Dosimetry challenges for implementing emerging technologies

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Abstract. During the last 10 years, radiation therapy technologies have gone through major changes, mainly related introduction of sophisticated delivery and imaging techniques to improve the target localization accuracy and dose conformity. While implementation of these emerging technologies such as image-guided SRS/SBRT, IMRT/IMAT, IGRT, 4D motion management, and special delivery technologies showed substantial clinical gains for patient care, many other factors, such as training/quality, efficiency/efficacy, and cost/effectiveness etc. remain to be challenging. This talk will address technical challenges for dosimetry verification of implementing these emerging technologies in radiation therapy.

1. Introduction
ASTRO regards any technology, yet to be optimally implemented, as having the potential to improve the effectiveness and efficiency of current radiation therapy practice by providing better definition of the treatment target, more conformal dose distribution, more accurate treatment delivery, and modification of dose scheme. The rapid implementation of emerging technology in radiation therapy has provided an excellent opportunity to provide high quality radiation therapy to patients. However, it also posts substantial challenge to clinic professionals who wish to rapidly implement these technologies in an accurate and safe manner. In this presentation we highlight some of the key clinical techniques where more comprehensive, and 3D dosimetry techniques, may be able to facilitate accurate clinical implementation.

2. SRS/SBRT: small field dosimetry (Refs 1-4)
Treatment of SRS and SBRT requires dosimetry of small fields down to a few mm beam apertures. Measurement of beam characteristics with such small fields are very challenging, giving the effect of partial volume of detector responses, radiation lateral scatter, etc. Errors are often devastating due to the nature of high prescription dose. Such serious treatment errors have been reported in the media resulting in compromised patient care. One effective measure to avoid these problems is to measure the dosimetry of the treatment planning system with 3D dosimeter. That equally requires high resolution, high sensitivity and stable 3D dosimetry measurement device, and robust dosimetric verification protocol. Currently this is not available although SRS/SBRT is widely available clinically.

3. IMRT/VMAT: complicated dosimetry (Refs 5-10)
IMRT/VMAT involves not only small fields, but also sophisticated mechanical movement of MLC and gantry, as well as dynamic change of dose rate. In addition to complicated treatment modification from the conventional treatment unit, some new developments use very special techniques for
radiation delivery, such as robotic moving beam with Cyberknife and spiral delivery using Tomotherapy. Any deviation of these parameters could have substantial dosimetry impact on the planned treatment. Due to its complicated dose distribution and high modulated nature, typical 2D dosimetry may have difficulty to detect these variations at all regions. It is desirable to have high resolution and 3D dosimetric information, which is not yet available for routine clinical practice.

4. IGRT: imaging dosimetry (Refs. 11-23)
A variety of imaging systems are being introduced into the radiation oncology for real-time target localization and verification, such as stereoscopic imaging, cone-beam CT with both kV and MV sources, etc. Some clinical trials also require repeated imaging during treatment course. Over exposure to patient during imaging has been reported in the media. Those technologies have substantially improved the localization accuracy. However, imaging dose is also becoming an increasing concern especially because the imaging volume is much larger than the treatment volume. For example, dose to the eye and other components when imaging for treating head and neck patients, dose to the lung and to the contra-lateral breast when imaging chest are concerning factors for treatment complication and increased probability of radiation induced cancer. Accurate measurement of that dose would be very critical for developing imaging protocols and for imaging dose calculations.

5. Organ motion: 4D dosimetry (Refs. 24,25)
Dosimetry of moving target is not well known for many reasons. Not only because the target is moving, but also the target involve substantial non-uniform tissue organs. Motion is often not uniform in all directions, the pattern of motions of different organs is typically different, and the organ may be deformable. Dose measurement of moving target using 2D dosimetry is extremely challenging if not possible. Precise measurement of such dosimetry will need to be at least at three dimensional and high resolution. Tracking the dose along different treatment fractions is also challenging.

6. Dosimetry tools
The sections above outline the many areas of emerging technologies where comprehensive 3D dose measurements would be highly desirable. At present many clinics are using 2D dosimeters to verify complex distributions, including film, diode/chamber arrays, and EPIDS. This applies even to the commissioning phase, where extensive measurements and more time and resources are allocated for verification. Many of these devices have the major advantage of convenience, and many provide near real-time feedback with results. Much can be achieved with these devices. Two basic limitations that accompany many such devices however, include poor spatial resolution, and limited coverage of the whole distribution to be verified. The 3D techniques described in this meeting (including optical-CT, MRI, x-ray-CT and other approaches) can certainly improve on the limitations. The factors of convenience and real-time feedback of results continue to improve, and we shall see during the meeting the current state of the art.

An important factor in the transition of these technologies into the clinic is determining a clear context of use. At present gamma criteria are commonly used to evaluate agreement on 2D planar dosimetry measurements. Dose distributions are not 2D entities however, and extending the analysis to three dimensions is an important goal. This subject is addressed in a dedicated session in this meeting. Determining accepted threshold for agreement is not consistently applied at present, and the clinical implementation needs strengthening.

Another important aspect for any dimensional dosimetry is related to the quality management. Dosimetry tools are primary used for quality assurance of treatment delivery accuracy. However, the accuracy of dosimetry devices is equally important to ensure the measurement accuracy. Therefore, quality assurance and proper calibration of dosimetry tools should be part of routine practices in all
clinics. The accurate dosimetry information is also dependent on the measurement methods and proper use of dosimetry tools.

7. Summary
Dosimetry could be regarded as a classical topic because it has been applied and used for decades. However, it is also an emerging technology because we yet to reveal techniques and devices to measure challenging dosimetry listed above and to reveal many unknown factors and mechanisms of different measurement devices. In addition to the dosimetric topics above, some other emerging dosimetry problems are also need to be explored, such as particle therapy, brachytherapy both using by-product and/or electronic brachytherapy, as well as sophisticated combined modality treatment. The dosimetry for fast growing proton therapy is specially challenging due to no exit dosimetry information. Therefore, it is fair to say; 3D and 4D dosimetry coupled with effective and accurate measurements will be one of most challenging topics for implementing emerging technologies in modern radiation therapy. We not only need to perform accurate dose measurement but also need to secure accurate measurement devices.

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