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Intercranial stereotactic RT

A comprehensive evaluation of treatment accuracy, including end-to-end tests and clinical data, applied to intracranial stereotactic radiotherapy

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ABSTRACT

Background and purpose: A methodology is presented to quantify the uncertainty associated with linear accelerator-based frameless intracranial stereotactic radiotherapy (SRT) combining end-to-end phantom tests and clinical data.

Methods and materials: The following steps of the SRT chain were analysed: planning computed tomography (CT) and magnetic resonance (MR) scans registration, target volume delineation, CT and cone beam CT (CBCT) registration and intrafraction-patient displacement. The overall accuracy was established with an end-to-end test. The measured uncertainties were combined, deriving the total systematic (Σ_T) and random (σ_T) error components, to estimate the GTV-PTV margin.

Results: The uncertainty in the MR-CT registration was on average 0.40 mm (averaged over AP, CC and LR directions). Rotational variations were smaller than 0.5° in all directions.

Interobser variation in GTV delineation was on average 0.29 mm.

The uncertainty in the CBCT-CT registration was on average 0.15 mm. Again, rotational variations were smaller than 0.5° in all directions.

The systematic and random intrafraction displacement errors were on average 0.55 mm and 0.45 mm, respectively.

The systematic and random positional errors from the end-to-end test were on average 0.49 mm and 0.53 mm, respectively.

Combining these uncertainties resulted in an average $\Sigma_T = 0.9$ mm and $\sigma_T = 0.7$ mm and an average GTV-PTV margin of 2.8 mm.

Conclusion: This comprehensive methodology including end-to-end tests enabled a GTV-PTV margin calculation considering all sources of uncertainties. This generic method can also be used for other treatment sites.

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Intracranial stereotactic radiotherapy (SRT) refers to the delivery of high radiation doses, in a single or few fractions, which results in a more potent biological effect than conventional fractionation [1]. In order to minimize the normal tissue toxicity, conformation of high doses to the target and rapid dose fall-off away from the target is essential. The practice of SRT requires therefore a high level of confidence in the accuracy of the entire treatment delivery process [2].

The linear accelerator – based frameless SRT delivery process consists of several steps as illustrated in Fig. 1. The overall accuracy of the treatment process depends on the accuracy of the individual steps. Several reports can be found in literature on the evaluation of the treatment accuracy of the different parts of the SRT treatment chain. Considerations on the registration of magnetic resonance and computed tomography images can be found for example in Cattaneo et al. [3] and Webster et al. [4]. Sidhu and co-workers [5] looked at interobserver delineation variations on CT images for brain metastases. Weltens et al. [6] assessed the impact of the addition of MR imaging on the interobserver variability of brain tumour delineations. Patient setup and immobilization device accuracy has been studied by for example Meyer et al. [7], Ramakrishna et al. [8] and Guckenberger et al. [9].

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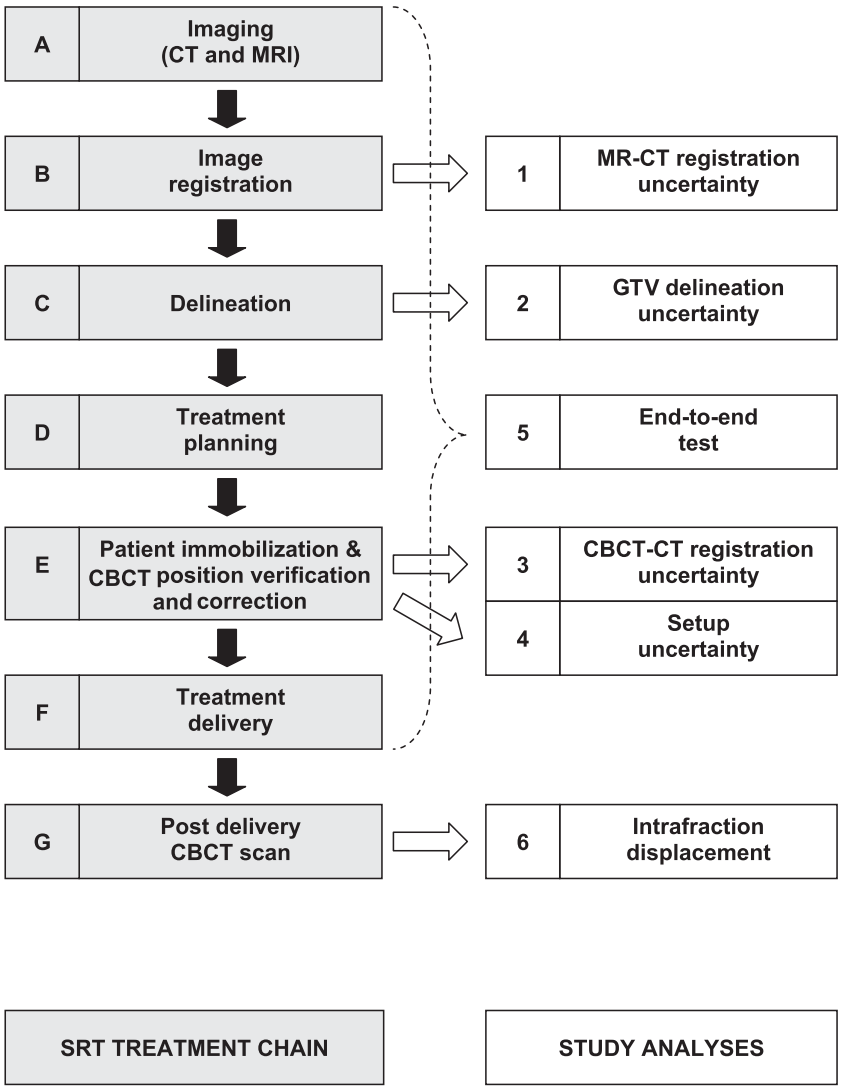

Fig. 1. Treatment chain (steps A–G) of intracranial stereotactic radiotherapy (SRT) at the Catharina Hospital Eindhoven, The Netherlands, and the different measurements (1–6) of uncertainties associated with the individual steps or the whole treatment chain, as determined in the present study.

End-to-end tests are used to measure the overall geometrical and dosimetric accuracy of the treatment chain for an ideal patient. For example, Welleweerd et al. investigated the geometrical accuracy of a linear accelerator equipped with a CBCT system to be used for radiosurgery performing a strip test, star shot procedure and an end-to-end test with a dedicated phantom [10]. Verellen et al. assessed the dosimetric and positional accuracy of the radiation delivery to the target by an anthropomorphic phantom which allows the insertion of dosimeters and lead beads [11]. Coscia et al. [12] evaluated the isocenter repositioning error during several treatment sessions comparing calculated dose distributions and corresponding film measurements. Schulz et al. employed a Fricke-gel dosimeter to confirm the dosimetric accuracy of stereotactic radiation treatment delivery [13]. However, intrafraction movement and target volume delineation uncertainty are not considered in such procedures.

We believe that for a comprehensive evaluation of the overall accuracy of a certain treatment technique results of end-to-end tests [38,39] need to be combined with clinical data (e.g. setup data), as for example recommended by Thwaites [14].

In this work, we quantified the uncertainty associated with the steps of the SRT treatment chain (Fig. 1). In particular, we looked at the uncertainty associated with: (1) the registration of the planning CT and MR scan, (2) interobserver variation in target volume delineation, (3) CT and CBCT registration, (4) setup uncertainty and (6) patient intra-fraction displacement. Moreover, an end-to-end test, using film embedded in a phantom, was performed mimicking the clinical procedure (5). By means of the end-to-end test potential systematic and random components of image guided registration/positioning error and mechanical delivery error can be assessed.

The obtained information was used to assess the overall systematic and random uncertainties and the adequateness of the employed GTV-PTV margin.

Methods and materials

In Fig. 1 the stereotactic radiotherapy treatment chain at Catharina Hospital, Eindhoven, the Netherlands, is depicted.

For each step included in the uncertainty analysis, the method used to quantify the uncertainty is explained in the following sections. Subsequently, the end-to-end test is described. The last section describes how the data were combined to derive the GTV-PTV margin. All analyses have been performed and reported