Short Communication

The influence of a six degrees of freedom couch and an individual head support in patient positioning in radiotherapy of head and neck cancer

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ABSTRACT

Reproducible patient positioning is important in radiotherapy (RT) of head-and-neck cancer. We therefore compared set-up errors in head-and-neck RT resulting from three different patient positioning systems. Patients were either treated with a standard head support (SHS) and conventional treatment couch (SHS-3, n = 10), a SHS and rotational couch (SHS-6, n = 10), or an individual head support (IHS) and rotational couch (IHS-6, n = 10). Interfraction mean translation vector lenghts were significantly lower for IHS-6 compared to SHS-3 (0.8 $\pm$ 0.3 mm vs. 1.4 $\pm$ 0.7 mm, P = 0.001). Intrafraction displacement was comparable among cohorts. This study showed that the use of a six degrees of freedom couch combined with an IHS in head-and-neck RT resulted in better interfraction reproducibility.

1. Introduction

In head-and-neck radiotherapy, set-up errors during the course of treatment should be reduced to a minimum using adequate patient immobilization and correction of positioning errors. In attempts to reduce planning target volume (PTV) margins and prevent anatomic deformation, several small series have analysed set-up reproducibility by adding an individual head support (IHS) to the immobilization system [1–11]. Of these studies, five used cone-beam CT (CBCT) imaging with online correction protocols [1,4,5,10,11]. To account for any uncorrected deviations, clinical target volume (CTV) – PTV margins of 5 mm are commonly used [12,13]. As opposed to three degrees of freedom (3DOF), six degrees of freedom (6DOF) couches permit further optimization of set-up by enabling correction of rotational errors [14]. Most studies investigating the use of a 6DOF couch focused on intracranial lesions but there are only few studies on head-and-neck cancer (HNC) [5,14–16]. To our knowledge, no previous study has compared 3DOF to 6DOF couches and different head supports in head-and-neck radiotherapy. Therefore, the aim of this comparative study

was to evaluate the benefit of a 6DOF couch and an IHS using online CBCT position verification and correction in HNC patients.

2. Materials and methods

2.1. Patient cohorts and treatment technique

Twenty patients were prospectively included from August 2017 until December 2017. After obtaining local ethics committee approval and written informed consent, another ten patients were included from January 2018 until May 2018. All patients were diagnosed with HNC or skin cancer with cervical lymph node metastasis and consecutively assigned to three cohorts, each consisting of ten patients. The first cohort (SHS-3) was treated with a standard head support (SHS) and conventional 3DOF couch (Elekta AB, Stockholm, Sweden) according to former department protocol. The second cohort (SHS-6) was treated with a SHS and 6DOF couch (HexaPOD evo RT System, Elekta AB, Stockholm, Sweden), whereas the third cohort (IHS-6) was treated with an IHS and 6DOF couch. Prescribed dose to the PTV, derived by 5 mm

expansion of the CTV, was planned with intensity modulated radio-therapy (IMRT) or volumetric modulated arc therapy (VMAT) (Supplementary Table 1) and delivered in daily fractions in all patients.

2.2. Immobilization and set-up

Patients were positioned supine with a knee and feet support fixed to the carbon fibre baseplate (ProStep, ITV, Innsbruck, Austria) using indexing bars for individual set-up reproducibility and comfort. All patients were treated with five-point thermoplastic masks (MacroMedics, Waddinxveen, The Netherlands), which were marked with reference points indicating the isocentre. The CT scanner and accelerators were each equipped with a SHS (Posifix Supine Headrests, Hyperextended, Cablon Medical, Leusden, The Netherlands) in the SHS-3 and SHS-6 cohorts. For all patients in the IHS-6 cohort a customized head support (Head and shoulder AccuCushion R550-T, Klarity Medical Products, Newark, Ohio, USA) was moulded around an in-house produced styrofoam adaptor to allow fixation to the baseplate for set-up reproducibility. It supported the lower neck and shoulders in addition to standard head and upper neck support (Supplementary Figure). The water equivalent thickness of the IHS is approximately 5 mm. We calculated that a limited dose will be delivered through the IHS, resulting in minimal effect on the skin, which was considered not clinically relevant.

2.3. Imaging and online correction protocol

The planning-CT was acquired with 3-mm slice thickness on a Big Bore CT scanner (Philips Medical Systems, Bothell, WA, USA). In all fractions, daily online position verification consisted of a CBCT-scan before correction. If a translation ≥ 2 cm and/or a rotation ≥ 3 degrees was found, the setup procedure was repeated from the start. This was verified with an extra CBCT-scan. Translational setup errors were corrected in all directions. After correction and after treatment, a CBCT-scan was acquired in the first four fractions and twice a week for the remaining part of treatment. At initial set-up, the patient was positioned using the reference lines on the thermoplastic mask. Afterwards, further couch corrections (3DOF: Remote Automatic Table Movement, Elekta AB, Stockholm, Sweden; 6DOF: iGuide, Elekta AB, Stockholm, Sweden) were derived from matching a rectangular alignment box encompassing the PTV on planning-CT (clipbox) to the corresponding region of interest on daily CBCT (XVI imaging technology, Elekta AB, Stockholm, Sweden). A bone match with translations and rotations was performed.

2.4. Translation and rotation

Interfraction displacements were determined by comparing the CBCT after correction to the planning-CT. Intrafraction displacements were determined by comparing the CBCT after correction to the CBCT after treatment. Patient translations (LR, AP, CC) and rotations (LR, AP, CC) were assessed. Translations were reported as mean vector lenght with standard deviation (SD). In a similar way, rotations were reported as the L^2-norm of the rotations around the three axes, with SD.

All matching procedures were executed by the same radiation therapist (SV) and results derived from the matching procedure were checked for any inconsistencies by a medical physics engineer (JvE).
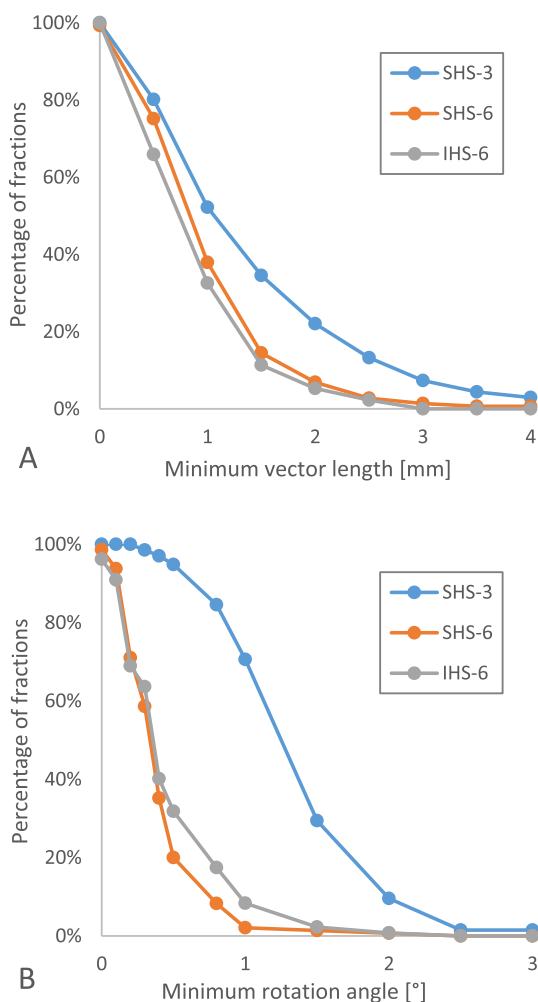
2.5. Statistical analysis

Mean and SD of translation vector lenghts and rotation norm were calculated. To assess differences in age and monitor units across cohorts, a one-way ANOVA was executed. To take individual patient variation into account, a repeated measures analysis was performed. Therefore, a linear mixed model was used to study differences in mean vector lenghts between the cohorts. The vector lenghts were used as dependent variables. Normality tests were executed in advance and when data was skewed a log transformation was performed. Fraction 1 was set as reference category and 'group' as factor. 'Fraction minus 1' was used as continuous variable. 'Group', 'fraction minus 1' and the interaction between 'fraction minus 1 and group' were included as fixed effect. A compound symmetry covariance structure was selected for errors as it has the lowest Akaike's Information Criterion compared to alternative covariance structures tested. The model was fitted using the restricted maximum likelihood method. To look into the effect of the 6DOF couch, an exploratory analysis was performed by combining the IHS-6 and SHS-6 cohorts and comparing them to SHS-3. P-value ≤ 0.05 was considered indicative of statistical significance. Statistical analysis was performed using IBM SPSS version 22 (IBM Corp, Armonk, NY, USA).

3. Results

For this study we analysed 827 CBCT's. Patient characteristics are summarized in Supplementary Table 1. Seventy percent of patients were male (n = 21). Mean age was 67 ± 8 years in SHS-3, 60 ± 15 years in SHS-6, and 62 ± 12 years in IHS-6 ($P = 0.4$). Mean monitor units per fraction was 444 ± 111 in SHS-3, 433 ± 180 in SHS-6, and 558 ± 140 in IHS-6 ($P = 0.1$).

Interfraction mean translation vector lenghts were 1.4 ± 0.7 mm in

Table 1
Interfraction errors: mean translation vector length of the clipbox match.

SHS-3			SHS-6			IHS-6		
	Vector [mm]			Vector [mm]			Vector [mm]	
Patient	mean	(SD)	Patient	mean	(SD)	Patient	mean	(SD)
1	1.9	(1.0)	11	1.0	(0.5)	21	0.8	(0.3)
2	2.8	(0.9)	12	1.3	(0.5)	22	0.5	(0.3)
3	0.5	(0.2)	13	0.6	(0.2)	23	0.8	(0.4)
4	1.3	(0.6)	14	0.8	(0.4)	24	1.2	(0.9)
5	1.4	(1.1)	15	1.8	(1.2)	25	1.3	(0.5)
6	0.8	(0.4)	16	0.7	(0.4)	26	0.9	(0.3)
7	1.1	(0.5)	17	0.5	(0.3)	27	0.7	(0.4)
8	1.7	(1.3)	18	0.4	(0.1)	28	0.4	(0.2)
9	1.6	(0.7)	19	1.2	(0.3)	29	1.1	(1.0)
10	0.6	(0.4)	20	1.3	(0.6)	30	0.6	(0.4)
Mean [mm]:	1.4	(0.7)	Mean [mm]:	1.0	(0.5)	Mean [mm]:	0.8	(0.5)
SD [mm]:	0.7		SD [mm]:	0.4		SD [mm]:	0.3	

SHS-3, standard head support and 3 degrees of freedom couch; SHS-6, standard head support and 6 degrees of freedom couch; IHS-6, individual head support and 6 degrees of freedom couch.

Fig. 1. Clipbox match: (A) Minimum translation vector length. (B) Minimum rotation angle in either LR-, AP- or CC-direction. Blue line: SHS-3; Orange line: SHS-6; Grey line: IHS-6. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

SHS-3, 1.0 ± 0.4 mm in SHS-6, and 0.8 ± 0.3 mm in IHS-6 (Table 1). When comparing cohorts, these vector lenghts only differed significantly for SHS-3 vs. IHS-6 (*P* = 0.001). Interfraction translation vector lenghts of ≥ 2 mm were seen in 22% of all fractions in SHS-3, 7% in SHS-6, and 5% in IHS-6 (Fig. 1A). This difference was mainly the result of a large difference in CC translations (Supplementary Table 2). Interfraction mean rotation norm were 1.63 ± 0.41 degrees in SHS-3, 0.48 ± 0.15 degrees in SHS-6, and 0.54 ± 0.31 degrees in IHS-6. A significant decrease in rotations was found when using the 6DOF table (*P* < 0.001). No significant differences were found between SHS-6 and IHS-6 (*P* = 1.0). Rotation angles of ≥ 1 degree were seen in 71% of all fractions for SHS-3, as opposed to < 8% of all fractions in the other cohorts (Fig. 1B). The combined interfraction mean translation vector lenght of IHS-6 and SHS-6 was significantly lower compared to SHS-3 (*P* = 0.02).

Intrafraction differences were comparable: mean translation vector lenghts were 1.0 ± 0.5 mm in SHS-3, 0.8 ± 0.4 mm in SHS-6, and 0.7 ± 0.3 mm in IHS-6 (*P* > 0.1 for the three paired comparisons), and mean rotation norm were 0.55 ± 0.24 degrees in SHS-3, 0.52 ± 0.14 degrees in SHS-6, and 0.51 ± 0.21 degrees in IHS-6.

4. Discussion

This comparative study in 30 HNC patients showed that patient displacement was lowest when an IHS was combined with a 6DOF

couch, as compared to a SHS and a 3DOF couch. Overall, interfraction mean translation vector lenghts were < 1.5 mm, indicating satisfactory set-up accuracy. Only one patient in the SHS-3 cohort had a mean translation vector lenght exceeding 2 mm. Intrafraction translations and rotations were limited in all cohorts confirming proper immobilization and suggesting comfortable positioning of patients.

Several studies investigating position verification in HNC used standard bony landmarks as match structures [3,6,17]. According to the ESTRO guideline it may be prudent to define primary match structures in close proximity to the target which will determine the position of the clipbox. Secondary match structures should be used for guidance purposes only [18]. A key application of image guidance with CBCT is targeting the tumour itself and not the bony anatomy [14].

Radiation to the head and neck is known to cause toxicity to radiation-sensitive organs affecting quality of life. Reduction of toxicity in patients with HNC can be achieved by using reduced PTV margins combined with daily CBCT-guided VMAT [19]. Our approach to reduce toxicity while maintaining local control is through optimizing patient set-up since organs at risk in HNC may be adjacent to the target volume. Provided that immobilization and correction of set-up errors are fully optimized, PTV margins can be reduced. Therefore, we believe that a 6DOF couch should be standard of care in HNC treatment. However, it should be noted that when doing so, other sources of geometric uncertainties such as delineation uncertainties and linac inaccuracies need to be taken into account.

The 6DOF couch provides optimal patient position correction. Nowadays, this type of couch is increasingly used and is considered state of the art care [5,14–16,20]. It is able to achieve submillimetre positioning accuracy [20]. Wang et al. recently showed that residual set-up errors in this range can be achieved in HNC patients treated with an IHS and 6DOF couch [5]. This study was however limited by the use of a single cohort. Our findings are in line with Wang et al. Moreover, to identify the effect of both the IHS and the 6DOF couch on positioning accuracy, we studied different cohorts. When comparing couches, the percentage of fractions with a translation of ≤ 4 mm was lowest when using a 6DOF couch. Although IHS-6 showed significantly less translations compared to SHS-3, no difference was found between SHS-6 and SHS-3. However, mean translations of the two 6DOF cohorts combined were significantly lower compared to SHS-3. This suggests that the 6DOF couch corrects translations more accurately than the 3DOF couch. Others investigating two different masks and position correction in 3DOF and 6DOF in HNC patients also found less displacement in the 6DOF cohort [15]. It could be argued that a distinct effect of the 6DOF couch was not seen in our primary analysis due to the fact that our study is limited by the small number of patients and/or the lack of a fourth cohort (IHS and 3DOF couch). As expected the 6DOF couch adequately corrected rotations (92% of fractions showed a residual rotation of ≤ 1 degree).

Currently, various individual head supports are commercially available. We selected the Klarity AccuCushion, for which previous studies reported to have found satisfactory results [5,6]. This type of IHS fully supports head, neck and shoulders and takes 10–15 min to prepare. In contrast to a vacuum bag, this IHS seems to retain its shape during the course of treatment. Adverse circumstances with vacuum bags were reported showing air leakage and needed to be re-vacuumed [1,9].

Although it has been suggested that rotations could be reduced by using an IHS [11], we did not find any difference in rotations between IHS-6 and SHS-6. Remarkably, Hansen et al. found significantly lower random rotational errors in a cohort in which a SHS was used compared to cohorts using a vacuum IHS [10]. It is unclear whether this was the result of the type of head support or other immobilization factors, since these also differed between cohorts. In contrast to others [2,6], we did not observe an improvement in intrafraction stabilization using an IHS compared to a SHS.

In conclusion, a 6DOF position correction in combination with an

IHS reduces interfraction translations and rotations in patients with HNC when using an online CBCT-based correction protocol. These techniques may facilitate limited margin reductions in treatment of HNC, when taking into account other random and systematic errors.

Acknowledgements

Declaration of Competing Interest

None.

Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.phro.2019.07.001.

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