Physica Medica 65 (2019) 94–98

Contents lists available at ScienceDirect

Physica Medica

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

Original paper

Radiotherapy dosimetry audits carried out in Ireland at the request of the National Radiation Safety Committee in 2014 & 2017

Fintan L. Bradley*

National Radiation Safety Committee, Health Service Executive, Ireland

ARTICLE INFO

Keywords:
Dosimetry audit
Quality assurance
IMRT
Ireland

ABSTRACT

Purpose: Two requests were issued by Ireland's National Radiation Safety Committee (NRSC) to radiotherapy centres in Ireland to participate in external dosimetry audits in order to demonstrate compliance with the requirement for clinical audit in medical radiological procedures.

Methods: Centres were requested to carry out the phantom irradiation offered by the MD Anderson Dosimetry Laboratory (MDADL) for prostate IMRT in 2014 and were subsequently requested to irradiate the same organisation's head and neck phantom in 2017.

Results: A total of 22 audits were performed across 11 radiotherapy centres, capturing the full range of planning and c-arm linear accelerator combinations in use in Ireland at the time of the audits. The mean MDADL vs. institution measured dose for Planning Target Volume (PTV) points was 0.999 ± 0.026 (1SD). The mean PTV gamma pass rate (and lower 95% confidence interval) at 7%/4 mm was 97% (90%). A significant difference was observed between prostate and head and neck irradiations but for no other subdivisions of data e.g. fixed gantry angle IMRT and VMAT.

Conclusion: Radiotherapy centres in Ireland participated in a co-ordinated set of external audits with all centres satisfying the phantom irradiation component of the MDADL credentialing process.

1. Introduction

In Ireland, the requirement for clinical audit of medical radiological procedures was laid down in legislation [1]. Comprehensive guidance on the scope of audit in medical radiological practice is available from the European Commission [2] and this guidance has been accepted by Ireland's Medical Council, Faculty of Radiologists, National Radiation Safety Committee and Health Service Executive as best practice and has been recommended for use [3]. Notwithstanding these facts, the need for and importance of performing dosimetry audit – which is just one component of radiotherapy clinical audit – has been understood for many decades, with availability of such services commencing in the 1960s [4]. Following the findings of the first comprehensive national photon dosimetry audit in the UK [5], a more co-ordinated response to the need for dosimetry audit in Ireland was prompted. These initial efforts ensured that radiotherapy centres in Ireland were linked to the UK Interdepartmental Dosimetry Audit Network for megavoltage, electron and kV treatment units [6].

Since the 1990s, dosimetry audit practice in Ireland has evolved on a more ad hoc basis. Its importance is grasped by the medical physics community but there is insufficient infrastructure currently to support development of a cohesive and formulated strategy. An early attempt to acquire resources through a cross border "North/South technology group" did not meet with success [7]. Thus, formal national linkage to the UK network [8] for reference dosimetry has been lost, although it is likely that many centres have maintained an informal linkage at a minimum, through continued links by some individual centres and interdepartmental audit activity between those centres and other hospitals in Ireland. Apart from attempts to maintain dosimetry audit practice within the medical physics community, the Environmental Protection Agency and its antecedents have, for many years, required independent external audit of reference beam dosimetry for new treatment units as a pre-requisite for issuing a licence for clinical use.

With regard to establishing an indigenous audit programme, additional complexity was added to the Irish radiotherapy landscape as a result of the dramatic increase in the number of centres and clinical linear accelerators in operation over the first decade of the new millennium. Perhaps inevitably, some centres have engaged external audit services on an individual basis to ensure appropriate, regular dosimetry audit was carried out in the face of increasing treatment complexity and to cover the wider range of available treatment modalities where this was relevant e.g. [9].

* Address: Medical Physics Department, Cork University Hospital, Cork T12 DC4A, Ireland.
E-mail address: fintan.bradley@hse.ie.

https://doi.org/10.1016/j.ejmp.2019.08.002
Received 12 June 2019; Received in revised form 25 July 2019; Accepted 1 August 2019
Available online 20 August 2019

2. Materials and methods

Although the dosimetry audit infrastructure in place in some countries is lacking in Ireland, a driver for some level of co-ordinated audit can be found in the medical exposures' legislation. The legislation requires that some clinical audit is performed, with the cost of the audit borne by individual institutions. To enhance confidence that clinical dosimetry of more complex treatments is accurate and that hospital QA procedures are adequate, a request was issued to all centres in 2014 by the National Radiation Safety Committee (NRSC) to conduct the audit offered by the MD Anderson Dosimetry Laboratory (MDADL) involving irradiation of its IMRT prostate phantom. This was followed by a request in 2017 to carry out the same organisation's IMRT head and neck phantom irradiation. Details of the audit methodologies are described elsewhere [10,11]. Centres submitted a copy of the final report returned by the MDADL for review by the NRSC. The head and neck audit took some time to complete, as the last Centre to report back to the NRSC did so at the close of 2018.

For most participating Centres, the audit reports for prostate phantom irradiation identified the Treatment Planning System (TPS) algorithm used, and as may be expected for planning this treatment site and the time of the audit, a few Centres used algorithms which do not consider changes in electron transport. A large majority of the reports for Head & Neck phantom irradiation did not identify the TPS algorithm used. Similarly, comprehensive reporting of the photon energy used occurred for prostate phantom irradiation only – 6MV in all centres.

Statistical analysis was performed (SPC for Excel v5.02) on ratios of MDADL to Institution measured doses and gamma index results (Mann-Whitney *U* test), sub-dividing the data as follows: between fixed gantry angle IMRT and VMAT; by combination of treatment planning system (TPS) and linac manufacturer; by treatment site and between public and private hospitals. In the case of TPS and linac manufacturer, the number of cohorts that could be compared was just two due to the limited dataset: ECLIPSE-Varian and 'Other', where 'Other' comprised a mix of TPS and linac vendors. The approach taken is similar to that reported in [12]. The threshold for high significance was $p < 0.01$.

3. Results

A total of eleven radiotherapy centres carried out each irradiation. At the time of the audits, there were twelve radiotherapy centres in Ireland. Of these twelve, three belong to a single network of Centres and two of these three operate with similar equipment and techniques. Consequently, participation in the audits on an institutional basis can be considered to be 100%.

Ten centres passed the prostate audit on the first irradiation. The centre that did not pass on the first irradiation reported a communication error had occurred that invalidated the aims of the audit. The audit was passed on the second irradiation. Nine centres passed the head and neck audit on the first irradiation. In cases where the audit was not passed on first irradiation, a pass was achieved on the second irradiation. No reasons were provided for not passing the first irradiation. Centres submitted the reports for irradiations that passed the audit criteria.

An anonymised summary of the results obtained for both treatment sites is provided in Figs. 1 and 2 below. Institution number is consistent over the two audits. The scale of the primary Y axis shows the percentage of pixels passing the gamma-index criteria of 7% and 4 mm, with the dashed line showing the minimum acceptable percentage of pixels that must pass (85%). The secondary Y axis shows the ratio of measured to institution reported PTV dose. The minimum and maximum values on the axis have been chosen to reflect the passing criterion for the audit (0.93–1.07). The solid line indicates a measured to reported ratio of 1.00.

Significant differences were observed between gamma analyses for the two treatment sites audited. No other subdivisions yielded significant differences, as shown in Table 1.

Although the distributions of data cohorts are not normal, there remains value in quoting the standard deviation for ratios of measured and reported doses. Gamma index data are not normally distributed either but the uncertainty introduced by using limits based on a 95% confidence interval ($\pm 2\sigma$) is low [12].

It should also be noted that the 7% criterion used by the MDADL for passing is determined using the average PTV TLD dose and is not a local point comparison. Therefore a ratio outside 7% in the "Organs at Risk TLD" row and the "All TLD measurements" row of Table 1 does not imply an audit failure.

4. Discussion

4.1. Lessons

All centres completed both audits and eventually satisfied the phantom irradiation component of the credentialing process to enter patients into certain protocols that allow the use of IMRT. Nevertheless, the results of the audits suggest that some recommendations in the literature should be noted as 'take-home' messages by some participating Centres and may support Centres in other countries prior to participation in similar audits:

(i) The majority of IROC-Houston head and neck phantom irradiation failures are associated with errors in the TPS beam modelling highlighting the importance of close attention to performance of this task by medical physicists [14].
(ii) The benefits of careful commissioning using tools such as AAPM's Task Group Report 119 prior to clinical use and external audit should be considered [13].
(iii) It should be widely understood that algorithms that consider electron transport are required for treatment sites with heterogeneities and a list of appropriate and inappropriate algorithms is available on the website of the MD Anderson Dosimetry Laboratory's overarching organisation – The Imaging and Radiation Oncology Core – Houston (IROC-Houston) [15].
(iv) MDADL's audits are not dependent on the use of fixed gantry angle IMRT. Where VMAT is the technique routinely used in the clinic, it should be used for the audit.

4.2. Audit tolerances and dose calculation

More recently IROC-Houston has been assessing the possibility of tightening the passing criteria for audits using the anthropomorphic head and neck phantom: 5%TLD and 5%/4 mm gamma criteria are being considered as practically and theoretically achievable. The main reason for this is the improved pass rates for the existing audit criteria: when the audit was first offered in 2001, the pass rate was as low as 66% but has improved to better than 90% in recent years. However, when 5%/4 mm are used the failure rate increases to 23% [16]. Based on the results presented in this work, some centres could find meeting revised criteria challenging, on the assumption that the same minimum percentage of pixels passing the gamma index criteria applied (85%). This is of concern, as passing criteria for IROC-Houston audits are relatively loose. Moreover, significant limitations with use of measurement-based methods for institution based IMRT QA, based on current clinical practice, are known to exist and recent work in this area suggests that an independent recalculation can outperform them with respect to sensitivity to failures [17]. A first order step to improving IMRT audit results in Ireland and elsewhere may be to address the weak link of dose calculation. Traditionally the medical physicist acquires linac beam data and models those data for the TPS. However, in general, this is an infrequently performed activity and the best modelling results are likely to be achieved, for a greater number of service providers, through close and careful collaboration between TPS vendor and medical

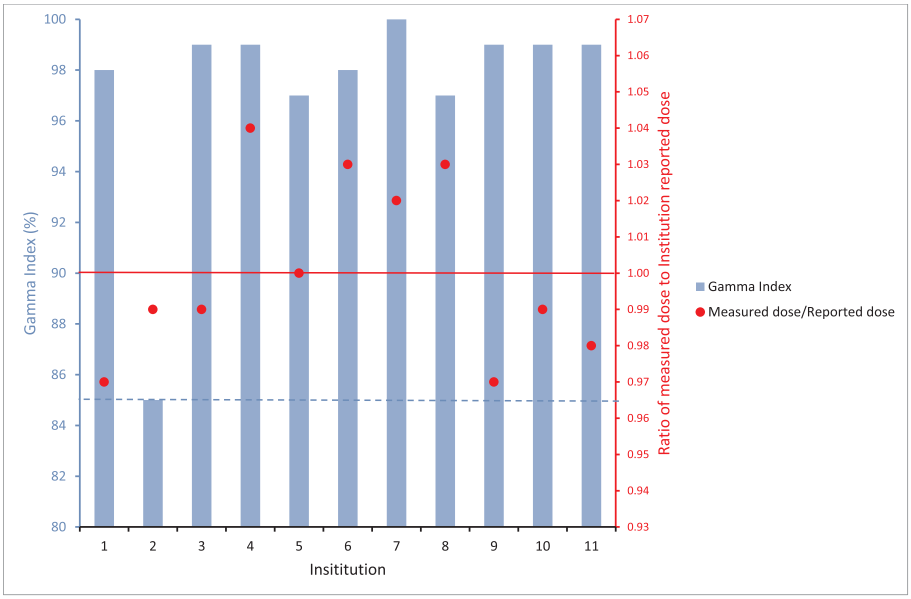

Fig. 1. Values of least favourable gamma index (%) and poorest measured to reported PTV dose ratio across 11 centres carrying out the MD Anderson Dosimetry Lab IMRT prostate phantom irradiation.

physicist. There are signs of tools becoming available that could assist in achieving this outcome [18,19]. Careful implementation of this step may also allow the spread of audit passing criteria reported in the literature to be reduced and help illuminate the way ahead for better institution based IMRT QA.

4.3. Subdivisions of data

Some studies have observed moderately significant differences between some subdivisions [12,20]. For example fixed gantry angle IMRT and VMAT, and single and mixed vendor TPS – delivery systems which suggested that VMAT plans and single vendor systems can achieve better results. In this study, other than for treatment site, subdivisions yielded no significant differences.

4.4. Future audit arrangements

The IROC-Houston phantom based audits are examples of remote audits. There are benefits of on-site audits [12] but these have not been resourced in Ireland. In the UK, cost efficiency of on-site audits has been justified on the basis of past failures to resource its original comprehensive photon intercomparison which discovered one serious calibration error. Moreover, that intercomparison may also have discovered another serious error had the original design aspirations of the audit been supported [21]. In the USA on-site audits have been available for about 50 years which has provided IROC-Houston with a rich database that enables it to provide assistance to institutions in identifying calibration errors [22]. It is difficult to envisage a small country developing a national infrastructure that ensures participation in a comprehensive audit system that responds adequately to continually

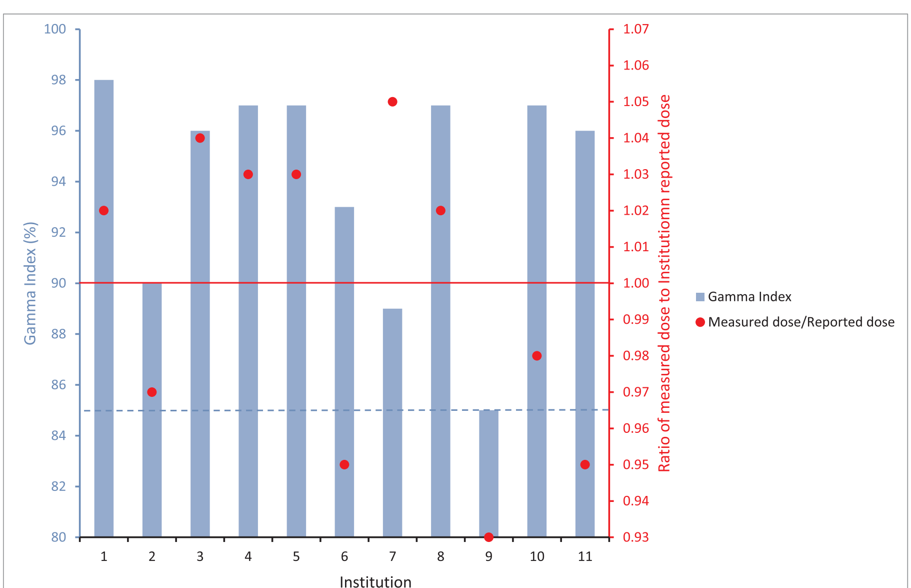

Fig. 2. Values of least favourable gamma index (%) and poorest measured to reported PTV dose ratio across 11 centres carrying out the MD Anderson Dosimetry Lab IMRT head and neck phantom irradiation.

Table 1
Mean ratios of MDADL vs. Institution measured dose and mean gamma pass rates for different radiotherapy delivery combinations. Round brackets show the standard deviation of the dose ratios and also the lower 95% confidence interval (mean – 2σ [13]) for gamma pass rates. Square brackets show the range for the whole cohort. P-values for sub-group comparison are shown below each group.

Category	Total No. of points	Mean MDADL vs. Institution measured dose	Gamma analysis pass rate tolerance 7%/4 mm		
			Mean % of all pixels passing	Mean % of coronal/axial pixels passing	Mean % of sagittal pixels passing
All delivery combinations (PTV)	88	0.999 (0.026) [0.93–1.05]	97 (90) [85–100]	98 (93) [89–100]	97 (88) [85–100]
All TLD measurements	132	0.998 (0.031) [0.95–1.14]	–	–	–
All OAR TLD measurements	44	0.998 (0.039) [0.95–1.14]	–	–	–
By technique (PTV TLD measurements)					
Fixed gantry angle IMRT	54	0.999 (0.025) [0.93–1.04]	97 (89) [85–100]	98 (94) [93–100]	96 (86) [85–100]
VMAT	34	0.997 (0.028) [0.95–1.05]	97 (91) [89–98]	97 (90) [89–100]	97 (93) [93–100]
p value		*0.73*	*0.27*	*0.57*	*0.40*
By TPS-linac (PTV TLD measurements)					
ECLIPSE-Varian	40	1.002 (0.029) [0.93–1.05]	97 (89) [85–100]	97 (90) [89–100]	97 (88) [85–100]
Other*	48	0.996 (0.023) [0.95–1.04]	97 (90) [85–100]	98	96 (87) [85–100]
p value		*0.13*	*0.36*	*0.21*	*0.92*
By treatment site (PTV TLD measurements)					
Prostate	22	1.001 (0.020) [0.97–1.03}	98 (92) [85–100]	99 (96) [97–100]	98 (89) [85–100]
Head & Neck	66	0.998 (0.028) [0.93–1.05]	96 (89) [85–99]	96 (90) [89–99]	95 (87) [85–99]
p value		*0.85*	*0.00002*	*0.002*	*0.003*
By Public/Private (PTV TLD measurements)					
Public	32	0.997 (0.022) [0.95–1.03]	97 (89) [85–100]	98 (97) [97–100]	95 (85) [85–100]
Private	56	0.999 (0.028) [0.93–1.05]	97 (91) [85–100]	97 (91) [89–100]	97 (90) [85–100]
p value		*0.52*	*0.44*	*0.45*	*0.27*

*Pinnacle-Elekta (2), Monaco-Elekta (2), OMP-Elekta (1), OMP-Siemens (1), ECLIPSE-Siemens (1), CMS XiO-Elekta (1).

advancing radiotherapy technology without considerable investment. However summary guidance on the resources required to develop a Dosimetry Audit Centre is available [23]. A simpler mechanism, not without costs itself, would be to engage more formally with an audit institution established at a European, other international, or global level.

5. Conclusion

An audit programme delivering some functions that would be expected of a formal Dosimetry Audit Network was performed in Ireland in 2014 and 2017 and all participants were able to pass the audits. On the basis of existing results, some centres could find passing the audits challenging if IROC-Houston issue revised, tighter passing criteria. As a result of hard lessons, dosimetry audit has become a well organised and funded practice in some developed countries. Also, as radiotherapy treatments have become more complex, the need for audit systems that test these treatments has grown and efforts to extend the capability of audit techniques continues. Moreover, it is essential to understand that measurement audit should not exist in isolation but should be part of a wider set of comprehensive audit of facility and systems performance. With the relatively large number of advanced radiotherapy centres in Ireland, careful thought should be given to the resourcing of and strategy for comprehensive audit. Under new legislation [24], the responsibility for considering these issues has now transferred primarily to the Health Information and Quality Authority (HIQA).

Acknowledgements

The NRSC would like to thank the institutions that participated in the audits: Beacon Hospital, Dublin; Cork University Hospital, Cork; Galway Private Clinic, Galway; Hermitage Medical Clinic, Dublin; Mater Private Hospital, Dublin; St. Luke's Radiation Oncology Network, Dublin; St. Vincent's Private Hospital, Dublin; University Hospital Galway, Galway; University Hospital Limerick, Limerick; UPMC Hillman Cancer Centre, Waterford.

References

[1] Statutory Instrument No. 478 (2002), European Communities (Medical Ionising Radiation Protection) Regulations (2002), Dublin.
[2] European Commission. Radiation Protection 159. European Commission Guidelines on Clinical Audit for Medical Radiological Practices (Diagnostic Radiology, Nuclear Medicine and Radiotherapy), EC (2009).
[3] Health Service Executive and Faculty of Radiologists, Royal College of Surgeons in Ireland. Requirements for Clinical Audit in Medical Radiological Practices (Diagnostic Radiology, Radiotherapy and Nuclear Medicine), HSE & FR RCSI (2011).
[4] Svensson H, Hanson GP, Zsdénszky K. The IAEA/WHO TL dosimetry service for radiotherapy centres 1969–87. Acta Oncol 1990;29:461–7. https://doi.org/10.3109/02841869009090030.
[5] Thwaites DI, Williams JR, Aird EG, Klevenhagen SC, Williams PC. A dosimetric intercomparison of megavoltage photon beams in UK radiotherapy centres. Phys Med Biol 1992;37:445–61. https://doi.org/10.1088/0031-9155/37/2/011.
[6] Nisbet A, Thwaites DI, Sheridan ME. A dosimetric intercomparison of kilovoltage X-rays, megavoltage photons and megavoltage electrons in the Republic of Ireland. Radiother Oncol 1998;48:95–101. https://doi.org/10.1016/S0167-8140(98)00041-3.
[7] North/South Ministerial Council. Annual Report 2002. Joint Secretariat, Armagh available at https://www.northsouthministerialcouncil.org/publications/annual-report-2002 Last accessed 18th July 2019.
[8] Thwaites et al The UK radiotherapy dosimetry audit network. IAEA Proceedings Series. Standards and codes of practice in medical radiation dosimetry. IAEA-CN-96/81 (ISSN 0074 1884) Vol 2 183-190; 2003.
[9] Awunor O, Berger D, Kirisits C. A multicenter study to quantify systematic variations and associated uncertainties in source positioning with commonly used HDR afterloaders and ring applicators for the treatment of cervical carcinomas. Med Phys 2015;42(8). https://doi.org/10.1118/1.4923173.
[10] Guidelines for planning and treating the RPC IMRT prostate phantom, The Imaging and Radiation Oncology Core, available at: http://rpc.mdanderson.org/rpc/Services/Anthropomorphic_%20Phantoms/files/Instructions%20Prostate%20phantom_revised%20June%202013.pdf 2013 Last accessed 18th May 2019.
[11] Guidelines for planning and treating the RPC IMRT head and neck phantom The Imaging and Radiation Oncology Core, available at: http://rpc.mdanderson.org/rpc/Services/Anthropomorphic_%20Phantoms/files/Instruction%20head%20and%20neck%20phantom_8%20IROC%202-2014.pdf 2014 Last accessed 18th May 2019.
[12] Eaton DJ, Tyler J, Backshall A, et al. An external dosimetry audit programme to credential static and rotational IMRT delivery for clinical trials quality assurance. Phys Med 2017;35:25–30. https://doi.org/10.1016/j.ejmp.2017.02.012.
[13] Ezzell GA, Burmeister JW, Dogan N, LoSasso TJ, Mechalakos JG, Mihailidis D, et al. IMRT commissioning: multiple institution planning and dosimetry comparisons. Med Phys 2009. https://doi.org/10.1118/1.3238104.
[14] Kerns JR, Stingo F, Followill D, et al. Treatment planning system calculation errors are present in most Imaging and Radiation Oncology Core-Houston phantom

failures. Int J Radiat Oncol Biol Phys 2017;98(5):1197–203. https://doi.org/10.1016/j.ijrobp.2017.03.049.
[15] Heterogeneities: Approved algorithms IROC Announcements available at: http://rpc.mdanderson.org/rpc/Services/Anthropomorphic_%20Phantoms/TPS%20-%20algorithm%20list%20updated.pdf Last accessed 18th May 2019.
[16] Carson ME, Molineu A, Taylor PA, Followil DS, Stingo FC, Kry SF. Examining credentialing criteria and poor performance indicators for IROC Houston's anthropomorphic head and neck phantom. Med Phys 2016;43(12):6491–6. https://doi.org/10.1118/1.4967344.
[17] Kry SF, Glenn MC, Peterson CB, et al. Independent recalculation outperforms traditional measurement-based IMRT QA methods in detecting unacceptable plans. Med Phys 2019. https://doi.org/10.1002/mp.13638.
[18] Narayanasamy G, Saenz DL, Defoor D, Papanikolaou N, Stathakis S. Dosimetric validation of Monaco treatment planning system on an Elekta VersaHD linear accelerator. J Appl Clin Med Phys 2017;18:123–9. https://doi.org/10.1002/acm2.12188.
[19] Texas Center's linacs ready to treat in record time, Elekta's on-line magazine, Focus, available at https://focus.elekta.com/2018/09/texas-centers-linacs-up-and-ready-to-treat-patients-in-record-time/2018 Last accessed 24th July 2019.
[20] Clark CH, Hussein M, Tsang Y, Thomas R, Wilkinson D, Bass G, et al. A multi-–institutional dosimetry audit of rotational intensity–modulated radiotherapy. Radiother Oncol 2014;113:272–8. https://doi.org/10.1016/j.radonc.2014.11.015.
[21] Clark CH, Aird EGA, Bolton S, Miles EA, Nisbet A, Snaith JAD, et al. Radiotherapy dosimetry audit: three decades of improving standards and accuracy in UK clinical practice and trials. Br J Radiol 2015;88:20150251. https://doi.org/10.1259/bjr.20150251.
[22] Ibbott GS, Thwaites DI. Audits for advanced treatment dosimetry. J Phys Conf Ser 2015;573. https://doi.org/10.1088/1742-6596/573/1/012002.
[23] Izewska J. Setting up a dosimetry audit centre: Infrastructure and resources. SSDL Newsletter No.66 June 2017, 9-18. Available at: https://www-pub.iaea.org/MTCD/Publications/PDF/Newsletters/SSDL-66.pdf Last accessed 24th July 2019.
[24] Statutory Instrument No. 256 (2018), European Union (Basic safety standards for protection against dangers arising from medical exposure to ionising radiation) Regulations (2018), Dublin.