

On the quality assurance and verification of modern radiation therapy treatment

Modern radiation therapy has advanced considerably in the recent decades through the development of conformal techniques that better shape the high dose to tumour volumes while minimizing the dose to surrounding normal tissue. Techniques such as Intensity Modulated Radiation Therapy (IMRT) and Volumetric Modulated Arc Therapy (VMAT) are now available, where the intensity within a radiation field is varied dynamically during treatment, and thus sophisticated dose painting is enabled. New treatment advances such as '4D' delivery, in which target motion is compensated or followed, and Adaptive Radiation Therapy (ART), in which a patient's treatment may be modified during the course of care based on new information gained, for example, through cone beam images obtained during Image Guided Radiation Therapy (IGRT) or through functional imaging used to assess treatment response, only add to the complexity of radiation treatment.

The rapid pace of these developments and the significant increase in the associated complexities, have introduced considerable new challenges to the radiation treatment team. This is particularly true for the clinical medical physicist, whose role it is to ensure the correct delivery of the radiation dose distribution which the oncologist has prescribed and approved for a patient's treatment. The challenges for patient treatment verification have motivated the development of increasingly sophisticated strategies, tools and equipment to measure dose and to analyse the measurements so that the physics team can assess safe delivery. These technical developments have, in turn, renewed discussion and debate in the community as to which tests are appropriate, what devices should be used, and what analysis is required. In the last year, I have had the opportunity to attend three meetings dedicated in a large part to this discussion: the International Conference on Three Dimensional Dosimetry (IC3D) in Hilton Head USA; the IAEA's International Symposium on Standards, Applications and Quality Assurance in Radiation Dosimetry (IDOS) in Vienna Austria; and, the recent Joint Meeting

of the Canadian Organization, and American Association, of Medical Physicists (COMP and AAPM) in Vancouver, Canada.

The devices discussed at these conferences spanned the traditional point dosimeters such as ion chambers, thermoluminescent dosimeters and diodes, that have been used for decades to commission treatment units, to calibrate output and to verify dose delivery at single points in a phantom; the 2D dosimetry techniques such as silver-halide and radiochromic film or digital systems incorporating flat panel arrays of ion chambers or diodes that are often used in IMRT delivery validation; and, the full 3D dosimeters such as scintillator detector arrays or volumetric chemical dosimeters probed by Magnetic Resonance Imaging (MRI) or by radiographic examination and optical computed tomographic (CT) techniques for IMRT and VMAT validation. Indeed, there was a considerable interest in the promise of 3D measurement using the newer ion chamber/diode arrays arranged in non-planar geometry, and on gel and radiochromic plastic chemical dosimeters which provide high resolution dose measurement throughout volumes up to a few litres. Also promising were the reports of approaches based on Electronic Portal Imaging Device (EPID) measurements, which when used together with appropriate forward fluence calculation modules in treatment planning systems or sophisticated model-based dose reconstruction algorithms, can be used as either as a 2D fluence or 3D dose verification.

A superficial review of the presentations in the three meetings could condense their content to a simple technical description of the various tools available in the quality assurance (QA) arsenal. However, a more complete review would have to note that, while the content of multiple proffered presentations did report on the successful use of most of these modalities in some particular QA test or treatment verification, discussions and questions after the presentations often seemed to query whether the tests were appropriate, or if other techniques would have been better suited for the task. Hence, the challenge for the medical physicist seems still to be to establish which particular tool would be of the greatest benefit for a particular QA test at a particular time. This challenge may be best reviewed by looking at the various tools from point through planar to volumetric detectors.

Modern dose delivery has tested the role of point

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| | <p>DOI:</p> <p>10.4103/0971-6203.89963</p> |

detectors, such as ion chambers. Highly conformal and often intentionally inhomogeneous dose delivery mandates that great care be taken when using ion chambers in the modern setting. The non-standard delivery approaches of modern therapy techniques challenge even output calibration, as the tested beams cannot achieve the standard AAPM Task Group 51 (TG51) specified conditions for field size and measurement depth.^[1] The clinical physicist must understand the limitations of the detector being used (e.g., the volume of measurement and detection point) and ensure that the device is appropriate for the test. While it may seem trivial to stress that all physicists understand these limitations, treatment accidents with small field techniques in France and the United States of America have shown that even basic and fundamental concepts such as these need to be emphasized continuously.^[2] The challenge for the use of point detectors in small field, conformal or IMRT treatment verification is even greater. The high dose gradients that can occur in the treatment volume make locating the point dosimeter in a complex dose plan problematic. Again, this problem can be managed in most cases; however, great care is needed.^[3]

The problems above have motivated a move from point to 2D dosimetry for treatment delivery validation. 2D detectors enable the additional spatial assessment of the dose distribution in at least one plane through a test tool, phantom or EPID. In many clinics a delivery plan, particularly if by IMRT, is transferred to the test tool and then the irradiation is initiated on the test system, which may contain a film or an ion chamber or diode array, before patient treatment. Because of the added spatial dimension in the assessment, results are typically analysed by a software that provides some measure of the percentage dose agreement or of the distance to agreement (e.g., a Low's gamma map^[4]).

While 2D techniques may overcome the limitations of point dosimetry, new factors are introduced. Film dosimetry requires careful consistent procedures to ensure that the dose measurement is corrected for film history and processing, the spatial variation that may be inherent in the readout systems, and other factors. Point detector arrays require careful calibration and can move out of true if the tested delivery deviates from the conditions of the calibration (e.g., if the multileaf collimators are being driven hard in a delivery and are delineating small fast moving fields). Also, the inherent resolution of 2D detector arrays often requires the interpolation of measured data in the software analysis tools; and, this must be understood in the treatment validation. Another limitation of all 2D treatment validation techniques is that when errors are detected, it may be difficult to determine the clinical significance to the patient. EPID based dosimetry is developing into an attractive validation tool, but in the 2D realm, EPID dosimetry is usually used via exit

fluence calculation at the imaging panel or through dose reconstruction algorithms that have to be corrected for the scatter and detector response. Again all these details of 2D dosimetry must be clearly understood by users so that the results of the dosimetry stay valid.^[5]

There have been considerable advances in 3D dosimetry in recent years. 3D systems based on detector arrays through a volume (e.g., using scintillator detectors), or more sparsely in a ring or non-planar array, have been designed primarily to provide fast convenient validation of IMRT and VMAT dose delivery. Full volumetric 3D dosimetry is possible with a number of gel and radiochromic plastic dosimeters. Such volumetric chemical dosimetry has advanced considerably in the last decade, primarily because many of the technical issues from the early years have been overcome. New stable non-toxic dosimeter materials have been developed that can be purchased or prepared in the clinical setting. The development of new readout systems such as optical computed tomography^[6] has expanded the clinical practicality.^[7] 3D dosimetry techniques based on dose reconstruction of exit fluence EPID measurements are also coming to fruition.^[8,9] With all these developments, true 3D dosimetry seems to be ready for broad clinical adoption. However, 3D dosimetry involves complex systems. Chemical dosimeters can be sensitive to handling, history, and time between irradiation and measurement. Other factors inherent to the readout techniques may be important in the measurement (e.g., scatter or stray light perturbations in optical CT readout of volumetric dosimeters). EPID dose measurements will be influenced by deviation from calibration conditions for scatter corrections. Also, all 3D techniques involve complex analysis of large dose data sets that must be registered and compared to a reference dose distribution. All to say, the caveats introduced for the 2D systems are again in play.

What does all this mean for the medical physics community? It is clear that one must carefully assess the appropriateness of a particular dosimetry for a particular task before adopting a delivery validation system. This assessment will have many components, including determining whether a device is suitable for dose measurement in a certain radiation delivery; whether another dosimeter is simpler to use or provides results that are more easily analysed and interpreted; whether or not the software supplied by a particular vendor for a particular device is well documented so that the output can be validated independently; whether the dosimetry system is readily commissioned and can be validated against other dosimetry systems already well-established in your clinic etc. All these points must be addressed by the medical physics team, particularly before a new dosimetry scenario is adopted (for example, using a point dosimeter for a new dynamic irradiation involving small fields or, perhaps, commissioning a new detector array for VMAT delivery).

This leads to my editorial point #1: ‘know and understand your dosimetry system completely, including its limitations, before applying it to a particular validation task’.

There are a number of strategies that can enable a medical physics program to move through this seemingly intractable problem. For example, locally in the province of Ontario in Canada, clinics are sharing experience through meetings, workshops and the formation of a physics QA committee with membership from multiple centres. This effort is aided through a program that enables the sharing between clinics of dosimetry systems with trained users, so that local physicists can compare their hardware and software tools to some independent system. The effort has also motivated clinics to reinvigorate clinical research with the resulting systematic analysis, and reporting of different validation techniques and their clinical practicality. For such work to be useful, these reports need to have included a clear description of the protocols used. The *Journal of Medical Physics* would be a good forum for reporting such clinically relevant work. This is an area of research nearly every clinic could participate in. My editorial point #2 therefore becomes ‘engage in the clinical exchange of ideas and knowledge through publication in scientific journals, and, perhaps more importantly, through regular communication, meetings and workshops with colleagues locally, nationally and internationally’.

The burden presented by modern radiation delivery validation is significant. The work to develop the required robust treatment QA presents real and timely challenges for us working in the clinic. However, the work is exciting, and I believe the medical physics community is more than up to the task.

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How to cite this article: Schreiner LJ. On the quality assurance and verification of modern radiation therapy treatment. *J Med Phys* 2011;36:189-91

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