BRACHYTHERAPY DOSIMETRY SPECIAL FEATURE: REVIEW ARTICLE

Dosimetric audit in brachytherapy

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ABSTRACT
Dosimetric audit is required for the improvement of patient safety in radiotherapy and to aid optimization of treatment. The reassurance that treatment is being delivered in line with accepted standards, that delivered doses are as prescribed and that quality improvement is enabled is as essential for brachytherapy as it is for the more commonly audited external beam radiotherapy. Dose measurement in brachytherapy is challenging owing to steep dose gradients and small scales, especially in the context of an audit. Several different approaches have been taken for audit measurement to date: thimble and well-type ionization chambers, thermoluminescent detectors, optically stimulated luminescence detectors, radiochromic film and alanine. In this work, we review all of the dosimetric brachytherapy audits that have been conducted in recent years, look at current audits in progress and propose required directions for brachytherapy dosimetric audit in the future. The concern over accurate source strength measurement may be essentially resolved with modern equipment and calibration methods, but brachytherapy is a rapidly developing field and dosimetric audit must keep pace.

THE NEED FOR AUDIT
Audit is required in a multitude of scenarios in medicine, and the term has acquired different meanings over time in relation to health care quality. Clinical audit, for example, might involve systematically looking at the procedures for diagnosis, care and treatment, examining how resources are used, investigating the effect care has on patient outcomes, and importantly recognizing audit as a quality improvement process and not just a monitoring system. Audit might consider any aspect of infrastructure, procedure or outcome to ensure safe, effective and best-practice processes and enable improvements. NHS England has defined clinical audit as “a way to find out if healthcare is being provided in line with standards”, and importantly “the aim is to allow quality improvement to take place where it will be most helpful and will improve outcomes for patients”. Audit therefore needs to be undertaken, and it needs to be directed appropriately. In this review, we limit our scope to the specific consideration of dosimetric audit of brachytherapy.

In radiotherapy physics, a key component of auditing is to review the most fundamental of requirements, which is whether prescribed radiation doses are being accurately delivered. This might involve testing the dissemination of dosimetry calibration from national standard laboratories, verifying dose or dose distribution for particular complex treatment techniques, or assuring dose delivery for compliance with clinical trial protocols. With regard to the latter, it has been demonstrated that the number of patients required in a randomized clinical trial may be reduced by introducing appropriate dosimetry quality assurance (QA), as the risk of under-powering the study is minimized. The largest dosimetric audit networks at present are operated by the International Atomic Energy Agency (IAEA), the American Radiological Physics Centre (RPC) and in Europe the European Society for Radiotherapy and Oncology (ESTRO) Quality Assurance network (EQUAL). The reader is directed to the proceedings of a 2010 IAEA International Symposium on Standards, Applications and Quality Assurance in Medical Radiation Dosimetry (IDOS) for a number of papers on external beam audit. There are also many national audit groups, for example, in the UK, auditing is co-ordinated by the Institute of Physics and Engineering in Medicine (IPEM) via a number of regional groups. This network arose following an IPEM co-ordinated national megavoltage photon beam dosimetry audit and a later national electron beam dosimetry audit. In 2012, the IAEA surveyed the worldwide coverage of dosimetry audit programmes for radiotherapy, finding...
audit activity in 45 countries, of which 16 had a mandatory requirement for participation, but with around one-third of world radiotherapy centres having no independent assessment. In the UK, a consortium of professional bodies published “Towards Safer Radiotherapy”, which recommends that “all centres should participate in dosimetric audit networks” and that “comparative audits between departments can provide valuable opportunities to ensure safe delivery of radiotherapy and consistency of patient outcomes”. The National Health Service (NHS) National Cancer Peer Review Programme Manual for Cancer Services: Radiotherapy Measures\(^{14}\) requires centres to take part in local audit networks. This is typical of publications from several bodies in recent years suggesting how radiotherapy could be made safer. Dunscombe\(^ {15}\) has analysed seven authoritative documents, including “Towards Safer Radiotherapy”, to find commonalities between the recommendations. “Dosimetric audit” was one of the 12 topics identified in \( \geq 3 \) documents as being pertinent to the improvement of patient safety in radiotherapy. Dunscombe\(^ {15}\) states that “organizations like the RPC and EQUAL-ESTRO have had, and continue to have, a huge positive influence on the safety and quality of radiotherapy”. However, Dunscombe\(^ {15}\) also discusses that dosimetric audits are not always carried out appropriately, stating audits should “take place prior to the first clinical use” and enable “testing the device under conditions other than those used to calibrate it”, citing a treatment error from Ontario as an example that might be avoided if audits were optimally used.\(^ {16}\)

The increasing complexity of radiotherapy planning and delivery makes dosimetric audits challenging, and it is probably no longer sufficient to verify only the absolute dose delivery at a reference point, which had been the standard approach in the past two decades. Kron et al\(^ {17}\) states the focus of current research is to adapt dosimetry audit for even more diversified radiotherapy procedures including image-guided/adaptive radiotherapy, motion management and brachytherapy. This review considers the latter, specifically, physics aspects of dosimetric audit for brachytherapy in the radiotherapy clinic.

**THE NEED FOR AUDIT IN BRACHYTHERAPY**

In comparison with external beam radiotherapy, the physical processes by which the majority of brachytherapy equipment calculates and delivers treatment is relatively simple. However, this does not mean that dosimetric audit is without complexity. Indeed, the high-dose gradients, orders of magnitude variation in dose deposition across clinical regions of interest and small scales, mean measurements to verify absolute dose and dose distribution are challenging. Haworth et al\(^ {18}\) states “to date, dosimetric audits of high dose rate (HDR) facilities have not been conducted in Australia despite the high risks associated with these treatments due to the challenges presented by measuring doses in steep dose gradients”. In the UK, the National Cancer Peer Review Programme Manual for Cancer Services: Radiotherapy Measures\(^ {14}\) states there is a requirement that “the department should have taken part in the External Quality Control programme”, but this is only specifically listed within the external beam radiotherapy measures, not within the brachytherapy measures. This may be owing to the lack of availability of brachytherapy dosimetric audit at that time, difficulties in implementation or prioritization of need. However, in the more recent NHS England Service Specification document for 2013/14 for brachytherapy,\(^ {19}\) it is stated that “to ensure that the services being delivered offer high quality brachytherapy to patients”, one of the specific requirements is that “the provider department must participate in the national inter-departmental dosimetry audit programme (national audit of HDR brachytherapy)”.

In the past few years, numerous commercial detectors and phantoms have been specifically developed to verify dose distributions in external beam radiotherapy, partly driven by the adoption of intensity-modulated radiotherapy and volumetric-modulated arc therapy (VMAT) techniques. These active detectors might conveniently be adopted for dosimetric audit.\(^ {20}\) However, there have been no similar commercial developments for brachytherapy. Well-type ionization chambers have been adopted for source strength determination, and commonly thermoluminescent detectors (TLDs) have been used for point-dose measurements, but there is no clear consensus on techniques for verification of dose distribution measurement in brachytherapy. Many dosimetry systems have been investigated in the past decade for brachytherapy measurement, including gel dosimetry, TLDs, semiconductor diodes, ionization chambers, metal oxide semiconductor field effect transistor (MOSFET) detectors, alanine, radiochromic film, radiochromic plastic, calorimetry and optically stimulated or radioluminescent detectors.\(^ {21}\)

The need for dosimetric audit in brachytherapy exactly mirrors the need in external beam radiotherapy: to detect any errors, to provide reassurance, to enable improvements and to demonstrate compliance. There are of course numerous sources of uncertainty in brachytherapy,\(^ {22}\) and there have been previous errors in brachytherapy delivery,\(^ {23–26}\) including well-type chamber calibration error,\(^ {27}\) confusion over units\(^ {28}\) and media reports of at least two incidents involving incorrect dwell positions.\(^ {29–32}\) The pace of change in brachytherapy equipment, physics and clinical processes has also been rapid in recent years with the integration of multimodality 3D imaging, improved dosimetry and treatment planning including patient-specific optimization, volume prescribing and new equipment and applicators.\(^ {32–34}\) Treatment planning algorithms in brachytherapy might also be on the verge of a step change in complexity and a move from standard planning to fully flexible optimization might have widespread uptake.\(^ {35}\) To contribute to the overall quality, safety and reassurance, brachytherapy should be subjected to the same rigour of local quality checks\(^ {36}\) and audit mechanisms as external beam radiotherapy.

**DOSIMETRIC AUDITS IN BRACHYTHERAPY**

A systematic review was conducted on journal articles discussing concepts, research and practices of dosimetric audit in the clinic for brachytherapy over the past three decades. MEDLINE and Embase databases were searched, internet search engines utilized and several brachytherapy experts across the world consulted. Eight peer-reviewed journal publications were obtained that presented results of fully completed audits or pilot audits at several centres, involving dosimetric measurements\(^ {38–43}\) and one concerned with a geometric applicator reconstruction
Conducted by de Almeida et al.\textsuperscript{38} in 1999, who compared sources. A comparison of calibration procedures for Ir-192 HDR was 3.0% between the two measurements.

All results within 2.8% of the manufacturer host and visiting equipment for the local Ir-192 HDR source. Centre and the reference air kerma rate compared between the departments in the Netherlands and Belgium participated. An ESTRO laboratory, which has provided external audits in Cancer Centre, TX, USA, did not have remote measurement communication. Until recently, the RPC at the MD Anderson countries (A Veres, EQUAL-ESTRO Laboratory, 2013, personal communication). Until recently, the RPC at the MD Anderson Cancer Centre, TX, USA, did not have remote measurement capabilities for brachytherapy, relying instead on credentialing audits performed by questionnaires, patient plan checks and benchmark treatment plans.\textsuperscript{54} The recent development of a remote audit tool at the RPC is discussed below.\textsuperscript{43} A summary of dosimetric audits in brachytherapy is provided in Table 1.

One of the first reported dosimetric audits in brachytherapy was from Venselaar et al.\textsuperscript{37} in 1994, in which 13 radiotherapy departments in the Netherlands and Belgium participated. An ionization chamber with an in-air jig was transported to each clinic. Each clinic was asked to prepare a plan to deliver a prescribed dose at the ionization chamber. A transit dose correction was applied to the measurement to enable direct comparison with treatment planning systems that did not make transit corrections. The agreement between measured and treatment planning system-calculated dose at the chamber was found to be within ±5.0% in all but one clinic, where a 6.8% deviation was recorded and attributed to an error in the source strength value on the source certificate. It was stated that a 2 mm error in the source position, nominally aligned with the chamber, would result in a deviation of the measured dose of only 0.2% in the audit configuration used. Therefore, additional dwell positions were measured at +20 mm and −20 mm to assess the source position accuracy. Results stated seven clinics had source position errors >1 mm, three of which exceeded 2 mm.

Heeney et al.\textsuperscript{40} designed an in-air jig for Farmer-type ionization chambers to measure the reference air kerma rate at nine clinics, auditing five HDR units and six LDR units, in Ireland, Scotland and the north of England. The measurement apparatus was essentially a cruciform of acrylic material with two locations for ionization chambers (reference and field chambers) with a gradient correction being applied and two holders for straight treatment catheters, at variable source to detector distances. Results showed a mean difference between the host and auditor determination of the reference air kerma rate of 0.8% (range, −0.9% to +1.5%) for HDR units and a mean of 0.3% (range, −3.8% to +2.4%) for LDR units.
<table>
<thead>
<tr>
<th>Reference</th>
<th>Equipment audited</th>
<th>Dosimeter used</th>
<th>Region</th>
<th>Number of audits</th>
<th>Results</th>
</tr>
</thead>
<tbody>
<tr>
<td>Venselaar et al37 (1994)</td>
<td>HDR</td>
<td>Thimble-type ionization chamber with an in-air jig</td>
<td>Netherlands and Belgium</td>
<td>13</td>
<td>Auditor compared with local measurement: mean, +1.3%; range, −0.4% to +3.0%</td>
</tr>
<tr>
<td>De Almeida et al38 (1999)</td>
<td>HDR</td>
<td>Thimble-type ionization chamber with an in-air jig and/or well-type ionization chamber</td>
<td>Brazil</td>
<td>10</td>
<td>Visiting centres compared with reference measurement: all within ±3.0%, one error detected, result at −4.6%, calibration factor</td>
</tr>
<tr>
<td>Elfrink et al39 (2001)</td>
<td>HDR, PDR, LDR-afterloader</td>
<td>Thimble-type ionization chamber in solid cylindrical PMMA phantom with three straight catheters</td>
<td>Netherlands and Belgium</td>
<td>33</td>
<td>Measured compared with prescribed: for HDR mean +0.9% ± 1.3% (1 SD) for PDR mean +1.0% ± 2.3% (1 SD) for LDR mean +1.8% ± 2.2% (1 SD) One error detected, LDR result at 6.8%, source strength certificate</td>
</tr>
<tr>
<td>Heeney et al40 (2005)</td>
<td>HDR, LDR-afterloader</td>
<td>Thimble-type ionization chambers custom-designed in an air jig</td>
<td>Ireland, Scotland and the north of England</td>
<td>11 units at 9 clinics</td>
<td>Auditor compared with local measurement: for HDR, mean, +0.8% ± 1.5% for PDR, mean, +0.3% ± 2.4%</td>
</tr>
<tr>
<td>Roue et al41 (2007) EQUAL-ESTRO Laboratory</td>
<td>HDR, PDR</td>
<td>Mailed TLD with phantom comprising three PMMA tubes around central dosimeter, in water</td>
<td>Europe</td>
<td>17</td>
<td>Measured compared with treatment planning system: range, −4.7% to +4.7% One error detected, calibration coefficient</td>
</tr>
<tr>
<td>Carlsson Tedgren and Grindborg42 (2008)</td>
<td>HDR, PDR</td>
<td>Well-type ionization chamber</td>
<td>Sweden</td>
<td>14 units at 7 clinics</td>
<td>Auditor compared with local measurement: all within ±1.0%, except one within +3% Auditor to certificate and local to certificate: range, −1.5% to +3%</td>
</tr>
<tr>
<td>Palmer et al43 (2011)</td>
<td>I-125 seed</td>
<td>Mailed seed with NPL calibration certificate for local well-type ionization chamber</td>
<td>Central–southern England</td>
<td>6 clinics, each audited twice</td>
<td>Local measurement to seed calibration certificate all within ±2.8%</td>
</tr>
</tbody>
</table>
In 2007, Roue et al. published a report on the development of a remote mailed dosimetry audit system using a custom phantom and TLD. The methodology was developed by the ESTRO BRAPHYS Physics Network and the EQUAL-ESTRO laboratory and is the most significant brachytherapy audit to date. The audit has been available to clinics since 2004 via the EQUAL-ESTRO Laboratory. The phantom consists of three PMMA tubes supporting HDR treatment unit catheters at 5 cm radially from, and equally spaced at 120° around, a central TLD holder. The phantom has similar geometry to the equipment used by Elfrink

Table 1. (Continued)

<table>
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<th>Reference</th>
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</tr>
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<tr>
<td>Eaton et al. (2013)</td>
<td>Electronic intraoperative brachytherapy</td>
<td>Ionization chamber, TLD, radiochromic film</td>
<td>UK</td>
<td>7</td>
<td>Auditor compared with local measurement: mean output -3.2% ± 2.7% Other parameters within experimental uncertainty</td>
</tr>
<tr>
<td>Haworth et al. (2013)</td>
<td>HDR, PDR</td>
<td>“End-to-end” audit. TLD with phantom comprising three PMMA tubes around central dosimeter, in water</td>
<td>Australia</td>
<td>7</td>
<td>Measured compared with treatment planning system: all results within ±5% One large error detected (25%), incorrect step size used at treatment unit compared with TPS</td>
</tr>
<tr>
<td>Casey et al. (2013) Radiological Physics Centre</td>
<td>HDR</td>
<td>Optically stimulated luminescence natoDots (quantity two per measurement) in small mailable polystyrene phantom</td>
<td>USA</td>
<td>8</td>
<td>Measured compared with treatment planning system: mean, 0.0% ± 1.2% (1 SD)</td>
</tr>
<tr>
<td>Palmer et al. (2013) Institute of Physics and Engineering in Medicine</td>
<td>HDR, PDR</td>
<td>“End-to-end” audit. Radiochromic film (dose distribution and point dose), clinical brachytherapy applicator in custom Solid Water® phantom</td>
<td>UK</td>
<td>In progress, (22/46 complete in February 2014)</td>
<td>Measured compared with treatment planning system: full results not yet available. Results of first two pilot audits: mean distance to agreement at Point A is 1.2 ± 1.1 mm (k = 2), Mean gamma passing rate at 3% (local), 3 mm criteria = 98.6%</td>
</tr>
<tr>
<td>Chris Lee, The Clatterbridge Cancer Centre (personal communication)</td>
<td>HDR, PDR</td>
<td>Well-type ionization chamber</td>
<td>UK</td>
<td>In progress</td>
<td>Auditor compared with local measurement: full results not yet available. Results of five centres: range, -0.1% to 0.05%</td>
</tr>
<tr>
<td>NCRI Radiotherapy Trials Quality Assurance Group, with NPL</td>
<td>HDR, PDR</td>
<td>Three stacks of alanine and thimble-type ionization chamber around central source in Solid Water and Perspex® block</td>
<td>UK</td>
<td>In progress</td>
<td>Results not yet available</td>
</tr>
</tbody>
</table>

HDR, high dose rate; LDR, low dose rate; NPL, National Physical Laboratory, UK; PDR, pulsed dose rate; PMMA, polymethyl methacrylate; SD, standard deviation; TLD, thermoluminescent detector; TPS, treatment planning system.
A dosimetric audit of source strength determination in Sweden for HDR and PDR Ir-192 brachytherapy sources was reported by Carlsson Tedgren and Grindborg in 2008. All 7 Swedish centres were audited, comprising 14 afterloading treatment units, using a well-type ionization chamber with plastic transfer catheter. The ratio of the measured reference air kerma rate by the auditor and by the host centre to the vendor’s source certificate was determined. All ratios of measurement to certificate were between 0.85 and 1.03, being within the ±3% source calibration uncertainty (k = 2) quoted by the vendors. The agreement between the auditor and local determination of reference air kerma rate was all within 1%, except in one case, which was within 3%.

The final two publications on completed dosimetric brachytherapy audits were both reported in the literature in 2013 and marked a change from prior approaches. One incorporated brachytherapy imaging to assert full system test, and the other used optically stimulated luminescence (OSL) dosimetry as a novel detector for brachytherapy audit. The “end-to-end” brachytherapy audit was conducted at seven clinics in Australia, reported by Haworth et al., as a pilot study to demonstrate feasibility prior to a more complex audit to be devised. The current phantom was based on the design described by Roue et al., using two source dwell positions (±30 mm) in each of the three straight catheters with a central TLD measurement in a homogeneous dose region. The phantom was filled with water and CT imaged using normal clinical protocols, identifying source catheters and radio-opaque markers in the position of the central TLD. A host treatment plan was produced to deliver 1 Gy to the TLD and delivered using normal clinical processes. All results were within the stated “optimal” tolerance of ±5%, except one centre in which a 25% error was reported, outside the “emergency” tolerance level. This was caused by the use of a 5 mm step size at the treatment console for delivery, rather than the 2.5 mm step size that had been used at the treatment planning system. Once this had been rectified a repeat audit was within the “optimal” tolerance.

OSL dosimetry was developed for use in brachytherapy dosimetric audit by Casey et al., at the RPC. A manageable phantom was designed for centres participating in National Cancer Institute-funded cooperative clinical trials, comprising an 8 × 8 × 10 cm³ block of polystyrene (density, 1.04 g cm⁻³) with a single 2 mm diameter channel to admit a six French or smaller catheter. The phantom had two slots for nanoDot OSL dosimeters (Al₂O₃:Ce), orientated with their smallest dimension across the highest dose gradient, at 2 cm from the source channel on opposite sides. Audited centres were asked to produce treatment plans to deliver 1 Gy to a line 2 cm from the catheter over a 5 cm active length. A correction factor was applied for the lack of scatter in the small phantom, the limited size being a necessity for convenient mailing. A different scatter correction was derived for Nucletron™ (Veendenaal, Netherlands) and Varian (Palo Alto, CA) sources, due to differences in the sources’ physical geometry, and the correction was also reported as being OSL dosimeter batch dependent. Results of eight pilot audits are reported in the article by Casey et al., in which all RPC-measured OSL dosimeter doses were within 2% of the host centre treatment planning system reported dose, with a mean deviation of 0%. The stated OSL dose measurement uncertainty was 2.4% and 2.5% (k = 2) for Nucletron and Varian HDR sources, respectively, sufficient for the RPC to establish a ±5% acceptability criterion. It is anticipated the OSL mailed phantom will become the basis of future official RPC audits for Ir-192 HDR brachytherapy sources.

The dosimetric audits discussed thus far have had the objective of accurate confirmation of source strength, using straight catheters for irradiation, with dwell patterns designed to generate homogeneous dose deposition regions at the dosimeter. Indeed, audits have been designed to minimize the effect of source positioning errors on the measured dose: the design by Casey et al. stated “variations in distal/proximal source positioning up to 10 mm had minimal effect on dose measurement accuracy”. An alternative is to audit the dose delivered in typical clinical situations, assessing the combined effect of all uncertainties on dose deposition, including dwell position length, dwell paths in treatment applicators and attenuation by the applicators, as well as source strength calibration. This is a more complex measurement challenge that might result in increased uncertainty, with a lack of specificity of any errors, but at the benefit of a more “clinically realistic” dosimetric audit. Palmer et al. were the first to report on the design and implementation of a pilot “end-to-end” system audit for brachytherapy, involving radiochromic film measurement of dose distribution around clinical treatment applicators with comparison with treatment planning system calculations. The test object consisted of a near full-scatter water tank with applicator and film supports constructed of Solid Water®, accommodating any typical HDR/PDR cervix treatment applicator. The applicator and phantom were CT scanned and taken through the full brachytherapy treatment process. Radiochromic film dosimeters were accurately held in position in four orthogonal planes bisecting the intrauterine tube of the applicator to measure point dose at Manchester Point A and to compare dose distribution against DICOM RTDose file export from the treatment planning system. Typical clinical dwell patterns and prescription doses were used for the audit. The results from just two pilot audits are
presented in the article by Palmer et al., using Co-60 and Ir-192 HDR sources, with comparison of planned and delivered dose distributions having the mean γ passing rate of 98.6% at 3% local normalization and 3 mm criteria, and the mean distance to agreement at Point A of 1.2 mm. The phantom is currently being used (2013–2014) to audit all brachytherapy centres in the UK.

There are three other brachytherapy audits currently in progress in the UK. Chris Lee, from The Clatterbridge Cancer Centre NHS Foundation Trust (Wirral, UK), is leading an intercomparison of well-type chamber source strength measurements for Ir-192 brachytherapy units, by sending a reference well-chamber to each centre for comparison with their own equipment. This audit was devised following the adoption of a new IPEM code of practice for source strength determination using a well-type ionization chamber. Results from the first five centres had agreement between local and audit measurements of source strength within the range −0.1% to +0.05%, all being within ±0.4% of manufacturers' source certificate (C Lee, The Clatterbridge Cancer Centre NHS foundation Trust, 2012, personal communication).

The National Cancer Research Institute (NCRI) Radiotherapy Trials Quality Assurance Group, in collaboration with the National Physical Laboratory, are also currently auditing in the UK, led by Patty Diez and Edwin Aird, of the Mount Vernon Cancer Centre (Northwood, UK). The audit is being conducted as a QA requirement for the INTERLACE clinical trial (a trial of chemotherapy before chemoradiation for cervical cancer) (http://www.rtrialsqc.org.uk). A pre-audit treatment planning system calculation check precedes a dosimetric audit site visit. The phantom consists of a Solid Water block, surrounded by Perspex® for full scatter, with a central straight channel to accept a plastic transfer catheter, surrounded by three cavities for alanine detectors at 20 mm radial distance from the source channel, equally spaced at 120°, and a cavity for a Farmer-type ionization chamber, 50 mm radial distance. A series of nine dwell points in the catheter are used to irradiate the alanine detectors to 10 Gy, a high dose being required for alanine dosimetry. The phantom uses a “three equally spaced radial positions” geometry common with other audit phantoms, but uniquely uses three dosimeters around a central source channel, others having used three source channels around a single central dosimeter. This potentially enables an assessment of radial anisotropy of the source. Results of the audit are expected late 2014.

The final brachytherapy audit being conducted at several centres in the UK is based on a design described by Awunor et al., who have developed an audit process for the direct reconstruction of dwell positions in ring applicators using a universal jig and radiochromic film. Whilst this is not a dosimetric audit, in that no dose measurements are made, the accuracy of dwell positions in rings is a subject much debated and might impact on the accuracy of clinical dose delivery. Eight ring applicators were assessed in the pilot audit, with results showing up to 6 mm deviation of the source dwell from its expected position in a ring.

This review has considered dosimetric audits for traditional radionuclide-based brachytherapy. Electronic brachytherapy is an emerging technology; guidance is available from The American Society for Radiation Oncology (ASTRO) on electronic brachytherapy and the American Association of Physicists in Medicine (AAPM) have formed TG-182 to provide recommendations for electronic brachytherapy quality management. Audits are particularly relevant for new techniques, and the first comprehensive dosimetric audit of electronic intraoperative brachytherapy has been completed by Eaton et al. All seven clinical sites in the UK were audited. An ion chamber was used to measure the output, thermoluminescent dosemeters to measure the isotropy and radiochromic film to measure the depth dose. Agreement within measurement uncertainty was found between the host and auditor for all parameters at all centres, providing confidence in delivery of this new modality.

The results of the 12 dosimetric brachytherapy audits discussed above show that in general the average agreement between auditor and local measurement, or auditor measurement and treatment planning system calculation, is sufficient to be within stated acceptable tolerances of the audits or within clinically acceptable parameters. This provides confidence in the general consistency of brachytherapy dosimetry at the level of source strength, within the tolerances applied in the audits. However, in one-third of the published audits, errors were detected at one centre in each audit, which appears to be clinically significant. The majority of incorrect audits were detected in the earlier studies. The causes of the errors were stated as calibration factor, calibration coefficient, certificate source strength, and step-size mismatch between planning system and delivery system. Considering the reports cover a 20-year period, there are a limited number of publications on brachytherapy audit. Results appear to be relatively consistent through this period, but in the last year only have audits increased in complexity from source strength or point-dose verification, moving to system audit including the effect of imaging in the dosimetric assessment, and inclusion of clinical applicators and dose distribution measurement.

**THE FUTURE OF DOSIMETRIC AUDITS IN BRACHYTHERAPY**

There is no doubt that clinical and physics aspects of brachytherapy will continue to develop at a significant rate, including the realization of advanced and functional imaging in brachytherapy, a new era of dose calculation algorithms for brachytherapy and an evolution away from traditional template planning to fully patient-specific optimization. As a result, the scope of dosimetric audit in brachytherapy will continue to be challenged to be fit for purpose.

Dosimetric audit in brachytherapy has until recently been solely concerned with the verification of source strength for after-loading equipment, especially as there had been a lack of primary standard for Ir-192 and the uncertainty of source strength quoted by manufactures some years ago was ±10%. The uncertainty quoted by manufacturers is now often ±5% at k = 3, with their source strength measurements traceable to national standard laboratories. The ability for local radiotherapy clinics to determine source strength has also improved, with the development of well-type ionization chambers designed specifically for brachytherapy, which are more robust, less sensitive...
to positional inaccuracies and room-scatter effects, and produce higher ionization currents than does free-in-air measurements with smaller ionization chambers. Early results from a UK well-chamber intercomparison demonstrated excellent agreement in source strength determination (C Lee. The Clatterbridge Cancer Centre NHS Foundation Trust, 2012, personal communication). While previous concerns of source calibration might now essentially be resolved, which should lead to reduced uncertainty in determination of source strength, it is important not to abandon audit checks of this fundamental parameter, but it does enable a shift in focus to more complex areas for audit. As discussed earlier, dosimetric measurements in clinical brachytherapy situations are problematic and measurement uncertainties might increase as we move closer to the clinical treatment situation. In the future, the gold-standard dosimetric audit may be verification by in vivo measurement and will certainly include an “end-to-end” system approach. It is important that brachytherapy equipment is tested under conditions other than those used for routine calibration, and assessment of dose distributions rather than point doses might also be required for robust assurance of treatment dose delivery in the future, either by measurement or in combination with remote plan analysis. This is true for all forms of brachytherapy: LDR seeds, HDR or PDR afterloading equipment, and electronic brachytherapy. Audit of brachytherapy procedures and infrastructure should also be undertaken, to at least qualitatively attempt assessment of the likelihood of random errors and offer any quality improvement suggestions to mitigate risks. Otherwise, dosimetric audit will be limited to the detection of systematic errors that might exist in brachytherapy physics.

CONCLUSIONS

In this review, we have established the need for dosimetric audit and discussed the limited number of publications on dosimetric audits for brachytherapy. External dosimetric audit is recommended in many authoritative documents, is a mandatory requirement in many countries and is advocated by the majority of physicists working in radiotherapy. Whether for improvements in patient care, reassurance of accuracy, fulfilling a legal requirement, credentialing for clinical trials, simple best-practice approach, minimizing the risk of error, avoiding litigation or adding security in a high-pressure environment, audit should no doubt be extended to brachytherapy as well as the more established procedures for external beam radiotherapy. Currently, external quality audits in brachytherapy are not common practice, but it is clear that future advancements in brachytherapy should be underpinned by the reassurance of comprehensive dosimetric audit. Assuring confidence in the clinical utility of brachytherapy requires many aspects of clinical audit, of which dosimetric audit is an essential component.

REFERENCES

Review article: Dosimetric audit in brachytherapy


