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Original Research Article

An on-site dosimetry audit for high-energy electron beams

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ABSTRACT

Background and purpose: External dosimetry audits are powerful quality assurance instruments for radiotherapy. The aim of this study was to implement an electron dosimetry audit based on a contemporary code of practice within the requirements for calibration laboratories performing proficiency tests. This involved the determination of suitable acceptance criteria based on thorough uncertainty analyses.

Materials and methods: Subject of the audit was the determination of absorbed dose to water, D_w, and the beam quality specifier, $R_{50,dos}$. Fifteen electron beams were measured in four institutes according to the Belgian-Dutch code of practice for high-energy electron beams. The expanded uncertainty ($k = 2$) for the D_w values was 3.6% for a Roos chamber calibrated in ^{60}Co and 3.2% for a Roos chamber cross-calibrated against a Farmer chamber. The expanded uncertainty for the beam quality specifier, $R_{50,dos}$, was 0.14 cm. The audit acceptance levels were based on the expanded uncertainties for the comparison results and estimated to be 2.4%.

Results: The audit was implemented and validated successfully. All D_w audit results were satisfactory with differences in D_w values mostly smaller than 0.5% and always smaller than 1%. Except for one, differences in $R_{50,dos}$ were smaller than 0.2 cm and always smaller than 0.3 cm.

Conclusions: An electron dosimetry audit based on absorbed dose to water and present-day requirements for calibration laboratories performing proficiency tests was successfully implemented. It proved international traceability of the participants value with an uncertainty better than 3.6% ($k = 2$).

1. Introduction

External dosimetry audits are powerful quality assurance instruments for radiotherapy departments, allowing detection of potential systematic measurement errors [1,2]. In 2008 the Netherlands Commission on Radiation Dosimetry (NCS) issued a new Code of Practice (CoP) for high-energy photon and electron beams, NCS-18 [3], replacing the air-kerma based CoPs [4,5], based on the IAEA TRS-398 [6]. It focused on methods and equipment used in Belgium and the Netherlands. Differences between NCS-18 and TRS-398 are smaller than their combined uncertainties [3]. Most radiotherapy centres implemented NCS-18 for photon beams, but up to recently postponed doing so for electron beams. Therefore, the NCS decided to organize an electron beam dosimetry audit [7] similar to their photon audit [8]. The audit would become a service by VSL, the Dutch national metrology institute, under calibration and proficiency testing accreditations, i.e. ISO-17025 [9], and ISO-17043 [10].

Literature research revealed electron audits that were developed more than two decades ago [11–14], based on air-kerma CoPs while modern CoPs are based on absorbed dose to water. Currently, requirements for calibration laboratories and proficiency test have further developed [9,10] and were not considered in audits previously published.

The aim of this study was to implement an electron dosimetry audit based on absorbed dose to water with suitable acceptance criteria based on thorough uncertainty analyses, in agreement with present-day requirements for calibration laboratories performing proficiency tests, including correlations, which allows for increased sensitivity in detection of systematic errors.

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Table 1
Overview of the electron beams in this study for the four participating institutes. Here SSD is the Source Surface Distance and ‘isoc’ refers to the accelerator *iso*-centre.

Participant	Linear accelerator type	Nominal energies/MeV	SSD/cm	Field size at isoc[a]/cm^2
A	Elekta Synergy (MLCi)	6; 12; 18	95	10.5 × 10.5
B	Elekta Synergy (Agility)	4; 10; 15	100	10.5 × 10.5
C	Varian TrueBeam	6; 9; 22	100	10 × 10
D	Elekta Synergy (MLCi)	4; 12 4 (HDRE)	100	10.5 × 10.5 42 × 42[b]

[a] Field size is 10 × 10 cm^2 defined by the applicator: Elekta accelerators at 95 cm; Varian at 100 cm.
[b] Field size of ‘4 (HDRE)’ at *iso*-centre is fixed and larger than the surface area of the audit phantom.

2. Materials and methods

2.1. Audit protocol

The audit protocol fully implemented the requirements for proficiency tests and calibration laboratories according to ISO-17043 [10] and ISO-17025 [9] respectively. It contained the objective of the audit, the reference conditions and associated measurement uncertainties, leading to audit acceptance criteria. The subject of this audit was the determination of absorbed dose to water, D_w, at reference depth, z_{ref}, and the beam quality, specified by the 50% dose level beyond the dose maximum, $R_{50,dos}$, in high-energy electron beams. Four participating institutions performed their beam calibrations according to local procedures. The audit team performed on-site beam calibrations according to the procedures described in this study, with its own equipment on the same day. Table 1 summarizes the fifteen selected electron beams.

The audit was conducted as a comparison based on the difference between the beam calibrations of the participant, i.e. measured value, x, and by the audit team, i.e. measured reference value, X. All beam calibrations were performed at the participant’s source surface distance, SSD, and field size (Table 1). This was done to avoid additional corrections to take account for differences in SSD and related errors. The result of the audit was expressed as an E_n-score and the outcome was either ‘satisfactory’ if $|E_n| \leq 1.0$ or ‘unsatisfactory’ if $|E_n| > 1.0$, according to ISO-17043 [10]:

$$E_n = \frac{\Delta}{U_\Delta} \tag{1}$$

where U_Δ was the acceptance criterion, agreed upon prior to the audit and in this study based on the expanded uncertainty of Δ:

$$\Delta = x - X \tag{2}$$

The audit result in the beam quality, $\Delta_{R50,dos}$ in cm, was expressed as an absolute value:

$$\Delta_{R_{50,dos}} = R_{50,dos} - R_{50,dos,ref} \tag{3}$$

The audit result in the absorbed dose, Δ_{Dw}, was expressed as a relative value:

$$\Delta_{D_w} = \frac{D_w - D_{w,ref}}{D_{w,ref}} \tag{4}$$

Combining Eqs. (1), (3) and (4) leads to:

$$E_{n,R_{50,dos}} = \frac{\Delta_{R_{50,dos}}}{U_{\Delta_{R_{50,dos}}}} \tag{5}$$

and

$$E_{n,D_w} = \frac{\Delta_{D_w}}{U_{\Delta_{D,w}}} \tag{6}$$

$U_{\Delta,R50,dos}$, in cm, and $U_{\Delta Dw}$, in% were the expanded uncertainties and thus the acceptance criteria for the audit results in $R_{50,dos}$ and D_w respectively.

After setting up the audit equipment percentage depth ionization, PDI, curves and D_w were measured with a plane-parallel Roos chamber (PTW-34001, PTW Freiburg GmbH, Freiburg, Germany), calibrated in terms of D_w for ^{60}Co. For an electron beam with beam quality $R_{50,dos} > 7$ cm a cross-calibration of the Roos chamber against a cylindrical Farmer chamber (NE2571, Phoenix Dosimetry Ltd, Sandhurst, UK) was performed at the highest energy, as required by NCS-18 protocol, because of its reduced uncertainty in D_w compared to that with a ^{60}Co calibrated plane-parallel chamber. The audit team’s D_w measurements were repeated after the participant’s measurements. Temperature and pressure were monitored during the whole comparison session; chamber readings were corrected to reference temperature and pressure.

2.2. Water phantom and positioning

The audit team used a water phantom (PTW-MP1-T41025) with dimensions of 32 × 37 × 32 cm^3 ($L \times W \times H$) and PMMA wall thickness of 1 cm with an automated vertical translation stage. The waterproof Roos chamber was placed in the centre of the phantom, which was placed on the patient couch. The source to water surface distance, SSD, was determined according to the local method to avoid discrepancies in dose measurement due to geometric measurements.

2.3. Measurement of $R_{50,dos}$ and determination of z_{ref}

The reference depth for the D_w measurement, z_{ref}, was determined according to Eq. (9) in NCS-18 [3], based on the beam quality specifier, $R_{50,dos}$:

$$z_{ref} = 0.6 R_{50,dos} - 0.1 \tag{7}$$

$R_{50,dos}$ was determined twofold: first it was based on $R_{50,ion}$, measured with the Roos chamber and converted to $R_{50,dos}$. $R_{50,ion}$ was defined as the depth beyond the dose maximum, where the PDI had a value of 50%. Second, $R_{50,dos}$ was determined from the percentage depth dose curve, PDD, converted from PDI to PDD as described by Andreo et al. [6]. Differences between the two methods were smaller than 0.03 cm thus considered insignificant.

All PDIs except the ‘4 (HDRE)’ beam at participant D were measured with a beam size close to 10 × 10 cm^2 despite the recommended use of 20 × 20 cm^2 fields at the higher electron energies with $R_{50,dos} > 7$ cm. The effect of potential insufficient scatter on the determination of $R_{50,dos}$ at 10 × 10 cm^2 [15] was measured for 10 × 10 cm^2 and 20 × 20 cm^2 beams at participant C (22 MeV) and found to be insignificant (i.e. < 0.04 cm) with respect to the uncertainties in this study. Changes of the chamber’s polarity correction, k_{pol}, with depth between $R_{100,ion}$ and $R_{50,ion}$ were considered negligible, as well as the variation in stem effect close to the PDD 50% point. Ion recombination is known to depend on the dose per pulse and thus varies with depth. k_s was not measured at each depth, however it was determined at depth by assuming a proportional relation between the corrected chamber signal and the fraction of incomplete charge collection (i.e. $k_s - 1$). This was based on the k_s measurement at z_{ref}, neglecting initial recombination. It was taken into account by an additional standard uncertainty of 0.003 cm in the uncertainty for $R_{50,dos}$ based on the chosen method compared to if charge measurements would have been done to determine k_s at all depths with an uncertainty of 0.1% as applied for k_s (see also Section 2.5 and Table A1). During the PDI measurements a monitor ion chamber (PTW-31013 Semiflex) was mounted at the edge in the beam read out simultaneously with the Roos chamber while the translation stage moved stepwise in vertical direction upwards.