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Title: The effect of 4D-MRI motion mapping to CT image for use in liver 4D dose calculations
Target audience: Motion in Radiotherapy, Medical Imaging and Medical Physics

Purpose: 4D-CT imaging is widely used in radiotherapy planning to account for the motion and provide density information – especially needed for dose calculation in particle therapy. However, this approach does not account for motion variability, resulting in imaging artefacts and also gives a non-negligible radiation dose. 4D-CT(MRI) is a technique developed in our group for simulating many 4D-CT data sets from a static reference CT and a data-base of motion extracted from 4D-MRI studies of volunteers. It has been demonstrated for a single liver case thus-far [1]. In this work, we have tested this approach on a wider number of liver cases and evaluated the impact on 4D proton treatment plans relating to different motion extraction models.

Methods: The 4D-CT(MRI) approach (Fig. 1a) has been studied for 5 liver patients with conventional 4D-CT data available. For all cases deformation fields were obtained from: (i) registration of 4D-CT series from the same patient as the static CT used (4D-CT(SIM), as a proof of principle), and (ii) by selecting the 'most-similar' motion from a 4D-MRI motion library consisting of liver motion obtained from multiple breathing cycles of 13 volunteers, 4D-CT(MRI) [2]. Two modes of 4D-CT(MRI) were investigated. For the population-based method, the reference deformation was obtained from 4D-CT registration of each patient. The 'most similar' motion was then extracted from 4D-MRI motion library. For the subject-specific approach, 4D-CT(MRI) images were generated as a reference using an example motion cycle of a volunteer and patient's CT. The 'most-similar' motion was determined from a restricted motion library consisting of the remaining motion cycles for the same volunteer. In order to evaluate the effectiveness of the 4D-CT(MRI) approach for proton therapy, 4D dose calculations (4DDC) were performed for all generated data sets (Fig. 1d).

Results: 4D-CT registration was evaluated visually and validated with mean position error (MPE<4mm) of implanted fiducials (Fig.1b). For motion extracted with the population-based 4D-CT(MRI) method, the MPE were less than 5mm in 4/5 cases; 6mm for last case. Matching of patient motion to the volunteer library was quantified with Summed-Square Difference (SSD, example in Fig. 1c), ranging at 1-11 mm. Compared to 4DDC's calculated on the reference 4D-CT data, 80(±12%) of points agreed within 3%/3mm. The subject-specific approach showed an improved maximum SSD of 1mm, and dosimetric agreement improved to 98(±3%) of CTV points agreeing within 3%/3mm.

Discussion: Subject-specific modelling appears more accurate than the population-based approach. However, the latter is presently limited by a small database of volunteer data (n=13). A reasonable dosimetric agreement can still be found for most cases, indicating the promise of this approach upon planned expansion of the motion library. Independent of the approach used, 4D-CT(MRI) extends the capabilities of motion modelling for dose calculations, accounting for realistic motion patterns over many breathing cycles.

Conclusion: In summary, 4D-CT(MRI) technique can be used to generate realistic 4D-CT data sets for 4D dose calculations in liver.

References:
[1] Boye D, Lomax T, Knopf A. Mapping motion from 4D-MRI to 3D-CT for use in 4D dose calculations: a technical feasibility study. Med Phys. 2013 Jun;40(6):061702.
[2] von Siebenthal M, Székely G, Gamper U, Boesiger P, Lomax A, Cattin P. 4D MR imaging of respiratory organ motion and its variability. Phys Med Biol. 2007 Mar 21;52(6):1547-64.

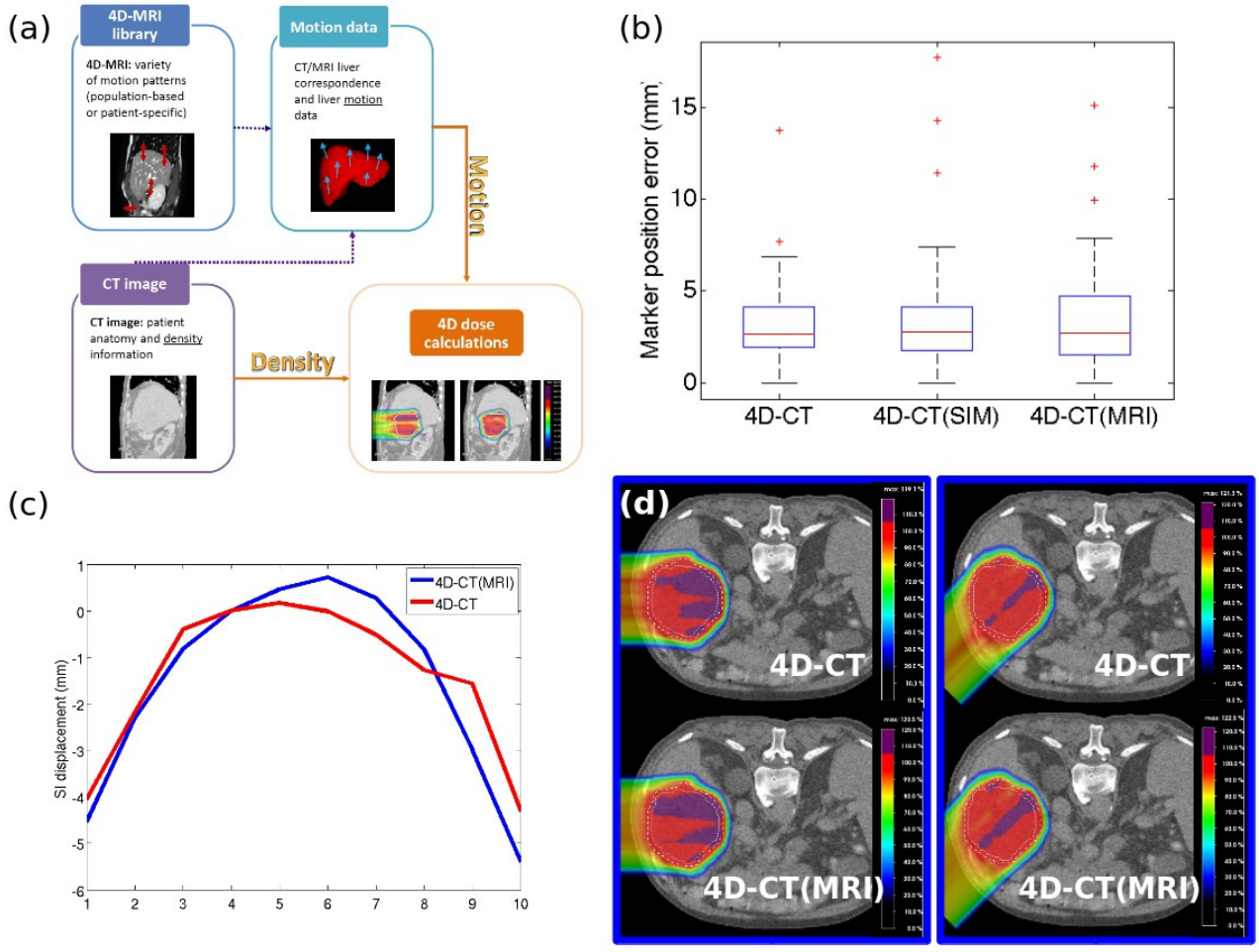

Figure 1. (a) 4D-CT(MRI) method for proton dose calculations in liver. (b) MPE for deformation vector fields extracted from 4D-CT, 4D-CT(SIM) and matched 4D-CT(MRI) for all of the studied cases. (c) Differences in mean SI motion of corresponding points in liver (SSD=1.5±3.4mm). (d) Effect of simulated image data on calculated dose for 2 different treatment fields.