Physics and Imaging in Radiation Oncology 6 (2018) 5–11

Contents lists available at ScienceDirect

Physics and Imaging in Radiation Oncology

journal homepage: www.elsevier.com/locate/phro

Original Research Article

Dosimetric end-to-end tests in a national audit of 3D conformal radiotherapy

Joerg Lehmann[a,b,c,d,*,1], Andrew Alves[a], Leon Dunn[a,2], Maddison Shaw[a,d], John Kenny[a], Stephanie Keehan[a,d,3], Jeremy Supple[a], Francis Gibbons[a,4], Sophie Manktelow[a], Chris Oliver[a], Tomas Kron[a,d,e], Ivan Williams[a], Jessica Lye[a]

[a] Australian Clinical Dosimetry Service (ACDS), Australian Radiation Protection and National Safety Agency (ARPANSA), 619 Lower Plenty Road, Yallambie, VIC 3085, Australia
[b] Institute of Medical Physics, School of Physics A28, University of Sydney NSW 2006, Australia
[c] School of Mathematical and Physical Sciences, The University of Newcastle, University Drive, Callaghan, NSW 2308, Australia
[d] School of Science, Royal Melbourne Institute of Technology (RMIT) University, 124 La Trobe Street, Melbourne, VIC 3000, Australia
[e] Department of Radiation Oncology, Peter MacCallum Cancer Center, 305 Grattan Street, Melbourne, VIC 3000, Australia

ARTICLE INFO

Keywords:
Radiation therapy audit
End-to-end test, Level III
Australian Clinical Dosimetry Service
3D-CRT

ABSTRACT

Background and purpose: Independent dosimetry audits improve quality and safety of radiation therapy. This work reports on design and findings of a comprehensive 3D conformal radiotherapy (3D-CRT) Level III audit.
Materials and methods: The audit was conducted as onsite audit using an anthropomorphic thorax phantom in an end-to-end test by the Australian Clinical Dosimetry Service (ACDS). Absolute dose point measurements were performed with Farmer-type ionization chambers. The audited treatment plans included open and half blocked fields, wedges and lung inhomogeneities. Audit results were determined as Pass Optimal Level (deviations within 3.3%), Pass Action Level (greater than 3.3% but within 5%) and Out of Tolerance (beyond 5%), as well as Reported Not Scored (RNS). The audit has been performed between July 2012 and January 2018 on 94 occasions, covering approximately 90% of all Australian facilities.
Results: The audit pass rate was 87% (53% optimal). Fifty recommendations were given, mainly related to planning system commissioning. Dose overestimation behind low density inhomogeneities by the analytical anisotropic algorithm (AAA) was identified across facilities and found to extend to beam setups which resemble a typical breast cancer treatment beam placement. RNS measurements inside lung showed a variation in the opposite direction: AAA under-dosed a target beyond lung and over-dosed the lung upstream and downstream of the target. Results also highlighted shortcomings of some superposition and convolution algorithms in modelling large angle wedges.
Conclusions: This audit showed that 3D-CRT dosimetry audits remain relevant and can identify fundamental global and local problems that also affect advanced treatments.

1. Introduction

Quality of Radiation Therapy delivery directly impacts the outcome of the treatments delivered to patients. This includes avoiding catastrophic failures but also adherence to the details of dosimetric procedures, which can have a measurable impact on clinical outcomes [1]. The role of dosimetry audits in the context of clinical trials has been established [2–5] and dosimetry audits for clinical trials are being performed worldwide [6]. The role of dosimetry audits as a quality assurance tool outside clinical trials is expanding [7,8]. They are part of government efforts to improve and maintain quality in radiation therapy. Participation in dosimetry audits has become a component of licensing processes in some jurisdictions.

Level III audits commonly use a phantom which is put through the

* Corresponding author at: Department of Radiation Oncology, Calvary Mater Newcastle, Edith and Platt St, Newcastle NSW 2300, Australia.
E-mail addresses: Joerg.Lehmann@sydney.edu.au (J. Lehmann), Andrew.Alves@arpansa.gov.au (A. Alves), Leon.Dunn@epworth.org.au (L. Dunn), Maddison.Shaw@arpansa.gov.au (M. Shaw), John.Kenny@healthstemsolutions.com (J. Kenny), Stephanie.Keehan@petermac.org (S. Keehan), Jeremy.Supple@arpansa.gov.au (J. Supple), FranGibbons@gmail.com (F. Gibbons), Sophie.Manktelow@arpansa.gov.au (S. Manktelow), Chris.Oliver@arpansa.gov.au (C. Oliver), Tomas.Kron@petermac.org (T. Kron), Ivan.Williams@arpansa.gov.au (I. Williams), Jessica.Lye@arpansa.gov.au (J. Lye).
[1] Department of Radiation Oncology, Calvary Mater Newcastle, Edith and Platt St, Newcastle, NSW 2300, Australia.
[2] Epworth Radiation Oncology, 32 Erin Street, Richmond, VIC 3121, Australia.
[3] Department of Radiation Oncology, Peter MacCallum Cancer Center, 305 Grattan Street, Melbourne, VIC 3000, Australia.
[4] Adem Crosby Centre, Sunshine Coast University Hospital, 6 Doherty Street, Birtinya, QLD 4575, Australia.

https://doi.org/10.1016/j.phro.2018.03.006
Received 4 October 2017; Received in revised form 14 March 2018; Accepted 14 March 2018

entire chain of procedures that a patient would go through during radiation treatment simulation, planning and delivery [2]. Substantial experience in Level III and other comprehensive dosimetry audits has been reported on from the northern hemisphere; including audits in the United Kingdom (UK) [7,9–11] and those offered by Imaging and Radiation Oncology Core (IROC) [12–18]. Audits use different dosimeters, including thermoluminescence detectors (TLD) [19], optically stimulated luminescence detectors (OSLD) [18,20,21], Alanine [7], radiochromic film [22], ionization chambers [10,23,24] and electronic portal imaging devices [25,26] the choice of which impacts accuracy and timeframe of result availability. High level audits often rely on volunteer efforts [7], and some comprehensive audits have been cut back due to financial constraints [18]. Many high level audits nowadays focus on the use of advanced treatment modalities [27–29].

The presented Level III (end-to-end test) dosimetry audit for 3D conformal radiotherapy (3D-CRT) differed from similar audits in several aspects: Using primary standard calibrated dosimeters and an onsite audit approach with a team exclusively dedicated to radiotherapy audits the audit was able to have lower uncertainties and tighter action levels. Combined with covering almost an entire country and continent, including private and public providers alike and irrespective of clinical trials participation, this meant that the audit did not only give an overview of the status of the dosimetry therein, but it was also able to identify even small problems and trends with certain equipment combinations.

2. Material and methods

2.1. Australian Clinical Dosimetry Service

Starting in 2011 Australia has implemented a national dosimetry audit program with the Australian Clinical Dosimetry Service (ACDS). The program had initially been trialled as a government funded pilot project [30] and is now self-funded (as of January 2017). The ACDS has built their audit system utilizing the work of others [7,31,32] while further improving the methods [20,30,33] and adapting to the dimensions, population densities and technological diversity of Australia and to the rules of the pilot funding [30,34]. The latter included deliverables for a three year time line, a focus on general clinical needs rather than on clinical trials, and inclusion of 3D conformal therapy audits. Details of ACDS Level I and Level II audits have been reported [23,35]. So have selected findings of the Level II and III audits [36]. This work reports comprehensively on the Level III 3D-CRT audit. Following four field trials, February-April 2012, the audit has been performed on 94 occasions between July 2012 and January 2018, covering approximately 90% of all Australian facilities.

2.2. Onsite audit

This audit was designed as an onsite audit. Prescribed planning, quality assurance (QA) and delivery were performed by clinical staff from the audited facility while an audit team measured the dose delivered to the phantom. Outreach to radiation therapists through presentations at their national meetings and a publication in their journal helped to closer involve them in the audit process [37].

The onsite approach was chosen over a postal audit as it allowed the program to start quickly with a single phantom and to use ionization chambers. Being onsite during the audit provided the opportunity for the audit team to observe any problems with the audit procedures. Additionally, an onsite audit team could help with troubleshooting in case of suboptimal audit results, bringing the facility back to high quality patient treatment more quickly.

2.3. Dosimetry equipment

Ionisation chambers offer the highest accuracy for field measurements and immediate readout and therefore quick availability of (preliminary) audit result. Farmer type PTW 30013 chambers (Physikalisch Technische Werkstätten, Freiburg, Germany) were selected for this audit, as they were for the ACDS Level Ib audit [30]. This overlap and the chamber's known quality and robustness were accepted as a trade-off for their larger volume compared to available smaller chambers.

The “PC electrometer” (Sun Nuclear, Melbourne, FL, USA) was selected for its small size, enabling the audit team to also bring a backup device. The lightweight two channel electrometer was thoroughly tested before deployment. The presence of a second channel allowed for concurrent measurement at two locations in the phantom. Some of the secondary measurement locations were considered interesting but not critical for evaluation and potentially subject to larger uncertainties. For those points the “Reported Not Scored”, RNS category was introduced, which is also used in the ACDS Level II audit [23]. The electrometer's log function provided a record of all measurements.

Facility independent equipment including backup was brought onsite. Ionization chambers and electrometers had been directly calibrated by the Australian Primary Standards Laboratory. See Supplemental Material for details regarding logistics.

2.4. Audit phantom

The commercial anthropomorphic “IMRT Thorax Phantom Model 002LFC” (CIRS, Norfolk, VA, USA) had been initially chosen over a custom phantom to reduce the risk of downtime if the phantom was lost or damaged in transport. This choice also allowed facilities to replicate audit conditions when troubleshooting.

To reduce its weight and size for easier transport, the phantom (Supplementary Fig. 1) was shortened by seven slices. In mid-2016 the commercial phantom was replaced with a custom phantom designed to accommodate both, the here discussed 3D-CRT fields, some of which are continued to be used, and new, intensity modulated and volumetric arc therapy fields for additional checks, which are beyond the scope of this work. The risk of downtime due to loss or damage remains and will be mitigated by maintaining two phantoms.

2.5. Audit cases and measurement locations

At the time of the audit set-up (2012) the majority of patients in Australia were treated with 3D-CRT. Conformal treatment plans were chosen to test performance with wedges, asymmetric fields and low density inhomogeneities.

Measurements were performed as absolute dose measurements using an adapted TRS 398 [38] approach. This included corrections for temperature and pressure. The correction factor k_Q was calculated based on the facility provided beam quality information, while standard correction factors k_s and k_{pol} were used based on experience with each ionization chamber.

For efficiency reasons all cases were initially only delivered with standard (flattened) 6 MV beams. Higher energy 3D-CRT beams were introduced in mid-2016 and are not discussed here.

Case 1 investigated system performance close to reference conditions in a surface distance based setup at 3 cm depth (Point 1). Illustrations of all cases are in Supplementary Figs. 2–5. Table 1 in [36] lists plan details. Point 10 was used to assess depth dose accuracy. A measured correction factor of ~1% was applied to compensate for the increased dose at Point 10 due to the presence of a chamber at Point 1.

Case 2 tested performance with a wedge on an oblique body surface using a single field plan adapted from [32]. Point 1 was the isocenter and prescription point. Point 4 was located upstream and posteriorly, moving it towards the thinner end of the wedge. Point 7 was measured as RNS to gain understanding about the performance of the planning system for points far outside the field.

Case 3 was a three field plan with an anterior field and two half-