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Editorial

Surveying the clinical practice of treatment adaptation and motion management in particle therapy

Surveys on radiation oncology practice are like a snapshot of the real world, offering insights into the current state-of-the-art treatment planning and delivery while also highlighting the degree of clinical translation of research findings. In particular in a field like real-time adaptive particle therapy (PT), it is crucial to assess the acceptance level of guidelines, given their relatively recent establishment [1–4].

While several review papers on real-time intrafractional respiratory motion management (RRMM) and adaptive particle therapy (APT) for interfractional changes were published within the last decade [5–13], the recently published survey papers by Zhang and Trnkova and their co-workers are the first of their kind [14,15]. Following up on a similar initiative addressing photon-based radiotherapy [16,17], these two surveys report on the clinical practice and associated barriers of 70 particle therapy centres (68 operating) from 17 countries [14,15]. Proton and particle therapy is a relatively small, yet growing field, and the surveys report on the practice of two-thirds of the 105 particle therapy centres that were operative in 2020 (this number has already increased to 123); all located in high-income countries and with a strong academic background. The surveys further attempt to probe the time trend through questions on wishes and plans for expansion. With this editorial we acknowledge this commendable initiative and seek to increase the understanding of the interlocked strategies for inter- and intrafraction motion management reported for PT, as well as to make comparisons to the current practice of photon-based radiotherapy.

The survey by Zhang et al. found that 85% of the clinically operating centres used RRMM [14]. Rescanning is a passive form of RRMM only relevant for particle PBS [18,19] that was implemented or foreseen to be implemented within two years in nearly all pencil beam scanning treatment facilities . About two-thirds of the responders used active RRMM, mainly as breath-hold gating or respiratory gating for lung, liver or pancreas, guided by a surrogate respiratory signal. In a few centres (10% for liver), gating was guided by internal motion monitoring. There was a clear wish to expand the use of active RRMM to new treatment sites or to widen the use for sites already treated with active RRMM. Barriers for implementation included technical limitations or limited resources (equipment, human) rather than reimbursement or lack of interest or training. Overall, the survey found a broad and growing use of RRMM for PT which is likely to continue.

In addition to reporting on the RRMM practice patterns, Zhang et al. included a DELPHI consensus analysis performed by the authors. It named 4D dose calculation including uncertainty evaluation as the most required software feature in the next two years following many recent publications [20–24] and recommendations from the TG290 report on respiratory motion management for PT [1].

In the APT survey paper, Trnkova et al. [15] reported that 84% of the operating centres performed some form of adaptation, mostly offline as also reported in recent literature [25–27]. Only two centres (3%) performed online APT by applying a plan-library approach, and no centre performed online daily re-planning, although the methods to perform and trigger online APT are currently being investigated [28–31]. Plan adaptation was most frequently needed for head-and-neck cancer patients, followed by lung cancer patients. Plan adaptations were mostly triggered by dose re-evaluations, often performed on (synthetic) computed tomography (CT) scans, with around 70% of centres acquiring sequential (or control) imaging as part of their APT workflow [32]. Only 19% of the centres performed daily volumetric imaging. Most components of the APT workflow were performed manually, with only a few components (e.g., organ-at-risk contouring and image registration) being performed semi-automated by around half of the centres as this is known to reduce the uncertainty of proton dose prediction [33,34]. Full automation of all components, except adaptation triggering, was identified by the authors as a requirement for APT with daily online re-planning.

There was a strong wish to improve and increase the use of APT among the responders, not differentiating between online and offline APT [14]. It might still have to be established whether online APT is needed for all treatment sites, or if certain treatment sites will benefit more than others [35]. Even though the authors deemed online APT to be prevalent in ten years, they did not agree on whether offline adaptation would still be needed.

A major conclusion of both surveys was that a strong collaboration between industry, researchers and clinical users is the major requirement for a successful translation from research innovations into (broad) clinical application. Limited human and financial resources as well as a lack of equipment were identified as barriers in both surveys. Technical limitations dominated the field of RRMM, while the integration of the workflow was relevant for the implementation of APT. As the technical concept behind APT remains the same, independent of the frequency, trigger information or re-plan imaging, the survey questions focused on workflow details including quality assurance aspects. On the contrary, RRMM strategies differ essentially on a technical basis. While rescanning and abdominal compression do not require a highly sophisticated optimised workflow, active RRMM strategies do. Automation and artificial intelligence were identified as a requirement for an efficient APT

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workflow, but it was not part of the survey for RRMM, even though it gains large impact for real-time motion monitoring and adaptive treatment concepts [36–38].

Due to the limited number of particle therapy centres worldwide, the outcome of these two surveys is very powerful and proved a broad overview of actual clinical practice. Assessing treatment strategies in photon therapy in the frame of a survey differs mainly by the fact that the total number of photon therapy centres is much more difficult to assess. However, the pool of responders for the photon and particle therapy surveys was overall quite comparable. In the previous surveys it was shown that 90% of the photon centres applying adaptive or motion management concepts were located in high-income countries, with no responding centres from a low-income country but many from academic institutes.

The main tumour sites for adaptive treatment or RRMM were identical for photon and particle therapy. For adaptive therapy workflows, the results agreed in different aspects, e.g., the trigger for plan adaption was CT or cone-beam CT in more than 80% of the cases. The use of additional magnetic resonance (MR) imaging information for adaptation was comparable even though it needs to be underlined that MR-Linac users were the group reporting the most on online daily re-planning. For intrafraction motion compensation, results were less comparable due to technical differences, i.e., rescanning is a technique purely dedicated to particle therapy. The higher sensitivity of particle beams to anatomical changes resulted in motion management techniques being applied for lung, liver, and pancreas at almost all centres, while not more than 40% of the photon centres applied any RRMM technique for these indications. Motion surrogate signals (such as surface imaging or external markers) were reported to be the main technique for monitoring and 4D-CT reconstruction for both photon and particle therapy.

The aspect of timing seems to be crucial as it does not only affect the efficacy of real-time adaptive treatment strategies but also the value of surveys on clinical practice. The high response rate underlines that the two surveys found a good balance between a comprehensive question catalogue and a reasonable time needed for answering. By that, these two papers provide results of high scientific quality and relevance for the particle therapy community.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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