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Three dimensional variability in patient positioning using bite block immobilization in 3D-conformal radiation treatment for ENT-tumors

Jochen Willner*, Ulrich Hädinger, Michael Neumann, Franz J. Schwab, Klaus Bratengeier, Michael Flentje

Department of Radiation Oncology of the University of Würzburg, Josef-Schneider-Str. 11, D-97080 Würzburg, Germany

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Abstract

Background and purpose: The aim of this prospective study was to analyze the three-dimensional (3D) reproducibility of the isocenter position and of patient positioning with the use of bite block immobilization by means of a simple verification procedure for a complex beam arrangement applied for ENT-tumors.

Materials and methods: We analyzed the positioning data of 29 consecutive patients treated for ENT-tumors at the Department of Radiotherapy and Oncology of the University of Würzburg. A total of 136 treatment sessions were analyzed. Patients were positioned and immobilized using an individualized bite block system and a head and neck support. A complex beam arrangement was applied combining two offset rotational and two oblique wedge fields on a 5 MV linear accelerator. Orthogonal verification films were taken once weekly. Four to six film pairs per patient were obtained (during 4–6 weeks) with a mean number of 4.7 film pairs per patient. These were compared to the corresponding orthogonal simulator films taken during primary simulation. Deviations of the verified isocenter from the isocenter on the simulator film were measured and analyzed in three dimensions in terms of overall, systematic and random categories. A 3D-deviation vector was calculated from these 3D data as well as a 2D-deviation vector (for comparison with literature data) from the lateral verification films.

Results: The overall setup deviation showed standard deviations (SD) of 2.5, 2.7 and 3.1 mm along the cranio-caudal, anterior-posterior and medio-lateral axes, respectively. The random component ranged from SD 1.9 to 2.1 mm and the systematic component ranged from SD 1.8 to 2.2 mm. The mean length of the 3D-vector was 3.1 mm for the systematic as well as the random component. Ninety percent of 3D systematic and random deviations were less than 5 mm. The mean length of the 2D-vector was 2.4 mm for the random component and 2.2 mm for the systematic component. Ninety percent of 2D-random and systematic variations were less than 4 mm.

Conclusions: The presented individualized bite block immobilization device provides an accurate and reproducible patient positioning for 3D-conformal radiation therapy in the head and neck. Random and systematic deviations in each of the three directions are in the range of ±4 mm (2 SD, comprising 95% of the deviations) and are within the range or even less than deviations described for most thermoplastic or PVC-mask fixation devices. These deviations should be taken into account during definition of planning target volume in head and neck tumors. © 1997 Elsevier Science Ireland Ltd.

Keywords: Quality control; Bite block immobilization; Positioning verification; 3D conformal treatment planning; Head and neck cancer

1. Introduction

An accurate understanding of the variability in patient positioning is essential for appropriate treatment planning, especially in three-dimensional (3D) conformal radiotherapy. Underestimates of the variability may result in failure to treat the entire target volume, and overestimates may result in unnecessary irradiation of normal tissues. Setup variation is generally measured in terms of random or day-to-day variation and systematic deviation [5,16]. With the increasing use of 3D conformal treatment-planning, deviations also have to be analyzed in three dimensions. The importance of this problem has been stressed in patients with pelvic irradiation [8,14,17] but only few studies deal with variability in the treatment of head and neck cancer patients. Patients with head and neck tumors usually are

* Corresponding author.

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immobilized using face-masks or bite blocks. For masks setup inaccuracies in the range of 1–5 mm standard deviation (SD) in each of the three directions have been described [4,10,12]. For the different mask materials skin dose escalation and an increase in skin reactions due to a reduction of the skin sparing built-up region have been reported [9]. The use of bite block immobilization prevents this problem. Data concerning positioning reproducibility with the use of bite block immobilization are extremely rare [18] and to date have not been analyzed three dimensionally.

At the Department of Radiation Oncology of the University of Würzburg, patients with head and neck tumors are immobilized by means of an individualized bite block fixation device and a semi-standardized head and neck support (Fig. 1). Three-dimensional (3D) CT-planned conformal radiotherapy and complex beam arrangements are routinely performed in nearly every head and neck cancer patient. The introduction of the individualized bite block system and the method of its fabrication was published in 1983 by Bohndorf et al. [6] and since then it has been in routine use. Patient adjustment with bite block immobilization is a simple, time- and cost-saving procedure and is independent of changes of the patient's contour during the weeks of treatment. Since 1984 more than 2000 patients have been treated using this method. The aim of this study was to analyze the 3D reproducibility of the isocenter position and of patient positioning using the bite block system by means of a simple verification procedure for the complex beam arrangement applied.

2. Materials and methods

Simulation and verification films of 29 consecutive patients treated with 3D-conformal external beam radiotherapy for ENT-tumors at the Department of Radiation Oncology of the University of Würzburg between October 1994 and March 1995 were studied. A complex beam arrangement is applied combining rotational and oblique fields on a 5 MV linear accelerator [7]. Patients are positioned supine, head extended, using an individualized bite block immobilization device and a semi-standardized head and neck support which is molded concave in two directions (Fig. 1). Positioning corrections and fine adjustment can be done easily on the simulator or the treatment couch. A disadvantage of the system is the necessity of skin marks on the patient. The existence of at least two healthy teeth in the patient's upper jaw to guarantee good fixation to the bite block is a prerequisite. The angle of the bite block system determines the declination of the head. Fine adjustment is performed with the help of tattooed skin marks on the chin and jaw-angles, the jugulum and shoulders which are sequentially aligned to the room laser system before adjustment of the isocenter. These marks determine the longitudinal and rotational position of the head and neck. Like most fixation devices the system requires some patient cooperation, since the patient should bite moderately on the bite block during the whole treatment session. Most patients feel comfortable with the fixation system, since they don't have to suffer from the tightness of a face mask. The irradiation technique is described in Fig. 2. The beam arrangement consists of two arc fields and two oblique wedge fields. The four fields have a common isocenter which is positioned at the posterior border of the spinal cord. The arc fields have an 'offset' (asymmetric field jaws) beyond the central axis so the spinal cord is always outside the field. The arc fields cause a dose gradient in the anterior-posterior direction which is compensated by two oblique wedge fields with the wedge tips pointing in the posterior direction. Each field is individually shaped. The shape of the target volume

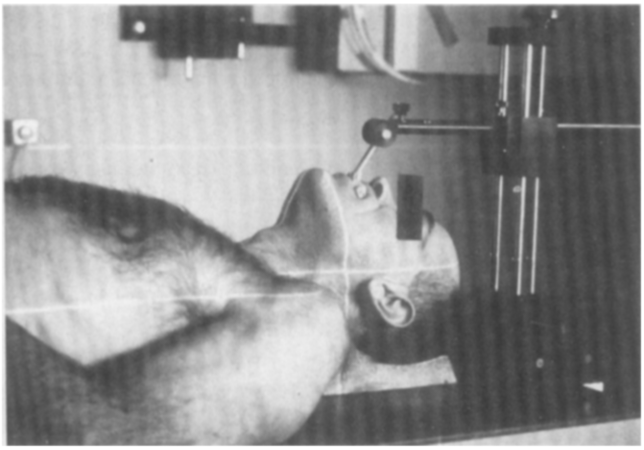

Fig. 1. Patient during pre-simulation in treatment position with individualized bite block immobilization and head and neck support on the simulator couch.

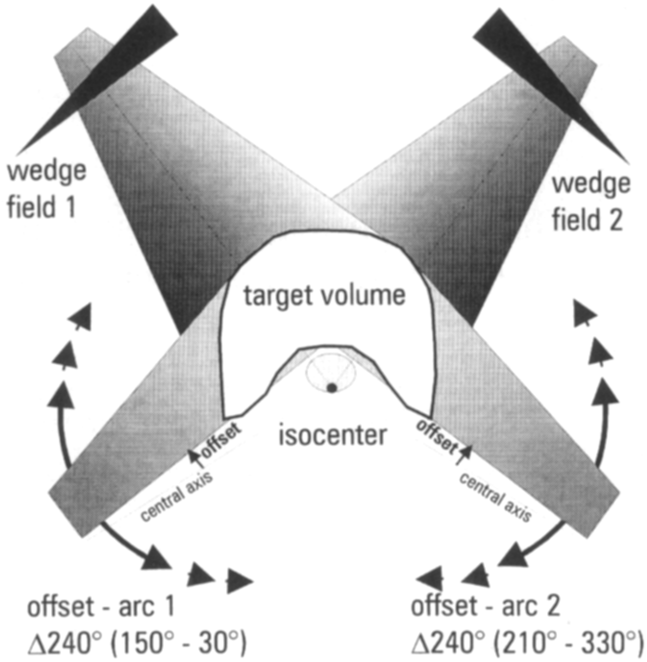

Fig. 2. Schematic description of beam arrangement.

forces the wedge fields to include the spinal cord. The resulting dose load to the spinal cord usually amounts up to 60%, allowing for treatment series ranging up to 70 Gy. With this technique usually 56 Gy are delivered in a first series on the primary tumor and the lymph nodes on both neck sides followed by a boost of 10–20 Gy on the primary tumor's region and involved lymph nodes using the same (eventually shortened) fields or different beam arrangements. Recently the boost dose has been delivered as a 'concomitant boost' during a second daily fraction.

During treatment simulation the position of the definitive isocenter is marked on the patient's skin and orthogonal simulator films are taken to determine its position. On the treatment table the patient is positioned in the same way as described above and finally the isocenter skin marks are aligned to the room laser system. Since all the beams of the beam arrangement have the same isocenter they are applied without moving the patient. After completion of a 3D-treatment session, once weekly orthogonal fields are set up (10×10 cm^2, 8–10 MU) with the isocenter marked by a metal pin (diameter, 1 mm) on the block tray. Verification films are taken from these fields using a fast film in order to minimize the additional dose load to the patient. Four to six pairs of verification films per patient were obtained during the treatment series resulting in a total of 136 verification film pairs from 136 treatment sessions of 29 patients. The mean number of film pairs per patient was 4.7. Since verification is performed after the session and positioning is not readjusted before verification, the deviations measured from these films reflect the worst displacement situation and might be smaller if verification is performed before treatment session. No additional special care was taken regarding positioning accuracy due to this prospective study nor were the technicians informed about the measured deviations. Using the field borders as a reference, a coordinate system was established relative to the isocenter. Bony landmarks close to the isocenter were identified on the verification films and the corresponding orthogonal simulator film. Distances of the isocenter of the verification films to these landmarks were measured in all three dimensions and compared with the corresponding distances of the simulator films. After correction for the magnification of the simulator film as well as the verification film, deviations of the isocenter in the three directions (dx, left-right (l-r); dy, anterior-posterior (a-p); and dz, cranio-caudal (c-c)) were obtained. The accuracy of measurements as estimated from repeated measurements was about 1 mm. Since identification of bony landmarks, as necessary for c-c deviations (e.g. upper border of vertebra) was considered more reliable on the lateral projections, we measured the deviation in the c-c direction only from the lateral films. Due to the relatively small bony landmarks and the complex mobility of the cervical spine, the base of the skull and the mandible rotational errors were not analyzed separately but were indirectly enclosed in the translational errors.

Displacements were studied in three dimensions in terms of overall, systematic and random categories according to El-Gayed et al. [8]. The systematic category indicates displacements that were persistent during the whole course of treatment. For individual patients it is represented by the mean value of displacements along a specific coordinate. For the whole group the distribution of systematic deviations is determined by the standard deviation (SD) of the values of the mean shifts of individual patients. Random category reflects displacements that may occur by chance and corresponds to day-to-day setup variations during the course of treatment. They are represented by the amount of dispersion of individual points around the mean. For the whole group of patients they are obtained from the individual displacement values of all patients after subtraction of their corresponding means and calculating the SD of the remaining values.

From the displacements (dx, dy, dz) in the three directions we calculated a 3D-deviation vector. Its length (d_{3D}) defines the shortest distance between the verified 3D isocenter position and the isocenter position of the corresponding simulator film pair. It can be calculated by the formula [3]

$$d_{3D} = \sqrt{dx^2 + dy^2 + dz^2}$$

For providing comparability to studies based on lateral portal film analysis overall, random and systematic displacements were calculated additionally in a two-dimensional (2D) way according to Rosenthal et al. [18], using only the lateral verification films. The 2D-deviation (d_{2D}) is defined as the shortest distance between the isocenter of each lateral verification film and the isocenter of the corresponding lateral simulator film. It can be calculated from the 3D deviations dy and dz by the formula

$$d_{2D} = \sqrt{dy^2 + dz^2}$$

where dy and dz are the corrected deviations in the a-p and c-c directions.

3. Results

3.1. Three-dimensional deviations

The overall average patient setup deviation showed a standard deviation of 2.5, 2.7 and 3.1 mm along the c-c, a-p and l-r axes, respectively (Table 1). Systematic and random deviations in all three directions did not differ from a normal distribution. Random or treatment to treatment variations were in the same range as the systematic error. The random component ranged from SD 1.9 to 2.1 mm. The systematic error ranged from SD 1.8 to 2.2 mm. Medio-lateral deviations were largest in the systematic as well as the random component. Random and systematic deviations were smallest in the c-c directions. The 3D distribution of the displacements is visualized using a projection in two planes as a scatter diagram. Fig. 3a,b show the

Table 1

Average displacement and standard deviation (SD) of the overall distribution and the distribution of systematic and random displacements along the three main axes for all 29 patients

Direction	Average displacement (mm) (n = 136)	Distribution of displacements (1 SD (mm))		
		Overall (n = 136)	Systematic (n = 29)	Random (n = 136)
Cranio-caudal	0.0	2.5	1.8	1.9
Anterior-posterior	–0.6	2.7	1.9	2.0
Medio-lateral	0.6	3.1	2.2	2.1

calculated systematic displacements in the c-c/l-r and c-c/a-p directions with each square representing the systematic component of each patient. Fig. 3c,d show the corresponding random error distributions with each point representing a treatment session. The length of the calculated 3 D-vectors for overall, systematic and random deviations are given as a cumulative distribution in Fig. 4. The ordinate gives the percentage of cases with deviations smaller than the value given on the abscissa. The mean systematic and random 3D deviation was 3.1 mm; the mean overall 3D-deviation was 4.2 mm. Ninety percent of systematic or random deviations were smaller than 5 mm; 90% of overall deviations were smaller than 7.8 mm.

3.2. Two-dimensional deviations

The cumulative distribution of overall, systematic and random error in patient positioning calculated two-dimensionally from the 136 lateral verification films (a-p and c-c directions) is shown in Fig. 5. The mean 2D random or day-to-day error was 2.4 mm and the mean value for 2D systematic deviations was 2.2 mm. The mean overall 2D-deviation was 3.1 mm. Ninety percent of 2D-random and systematic variations where smaller than 4 mm; 90% of overall 2D-deviations were within 6 mm from the simulated isocenter.

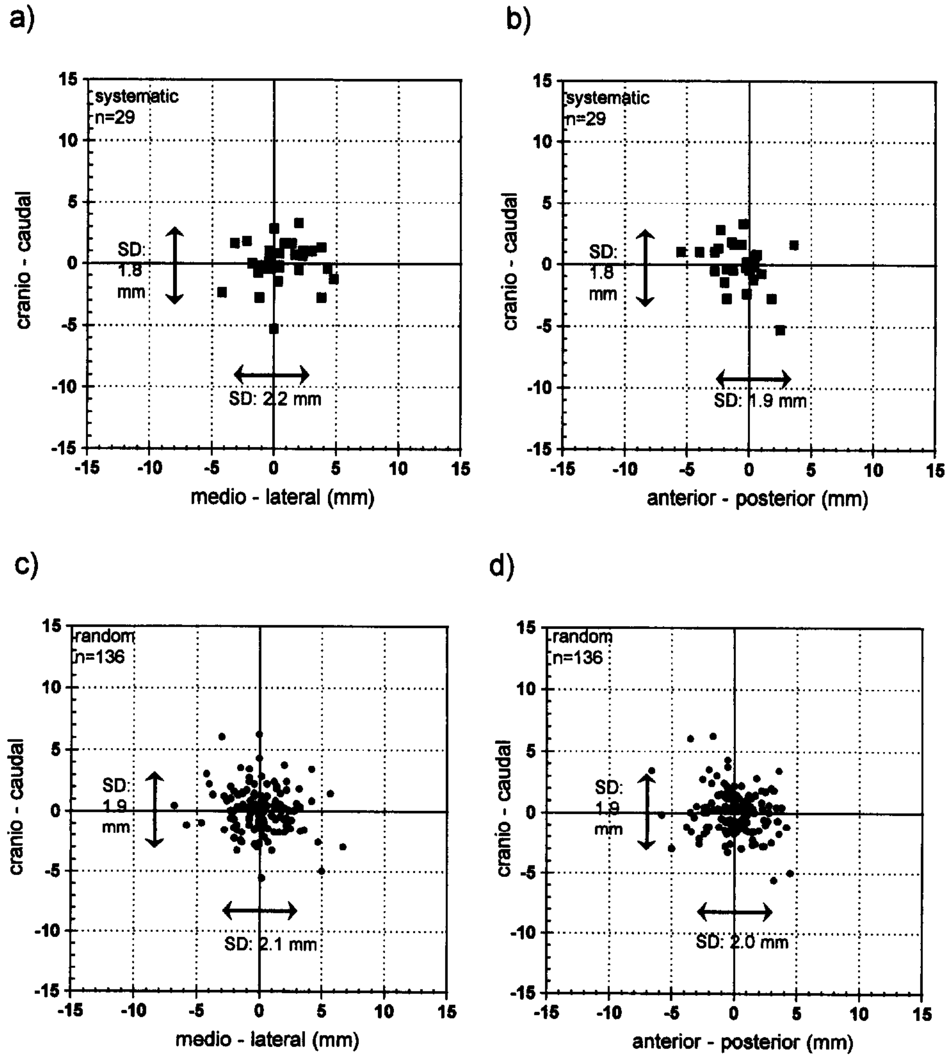

Fig. 3. Systematic and random displacements in cranio-caudal (c-c)/medio-lateral (l-r) direction (a,c) and c-c/anterior-posterior (a-p) direction (b,d) with squares representing the systematic component of each patient and small dots representing the corresponding random error distribution.

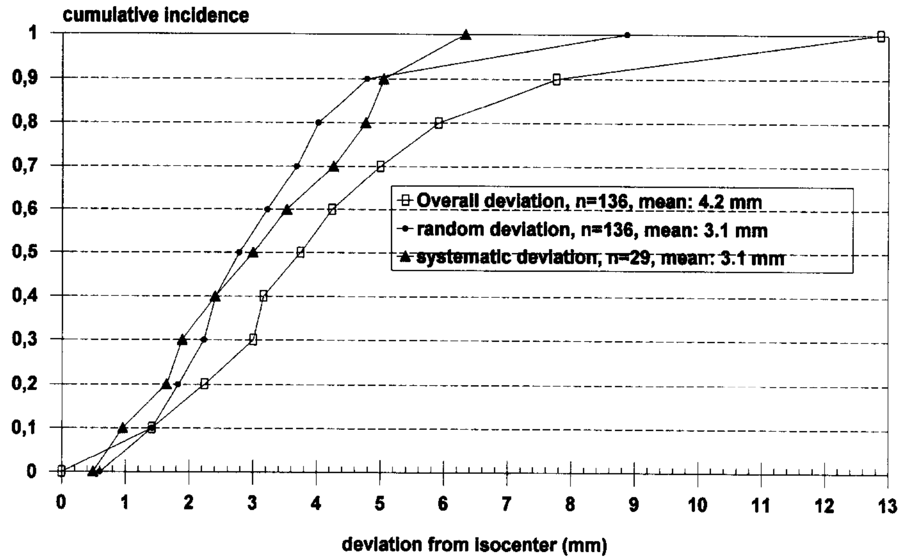

Fig. 4. Cumulative distribution of 3D-vector for overall, systematic and random error in patient positioning calculated from the 136 film pairs.

4. Discussion

In 3D-conformal treatment planning and during target volume definition physicians have to be aware of the positioning deviations occurring in spite of positioning devices like bite block or mask immobilization. Literature data on positioning reproducibility in the head and neck region are rare since 3D treatment planning is not yet routinely performed for patients with ENT-tumors. Comparison of positioning data from different authors, as presented in the following, has to be done with reservation because of major differences in the statistical methods and study designs. Any comparison should take into account whether deviations are presented separately for each direction, with or without consideration of direction, whether rotational errors are included, if a 2D- or a 3D-vector was calculated and whether these deviations are presented in terms of overall, or random and systematic components. These and other factors may influence the 'deviation values' given by different authors and make comparison difficult. If deviation is analyzed in terms of several different components (rotation, translation in different directions), the value of each component becomes smaller. The other way round the value of the 3D-vector is always larger than the value of the 2D-vector or the value for each direction separately. Data on head fixation for treatment of intracranial targets were excluded from the discussion since fixation and data collection of a rigid structure like the skull cannot be compared to fixation of a multi-articulation system like the neck and a comparison would lead to wrong conclusions. Our data are collected exclusively from patients with tumors of the naso-oro-hypopharynx, tongue, mouth floor or larynx.

Most of the authors reporting positioning data in the head and neck region use a mask fixation. Only one study [18]

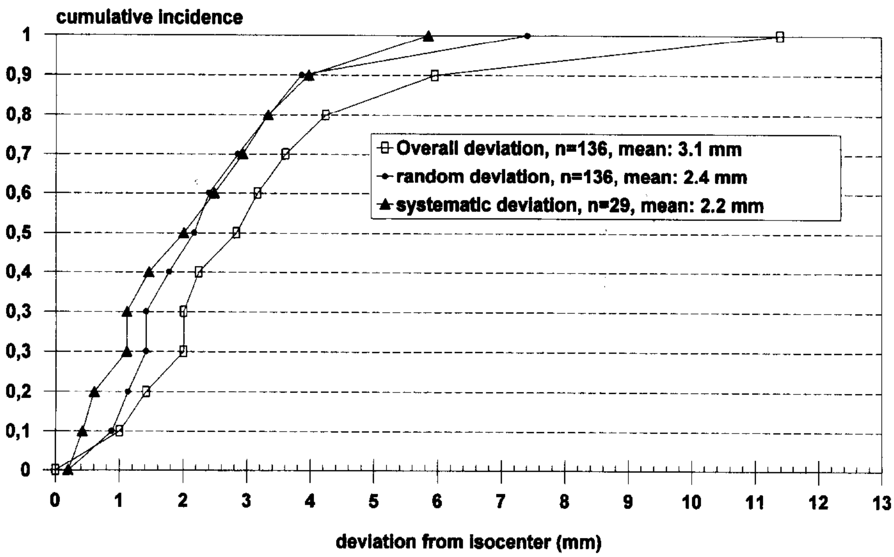

Fig. 5. Cumulative distribution of 2D-vector for overall, systematic and random error in patient positioning calculated from the 136 lateral verification films (anterior-posterior and cranio-caudal directions).

used a bite block system. Rosenthal et al. [18] analyzed simulation and portal film measurements for 318 portals in 51 head and neck patients using bite block immobilization in most cases. They measured 2D deviations and found a mean overall uncertainty of 8 mm (SD 4 mm). The mean values for random and systematic error were 4 and 7 mm (SD 2 and 4 mm, respectively). These variations using bite block fixation are clearly larger than those reported in this report. Unfortunately further information about the method of patient positioning is not given, especially if laser alignment or a head and neck support was used. This might be a cause of their larger deviations.

More data have been reported on mask fixation. Niewald et al. [15] found a maximum deviation of the isocenter of 3–5 mm from the simulation film in 10 patients with mask fixation in whom repeated simulator films were taken. Huizenga et al. [11] compared 55 simulator films and 138 corresponding lateral portal films of 22 patients treated for tumors of the head and neck using plastic cast head fixation. They measured 2D-deviations of 4–6 corresponding field points in relation to the patient's anatomy. An overall mean deviation (2D-vector) of 4.9 mm was noted. The overall deviation calculated separately in the a-p and c-c directions showed SDs of 3.9 and 4.2 mm, respectively. A rotation of 2.2° (1 SD) was noted. A subset analysis of 41 repeated portal films (random or treatment to treatment error) demonstrated an a-p translation of 2.0 mm (1 SD) and c-c deviation of 3.0 mm (1 SD). Kihlen and Ruden [13] reported on a cohort of 35 prospectively analyzed patients including 10 head and neck patients. Laser alignment and fixed contoured masks were used to immobilize patients. They measured 2-D random component of deviation and found an average variation of 4 mm for the head and neck patients. An analysis of systematic or overall error was not presented. Adamietz et al. [1] analyzed reproducibility of mask fixation using repeated simulation films. They marked deviation of the isocenter on simulation films in relation to anatomical landmarks and measured the maximum deviation of the isocenter in the frontal plane (4 patients, 12 simulation films) as well as in the sagittal plane (10 patients, 34 simulation films). With this method the random deviation was calculated. They found mean deviations of 2.6 mm in the sagittal plane and 3.4 mm in the frontal plane. Hunt et al. [12] determined 3D translational and rotational setup errors in 6 patients treated by a conformal boost technique for nasopharyngeal carcinoma. Patients were aligned with the help of skin tattoos and a thermoplastic mask. They calculated an average 3D-deviation-vector for each patient and found an average overall 3D deviation of 4.4 mm, which is comparable to our mean overall 3D-vector of 4.2 mm. The average magnitude of translational errors observed in their analysis was 1.4, 2.0 and 3.1 mm in the three directions (c-c, a-p, l-r); average rotations varied between 0.8° and 1.3° in the three main axes. Hess et al. [10] recently reported the results of field alignment in 95 head and neck patients treated with lateral opposed fields using mask immobilization. They compared simulation films with the first single check film of either side and measured overall deviation separately in the a-p and c-c directions. They found a standard deviation between 3.0 and 4.6 mm for the a-p and c-c directions. An estimation from their cumulative frequency distribution shows that 90% of absolute deviations in the a-p and c-c directions were less than 6.0 mm. They did not calculate a 2D- nor a 3D-vector representing the real distance between the simulated and verified isocenter which makes their data difficult to compare. Since only a single portal film was used to determine deviations, random and systematic error cannot be estimated from their data. For better comparison with the data of Hunt et al. [12] and Hess et al. [10] we reanalyzed our data in the c-c and a-p directions separately and found that 90% of our overall deviations were within 4.0 mm in the c-c and a-p directions (5 mm in the l-r direction) compared to 6 mm as can be seen from the Hess data. The corresponding mean values were 1.8, 2.1 and 2.2 mm for c-c, a-p and l-r deviations, respectively, which are comparable to the corresponding average deviations of 1.4, 2.0 and 3.1 mm from Hunt et al. Their translational deviations seem to be smaller in the c-c direction and a-p direction, but this might in part be due to their additional calculation of rotational error which is included in our translational error. Weltens et al. [20] compared masks made of polyvinylchloride to thermoplastic masks with respect to the accuracy of the treatment setup. They found random deviations in the range of 2.0–2.1 mm (1 SD) and systematic deviations of 3.5 mm (1 SD), regardless of the type of mask used.

The smallest positioning deviations with the use of mask fixations were reported from the Netherlands Cancer Center. In a recent study, Bel et al. [4] published an analysis of 3D translational positioning deviations in 31 patients treated for parotid gland and tonsillar tumors by two wedged oblique fields. They used metal markers in the outer ear for image correlation and found random displacements of 1.1–1.6 mm (1 SD) and systematic displacements of 1.7–2.0 mm (1 SD), respectively in the three directions. From these data the SD for overall displacement can be estimated at 2.0–2.6 mm. They additionally calculated a mean 3D-displacement vector, which is comparable to the 3D-vector of systematic component of our analysis. An estimation from their cumulative distribution reveals that 90% of all mean 3D setup deviations were smaller than 5 mm, which is exactly in the same range as the data for systematic error reported by us (Fig. 4). Their data on random displacements are superior to our deviations but the authors mentioned that their good results might be due to the special care regarding immobilization and positioning procedures taken by them during the prospective study and due to a biased patient sample. Our data have been obtained from the routine clinical practice without special care on positioning procedures and technicians were not informed about the measured deviations. Additionally, their data are obtained from image correlation with the help of metal markers in the outer ear, reflecting the positioning of the head more than the position of the neck and cervical spine. On the contrary, our data were obtained from correlation of anatomical landmarks (mostly vertebral bodies C2–C4). The larger mobility of the cervical spine might be another reason for our larger random deviations.

Data on other immobilization devices for the head and neck are rare. Rabinowitz et al. [16] published an analysis of simulator and portal films of 71 patients including 7 patients with head and neck tumors who had a head fixation using a mechanical head clamping device. They measured deviations of anatomical landmarks in relation to the field borders and found a mean 'worst case discrepancy' of 3.5 mm with 20% of field deviations exceeding 5 mm. These data have only limited comparability because of different statistical analysis. Alzen et al. [2] used repeated simulation films in 27 head and neck patients with a PU-foamed positioning device and compared positioning reproducibility to 15 patients without this positioning aid. They calculated overall deviation of the isocenter in the sagittal plane in c-c and a-p directions. Overall deviation in c-c direction showed an SD of 2.7 mm with the positioning aid and 5.5 mm without. The corresponding deviations in the a-p direction were 2.8 mm (SD) and 7.0 mm (SD), respectively.

5. Conclusion

To date there is a great need for standardization of positioning data to allow comparison between immobilization devices reported from different authors. The presented individualized bite block immobilization device combined with head and neck support provides an accurate and reproducible patient positioning for 3D treatment. Random and systematic deviations in the three directions are in the range of ±4 mm (2 SD, comprising 95% of the deviations) and are within the range or even less than deviations described for most thermoplastic or PVC-mask fixation. These deviations should be taken into account during definition of planning target volume in patients with head and neck tumors.

References

[1] Adamietz, I.A., Kremmin, B. and Emminger, A. Modifizierte Gesichtsmaskenvorrichtung zur Strahlentherapie von Kopf-Hals-Tumoren. Strahlenther. Onkol. 167: 477–479, 1991.

[2] Alzen, G., Böck, E.G., Thelen, M. and Kutzner, J. Polyurethan - Lagerungshilfen in der Strahlentherapie. Strahlentherapie 161: 374–378, 1985.

[3] Bartsch, H.J. Mathematische Formeln, 23rd edn. Fachbuchverlag, Leipzig, 1991.

[4] Bel, A., Keus, R., Vijlbrief, R.E. and Lebesque, J.V. Setup deviations in wedged pair irradiation of parotid gland and tonsillar tumors, measured with an electronic portal imaging device. Radiother. Oncol. 37: 153–159, 1995.

[5] Bijhold, J., Lebesque, J.V., Hart, A.A.M. and Vijlbrief, R.E. Maximizing setup accuracy using portal images as applied to a conformal boost technique for prostatic cancer. Radiother. Oncol. 24: 261–271, 1992.

[6] Bohndorf, W. and Richter, E. Zur Fixierung der Patienten bei Bestrahlungen des Hirn- und Gesichtsschädels. Strahlentherapie 159: 732–740, 1983.

[7] Bratengeier, K., Richter, J. and Bohndorf, W. Bestrahlungstechniken im HNO-Bereich. In: Bestrahlungsplanung, Aktueller Stand und Perspektiven, pp. 149–150. Editors: W. Bohndorf and J. Richter. Boegler Verlag, Würzburg, 1994.

[8] El-Gayed, A.A.H., Bel, A., Vijlbrief, R., Bartelink, H. and Lebesque, J.V. Time trend of patient setup deviations during pelvic irradiation using electronic portal imaging. Radiother. Oncol. 26: 162–171, 1993.

[9] Fiorino, C., Cattaneo, G.M., Del Vecchio, A., Fusca, M., Longobardi, B., Signorotto, P. and Calandrino, R. Skin-sparing reduction effects of thermoplastics used for patient immobilization in head and neck radiotherapy. Radiother. Oncol. 30: 267–270, 1994.

[10] Hess, C.F., Kortmann, R.D., Jany, R., Hamberger, A. and Bamberg, M. Accuracy of field alignment in radiotherapy of head and neck cancer utilizing individualized face mask immobilization: a retrospective analysis of clinical practice. Radiother. Oncol. 34: 69–72, 1995.

[11] Huizenga, H., Levendag, P.C., De Porre, P.M.Z.R. and Visser, A.G. Accuracy in radiation field alignment in head and neck cancer: a prospective study. Radiother. Oncol. 11: 181–187, 1988.

[12] Hunt, M.A., Kutcher, G.J., Burman, C., Fass, D., Harrison, L., Leibel, S. and Fuks, Z. The effect of setup uncertainties on treatment of nasopharynx cancer. Int. J. Radiat. Oncol. Biol. Phys. 27: 437–447, 1993.

[13] Kihlen, B. and Ruden, B.I. Reproducibility of field alignment in radiation therapy. A large-scale clinical experience. Acta Oncol. 28: 689–692, 1989.

[14] Kutcher, G.J., Mageras, G.S. and Leibel, S.A. Control, corrections, and modeling of setup, errors and organ motion. Semin. Radiat. Oncol. 5: 134–145, 1995.

[15] Niewald, M., Lehmann, W., Uhlmann, U., Berberich, W., Scharding, B., Dietz, R., Schnabel, K. and Leetz, H.-K. Erfahrungen bei der Verwendung von Gesichtsmasken zur Strahlentherapie von Kopf-Hals-Tumoren. Strahlentherapie 161: 681–684, 1985.

[16] Rabinowitz, I., Broomberg, J., Goitein, M., McCarthy, K. and Leong, J. Accuracy of radiation field alignment in clinical practice. Int. J. Radiat. Oncol. Biol. Phys. 11: 1857–1867, 1985.

[17] Rudat, V., Flentje, M., Oetzel, D., Menke, M., Schlegel, W. and Wannenmacher, M. Influence of the positioning error on 3D conformal dose distributions during fractionated radiotherapy. Radiother. Oncol. 33: 56–63, 1994.

[18] Rosenthal, S.A., Galvin, J.M., Goldwein, J.W., Smith, A.R. and Blitzer, P.H. Improved methods for determination of variability in patient positioning for radiation therapy using simulation and serial portal film measurements. Int. J. Radiat. Oncol. Biol. Phys. 23: 621–625, 1992.

[19] Verhey, L.J. Immobilizing and positioning patients for radiotherapy. Semin. Radiat. Oncol. 5: 100–114, 1995.

[20] Weltens, C., Kesteloot, K., Vandevelde, G. and Van den Bogaert, W. Comparison of plastic and Orfit masks for patient head fixation during radiotherapy: precision and costs. Int. J. Radiat. Oncol. Biol. Phys. 33: 499–507, 1995.