



Peculiarities of CT Volumetric Imaging Towards the Optimal Image-Guided Radiotherapy

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1. Introduction

Optimal irradiation of target tissues and preservation of adjacent tissues remain the main goals in the technical development of radiotherapy techniques. Methods and devices of Image-Guided Radiotherapy (IGRT) are elaborated with the aim of ensuring that the prescribed radiation dose is delivered accurately to the tumour while minimising the exposure to surrounding healthy tissues. Technical solutions ensure a few-millimetre, or even sub-millimetre precision of the irradiation beam, while with currently used mechanical means of patient positioning, unfortunately we can expect much bigger positioning deviations, reaching even centimetre range. Patient positioning deviation to a certain extent is related to changes in soft tissue density and volume, which change during the period of treatment. Therefore, the discovery of reliable reference structures in routinely performed daily Cone-Beam Computed Tomograms (CBCT) was essential.

The aim of this study was to identify residual misalignments that arise from inherent CT/CBCT image mismatch persisting even after couch corrections, and to evaluate their subsequent impact on dose delivery accuracy and possible changes in unwanted irradiation of tumour-surrounding critical organs.

2. Methods

2.1. Patients. This retrospective study involved patients with head and neck cancer treated at the Lithuanian University of Health Sciences Kaunas Clinics Affiliated Hospital of Oncology, Department of Radiotherapy. Ethical approval was obtained from the Kaunas Regional Biomedical Research Ethics Committee (approval number BE-2-90). For this analysis, 15 patients who showed a pronounced response to treatment, reflected by significant tumour shrinkage during therapy, were retrospectively selected. Volumetric CT images were acquired using a kV-CBCT system integrated into the Halcyon V3.1 linear accelerator (Varian Medical Systems, Palo Alto, CA, USA). All DICOM datasets were anonymized at the time of export from the Eclipse treatment planning system to ensure patient confidentiality. Each patient underwent 30 to 35 daily verification kV-CBCT scans, with each dataset consisting of 54–120 axial slices depending on tumour volume/size.

3. Results

Example of initial volumetric image (**Fig.2A**) with indicated slice, which is used to illustrate the patient's position deviation throughout the sessions of therapy (**Fig.2B**). The changes in tissue density and soft tissue shrinkage during the treatment is illustrated in consequent images of the same slice, but during different radiotherapy sessions (**Fig.2C,D,E**). The treatment sessions from which the images are compared are indicated as numbers in top-left of each image. The changes in tissue density in regard to the initial first session are highlighted in green. The slice images from different sessions were spatially aligned by hard tissue structures.

Patient position's deviation from the initial one throughout the whole radiotherapy course presented in translation and rotation estimates is shown in **Fig.3**. Certain trend in translation and rotation angles is clearly visible and indicates possible significant changes in irradiation of the tissues. The actual deviation in irradiation doses for critical organs caused by patient's position deviations is presented in **Table 1**.

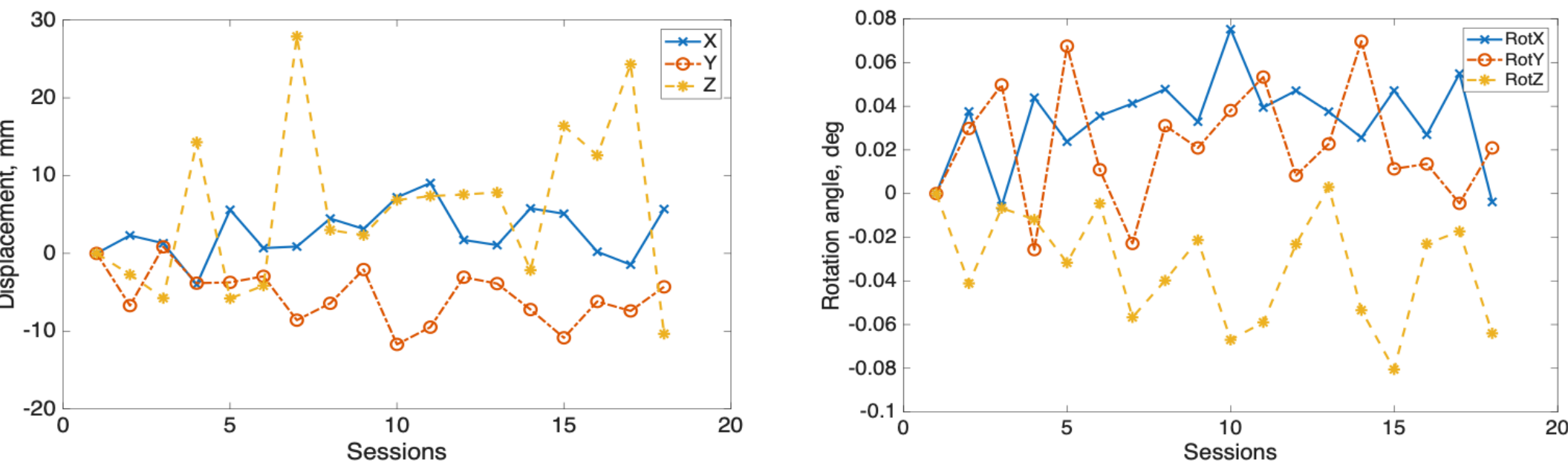


Fig.3. Example of patient position's deviation from the initial one during the sessions of treatment course: Translation in axes X,Y and Z - left graph; Rotation around the axes X,Y and Z - right graph.

Table 1. Actual deviation in irradiation doses for critical organs caused by patient's position deviations

Patient	Dose deviation, Gy/fraction Mean value (SD)				
	PTV	Spinal Cord	Parotids	Esophagus	Larynx
1	-0.016 (0.008)	0.026 (0.062)	0.013 (0.070)	0.005 (0.014)	0.005 (0.020)
2	-0.022 (0.071)	-0.024 (0.056)	0.004 (0.057)	0.001 (0.018)	0.004 (0.046)
3	-0.050 (0.148)	0.010 (0.201)	0.042 (0.179)	0.029 (0.095)	
4	-0.043 (0.019)	0.033 (0.073)	0.012 (0.085)	0.002 (0.017)	0.011 (0.021)
5	-0.057 (0.043)	-0.014 (0.091)	0.001 (0.182)	0.001 (0.035)	0.000 (0.010)
6	-0.025 (0.022)	0.076 (0.159)	0.011 (0.066)	-0.015 (0.088)	-0.011 (0.017)
7	-0.038 (0.024)	0.015 (0.083)	0.021 (0.045)	-0.001 (0.032)	-0.005 (0.093)

References:

1. Yadav, R., Chauhan, A. K., Kumar, P., Nigam, J., & Silambarasan, N. S. (2022). Setup Errors in Interfraction Radiotherapy in Patients of Head and Neck Cancer. SRMS JOURNAL OF MEDICAL SCIENCE, 7(02), 46-55.
2. Li, Y., Wei, Z., Liu, Z., Teng, J., Chang, Y., Xie, Q., ... & Chen, L. (2022). Quantifying the dosimetric effects of neck contour changes and setup errors on the spinal cord in patients with nasopharyngeal carcinoma: establishing a rapid estimation method. Journal of radiation research, 63(3), 443-451.

2.2. Estimation of Patient Positioning deviations through Volumetric Image alignment. Patient positioning deviations throughout the whole treatment were evaluated by estimation of necessary 3-D shift of the current session volumetric image till the perfect alignment with the initial one of the first treatment session. The hard tissue structures, in particular mandible and part of the skull, were segmented delineating high attenuation voxels by threshold selection method from grey-level histograms (Otsu's method) and adjusted using mathematical morphology algorithm (MatLab function "imerode" using structuring element "sphere"). We found these structures as reliable reference landmarks for patient position identification, because they do not change throughout the whole treatment. Example of superposition of the structures is given in **Fig.1**.

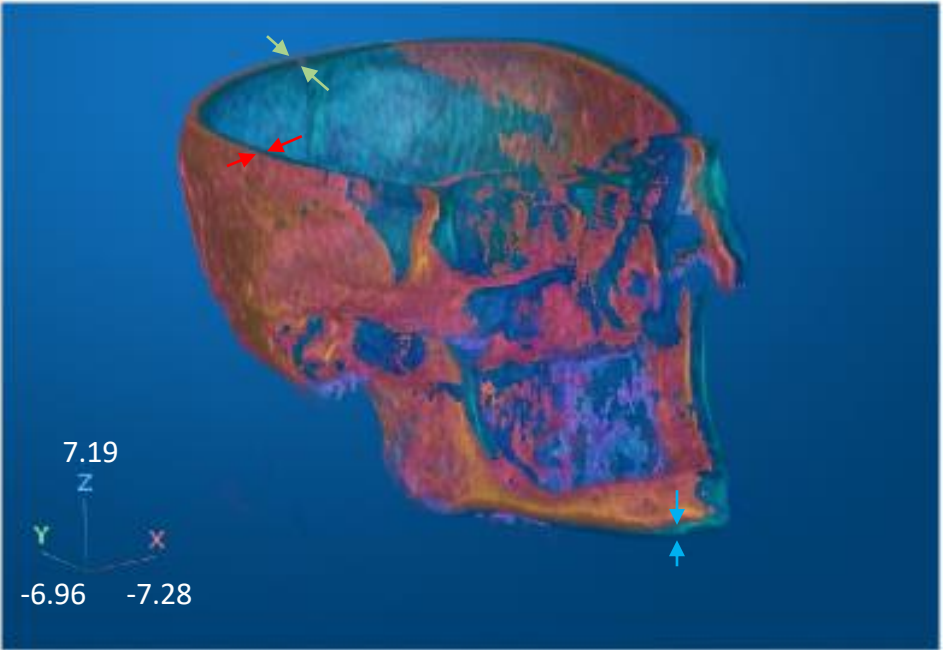


Fig.1. Example of superposed hard tissue structures from initial and 4th therapy session. The arrows show misalignment of two volumetric images corresponding to difference in patient's positioning. Actual difference of these cases is indicated in numbers in bottom-left of the figure.

2.3. Estimation of changes in irradiation of target and organs at risk. The measured daily positional deviations were used to recalculate the actual dose delivered to the treatment target and surrounding organs at risk, including the spinal cord, parotid glands, oesophagus, and larynx. These recalculations were performed using the Anisotropic Analytical Algorithm (AAA), a part of Eclipse TPS version 16.1 (Varian Medical Systems, USA). This approach enabled quantification of how real-world interfractional positioning variations may impact the irradiation of tumour structures and adjacent healthy tissues.

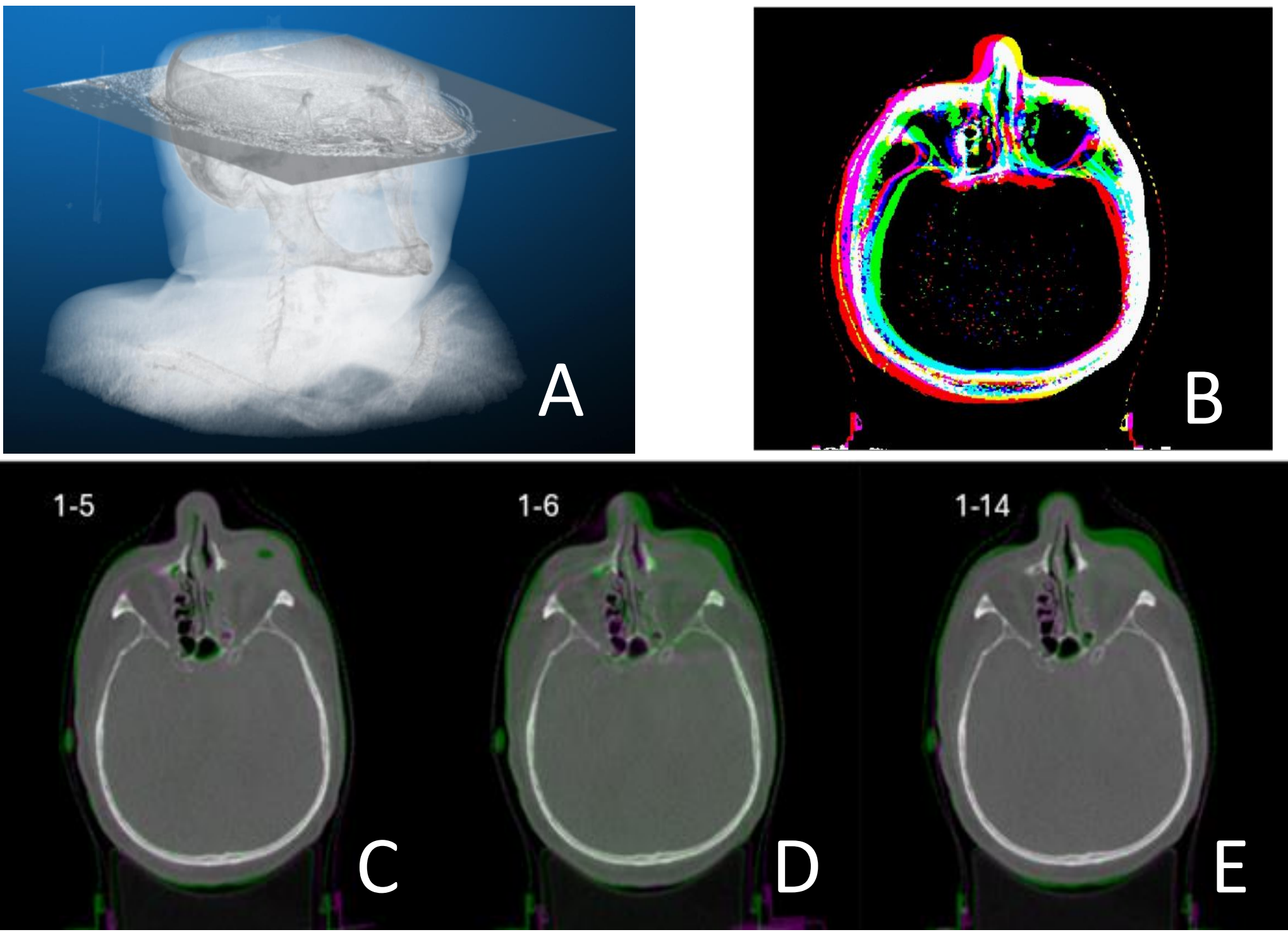


Fig.2. Example of initial volumetric image in first treatment session (A) with indicated slice, which is used to illustrate patient's position deviations throughout the treatment sessions (B) and changes in tissue density or soft tissue shrinkage (C,D,E). Differences in tissue density between current session and the initial one are highlighted in green. Slice images are spatially aligned by hard tissue structures.

4. Discussion

Detail investigation of the impact of patient's position deviations revealed that lateral (X-axis) or longitudinal (Z-axis) misalignments directly compromise targeted tumour coverage and potentially lower the treatment effectiveness. Y-axis displacements were linked with oesophageal dose deviations where even subtle shifts may expose this organ to higher doses than planned. Investigation showed that even subcentimeter deviations, often considered as minor in routine clinical practice, may translate into underdosage of the target or overexposure of organs at risk. Although the observed deviations were generally small, their clinical significance is supported by previous studies. Yadav et al. (2022) reported set-up errors of up to 4.4 mm, suggesting that a 5 mm margin is required to ensure adequate planning target volume coverage in modulated radiotherapy [13]. Similarly, Li et al. (2022) showed that in nasopharyngeal carcinomas, dose variations of up to 9.7% in the spinal cord were due to setup errors, while anatomical contour changes explained only 1.7%. These findings are consistent with our results and emphasise the critical need for daily review and the potential benefit of adaptive replanning in patients with significant anatomical changes.

5. Conclusions

- * Stable hard-tissue structures, such as the mandible and skull base, serve as reliable anatomical landmarks for accurate patient position assessment and tracking of positioning deviations throughout the entire radiotherapy course.
- * Dose recalculations incorporating actual daily positioning errors demonstrated measurable risks of unintended dose increases to organs at risk and reduced PTV coverage, underscoring the need for more adaptive and dynamic IGRT strategies to ensure safe and accurate dose delivery.

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