefore, we evaluated the relationship between patient characteristics such as age, weight and abdominal contour, measured at the level of the umbilical point, and the likelihood of positioning errors in a given direction. As sample sizes were small, we calculated non-parametric correlation coefficients (Spearman *R* correlation coefficient[11]).

Furthermore, we addressed the benefit of a constant couch-to-isocentre distance, represented by the vertical couch position, as an additional or alternative parameter for patient positioning in the AP direction. In both analyses, the vertical couch position was recorded after aligning the laser lines to the isocentre marks on the skin. For each patient, the day-to-day AP displacement and the day-to-day vertical couch shift were calculated. The use of a fixed vertical couch position for patient positioning in the AP direction assumes that the pelvis is relatively fixed with respect to the couch. If this is the case, then the day-to-day AP shift of the patient should correlate with the day-to-day vertical couch shift. Correlations were calculated by means of the Pearson *R* correlation coefficient.

RESULTS

Retrospective analysis

The graphs in Figure 1a show the distribution of the mean treatment-to-simulation errors in the posterior and lateral fields. In Table 1, the quantitative results of the set-up errors are presented. The largest shift is seen in the AP direction, with a systematic error of 3.5 mm and a random error of 2.7 mm, with an overall posterior offset between simulation and treatment.

The time-trend analysis revealed significant time trends in four patients, in all three directions: two patients in the CC direction (patient 2: slope 0.24, 95% CI [0.009–0.476]; patient 4: slope −0.21, 95% CI [−0.298 to −0.120]), one patient in the ML direction (patient 6: slope −0.21, 95% CI [−0.421 to −0.006]) and one patient in the AP direction (patient 10: slope 0.17, 95% CI [0.016–0.325]). The magnitude of the displacement resulting from these time trends during the time of observation ranged between 4.1 mm and 5.8 mm, with a median of 5.1 mm. All patients with significant time trends were male. Other clinical characteristics such as age, weight and abdominal contour did not differ between patients with or without a significant time trend.

Prospective analysis – implementation of a new correction protocol

Figure 1b shows the distribution of the mean treatment-to-simulation errors in the lateral and posterior fields. In Table 1, the quantitative results of the set-up errors are presented. Similar to the first analysis, the largest shift is seen in the AP direction, with a systematic error of 2.2 mm and a random error of 3.0 mm and an overall posterior offset between simulation and treatment.

Analysis of the pooled data (overall mean and SD) from both studies shows a significant

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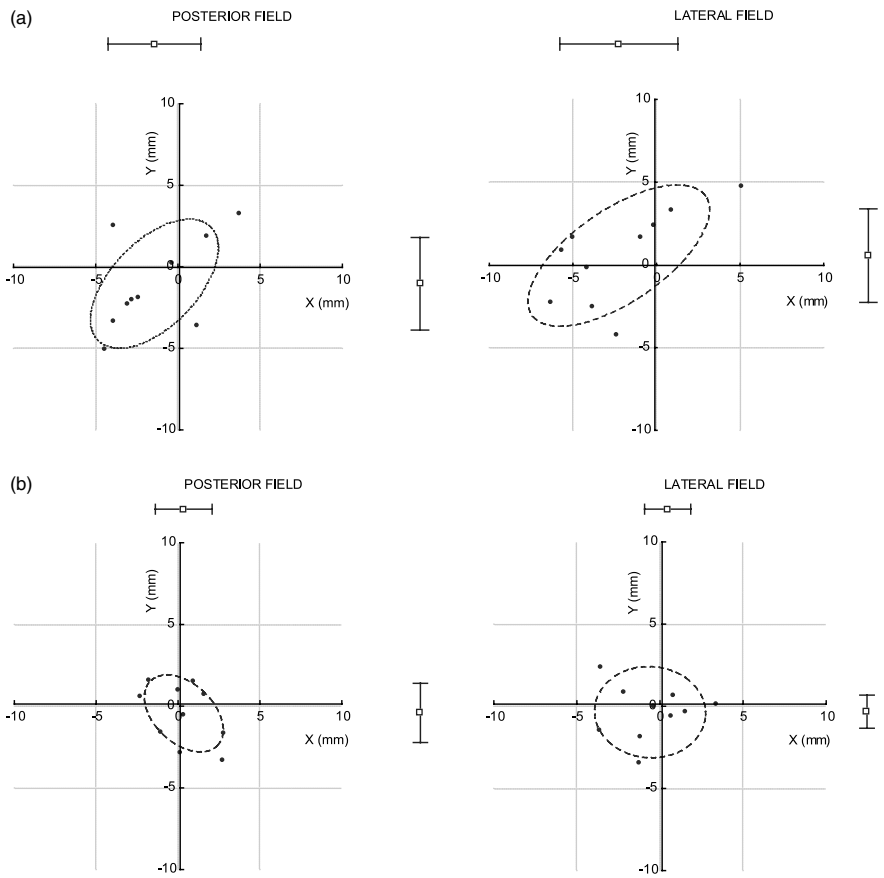

Figure 1. (a) Distribution of mean treatment-to-simulation displacement for all patients in the posterior and lateral fields for the first analysis (N = 10). Each point represents one patient. The whisker plots represent the mean over all patients (square) with one standard deviation from this mean (bars). The ellipses cover 95% of all data points. (b) Distribution of mean treatment-to-simulation displacement for all patients in the posterior and lateral fields for the second analysis (N = 10). Each point represents one patient. The whisker plots represent the mean over all patients (square) with one standard deviation from this mean (bars). The ellipses cover 95% of all data points.

reduction in systematic and random error ($p < 0.05$) (Table 2). To evaluate the clinical benefit, we defined an SM with the margin calculation proposed by van Herk et al. for both analyses.[10] A reduction of more than 3 mm in all three directions was seen (first analysis: SM AP 10.7 mm, SM ML 8.8 mm, SM CC 8.8 mm; second analysis: SM AP 7.6 cm, SM ML 5.6 mm, SM CC 5.5 mm).

Significant time trends were found in three patients, in the ML direction (patient 2: slope −0.30, 95% CI [−0.519 to −0.084]; patient 8: slope 0.14, 95% CI [0.014–0.270]) and in the AP direction (patient 9: slope −0.25, 95% CI [−4.445 to −0.059]). The resulting

Table 2. *Pooled results, significance of reduction using the Student's t-test (mean) and F-test (variances)*

	Mean (mm)	*p*	SD (mm)	*p*
First analysis				
AP	−2.6		4.2	
ML	−1.4		3.5	
CC	0.4		3.5	
ROT_{SAG}	0.2		1.7	
ROT_{FRON}	0.8		2.0	
Second analysis				
AP	−0.8	<0.001	3.8	0.27
ML	0.3	<0.0001	2.4	<0.0001
CC	−0.4	<0.05	2.8	<0.05
ROT_{SAG}	−0.2	<0.05	0.8	$<10^{-13}$
ROT_{FRON}	0.1	<0.01	1.3	<0.00001

AP: antero-posterior; ML: medio-lateral; CC: cranio-caudal; ROT_{SAG}: rotational error around the sagittal axis; ROT_{FRON}: rotational error around the frontal axis; SD: standard deviation.

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displacement during the time of observation ranged between 1.9 mm and 7.2 mm, with a median of 3.4 mm.

Analysis of the clinical data of all patients did not reveal significant correlations with the presence of time trends.

Correlation of positioning error with patient-related and treatment-unit-related factors

Patient-related factors

A significant relationship was present between the abdominal contour and the systematic rotational error around the sagittal axis and the random rotational error around the frontal axis in the first analysis (Spearman $R = 0.69$, $p < 0.05$, and Spearman $R = 0.79$, $p < 0.01$, respectively). In the second analysis, a significant correlation was found between the abdominal contour and the systematic rotational error around the frontal axis (Spearman $R = 0.64$, $p = 0.05$) and the systematic error in the ML direction (Spearman $R = 0.67$, $p < 0.05$). Variation in weight and age did not seem to affect the systematic or random set-up error in any direction.

Treatment-unit-related factors

In six of the ten patients in the first study and in seven of the ten patients in the second study, a positive correlation was found between day-to-day vertical couch shift and the day-to-day AP displacement of the patient (Figure 2, data from first analysis). In these patients, improvement in day-to-day reproducibility could be obtained by maintaining a given couch height for the vertical patient positioning instead of aligning the lateral skin marks. In the other patients (four out of ten in the first study, and three out of ten in the second study), no correlation was observed, suggesting that the pelvic bony anatomy was relatively 'mobile' in the vertical position with respect to the couch. In these patients, skin marks are more reliable for accurate positioning. Moreover, analysis of all positioning data in patients with a positive correlation revealed a significant larger random error in the AP direction than in the patients without correlation (first analysis: SD of overall mean 4.84 mm vs. 2.77 mm in patients with and without correlation respectively, $p < 0.00001$; second analysis: 4.27 mm vs. 2.47 mm, $p < 0.01$; Student's t-test). This suggests that in these patients, positioning by aligning skin marks induced random errors in the AP direction, which probably could have been anticipated by maintaining a fixed vertical couch position.

DISCUSSION

Both analyses in this study demonstrate that the systematic set-up error for pelvic treatment on a belly-board device using an offline correction protocol is within 4 mm, with an overall posterior offset or systematic difference between simulation and treatment.

Three other studies analysed positioning errors using a belly board or open table-top device. The first study reported systematic errors of 3.3 mm, 4.5 mm and 3.3 mm in the ML, AP and CC directions, respectively.[12] The second study showed a systematic error of 3.0 mm, 3.5 mm and 3.9 mm in the ML, AP and CC directions, respectively.[13] The corresponding systematic errors in the third study were 1.7 mm, 1.7 mm and 2.1 mm in the ML, AP and CC directions, respectively.[14] In the two latter studies, a correction protocol was used, whereas this was not clearly defined in the study of Rudat et al.[12] A review of set-up errors has been reported for general pelvic treatments, where nearly all patients were treated in a supine position. The systematic and random errors ranged from 1.0 mm to 3.4 mm with an SD of 3.0 mm; these were considered 'state of the art' for pelvic treatment techniques without the use of a correction protocol and irrespective of immobilisation.[15] Comparing the reviewed data with the results from Rudat et al.[12] and Allal et al.,[13] we can assume that the use of a belly-board device is associated with overall less accurate patient positioning. This was confirmed in the study by Allal et al.,[13] particularly for the AP direction, where a highly significant difference was found between patients treated in prone position with or without a belly board ($p < 0.0006$). These findings could be explained by less comfortable

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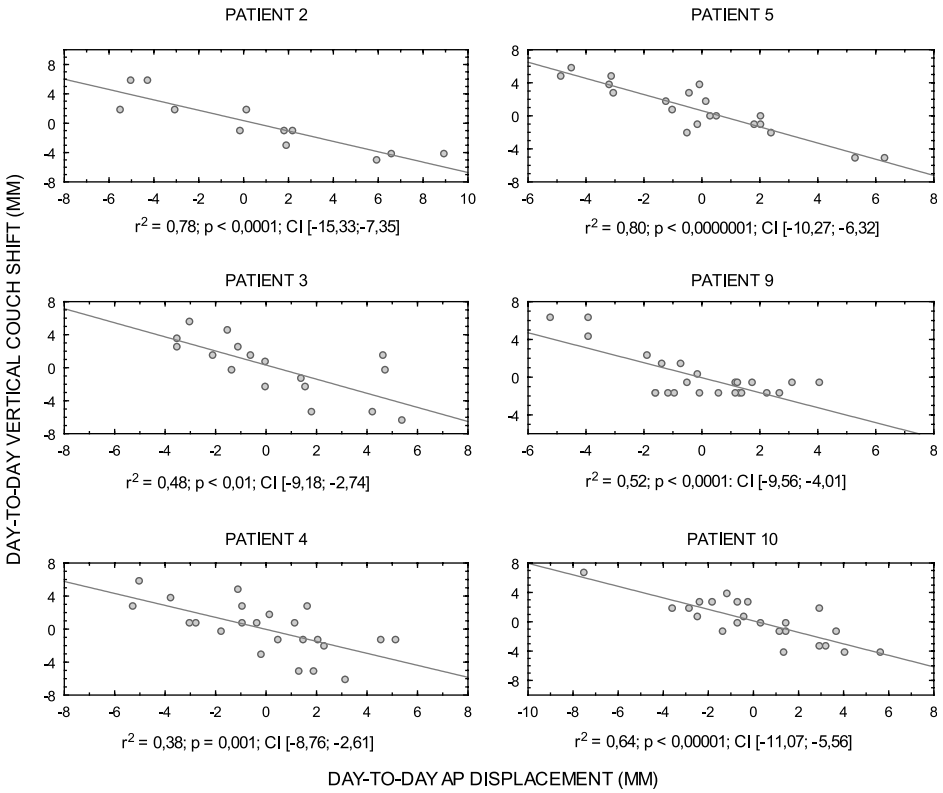

Figure 2. Correlation between the day-to-day variation in patient displacement in the AP direction (mm) and the daily vertical couch shift (mm) (first analysis).

positioning of the patient on this device, indicating that it could be useful to test immobilisation devices and/or custom-made belly-board devices to improve the set-up reproducibility.

Despite less reproducible positioning, a belly-board device is the most widely used non-surgical method for protecting small bowel during radiotherapy, resulting in a substantial decrease in gastrointestinal toxicity.[13,14,16,17]

The predominance of errors in the AP direction is mainly related to the use of skin marks to determine the isocentre height in combination with pelvic bones as a match structure. Skin movement may occur due to weight loss or relaxation of the patient and is more pronounced in the AP direction.[15]

The correlation in six out of ten patients (first analysis) and seven out of ten patients (second analysis) between the day-to-day variation of the vertical couch position and the day-to-day AP shift of the patient provides further evidence for the variability of the skin with respect to the bony anatomy and for a relative constant position of the bony pelvic structures with respect to the couch. In these patients, skin mark positioning is less reliable and a constant couch position could help in preserving a reproducible positioning. This has been suggested by Greer et al.[18] The lack of a correlation between the day-to-day variation of the vertical couch position and the day-to-day AP shift in the other patients (four in the first analysis and three in the second analysis) indicates a real shift of the bony anatomy relative to the couch, probably owing to relaxation of the patient in the belly aperture as he/she feels more comfortable during treatment. In these patients, skin marks are reliable for positioning in the AP direction. As all patients were positioned by aligning skin marks, the smaller random AP error confirmed that this set-up method was more valuable in patients with no correlation than in patients with a correlation.

Analysis of the set-up errors in relation to patient-related factors revealed a significant

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correlation between the abdominal contour and the systematic or random rotational error and the systematic error in the ML direction. Other patient-related factors, such as age and weight, were not relevant to the measured set-up errors. Although there were no major differences in the treatment of both study groups, the limited patient samples and the time interval between the two analyses prevent us from drawing firm conclusions. In two other studies on set-up errors in obese patients treated in a supine position, the greatest positioning error was found in the ML direction.[19,20] Rotational errors were not analysed. From these results and our analyses, we can conclude that obese patients are more at risk for set-up errors when skin marks are used for initial positioning, the main cause being the increased mobility of the skin relative to the bony structures, making skin marks less reliable for patient positioning. Mobility of the skin might be more pronounced at the ventral side of the patient than above the spine or coccyx. This could explain the large displacements in the ML direction that were observed in obese patients treated in a supine position[19,20] compared with the relatively small ML displacements in our patients treated in a prone position. Irrespective of the direction of the set-up error, electronic portal imaging with online verification based on bony landmarks is recommended in obese patients.

Time trends were observed in four patients in the first analysis and in three patients in the second. Time-related shifts were present in all three directions. Their presence has been explained by the change in mental status of the patient.[9] During simulation and at the start of the treatment, some patients feel uncomfortable and stressed. This emotional status can be associated with a higher muscle tension. As the treatment course continues and the patient feels more familiar with the procedure, a gradual relaxation of the muscles can occur, causing progressive displacement in a certain direction. Other reasons for time trends could be inaccurate re-inking of the skin marks by the therapist[21] or changes in rectal or bladder status.

The influence of time trends on the dose distribution is less important in a conformal three-field box technique, where an SM of 10 mm covers the resultant displacement (between 4.1 mm and 5.8 mm for the first and 1.9 mm and 7.2 mm for the second analysis). However, when more conformal techniques are introduced with smaller set-up margins, detection of significant time trends becomes of particular importance. In our study, the implementation of a rigorous verification and correction protocol, with check-ups at regular intervals during treatment, could decrease time-dependent shifts. In two out of three patients from the second analysis, the time-dependent shift could not have been corrected because the resulting shift was below the limit for correction (1.9 mm and 3.6 mm). In the third patient, the resulting shift was large (7.2 mm). Here, offline verification showed a large shift on the third day of almost 8 mm in the ML direction, which was corrected only the next day. On the first and second day, the shift was close to 5 mm, just below the threshold for correction. These two factors could explain the resulting shift in this patient. However, it should be noted that the second analysis (6–13 PIs per direction per patient) offered less data for a time-trend analysis than the first analysis (10–25 PIs per direction per patient).

A significant reduction of the set-up error using accurate verification and correction procedures may allow a reduction in set-up margin. This would be of great benefit in highly conformal treatment techniques, where escalated doses could be administered to the tumour without compromising the surrounding normal tissue. Our results confirm that a reduction of the SM by more than 3 mm is possible in all three directions. However, only treatments with a highly reproducible set-up and target position might benefit from dose escalation without an increase in major complications. Therefore, it is useful to develop verification and correction protocols that take into account patient variability.

RECOMMENDATIONS

We recommend using the individual measured set-up variation during the early phase of the treatment as a parameter for set-up variability

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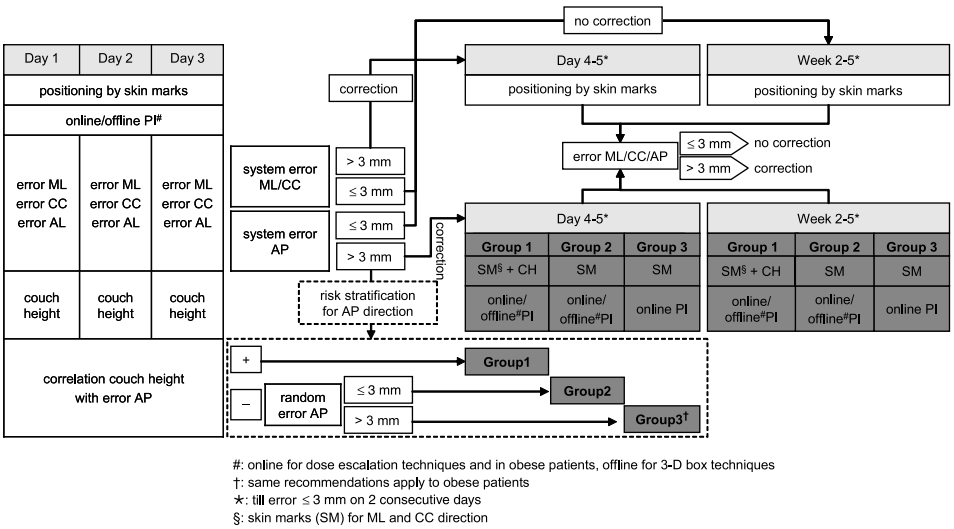

Figure 3. Schematic overview of recommended verification and correction protocol for patient positioning on a belly-board device. AP: antero-posterior; CC: cranio-caudal; CH: couch height; ML: medio-lateral; PI: portal imaging; SM: skin marks; system: systematic.

(Figure 3). During the first 3 days of treatment, the patient is positioned by aligning the skin marks to the laser lines and the vertical couch height is recorded. The position of the patient is verified with portal imaging. After 3 days, the systematic error is calculated for each direction. If the systematic error in the AP direction is >3 mm, we suggest correlating the daily measured set-up error in the AP direction with the variation in couch height. On the basis of this result, we can stratify patients into different risk groups according to the positioning reproducibility in the AP direction. If a correlation is detected between the AP error and the vertical couch position (Group 1), AP positioning may improve if couch height is fixed. Subsequent verification can be performed offline in this group. On the other hand, if there is no clear correlation between the AP set-up error and the couch height, we suggest looking at the random AP error of the first three fractions. If the AP random error is small (≤3 mm) (Group 2), skin marks are reliable for patient set-up in the AP direction and no benefit can be expected from a fixed vertical couch position. Here, verification can be continued offline, combined with a larger tolerance margin for the vertical couch position. If the AP random error is large (>3 mm) (Group 3), it is likely that the AP patient positioning is less reproducible than in the first and the second group. Here, we recommend continuing online verification.

In our analyses, skin marks seem reliable for ML positioning. Therefore, no additional set-up parameters are recommended. A reproducible positioning in the longitudinal (CC) direction can be obtained by aligning the lateral skin marks to a fixed point on the lateral ruler of the belly board.

Regarding the frequency of verification, we suggest performing verification on the first 3 days of treatment with a correction action level of 7 mm. If a correction is necessary on the basis of the measured systematic error (>3 mm), verification of the corrected position is required on two consecutive days, until the position is acceptable (≤3 mm). After this initial phase, verification is done on a weekly basis, with an action level of 3 mm for correction. During the first 3 days, we propose performing online verification in patients who are treated with dose escalation, whereas treatments with a three-field box technique can be verified with an offline protocol. Nevertheless, patients in Group 3 require online portal imaging after risk assessment, regardless of the treatment technique used. In obese patients, verification should start online from day 1.

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CONCLUSION

Our results suggest that patient positioning on a belly-board device using laser alignment to skin marks is reproducible within 4 mm. However, in some patients a fixed vertical couch position may be useful as an additional set-up parameter for the AP isocentre localisation. The systematic error should be identified and corrected during the first fractions of treatment. Thereafter, verification should be performed at regular intervals to correct for possible time trends. Positioning of obese patients seems more prone to set-up errors and requires online position verification.

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