SECONDARY CALCULATIONS

Revisiting Rationale,
Rethinking Methodologies

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Historical Background //

Before IMRT

It has long been the standard of care in radiotherapy to ensure the correctness of dosimetry calculations by means of an independent secondary calculation.

For Cobalt units, this was an independent calculation of the source exposure time. For linear accelerators, the number of Monitor Units (MU) that must be programmed to deliver the intended dose are traditionally verified. In either case, an incorrect calculation upfront can result in a delivered dose that varies from the physician's intent, potentially leading to serious medical complications or even death.[1]

Historically, secondary dosimetry calculations were hand calculations performed by the clinical physicist prior to treatment delivery. The goal of this effort was to prevent potential under- or over-dosing errors by independently confirming the number of MUs calculated by the original planner or Treatment Planning System (TPS) matched the MUs generated by the secondary check.

If a discrepancy was discovered, the clinical physicist would investigate whether there was an issue with the treatment planning calculations or their independent calculation. Much like the evolution of the TPS, secondary hand calculations evolved into the use of spreadsheets and macros that simplified and accelerated the process, and allowed for standardization across a radiotherapy department.

This approach provided a straightforward way to quality check the MUs prescribed by the TPS (and thus the dose delivered) for few-field, non-modulated radiotherapy.

1. W. Bogdanich, "Radiation Offers New Cures, and Ways to Do Harm," New York Times, January 23, 2010

The Advent of IMRT

The next evolutionary step of the secondary calculation process was MU verification software.

These software applications perform a secondary dosimetry calculation using beam data tables from the TPS and a rudimentary dose calculation method to account, in a limited manner, for scatter radiation from irregularly blocked fields (e.g., Clarkson technique). The output remains an MU value that is compared against the MU value from the TPS, with the understanding that a similarity of MU within tolerance results in the intended dose.

With the development of intensity modulated radiation therapy (IMRT) in the 1990s, MU verification software applications were rapidly adopted. IMRT, with its many irregular segments comprising a single treatment field of varying intensity levels, made the hand calculation process overly burdensome given the time it would require of a physicist to account for the impact of the varying scatter and partial dose contributions from all the segments to a selected calculation point. While some clinics maintained a hand or spreadsheet calculation procedure for simple static fields, the complexity of IMRT—and later volumetric modulated arc therapy (VMAT)—necessitated a computerized solution. **However, the convention of computing an MU value for a single calculation point comparison remained, which created some inherent weaknesses in the process.**

Intensity modulated fields are often generated by an inverse optimization algorithm with weighting factors not intuitively related to the dose at the calculation point. Furthermore, the single calculation point often falls on the edge or even outside the open area of many segments, a condition under which the Clarkson method breaks down. The impact of the calculation point falling in regions of high dose gradient and/or tissue inhomogeneities are not adequately handled by the simplistic MU algorithm, requiring clinical physicists to investigate and explain discrepancies that arise from this shortcoming.

Methods

The Historical Secondary MU Calculation Method

Given a dose (D) to a point (typically isocenter) inside the patient as prescribed by the physician, a typical method used by clinical physicists for multi-field, non-modulated radiotherapy is illustrated by the following equation from Khan:

$$MU = \frac{D}{\left(\frac{D}{MU}\right)_{ref} x\ TMR\ (d, FS_d)\ x\ S_C(FS_C) x\ S_P(FS_d)\ x\ InvSq}$$

Equation 1. Khan's The Physics of Radiation Therapy, Faiz Khan, Ph.D.

where $\left(\frac{D}{MU}\right)_{ref}$ is the dose per MU at the reference depth and field size
d is the depth of the point inside the patient
TMR (d,FS_d) is the Tissue Maximum Ratio for depth d and the field size at depth *d*
S_C (FS_C) is the collimator scatter factor for the collimator setting
S_P (FS_d) is the phantom scatter factor for the field size at depth *d*
InvSq is an inverse square correction accounting for the difference in the calibration distance and the source-to-axis distance

The physicist would be provided the dose to the point and the field size based on the physician prescription and treatment plan. The physicist would compute the depth of the point in the patient, and then look up *TMR*, S_c, *and* S_p based on these values. $\left(\frac{D}{MU}\right)_{ref}$ and *InvSq* are known based on the calibration of the treatment delivery device.

As previously discussed, MU verification software utilizes the basic approach as captured by Equation 1, however the primary and scatter dose components are separated and a modified Clarkson technique is used to account for the varying segments for IMRT and VMAT. This is described in detail in a study from Kung, et al.[2]

2. A monitor unit verification calculation in intensity modulated radiotherapy as a dosimetry quality assurance, J.H. Kung, et al., Med. Phys. 27, 2226, 2000.

Figure 1. Evolution of the secondary calculation process

The DoseCHECK™ Secondary Dose Calculation Method

One of the primary weaknesses of the traditional point-based MU verification approach is that there can be one or multiple significant dose discrepancies elsewhere in the field(s), beyond the regions that directly impact the chosen point(s). In IMRT and VMAT, complex intensity distributions exist within each field and contribute to optimized dose distributions in the full patient geometry that cannot be adequately verified by simple numerical comparisons. **Thus the logic of applying the hand calculation approach of MU determination for non-modulated radiotherapy as shown in Equation 1 to modulated-field radiotherapy is flawed. An alternative approach is required.**

The next and necessary evolution of the secondary dose calculation process will require verification of all patient dose distribution points (i.e., the full patient dose volume) to adequately account for the myriad variations inside the treatment fields as generated for IMRT, VMAT, and other complex modern treatment techniques.

The method utilized to perform this verification involves a secondary calculation of the full patient dose volume using a robust, modern dose calculation engine (e.g., Superposition/Convolution). The input for this process is the field intensities as a function of time, most often captured by the DICOM RT Plan object exported from the TPS, and the planning CT image of the patient. The full three dimensional dose is then computed and compared to the TPS planning dose volume.

This approach changes the secondary dosimetry calculation paradigm from one that asks "What MUs are required to deliver the prescribed dose to the point in the patient?" to "Does the patient dose volume that results from this distribution of MUs the TPS has calculated match the physician intent?" The different workflows for the two approaches are shown in Figure 2.

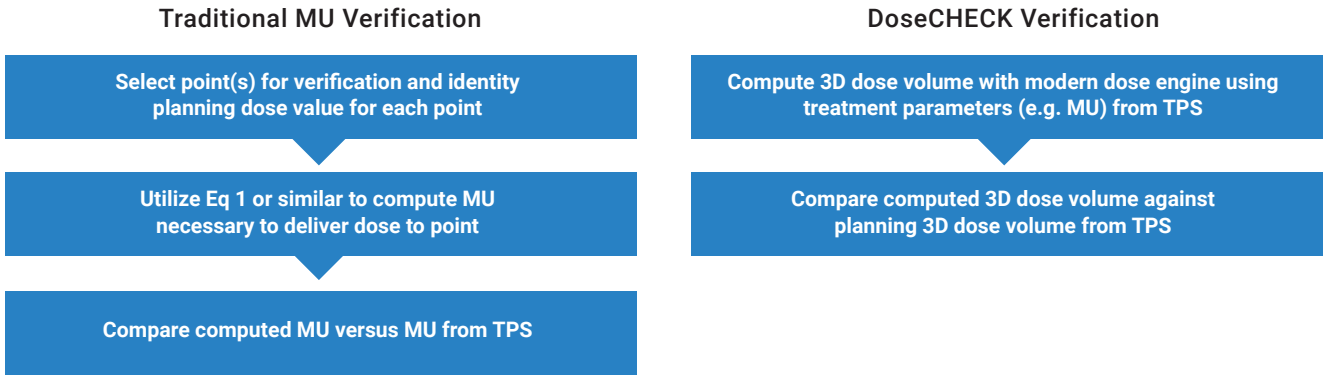

Figure 2. Comparison of secondary calculation workflows for: a) traditional MU calculations, and b) full 3D volume verification (e.g. DoseCHECK)

It can be reasonably postulated that verification of the dose distribution inside the patient was always the intent behind the secondary calculation process, rather than a verification of MUs impacting a single beam.

For non-modulated techniques, it is reasonable to conclude a calculation is correct for all points inside the patient if the MUs for each beam's calculation point are verified. However, this logic cannot be extended to IMRT or VMAT due to the complexities of the treatment fields and patient geometry. A verification of the patient dose volume could easily elucidate errors that a point-based MU verification would not, and can serve as a more robust quality check of the intended treatment plan and TPS.

The need to verify the full dose volume above and beyond simple MU comparisons can be demonstrated with an example. In this example, a treatment planning system has a suspect beam model due to incorrect off-axis softening. Traditional MU verification software would most likely indicate that this plan was acceptable, as calculation points in the target and around isocenter show no problematic areas. However, the full 3D *dose* volume comparison indicates that there is an issue, and where the issue exists.

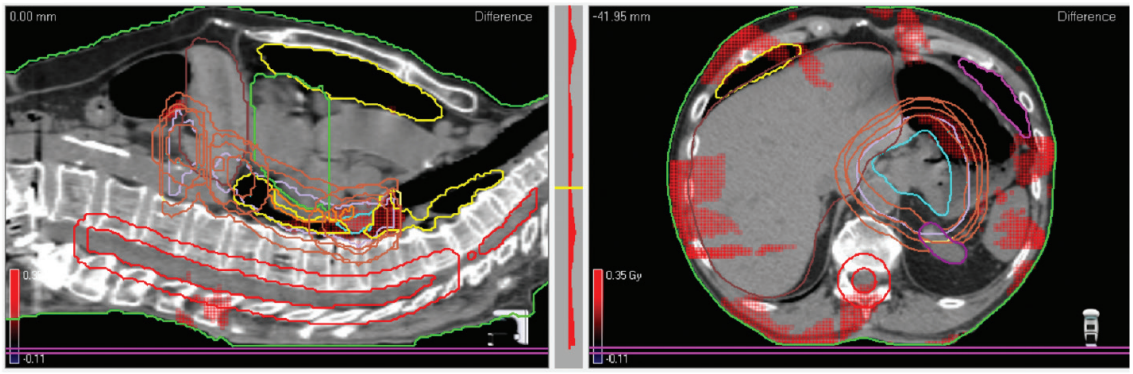

Figure 3. Difference colorwash, based on DoseCHECK calculation, indicates regions above 3% of the maximum dose for a commissioned TPS (errors with off-axis softening). There are only overdosed regions, some of which fall in organs at risk such as the spinal cord. The target region (light blue contour) indicates no differences beyond 3%.
This error would likely evade traditional MU verification software in which only a few verification points are used.

Practical Considerations for Adoption

Reimbursement and Regulations

A common misconception regarding reimbursement is that a secondary dosimetry calculation must include an MU value in order to be compliant with regulations. This may be due to the fact that because of historical methods a secondary calculation and MU verification are sometimes thought of as interchangeable. Upon inspection, the terms "MU" or "Monitor Units" do not always appear in the specific verbiage from guidance/regulations:

Source	Reference	Exact Verbiage
American Medical Association (AMA)	CPT® 77300, 2015	"Basic radiation dosimetry calculation, central axis depth dose calculation, TDF, NSD, gap calculation, off axis factor, tissue inhomogeneity factors, calculation of non-ionizing radiation surface and depth dose, as required during course of treatment, only when prescribed by the treating physician."
Council Directive 2013/59/ Euratom	Article 60	"Member States shall ensure that…appropriate quality assurance programmes and assessment of dose or verification of administered activity are implemented by the undertaking."
	Article 61	"Special attention shall be given to quality assurance programmes and the assessment of dose or verification of administered activity for these practices."

Specifically for reimbursement in the United States, the following from American Medical Accounting & Consulting, Inc., (AMAC) is pertinent: "DoseCHECK™ meets the criteria for documentation for MLCs and secondary dose calculations according to current LCDs, NCDs, AMA regulations and radiation and radiology society guidelines and opinions. This procedure, according to the previous regulations and guidelines, would be reimbursable as ordered by the radiation oncologist with appropriate medical necessity."

Clinical Implications

Secondary calculation that includes verification of the full 3D dose volume is more than an incremental improvement over traditional MU verification software. In light of complex modern treatment techniques, it has become necessary to ensure proper verification of all aspects of planned treatment parameters, including radiation field intensities and the resultant dose volume generated by the TPS. By doing so, clinics achieve an enhanced standard of care that assures safe and accurate treatment for their patients.

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