SP-0519
Errors and uncertainties in DIR-based accumulated dose
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The enabling technology for dose mapping, treatment evaluation and adaptation based upon cumulative dose is deformable image registration (DIR). Ideally, DIR creates an exact correspondence between tissue sub-volumes in the co-registered images. Realistically, DIR creates an approximate map of image content (e.g. grey-scales, landmarks, contours) between two images. As a result, current DIR algorithms yield an imperfect correspondence between tissue elements for both intra- and inter-fraction registration. Since tissue response is a function of the accumulated and per fraction dose to each sub-volume, registration errors add uncertainty to patient dose evaluation. Unfortunately, necessary and sufficient methods do not exist for automated patient DIR validation; however, several necessary but insufficient methods do exist. This presentation will (1) describe the use of inverse mapping consistency and unbalanced energy to detect DIR errors; (2) probe the correspondence of these metrics with dose mapping errors and cumulative dose uncertainty; (2) explain a 3D distance-to-difference (DTD) metric which can be used to determine DIR error tolerances sufficient to keep dose mapping errors below a user-specified threshold; (3) demonstrate the necessity for self-consistent registrations in adaptive treatment protocols in which accumulated dose is projected on to the anatomy of the day; (4) illustrate methods to evaluate random registration uncertainties and the corresponding dose uncertainties; and finally look at the impact of correlated registration errors on patient dose distributions. Even though DIR and dose mapping is imperfect, it can be clinically beneficial if it improves the estimate of the accumulated patient dose. Users must be keenly aware of potential errors and their consequences.

SP-0520
3D vs 4D CBCT: Clinical indications, implementation, and practicalities
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3D imaging represents a snapshot in time of the patient anatomy. By use of 4D imaging, either as imaging of the respiration cycle or as consecutive 3D images over the treatment course, dynamics of the anatomy can be measured and included in the treatment planning process. However, due to the added information/complexity by use of 4D imaging there can be some hesitations implementing 4D imaging clinically.

The intent of using 4D imaging can be numerous. Currently, the main purpose of CBCT imaging is to ensure the correct treatment position of the patient. Use of 4D CBCT can ensure that the tumour is imaged with less image artefacts and with the tumour in an average position. This can reduce the treated volume significantly. However, 4D imaging can also be used to e.g. monitor changes of the volume of a lung tumour over the treatment course. Studies correlating tumour volume changes to clinical outcome are starting to appear. Based on such a correlation it might be possible to adapt the treatment to the specific patient e.g. as an accelerated treatment. Similarly there are also studies which investigate the possibility to use CBCT as a way to predict expected toxicity. CBCT imaging can also potentially be used for recalculation of the treatment dose. For standard CBCT a unique link between electron density and CBCT value does not exist. This prevents calculation of dose which includes correction for density variations within the patient. The cause of the problem is scattered dose reaching the detector. The expected scatter contribution can be corrected by use of Monte Carlo techniques which is feasible today on small computer clusters within clinically relevant times.

The above use of 4D imaging requires different degree of image quality. Since image quality is related to imaging dose and time the specific goal of the imaging needs to be defined in order to get the maximum benefit of 4D CBCT. Having considered the imaging goal a number of practical issues related to the use of 4D CBCT appear e.g. which respiration phase should be used in validating patient position, which respiration phase should be used for treatment calculation, what if mediastinal nodes and lung tumour do not move synchronously, how to optimise workflow and minimise imaging dose, and what education is needed to evaluate the additional information.

Conclusion: 4D CBCT has been available for a number of years and has the potential not only to optimise the treatment position of the patient, but also to measure patient specific response to the delivered treatment. In implementation of 4D imaging it is obviously important to realise the main goal of the imaging, but also to realise that the additional acquired information adds a number of practical issues and that additional education of treatment staff is necessary in order to maximise the benefit of the imaging.

SP-0521
Target localisation challenges in gated radiotherapy by in-room image guidance
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Respiratory management can provide a potential for increasing positional precision, which can facilitate dose escalation with maintained healthy tissue toxicity. Respiratory management can include breath-holding, beam gating or tumour tracking during irradiation. However, performing such manoeuvres in a safe manner is not trivial, although the technical capabilities are to a large extent available. It has been shown that large variations in respiratory phase can be presented in both intra- and inter-fraction, and that correlation between respiratory surrogates and actual tumour motion may not be consistent from session to session. Target localisation through respiratory monitoring and correlation must therefore be performed in a consistent manner during treatment preparation, and for each instance of treatment delivery.

There are basically two challenges related to target localisation adequate for respiratory management; achieving target visibility and achieving representative positional information. Both of these challenges are most easily met by using more complex imaging methods over longer duration of time. However, there may on the other hand be motivation for limiting the amount and complexity of imaging, related to availability, workflow, risk management and cost-effectiveness.

This presentation goes through some specific examples exhibiting target localisation challenges, and solutions for balancing complexity and amount of imaging with these other factors.

SP-0522
Clinical implementation and challenges with tracking (using the VERO system).
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In radiation therapy, intra-fraction motion results in significant geometric and dosimetric uncertainties in the therapeutic dose delivery treating thoracic and abdominal tumours. Technological evolution has brought new possibilities into the field which enable active dynamic compensation of intra-fraction movements of the target limiting the volume of surrounding tissues exposed to high doses. Real-time tumor tracking (RTTT) is a fairly recent motion compensation technique, which involves a complex workflow. The currently available linac systems supporting this technique all use a so-called hybrid approach to locate the moving tumor during tracking. In a preparatory step, repeated X-ray images are acquired together with a synchronized acquisition of the breathing signal from the patient skin movement. A dedicated mathematical model is optimized to fit the correlation between external breathing signal and internal tumor motion. The motion compensation is driven by the external signal and the model. This allows reduction of additional imaging dose and can be used to introduce some robustness to irregular breathing. However it does also introduce some residual tracking error due to suboptimal fit and the correlation model prediction accuracy has a limited validity in time due to possible systematic drifts in the breathing pattern and movement of the patient. As such the performance of these RTTT solutions is dependent on the correlation model but also on the time efficiency, to minimize possible drifting.

The pre-treatment imaging, the treatment planning process and PTV volume definition should incorporate the dynamic nature of the RTTT process with 4D CT imaging and dose accumulation. In terms of quality assurance (QA), also for tumor tracking, the amount of patient specific QA and the machine related QA should be balanced. Moving phantom experiments can be performed in combination with various dosimetry techniques. However, RTTT is a type of radiotherapy treatment adaptation which involves a continuous interaction between a technical system and the patient. As such, part of the commissioning of such a system and also routine patient specific QA...