Determining critical objectives and importance factors for prostate IMRT treatment planning

Innovation/Impact: IMRT treatment planning is typically cast as a multi-objective optimization problem. The standard approach is to optimize a single composite objective function composed of the individual objectives weighted by importance factors. However, the determination of the importance factors relies on a trial-and-error process with minimal scientific guidance. Moreover, clinical treatment planning formulations often have many more objectives than needed, which leads to a large parameter space to search over. Identifying fewer but more critical objectives and more efficiently determining importance factors will make the current treatment planning system faster and more efficient. We develop an inverse optimization model (IOM)\(^1\) that uses a historical treatment plan as an input, and determines importance factors that make the given plan optimal with respect to a given set of objectives. We use the IOM for the identification of critical objectives for prostate IMRT treatment planning.

Identifying critical objectives:
A treatment planning problem with 18 candidate objectives was formulated. For each of the bladder and rectum, eight different objectives that linearly penalize dose above 0, 10, ..., 70 Gy were included, and objectives that minimize the maximum dose were included for the left and right femoral heads. Given a clinical treatment plan, the IOM determines importance factors for the 18 objectives. Table 1 shows the results for 12 patient treatments (theta denotes the threshold for the penalty objective). Objectives with larger importance factors or objectives that more often had non-zero importance factors were considered more “critical”. A combination of the objectives that minimize the mean dose (i.e., theta = 0) and that penalize a higher dose (i.e., theta = 50, 60, or 70) for the bladder and rectum, and the max-dose objectives for the femoral heads were critical.

Verification: A treatment planning problem was formulated with only six objectives: the objectives with thresholds theta = 0 and 50 for the bladder and rectum, and the max-dose objectives for the femoral heads. The IOM was re-solved to determine inversely-optimized importance factors for the six objectives, which are shown in Table 2. A treatment plan generated by the six objectives using the optimized importance factors in Table 2 was compared with one generated by the 18 objectives using the optimized importance factors in Table 1. The two plans were virtually identical: Figure 1 shows the comparison of dose-volume histograms (DVHs), Figure 2 compares the dose distributions, and Table 3 shows the clinical metrics achieved by the two treatment plans.

\(^1\) Note that “inverse optimization” differs from “inverse planning”. Inverse optimization determines values of parameters that make a given an intensity map or dose distribution optimal, while inverse planning determines the optimal intensity map given values of the optimization parameters. Inverse planning is simply “optimization” in the context of this study.
Summary: Inverse optimization can be used to identify optimization objectives that drive the treatment planning optimization problem for prostate IMRT. Using only these critical objectives and inversely-optimized importance factors, it is possible to reproduce a clinical-quality treatment – one generated with many more objectives. Having more objectives than needed may confound the optimization process, and does not guarantee a better treatment plan. The reduced number of objectives with inversely-optimized importance factors may minimize the need for trial-and-error iterations in treatment planning. The rectum and bladder objectives typically comprised 95% of the weight, though the specific objectives with the most weight varied across patients. As a next step of this research, we will study the effect of differences in patient anatomical geometries on the values of the importance factors.