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Original paper

A multi-institutional study of secondary check of treatment planning using Clarkson-based dose calculation for three-dimensional radiotherapy

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ABSTRACT

Purpose: As there have been few reports on quantitative analysis of inter-institutional results for independent monitor unit (MU) verification, we performed a multi-institutional study of verification to show the feasibility of applying the 3–5% action levels used in the U.S. and Europe, and also to show the results of inter-institutional comparisons.

Methods: A total of 5936 fields were collected from 12 institutions. We used commercial software employing the Clarkson algorithm for verification after a validation study of measurement and software comparisons was performed. The doses generated by the treatment planning systems (TPSs) were retrospectively analyzed using the verification software.

Results: Mean ± two standard deviations of all locations were 1.0 ± 3.6%. There were larger differences for breast (4.0 ± 4.0%) and for lung (2.5 ± 5.8%). A total of 80% of the fields with differences over 5% of the action level involved breast and lung targets, with 7.2 ± 5.4%. Inter-institutional comparisons showed various systematic differences for field shape for breast and differences in the fields were attributable to differences in reference point placement for lung. The large differences for breast and lung are partially attributable to differences in the methods used to correct for heterogeneity.

Conclusions: The 5% action level may be feasible for verification; however, an understanding of larger differences in breast and lung plans is important in clinical practice. Based on the inter-institutional comparisons, care must be taken when determining an institution-specific action level from plans with different field shape settings and incorrectly placed reference points.

1. Introduction

Monitor unit (MU) verification is an important step to ensure patient safety and accurate delivery of radiotherapy (RT). Even in the era of three-dimensional (3D) planning, including stereotactic radiotherapy (SRT) and intensity-modulated radiotherapy (IMRT), the highest numbers of adverse events have been reported in the treatment planning phase [1–9]. In response to several serious incidents, several bodies have recommended performing *in vivo* dosimetry and/or implementing independent MU verification as a part of pretreatment plan checks

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Table 1
Configuration of linear accelerators and treatment planning systems at the twelve institutions.

Institution	Linear accelerator	TPS	Dose calculation algorithm	Inhomogeneity correction ON/OFF	Calculation grid (mm)
A	Oncor (SIEMENS)	Xio (Elekta)	Superposition	OFF	4
B	CLINAC21EX (Varian)	Eclipse (Varian)	AAA	ON	2.5
C	Clinac iX (Varian)	Eclipse (Varian)	AAA	ON	2.5
D	CLINAC21EX (Varian)	Eclipse (Varian)	PBC	OFF	2.5
E	Synergy (Elekta)	Xio (Elekta)	Superposition	ON	3
F	Synergy (Elekta)	Xio (Elekta)	Superposition	ON	2
G	Clinac iX (Varian)	Eclipse (Varian)	AAA	ON	2.5
	Clinac iX (Varian)	Xio (Elekta)	Superposition	ON	2.5
H	ARTISTE (SIEMENS)	Pinnacle^3 (Philips)	Adaptive Convolve	ON	4
I	CLINAC21EX (Varian)	Eclipse (Varian)	AAA	ON	2.5
J	Trilogy (Varian)	Eclipse (Varian)	AAA	ON	2
K	Clinac iX (Varian)	Eclipse (Varian)	AAA	ON	2.5
L	Clinac iX-S (Varian)	Eclipse (Varian)	AAA	ON	2.5
	ONCOR Impression PLUS (SIEMENS)	Pinnacle^3 (Philips)	Adaptive Convolve	ON	4

AAA = anisotropic analytical algorithm; PBC = pencil beam convolution.

[1–12]. In terms of independent MU verification, various calculation methods such as spreadsheets, secondary treatment planning systems (TPS), and Monte Carlo calculations have been proposed [10,13–16]. The Clarkson-type calculation [17] is not new but is still commonly used.

The point prescription technique [18] is still often used in conventional radiotherapy. More recently, the volume prescription technique (XX% isodose line covers XX% of planning target volume) [19–21] has been increasingly employed in conventional plans. This is especially true for lung targets, where the prescription technique of both point and volume is used, resulting in delivery of a uniform dose to the planning target volume (PTV). The purpose of an independent verification calculation is to confirm the primary MU calculation. The AAPM Task Group 114 (AAPM-TG114) [10] noted that independent verification calculation helps assure that this goal is achieved for at least one representative point within the target volume. Thus, the dose verification at the point is as equally meaningful as the MU verification.

In clinical practice, it is necessary for a treatment plan secondary check to set action levels (ALs) to assure the plan's safety. In the U.S., AAPM-TG114 recommends that disagreement between the primary calculation and the verification for 3D radiotherapy, excluding IMRT, should be ≤ 3–5% in homogenous and heterogeneous conditions when using Clarkson type-calculations, including the use of wedge fields, off-axis and small fields, and/or conditions of low-density heterogeneity [10]. The tolerance levels recommended by the AAPM-TG114 were arrived at by consensus, because there have been few reports on the quantitative analysis of inter-institutional verification results. In Europe, there have been two multi-institutional studies of independent verification; these showed that under heterogeneous conditions there was a large disagreement between the primary calculation and the verification [22,23]. However, there have been few detailed investigations incorporating inter-institutional comparisons. In addition, differences would be affected by the differences in dose calculation engines, especially the effects of heterogeneity correction and missing tissue. The trends in the differences between sites surrounded by soft tissue (such as prostate) and sites close to or containing air (such as breast and lung) are also different.

The purpose of this multi-institutional study was therefore to determine action levels using quantitative retrospective analysis data from a total of 1904 treatment plans (5936 fields) collected from 12 institutions, while also evaluating the feasibility of the introduction into Japan and other countries of action levels from the U.S. and Europe. Retrospective analysis was performed to compare independent dose verification with confidence limits (CLs) of two-standard-deviations for each treatment site, employing verification software that used a Clarkson-based dose calculation. In addition, inter-institutional differences were evaluated to understand differences in the plan quality between institutions, as well as to show the impact of determination of institution-specific action levels.

2. Material and methods

2.1. Independent dose verification system

This study was performed at 12 institutions in Japan. A verification software program (Simple MU Analysis [SMU] ver.1.1.9, Triangle Products) was used at each institution as an independent calculation algorithm. Using the Clarkson-based algorithm, SMU calculates the physical length and radiological path length from the body surface to the dose reference (prescription) point using patient CT images, and thereby calculates the dose. SMU needs the tissue-maximum ratio (TMR), off-axis ratio in air (OAR-in-air), collimator scatter factor (S_c), phantom scatter factor (S_p), physical wedge factor (PWF), non-physical wedge factor (NWF), off-axis factor in air for physical wedge (OAR-in-air-PWF), multi-leaf collimator (MLC) transmission factor (MLC-TF), and dosimetric leaf gap (DLG) as beam data parameters for each energy.

Yamazaki et al. performed a comparison between the RADCALC verification program (Life Line Software Inc., Tyler TX, USA) and SMU in homogenous and heterogeneous conditions, to show the impact of different verification software programs on the secondary check [24]. RADCALC also uses a Clarkson-based algorithm. Radiotherapy plans including 1543 treatment fields were collected at three institutions