8 Patient position verification with oblique radiation beams

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Abstract

Purpose In this study we investigated whether the position of head and neck cancer patients during radiotherapy could be determined from portal images of oblique radiation beams. Currently applied additional anterior posterior (AP) and lateral verification beams could then be abandoned.

Method The patient position was determined from portal images of the oblique radiation beams and compared with that determined from AP and lateral verification beams. Seven hundred and fifty-one portal images of 18 different patients were analyzed.

Results The set-up errors of patients that were treated with oblique gantry angles could be determined with the same accuracy from the oblique beams as from the AP and lateral verification beams in the ventrodorsal and craniocaudal direction. An additional AP beam was necessary to obtain the same accuracy in the lateral direction, because the used beam directions were relatively close to lateral. The position verification of patients treated with both oblique gantry angles and isocentric table rotations was more accurate if AP and lateral verification beams were used.

Conclusions For patients treated with an irradiation technique with oblique gantry angles (and no isocentric table rotations) position verification can be performed by using these oblique radiation beams.

Introduction

In radiotherapy of head and neck cancer patients portal imaging to achieve accurate positioning is of major importance. Van Herk et al.[3] and Stroom et al.[8] studied the relationship between set-up variations and target margins. They concluded that the margin between clinical target volume (CTV) and planning target volume (PTV) can be decreased most effectively by decreasing the standard deviation of the overall systematic error.

This overall systematic error is predominantly determined by the difference in patient position between planning CT and linear accelerator (Linac) and can be decreased by using an off-line verification protocol. In our department we use the Shrinking Action Level (SAL) verification protocol by Bel et al.[1]. In the SAL protocol the patient position at the Linac is only corrected if the average set-up error exceeds a certain action level. The action level decreases with the number of measurements N according to the relation: $\alpha_N = \alpha_0/\sqrt{N}$, where α_0 is the initial action level, α_N the action level after N measurements and $N \leq N_{max}$. After N_{max} fractions, the second stage of the protocol starts in which only once a week portal images are collected and the action level stays equal to α_{Nmax}.

The set-up error has to be determined in a coordinate system that corresponds to the patient/couch directions: ventrodorsal/height, craniocaudal/longitudinal and lateral to be able to correct the patient position by means of table movements at the Linac. For patients that are treated with an irradiation technique that contains at least one lateral and one anterior posterior (or a posterior anterior) beam the set-up errors can be determined from the portal images of these treatment beams.

At our department there are two groups of patients treated with techniques with oblique beams only. The first group includes patients with double-sided lymph node metastases from squamous cell head and neck cancer, that are treated with a technique designed to spare the spinal cord. This technique is based on the technique described by Fogliata et al.[5] and will be discussed in more detail in the Materials and methods section. The main radiation beams have oblique gantry angles. In all other beams the spinal cord is blocked out and therefore, no vertebrae can be recognized on the portal images of these beams, which make these beams unsuitable for position verification. This technique is referred to as 'Bellinzona technique'.

The second group includes patients with pituitary adenomas that are treated with a technique in which the four radiation beams form a tetrahedron shape. In this technique, referred to as 'Tetrahedron technique', all radiation beams have oblique gantry angles and two beams also have a table rotation. For the position verification of these two patient groups additional anterior posterior (AP) and lateral verification beams are used.

We have calculated that the verification beams result in an extra dose to the spinal cord of about 1.0 Gy for the Bellinzona technique when the SAL verification protocol is used and in case one position correction is necessary (14 fractions with two verification beams of 4 MU). Because both patient groups are treated with advanced techniques in order to spare the normal tissue as much as possible, it was considered inappropriate to add a dose of about 1 Gy to a relative large area, just for verification. However, set-up errors can result in much larger dose effects, especially in the Bellinzona technique with a high dose gradient close to the spinal cord in ventrodorsal direction. Therefore, the main purpose of this study was to investigate the use of portal images of the oblique radiation beams of the Bellinzona and the Tetrahedron technique for verification as well. In case of a comparable accuracy, the anterior posterior and lateral portal images can then be abandoned.

Materials and Methods

Bellinzona technique

In the Bellinzona technique two oblique radiation beams are used covering the spinal cord: a right anterior oblique (RAO; gantry angle ≈ 290°) and a left anterior oblique beam (LAO; gantry angle ≈ 70°). In the other main beams the spinal cord is blocked out. In addition, several small beams are used to obtain a homogeneous dose distribution. All beams have a common isocenter. Only the right and left anterior oblique beams can be used for verification, because the other beams hardly contain any bony structures.

The patients were treated in supine position and immobilized with a five-point thermoplastic head mask (Efficast, Orfit Industries, Belgium). A SAL correction protocol was used with $N_{max} = 4$ and $\alpha = 5$ mm. The deviation of patient position on the Linac with respect to the planning CT was determined by comparison of portal images of an anterior posterior (AP) and a lateral verification beam of 4 MU and 10 × 15 cm^2 (15 cm in the craniocaudal direction) with the corresponding Digitally Reconstructed Radiographs (DRRs)[1].

Furthermore, portal images of the right and left anterior oblique radiation beams that are used for treatment were made and compared with the corresponding DRRs. The deviation in the patient coordinates determined from the oblique radiation beams was compared with that determined from the orthogonal verification images of the verification beams.

1 Actually the deviations of both the portal image and the DRR with respect to the simulator film were determined, from which the deviation of the portal image with respect to the DRR was calculated. This procedure was used because the image quality of the simulator film was much better than that of the DRR.

Tetrahedron technique

In the Tetrahedron technique, four radiation beams are used with equidistant angles of 109°. No opposing beams are used, which results in a steeper dose gradient between high and low dose regions. All beams have a common isocenter. Normally, the beams are oriented as described in Table 1. The gantry angle of beam 1 is chosen such that the beam does not hit the eyes. The angles of all other beams follow from the first beam. The patients were treated in supine position with the head in slight hyperextension and immobilized with a three-point thermoplastic head mask (Efficast, Orfit Industries, Belgium). A SAL correction protocol was used with $N_{max} = 4$ and $\alpha = 4.7$ mm. The deviation of patient position on the Linac with respect to the planning CT was determined by comparison of portal images of an AP and a lateral verification beam of 4 MU and 10x10 cm^2 with the corresponding DRRs[1]. Furthermore, portal images were made of the radiation beams 2 - 4 shown in Table 1. The craniocaudal from ventral beam (nr. 1 in Table 1) cannot be used for verification because the imager has to be removed from the gantry to be able to setup this irradiation geometry. The deviation in the patient coordinates determined from the oblique beams was compared with that determined from the AP and lateral images.

The 6 MV photon beam of an Elekta Sli Linac (Elekta AB, Stockholm, Sweden) was used for all irradiations. The portal images were collected with the Elekta camera based iView system. The deviation of the portal images and DRRs with respect to simulator films was determined with a software package called myView, which was developed at the radiotherapy department of University Medical Center Leiden.

Nr.	Field direction	Purpose	Typical gantry angle [°]	Table rotation [°]	Typical field size [cm^2]	Typical number of MU
1	Craniocaudal from ventral	Irradiation	55	90	5 × 5	50
2[a]	Craniocaudal from dorsal	Irradiation	164	90	5 × 5	50
3[b]	Caudocranial from left	Irradiation	79	-34	5 × 5	50
4[b]	Caudocranial from right	Irradiation	281	34	5 × 5	50
5[b]	Anterior posterior	Verification	0	0	10 × 10	4
6[b]	Lateral	Verification	90	0	10 × 10	4

[a] Field used for portal imaging if there was no danger of collision of imager with patient.
[b] Field used for portal imaging

Table 1 Summary of the most important beams used for irradiation and verification in the Tetrahedron technique.

Analysis of portal images of oblique radiation beams

In this study 751 portal images of 18 different patients were analyzed. The analysis of each portal image gives a projection of the 3D set-up deviation in the plane of the imager. The set-up deviation of the patient in all three patient directions: lateral, ventrodorsal and craniocaudal can be determined from at least two portal images of beams with different gantry angles by means of a coordinate transformation as described by Siddon[7]. The accuracy of the calculated set-up deviation in the patient directions depends on the difference in gantry angles. In theory it should be possible to determine the set-up deviation from portal images of oblique beams with the same accuracy as from AP and lateral beams if the difference in gantry angle is 90 degrees. In the appendix A a more detailed description of the analysis is given.

Results

Validation of the method

First, the method used for analysis of portal images of oblique beams was validated. For this purpose, a metal sphere was irradiated with the Tetrahedron technique and portal images were collected from both the oblique beams and the AP and lateral verification beams. The sphere was moved by introducing a table displacement. Portal images were collected for eight different sphere positions with an accurately known displacement with respect to the reference position (determined from the table position readout with a precision of 0.1 mm). The average difference between the displacements determined from the orthogonal portal images and the actual displacement was 0.4 mm (1SD = 0.5 mm) in the lateral , –0.3 mm (1SD = 0.7 mm) in the ventrodorsal and 0.1 mm (1SD = 0.4 mm) in the craniocaudal direction. For the portal images from oblique beams de average difference was 0.1 mm (1SD = 0.2 mm) in the lateral, 0.0 mm (1SD = 0.7 mm) in the ventrodorsal and 0.2 mm (1SD = 0.3 mm) in the craniocaudal direction.

Bellinzona technique

In Fig. 1, the lateral (a), ventrodorsal (b) and craniocaudal (c) set-up errors of nine patients treated with the Bellinzona technique are shown. On average portal images were collected from 10 irradiation fractions for each patient, which resulted in 93 sets of portal images from the AP and lateral verification beams and the left and right anterior oblique radiation beams. The set-up errors determined from the left and right anterior oblique beams were plotted as a function of those determined from the AP and lateral verification beams (circles). The lateral set-up errors showed a wide spread around the correspondence line. However, the set-up errors in the ventrodorsal and the craniocaudal direction showed a good correlation between the results from the oblique and the orthogonal beams. An overview of the Pearson correlation coefficients and the mean difference between the set-up errors from the oblique and orthogonal beams is given in the upper part of Table 2.

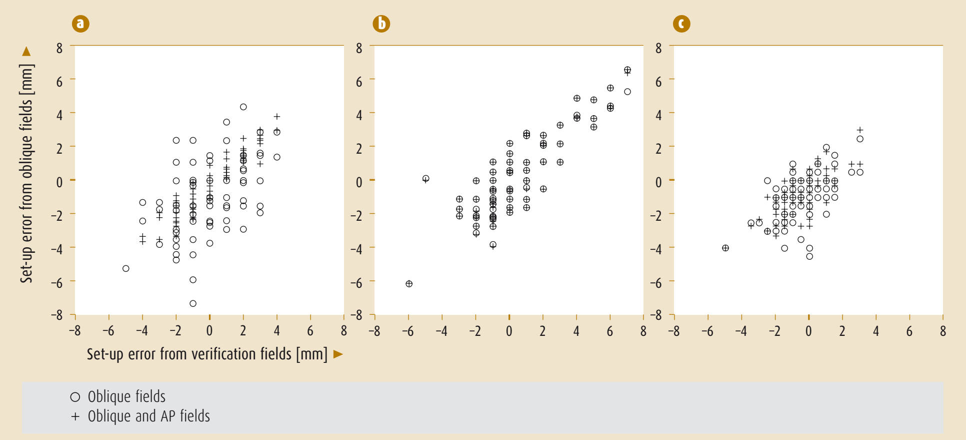

Figure 1 Set-up errors in the lateral, height and craniocaudal direction of patients treated with the Bellinzona technique. Set-up errors determined from oblique radiation beams are plotted as a function of those determined from orthogonal verification beams.

	Lateral	Ventrodorsal	Craniocaudal
LAO and RAO fields versus verification fields			
Pearson correlation*	0.50	0.85	0.54
Mean difference set-up error	-1.2 mm	-0.0 mm	-0.5 mm
1 SD difference set-up error	2.0 mm	1.3 mm	1.3 mm
LAO and RAO + AP fields versus verification fields			
Pearson correlation*	0.95	0.85	0.74
Mean difference set-up error	-0.3 mm	0.0 mm	-0.2 mm
1 SD difference set-up error	0.6 mm	1.3 mm	0.9 mm
*Sigma 2-tailed < 0.001			

Table 2 Comparison of set-up errors determined from the left anterior oblique (LAO) and right anterior oblique (RAO) irradiation fields and the verification fields of patients treated with the Bellinzona technique.

The gantry angles of the left and right anterior beams for the Bellinzona technique were about 70° and 290° for most patients. Therefore, it can be expected that the inaccuracy in the lateral set-up error determined from these oblique beams will be relatively large. Therefore, we investigated the effect of adding an AP verification beam to the left and right anterior oblique beams. The resulting set-up errors are represented by plus signs in Fig. 1.

The addition of the AP beam had a large effect on the spread of the scatter plot for the lateral set-up error. In the ventrodorsal direction there was no influence at all and in the craniocaudal direction there was little influence. An overview of the Pearson correlation coefficient and the mean difference between the set-up errors from the combination of the oblique irradiation plus the AP beam and the verification beams is given in the lower part of Table 2.

Tetrahedron technique

Portal images of nine patients treated with the Tetrahedron technique were analyzed. The radiation beams 2, 3 and 4 from Table 1 were imaged if possible. For two patients it was not possible to collect the radiation beam nr. 2 because of the danger of collision of the imager with the patient. In addition, an AP and one lateral verification beam were imaged. This resulted in 71 sets of portal images from two oblique and the verification beams and 51 sets of portal images from three oblique and the verification beams. In Fig. 2 the scatter plots of the set-up errors determined from the oblique beams versus those determined from the verification beams are given for the lateral (a), the ventrodorsal (b) and the craniocaudal (c) direction. The results calculated from two oblique radiation beams are indicated with circles and those from three oblique radiation beams with plus signs. An overview of the Pearson correlation coefficients and the mean differences between the set-up errors determined from the oblique radiation beams and the verification beams is given in Table 3. The results show a statistically significant correlation between the set-up errors determined from the oblique and the AP and lateral verification beams. However, the correlation coefficient is only 0.4-0.5 for two oblique beams and 0.5-0.7 for three oblique beams.

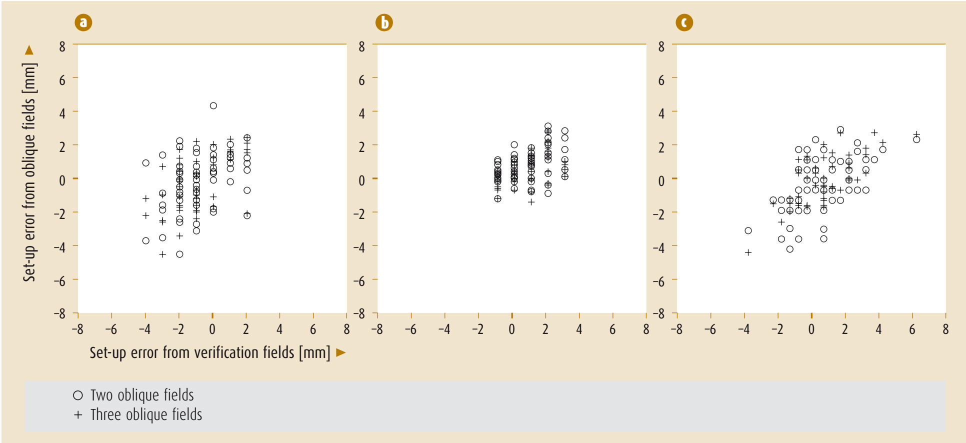

Figure 2 Set-up error in the lateral, height and craniocaudal direction of patients treated with the Tetrahedron technique. Set-up errors determined from oblique radiation beams are plotted as a function of those determined from orthogonal verification beams.

	Lateral	Ventrodorsal	Craniocaudal
Two oblique fields versus verification fields			
Pearson correlation*	0.40	0.44	0.52
Mean difference set-up error	0.7 mm	0.3 mm	-0.6 mm
1 SD difference set-up error	1.7 mm	1.2 mm	1.7 mm
Three oblique fields versus verification fields			
Pearson correlation*	0.54	0.53	0.69
Mean difference set-up error	0.9 mm	-0.1 mm	-0.5 mm
1 SD difference set-up error	1.6 mm	1.1 mm	1.3 mm
* Sigma 2-tailed < 0.001			

Table 3 Comparison of set-up errors determined from the oblique fields and the verification fields of patients treated with the Tetrahedron technique.

Discussion

The phantom measurements point out that the displacement could be determined from the oblique radiation beams of the Tetrahedron technique with the same accuracy as from the orthogonal verification beams. The differences between measured displacement and set-up displacement can completely be attributed to the accuracy of the table movement (0.1 mm precision), gantry rotation (1°) and the image resolution (0.4 mm per pixel).

However, this result only holds for phantoms and not for real patients. In the case of patient images the situation becomes much more complex. First, the interpretation of the images is more difficult. The contrast of the bony structures in the portal images is low and the images of the verification beams of only 4 MU are relatively noisy. Secondly, the head and neck region of a patient is not a rigid body. Therefore, also rotations and deformation can occur. In the portal images rotations can not always be distinguished from translations which lead to errors in the determination of the set-up error.

The problem with the interpretation of patient data is that the real set-up error is not known. It is current practice to determine the patient set-up error from portal images of an AP and a lateral verification beam. Therefore, we have compared the set-up errors from the oblique radiation beams with those determined from the AP and lateral beams. However, one should bear in mind that also the set-up error determined from the AP and lateral beams contains measurement errors.

Bel et al. have investigated whether a wedged pair of oblique beams could be used for the position verification of patients with parotid gland or tonsillar tumors[2]. They concluded that it was not possible to obtain consistent translational set-up deviations using bony structures, due to patient rotations.

The results of the patients treated with the Bellinzona technique show a good agreement between the set-up errors determined from the oblique radiation beams and from the orthogonal verification beams in the ventrodorsal and craniocaudal direction (Table 2). The inaccuracies in the set-up errors can be explained by the inaccuracies in the gantry angle (1°), in the review process of the portal images and in the calculation of the set-up errors from the oblique fields. The inter- and intraobserver variability in the review of patient images is about 1 mm (1 SD) in our institute (data not shown). Therefore, we assumed an accuracy of 1.0 mm (1 SD) in the set-up errors determined from the AP and lateral portal images. We assume a normal distribution of the set-up errors. This indicates an accuracy of 1.7 mm (1 SD) in the set-up errors determined from the oblique radiation beams in the lateral and 0.8 mm (1 SD) in the ventrodorsal and craniocaudal directions.

The accuracy of the calculation of the set-up errors from the oblique fields depends on both de difference in gantry angle between the oblique fields[6] and the distance to the isocenter of the bony structures used in the image analysis[4]. Based on the results of Kolkman-Deurloo et al. it can be expected that the maximum deviations in the calculation for the Bellinzona technique (with a difference in gantry angle of about 40 °) will be twice that of a calculation with a difference in gantry angle of 90°.

The difference between the oblique radiation and the verification beams has decreased in the lateral and in the craniocaudal direction by adding an AP verification beam to the oblique beams (Table 2). The difference in the ventrodorsal direction was not influenced by the addition of the AP beam. In this situation the AP verification beam is used in the determination of the set-up errors in both situations. Hence, the measurements are not independent anymore and a quantitative interpretation of these data is not possible. However, we assume that the lateral set-up error can be obtained with the same accuracy from the combination of the AP and oblique beams as from the AP and lateral beams. The accuracy of the set-up error in the ventrodorsal and craniocaudal direction determined from the combination of the oblique and AP beams is about 1 mm. Because the information content of the portal images (contrast, amount of bony structures, beam of view) of the oblique and orthogonal beams is comparable, this result is in agreement with what one would expect.

For the Tetrahedron technique with two oblique beams the accuracy in the set-up errors from the oblique beams will be 1.4 mm (1 SD) in the lateral and the craniocaudal direction and 0.7 mm in the ventrodorsal direction. If three oblique beams are used the accuracies (1 SD) are 1.2 mm in the lateral, 0.8 mm in the craniocaudal direction and 0.5 mm in the ventrodorsal direction. The accuracy in the ventrodorsal direction is much better than 1.0 mm. Only relatively small set-up errors were found in the ventrodorsal direction. However, the difference in set-up errors does not depend on the magnitude of the set-up error. Therefore, the most probable explanation is that the accuracy in the review process in the ventrodorsal direction is better than 1.0 mm (1 SD).

It is expected that the accuracy in the review of the radiation beams is less than that of the verification beams because the beam size and therefore the field of view is smaller and as a result less bony structures can be recognized and the interpretation of the images is harder. The results for the lateral and craniocaudal set-up errors are in agreement with this assumption. Especially if only two radiation beams are used the accuracy in the set-up errors determined from these radiation beams is less than that of the verification beams. In the ventrodorsal direction the accuracy of both methods seems to be comparable.

Conclusions

For the Bellinzona technique patient set-up errors can be determined with the same accuracy from the two oblique radiation beams combined with an AP verification beam as from an AP and a lateral verification beam. Furthermore, both a right and a left oblique beam are used instead of one lateral beam, which gives a better result in case of patient rotations around the length axis.

For the patients treated with the Tetrahedron technique using an AP and lateral verification beam gives the most accurate results for position verification and is therefore recommended.

Appendix A

The set-up deviation as determined from portal image i is defined as $R_{mv,i} = (u_i,v_i,w_i)$, where u_i and v_i lie in the plane of the imager and w_i is perpendicular to the plane of the imager. Therefore, only u_i and v_i can be determined from the portal image. In the patient coordinate system (x,y,z) the positive x-direction corresponds to the left, the positive y to the dorsal and the positive z tot the cranial direction. The set-up deviation in the patient coordinate system $R = (x,y,z)$ is related to $R_{mv,i}$ by an isocentric table rotation ϕ_i and a gantry rotation ϕ_i:

$$\begin{bmatrix} x \\ y \\ z \end{bmatrix} = \begin{bmatrix} \cos(\phi_i) & 0 & \sin(\phi_i) \\ 0 & 1 & 0 \\ -\sin(\phi_i) & 0 & \cos(\phi_i) \end{bmatrix} \begin{bmatrix} \cos(\theta_i) & 0 & \sin(\theta_i) \\ \sin(\theta_i) & 0 & -\cos(\theta_i) \\ 0 & 1 & 0 \end{bmatrix} \begin{bmatrix} u_i \\ v_i \\ w_i \end{bmatrix} \quad (1)$$

for a patient in supine position with the head in the direction of the gantry. Eq. 1 can be solved for ≥ 2 portal images with different gantry angles θ_i and θ_j. We have implemented the matrix transformation in an Microsoft Excel spreadsheet for n portal images and used the Microsoft Excel Solver (Microsoft Corporation, Redmond, WA) to find the solutions for w_i that minimize the function $C_n(w)$:

$$C_n(w) = \sum_{i,j=1}^{n} \left[x_i(w_i) - x_j(w_j)\right]^2 + \left[y_i(w_i) - y_j(w_j)\right]^2 + z_i(w_i) - z_j(w_j)\Big]^2 \quad (2)$$

The iteration process was performed with a convergence of 0.001 and a maximum of 100 iterations

References

1. Bel A, van Herk M, Bartelink H, et al., A verification procedure to improve patient set-up accuracy using portal images. Radiother Oncol 1993;29:253-260.
2. Bel A, Keus R, Vijlbrief RE, et al., Set-up deviations in wedged pair irradiation of parotid gland and tonsillar tumors, measured with an electronic portal imaging device. Radiother Oncol 1995;37:153-159.
3. van Herk M, Remeijer P, Rasch C, et al., The probability of correct target dosage: dose-population histograms for deriving treatment margins in radiotherapy. Int J Radiat Oncol Biol Phys 2000;47:1121-1135.
4. Fencil LE and Metz CE. Propagation and reduction of error in three-dimensional structure determined from biplane views of unknown orientation. Med Phys 1990;17:951-961.
5. Fogliata A, Cozzi L, Bieri S, et al., Critical appraisal of a conformal head and neck cancer irradiation avoiding electron beams and field matching. Int J Radiat Oncol Biol Phys 1999;45:1331-1338.
6. Kolkman-Deurloo I-KK, Visser AG, Idzes MHM, Levendag PC. Reconstruction accuracy of a dedicated localiser for filmless planning in intra-operative brachytherapy. Radiother Oncol 1997;44:73-81.
7. Siddon, RL. Solution to treatment planning problems using coordinate transformations. Med Phys 1981;8:766-774.
8. Stroom JC, Boer HCJ de, Huizenga H, et al., Inclusion of geometrical uncertainties in radiotherapy treatment planning by means of coverage probability. Int J Radiat Oncol Biol Phys 1999;43:905-919.