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Towards clinical implementation of ultrafast combined kV-MV cone-beam CT for IGRT of lung tumors within breath-hold: evaluation of dosimetry and registration accuracy based on phantom studies

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Combined ultrafast 90°+90° kV-MV cone-beam computed tomography (CBCT) within breath-hold of 15s is a promising approach to accelerate imaging for patients with lung tumors treated with deep inspiration breath-hold (DIBH). To judge clinical feasibility of kV-MV CBCT, two main properties have to be fulfilled: (1) image quality has to be sufficient for registration within 1mm accuracy, and (2) dose exposure has to be small compared to the prescribed dose.
The aim of this thesis was to develop concepts to test these properties of kV-MV CBCT based on a comparison study to clinically established CBCT methods. In particular, the main aspects were accomplished as follows:
Dosimetric properties: For a reliable measurement of the absorbed dose in the imaging process, accurate dose calibration was performed for kV and MV energy. Extensive research was done to determine beam quality for both energy ranges. For direct comparison of MV and kV dose output, the relative biological effectiveness was considered. To simulate the patient situation, measurements in various representative locations of an inhomogeneous thorax phantom were performed. Furthermore, the CT dose index (CTDI) was determined for future quality assurance purposes. A measured dose of 20.5mGE in the target region was comparable to the widely-used clinical imaging technique, whereas kV-MV spared healthy tissue and reduced dose to 6.6mGE (30%). These results show that from the dosimetric point of view, kV-MV CBCT is suitable for hypofractionated DIBH.
Registration accuracy: A detailed phantom registration study was performed with different tumor-mimicking tumor-shapes in an inhomogeneous thorax phantom. 10 random pre-selected isocenter shifts were applied using optical tracking with high accuracy of 0.05mm. Registration was performed with three methods: (1) manual, (2) automatic software provided by manufacturer, and (3) self-developed automatic registration framework. An objective evaluation was achieved with the self-developed registration method by automatic determination of identical region of interest around the tumor-shapes for all imaging techniques. Registration accuracy was in average maintained below 1mm, with maximum outliers still below 1.5mm.
In summary, the comparison studies conceptualized and accomplished in this thesis demonstrated that kV-MV CBCT is feasible for imminent clinical implementation.