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ORIGINAL ARTICLE

An IAEA survey of radiotherapy practice including quality assurance extent and depth

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ABSTRACT

Background: The IAEA recommends a quality assurance program in radiotherapy to ensure safe and effective treatments. In this study, radiotherapy departments were surveyed on their current practice including the extent and depth of quality assurance activities.

Methods: Radiotherapy departments were voluntarily surveyed in three stages, firstly, in basic facility information, secondly, in quality assurance activities and treatment techniques, and thirdly, in a snapshot of quality assurance, departmental and treatment activities.

Results: The IAEA received completed surveys from 381 radiotherapy departments throughout the world with 100 radiotherapy departments completing all three surveys. Dominant patterns were found in linac-based radiotherapy with access to treatment planning systems for 3D-CRT and 3D imaging. Staffing levels for major staff groups were on average in the range recommended by the IAEA. The modal patient workload per EBRT unit was as expected in the range of 21–30 patients per day, however significant instances of high workload (more than 50 patients per day per treatment unit) were reported. Staffing levels were found to correlate with amount of treatment equipment and patient workload. In a self-assessment of quality assurance performance, most radiotherapy departments reported that they would perform at least 60% of the quality assurance activities itemized in the second survey, with particular strength in equipment quality control. In a snapshot survey of quality assurance performance, again equipment quality control practice was well developed, particularly for the treatment equipment.

Conclusions: The IAEA surveys provide a snapshot of current radiotherapy practice including quality assurance activities.

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Introduction

The International Atomic Energy Agency (IAEA) has consistently stressed the importance of quality assurance activities in radiotherapy for safe and effective patient treatment through numerous publications [1–3] and this emphasis is supported by national and regional professional societies such as the American Society for Radiation Oncology (ASTRO), the European Society for Radiotherapy and Oncology (ESTRO) and the American Association of Physicists in Medicine (AAPM). Most recently, an IAEA publication on accuracy and uncertainty in radiotherapy recommended the implementation of a comprehensive quality assurance (QA) program [4] for managing accuracy and uncertainty in the clinic and resources such as IPEM Report 81 [5] provide guidance on implementation of quality assurance.

Operating a quality assurance program involves staff time and resources and management commitment. Quality assurance is defined as that part of quality management related to providing confidence that quality requirements will be met [6] while quality assurance in radiotherapy has been defined as all procedures that ensure the dose prescription is met in terms of target dose and minimum dose to organs at risk [7]. Quality control (QC), as a part of overall quality assurance, is the process of measuring performance, comparing with standards and maintaining performance [7]. Quality assurance in radiotherapy is not just limited to routine checking of the performance of equipment but involves a range of additional activities (often multi-disciplinary) related to the department, patient and equipment, such as incident reporting, patient-specific dosimetry measurements, and new

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patient planning meetings. Recent surveys of linear accelerator quality control in the UK [8] and medical physics practice [9] focus on the role of the medical physicist. The aim of this work was to survey the extent and depth of quality assurance activities in radiotherapy departments, including multi-disciplinary activities, around the world.

This work also presents the results of surveys of various factors which may influence quality assurance effort such as staffing levels, patient workload, amount of equipment and complexity of treatment techniques.

Material and methods

The surveys on practice and quality assurance in radiotherapy were designed in a series of three voluntary surveys. The 1st survey was the simplest, with respondents asked to provide basic facility details including staffing levels, amount and type of radiotherapy equipment, and types of services offered. The respondents were asked at the end of the survey if they wished to participate in a more detailed survey on quality assurance. If they answered yes only then were they sent the subsequent survey. The 2nd survey concentrated on quality assurance activities at a general level with the respondent expected to self-assess as to whether particular quality assurance activities were conducted at their department. The 2nd survey also focused on clinical techniques with respondents asked to provide details of external beam treatment techniques for four clinical scenarios: two different head and neck cases, a breast case and a palliative case. In the 3rd survey, the respondents were expected to provide a snapshot of activities in the department in a period of a month and in a single working day within that month with emphasis on external beam radiotherapy. The activities covered quality assurance and patient treatment. For the 3rd survey, the month and day of the survey was chosen by the IAEA officer collating the survey, not by the department themselves, in order to prevent potential data bias. Also, the date was set in the recent past so as to not allow the department to modify their work procedures based on the survey questions. For distribution of the 1st survey, the survey form was sent to by the IAEA to medical physics counterparts in countries throughout the world with a request to distribute the 1st survey within their country. The surveys were designed as a set of three surveys rather than one comprehensive survey to encourage responses. It was considered that radiotherapy departments would be more likely to complete three shorter sequential surveys rather than one large survey and even if the department did not proceed to the 2nd survey or 3rd survey the information obtained would still be useful.

A number of parameters pertinent to the radiotherapy process were able to be extracted from the surveys including staffing levels (1st survey), patient workload (3rd survey), amount of equipment (1st and 3rd surveys), quality assurance activities (2nd and 3rd surveys) and complexity of treatment techniques offered (all surveys). Correlations between various parameters were tested with the Pearson correlation coefficient and a *t*-test for significance of the correlation at the 1% level.

Table 1. Regional and country income distribution of returned surveys.

Number of returned surveys	1st survey 381	2nd survey 179	3rd survey 100
Regional distribution			
Asia/Pacific	46.4%	49.2%	55.0%
Europe	32.3%	29.6%	26.0%
N America	9.2%	9.5%	8.0%
L America	6.3%	5.0%	6.0%
Africa	5.8%	6.7%	5.0%
Country income group			
Low	1.1%	0.6%	0.0%
Low middle	29.9%	30.7%	34.0%
Upper middle	29.9%	33.5%	37.0%
High	39.1%	35.2%	29.0%

Results

The three surveys were distributed over 2014–2017. Given the sequential nature of the surveys, the respondents to the 2nd survey are a subset of the respondents to the 1st survey and the respondents to the 3rd survey are in turn a subset of the respondents to the 2nd survey. Table 1 shows the number of surveys collected, the distribution among geographical regions and the country income group based on World Bank classification in 2017. 456 completed surveys were received by the IAEA in 2014, 180 completed surveys were received in 2015, while 24 completed surveys were received over 2016–2017. Given that there are more than 7,000 radiotherapy departments worldwide according to the IAEA database of radiotherapy equipment DIRAC [10], the 381 departments who responded to the first survey represent approximately 5% of worldwide radiotherapy departments.

Staffing levels

Departments were surveyed for number of radiation oncologists (RO), medical physicists (MP), radiation therapists (RTT) and dosimetrists (DM). The 1st survey made no distinction between training positions and qualified positions; however, departments were asked about any academic affiliation and any training programs for medical physicists. The 1st survey found 10,501 full-time-equivalent (FTE) staffing positions over 381 departments with 53% RTTs, 26% ROs, 17% MPs and 4% DMs. Not surprisingly, staffing levels correlated strongly with amount of equipment (p values less than .001). There were on average 1.2 MPs per treatment unit, 1.8 ROs per treatment unit and 3.4 RTTs per treatment unit, where both EBRT and brachytherapy units are included in the definition of treatment unit. Of the 381 departments, only 35% employed dosimetrists, and at those departments there were on average 0.7 DMs per treatment unit and 1.1 MPs per treatment unit, while for those departments without DMs there were on average 1.3 MPs per treatment unit.

Departments that indicated they had an academic affiliation had a higher average number of staff per treatment

Table 2. Results from the surveys of radiotherapy departments.

Ortho/Super	Co-60 Tele	Linac	Stereo-tactic unit	Tomo-therapy	HDR BT	LDR BT
Total number of treatment units (1st survey)						
100	130	860	51	44	274	91
Percentage of departments with treatment unit (1st survey)						
24%	26%	93%	10%	9%	66%	24%

Percentage of departments with availability of imaging modality (1st survey)						
Conv Sim	Access to CT	Dept with CT	Access to MRI	Dept with MRI	Access to PET/CT	Dept with PET/CT
45%	98%	70%	75%	7%	56%	5%

Percentage of departments with treatment planning system capability (1st survey)				
2D	3D-CRT	IMRT	Brachytherapy	None
73%	96%	79%	69%	1%

Percentage of departments with clinical service (1st survey)					
1D	2D	3D-CRT	IMRT	IGRT	SRS/SRT
62%	78%	93%	72%	59%	37%

Percentage of patients treated with technique – all patients (3rd survey)				
1D	2D	2.5D	3D-CRT	IMRT
3%	19%	6%	49%	23%

Percentage of patients treated with technique - 10 selected patients (3rd survey)				
1D	2D	2.5D	3D-CRT	IMRT
5%	15%	7%	47%	26%

Percentage of departments performing at least one element of QC in a month (3rd survey)							
Ortho/Super	Co-60 Tele	Linac	Conv Sim	CT Sim	R&V	Dosim Equip	Patient Aids
100%	100%	100%	100%	91%	78%	61%	45%

unit that was statistically significant (7.1 staff FTE/treatment unit with academic affiliation compared to 5.9 staff FTE/treatment unit without).

Treatment equipment

External-beam radiotherapy (EBRT) treatment equipment recorded in the 1st survey was dominated by medical linear accelerators (linacs) with 73% of all EBRT treatment units being linacs (see Table 2) and 93% of departments having at least one linac. However, other technology such as Cobalt-60 teletherapy and orthovoltage x-ray therapy is also utilized. Specialized linacs such as dedicated stereotactic units and Tomotherapy units were less widespread. Two thirds of departments offered high dose rate brachytherapy, while low dose rate brachytherapy, which would encompass different sealed radioactive sources such as Cs-137, I-125 and Sr-90, was less prevalent. The ratio of linacs to Cobalt-60 teletherapy units is 6.6 to 1 and this value is very similar to the 6.0 to 1 ratio found in the IAEA DIRAC database [10].

Imaging equipment

Imaging for treatment planning was dominated by CT, with 98% of departments either having a dedicated CT simulator in the department or having access to a CT scanner for simulation. Conventional simulators were available in 45% of departments. Access to MRI and PET-CT imaging was not as prevalent as CT as shown in Table 2. Treatment room image guidance was surveyed through asking whether Image-Guided Radiotherapy (IGRT) was offered as a service and 59% of departments responded positively (see Table 2).

Treatment planning and network

Treatment planning system capability for 3D conformal radiotherapy (3D-CRT) was widespread as shown in Table 2 but so also was inverse planning capability for IMRT in 79% of departments from the 1st survey. Only four departments did not have computerized treatment planning, and these were all departments that only operated Cobalt-60 teletherapy units. Networking in the form a record and verify system was also prevalent with 89% of departments reporting this capability in the 1st survey.

Patient workload

In the 3rd survey, respondents were asked to provide the number of patients treated with EBRT on the selected day and the number of EBRT units used to treat those patients. A typical value of number of patients treated on an EBRT unit in a day is 32, given an average of 15 min per patient [11]

and an 8-hour shift. The most common number of patients treated per EBRT unit was in fact in the range from 21 to 30 patients per day (26 out of 100 departments) with next highest being 31 to 40 patients per day (20 departments). Underutilization was not common with only 8 departments reporting 20 patients, or fewer, treated per EBRT unit. More common was heavy utilization with 20 departments treating 51 to 70 patients per day per EBRT unit and 11 departments treating more than 70 patients per day per EBRT unit. In all cases the higher workload was achieved with more than one shift or a single shift longer than 8 h.

For those departments that completed all three surveys, total patient workload from the 3rd survey correlated significantly with total staffing levels ($r = 0.760$) and medical physics staffing ($r = 0.730$) from the 1st survey.

Treatment techniques

The 1st survey recorded the clinical services offered by each department with 93% of departments offering 3D-CRT, 72% of departments offering intensity modulated radiotherapy (IMRT) and 37% of departments offering an SRS/SRT service, as shown in Table 2.

The 2nd survey recorded treatment techniques for four clinical scenarios: two different head and neck cases, namely oropharynx and nasopharynx, a breast case and a palliative bone metastasis case. The details of treatment technique, modality and setup verification selected by departments are presented in Table 3. For the two head and neck cases, IMRT was the most commonly selected treatment technique, while for the breast case 3D-CRT was most common (65%). For the bone metastasis case, 2D and 3D-CRT were commonly selected. Megavoltage photon beams was the most common modality for all four cases, and 40% of departments used a photon/electron beam combination for the breast case. The EPID was widely selected for setup verification. For the head and neck cases, kV CBCT imaging was selected in up to 35% of departments. Imaging frequency was most commonly selected as 'weekly' for the head and neck and breast cases, while 'first setup only' was most commonly selected for the bone metastasis case. *In vivo* dosimetry was selected in less than 10% of departments.

The 3rd survey recorded treatment techniques for all patients treated with EBRT on a selected day. Almost half of all patients (49%) were treated with 3D-CRT with the next most frequent being the IMRT technique at 23% as shown in Table 2. Respondents were asked to randomly select 10 patients that were treated on the selected day and provide further information as to their treatment. Again, in this cohort of patients, the types of treatment were similarly spread, 47% were treated with 3D-CRT and 26% with IMRT. It is interesting to note the prevalence of IMRT in that in the 1st survey 79% of departments have IMRT treatment planning capability and 72% have IMRT in clinical use. In the 2nd survey, 63% of departments indicated they would use IMRT for a head and neck case and 13% for a breast case, and in

Table 3. Results from the 2nd survey on treatment techniques for four clinical scenarios.

	Percentage of respondents ($n = 179$)					
	Treatment technique					
Clinical scenario	Clinical Setup	2D	2.5D	3D	IMRT	No answer
Oropharynx	1%	7%	3%	29%	60%	0%
Nasopharynx	1%	7%	1%	26%	63%	2%
Breast	2%	9%	10%	65%	13%	1%
Bone mets	5%	42%	9%	40%	1%	3%
	Modality					
	MV ph	MV ph + e	MV ph + BT	MV ph + e + BT	Ortho	No answer
Oropharynx	85%	12%	1%	0%	0%	2%
Nasopharynx	83%	11%	1%	1%	0%	4%
Breast	58%	40%	1%	0%	0%	1%
Bone mets	96%	–	–	–	2%	2%
	Setup verification					
	Geo-metric	Film	EPID	kV planar	kV CBCT	MV CBCT
Oropharynx	18%	15%	48%	24%	33%	10%
Nasopharynx	17%	15%	49%	24%	35%	11%
Breast	21%	17%	64%	24%	12%	2%
Bone mets	21%	19%	53%	23%	8%	1%
	Imaging frequency					
	First setup only	Daily	Weekly	First setup and halfway	Only on request	No answer
Oropharynx	7%	29%	46%	13%	4%	1%
Nasopharynx	6%	28%	49%	14%	2%	1%
Breast	18%	16%	43%	14%	5%	4%
Bone mets	40%	11%	26%	6%	9%	8%
	In vivo dosimetry					
	Yes	No	No answer			
Oropharynx	8%	91%	1%			
Nasopharynx	8%	91%	1%			
Breast	7%	90%	3%			
Bone mets	6%	90%	4%			

ph: photon; e: electron; BT: brachytherapy; ortho: orthovoltage x-ray.

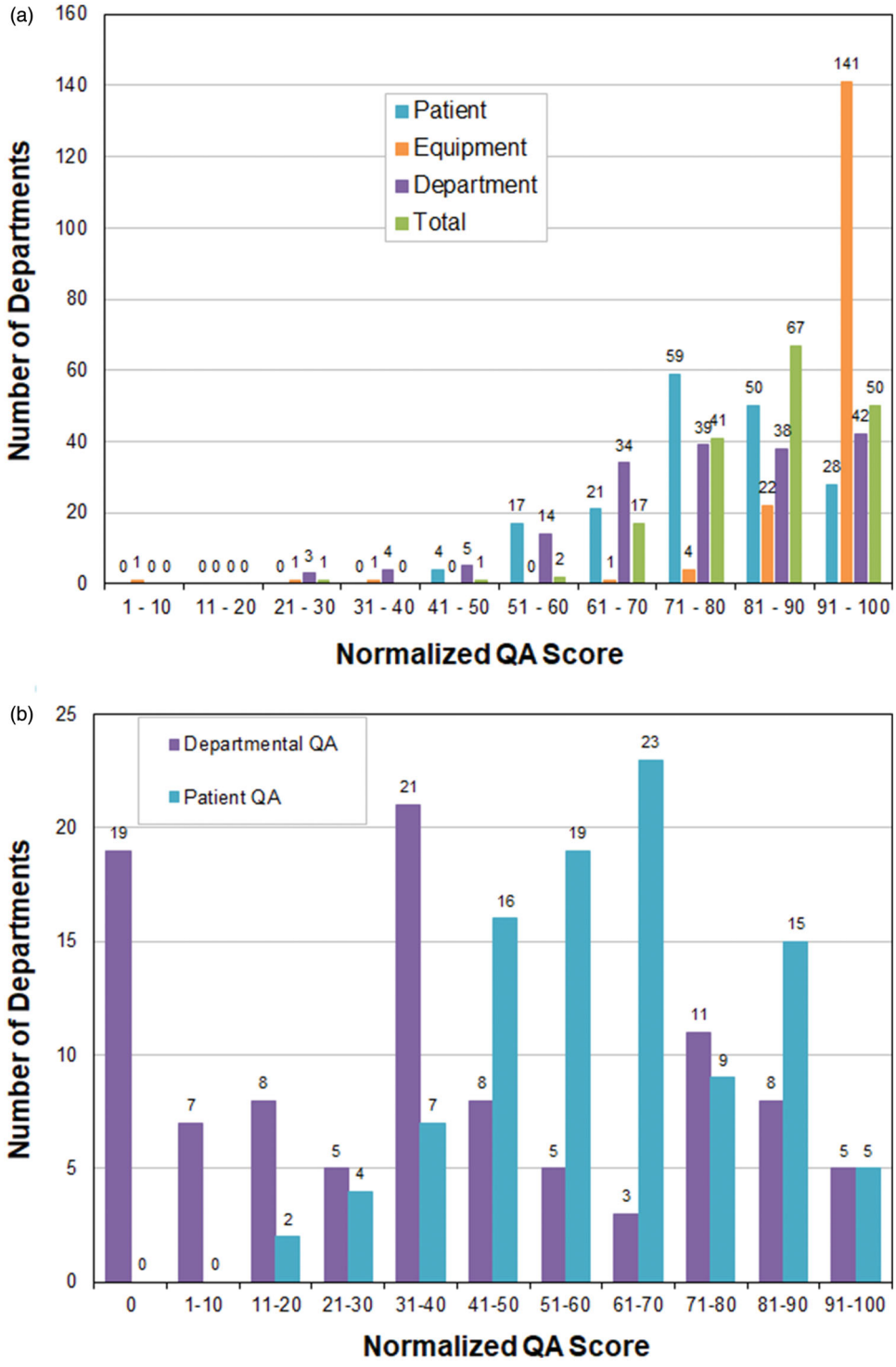

Figure 1. Normalized QA scores based on (a) responses to 34 questions from the 2nd survey and (b) responses to 33 questions from the 3rd survey indicating performance of the specific QA test in the designated month.

the 3rd survey, 23% of all patients across all departments were treated with IMRT.

Quality assurance extent and depth

The 2nd survey asked a series of yes/no questions on various aspects of quality assurance covering department, patient and equipment quality activities. This is essentially a self-assessment on the extent of quality assurance activities in each radiotherapy department. A QA score was created by equally weighting the answers to the 34 questions including 14 questions on departmental QA, 3 questions on equipment QC and 17 questions on patient treatment QC. 175 out of 179 departments indicated that they performed more than 60% of the QA activities included in the survey, as shown in Figure 1(a). 163 out of 179 departments indicated that they performed more than 80% of the equipment QC activities

including acceptance testing, commissioning and quality control baseline tests. There was a greater variation in scores among departments for departmental QA and patient QC as also shown in Figure 1(a).

The 3rd snapshot survey of quality assurance performance in a selected month was an opportunity to confirm the self-assessment of quality assurance activities reported in the 2nd survey. It was found that the departmental QA and patient QC scores reported in the 2nd survey correlated significantly with those from the 3rd survey with Pearson correlation coefficients 0.513 and 0.467 respectively. However, there were instances of low scores for departmental QA activities in the 3rd survey as shown in Figure 1(b).

Equipment QC effort was also found from the 3rd survey. The departments were asked if they performed a number of QC tests in a selected month or a selected day within that month for treatment equipment, imaging equipment and ancillary equipment. The QC tests in the 3rd survey were taken from those listed as recommended daily, weekly or monthly by the IAEA [1], AAPM TG 142 [12] and AAPM TG 66 [13]. For example, 16 different QC tests were listed in the 3rd survey for a Cobalt-60 teletherapy unit. Of the 17 departments that had at least one Cobalt-60 teletherapy unit, the median number of tests performed on the selected day was 5 out 16 QC tests, and the median number of tests performed during the selected month or selected day was 15 out of 16 QC tests. Parameters for the number of QC tests performed, including minimum, maximum, median, average and sample standard deviation for the radiotherapy departments surveyed, are shown in Table 4 for various types of equipment. The data for the linear accelerator is complicated by the fact that there are optional items such as MLC, imaging panels and electron beams. In this case, a percentage of the total number of QC tests expected based on the equipment configuration is presented in Table 4. Median and average number of QC tests performed in the month were close to the total number of QC tests in the 3rd survey for each type of equipment. For example, for the orthovoltage unit, the mean number of tests performed with the selected month, or on the selected day within that month, was 9.0, the average was 8.0 and total number of QC tests in the survey was 10. Of interest is the lower median score for the conventional simulator QC tests, where the median score was 12 out of 17 QC tests performed in the selected month or selected day. In this case, the median score was affected by low scores for image quality tests and radiography/fluoroscopy system tests.

A large number of departments (61 out of 100) reported performing dosimetry equipment QC in the selected day or month including any of cross-calibration, check source readings and linearity/leakage/recombination checks. QC of patient aids was indicated in the selected month or selected day in 45 out of 100 departments, while 67 out of 86 departments indicated performing QC on the record and verify system in the selected month or selected day. Some gaps in QC performance were found for the CT simulator, the record and verify system and patient aids in that not all departments performed QC tests on these items within the selected month (Table 2).

Table 4. Number of QC tests performed in a selected month or selected day within that month for treatment, imaging and ancillary equipment.

	Number of QC tests performed		
Parameter	Selected day	Selected month	Selected day or selected month
	Orthovoltage unit (12 departments, total of 10 QC tests)		
Minimum count	0	0	4
Maximum count	6	10	10
Median	3.5	4.0	9.0
Average	2.75	5.25	8.0
Std dev.	2.4	3.3	2.4
	Cobalt-60 teletherapy (17 departments, total of 16 QC tests)		
Minimum count	0	0	4
Maximum count	14	15	16
Median	5.0	6.0	15.0
Average	5.8	6.8	12.6
Std dev.	4.2	4.3	4.4
	Conventional simulator (45 Departments, total of 17 QC tests)		
Minimum count	0	0	2
Maximum count	17	17	17
Median	3.0	7.0	12.0
Average	4.2	6.8	11.0
Std dev.	4.0	5.5	5.0
	CT simulator (89 departments, total of 5 QC tests)		
Minimum count	0	0	0
Maximum count	5	5	5
Median	1.0	2.0	4.0
Average	1.3	2.2	3.5
Std dev.	1.4	1.7	1.7
	Linear accelerator (98 departments, up to 24 QC tests)		
Minimum count	0%	0%	30%
Maximum count	100%	96%	100%
Median	41%	49%	90%
Average	38%	47%	85%
Std dev.	22%	23%	16%

As part of departmental quality assurance, the 2nd survey included questions about audits. 41% of departments indicated that they perform internal audits, 39% indicated that they participate in comprehensive external audits and 85% had participated in dosimetry audits within the last two years. In the snapshot 3rd survey, 35% of departments indicated that they had performed an internal audit in the selected month and 24% had participated in a dosimetry audit in the selected month.

Discussion

The staffing levels found in the 1st survey can be compared with IAEA recommendations [11] from an activity-based algorithm. In the worked examples in that publication are calculated staffing levels from standard to advanced departments. The number of ROs per treatment unit was from 1.3 to 1.8, the number of MPs (including DMs) per treatment unit was from 1.1 to 3.0, and the number of RTTs per treatment unit was from 2.2 to 4.9. It is noted that the average number of MPs from the 1st survey of 1.2 per treatment unit is at the low end of the recommended range, while the numbers of RTTs and ROs are commensurate with the IAEA calculations.

The prevalence or IMRT has been noted already, however of note were 59 radiotherapy departments who offered IMRT without IGRT. Given the need for reproducible and accurate patient positioning for intensity modulated radiotherapy delivery, it is expected that IMRT would only be delivered with the support of IGRT [14]. Similarly, 10 radiotherapy departments indicated that they offered stereotactic radiosurgery/stereotactic radiotherapy (SRS/SRT) without also offering IGRT, however in these cases invasive frame based SRS is likely used without the need for IGRT.

The surveys aimed to elucidate levels of quality assurance activity in radiotherapy practice. The surveys indicated mostly high levels of quality assurance performance from the respondents, particularly in the area of equipment QC, both by self-assessment (Figure 1(a)) and through a snapshot of performance (Figure 1(b) and Table 3). Whether these survey results represent worldwide application of QA recommendations is unclear given the suspected bias in that those departments performing higher levels of QA were probably more likely to respond to the survey. However, it is inferred that the consistent message from the IAEA and relevant professional societies of the need for quality assurance in radiotherapy for patient safety as well as quality of patient treatment is being heeded.

Some of the findings of these surveys can be compared with a recent medical physics practice survey by Kisling et al. [9]. The survey investigated the practice of medical physicists and dosimetrists. One interesting finding was the use of in-vivo dosimetry by 47% of departments [9] and 50% of departments (IAEA, 2nd survey, patient QC). Dosimetry system constancy checks were found to be performed monthly in 19% of departments [9] and 27% of departments (IAEA) while Kisling et al. [9] found 72% of departments do these tests annually or at 6-month intervals. Patient workload was similar in that the modal workload was in the range of 21–30 patients per day per treatment unit but there was greater level of high patient workload (31% of departments with more than 50 patients/day) in the current survey compared to 8% more than 40 patients/day in [9].

It is noted that the survey forms themselves have some limitations which could be addressed in any future surveys. The surveys did not distinguish between staff in training and fully qualified staff, nor were vacant staffing positions surveyed. The term 'image guided radiotherapy' was not defined in the surveys and its definition is open to interpretation. The survey forms did not consider VMAT separately from IMRT, it was assumed that VMAT practice was included in responses to questions regarding IMRT. The 2nd and 3rd surveys concentrated on treatment techniques and quality assurance in external beam radiotherapy rather than brachytherapy. The surveys of quality control tests did not allow the possibility for the respondent to choose quarterly or annually for any of the QC tests. Given that some departments will likely have decided on for quarterly or annual frequency of some tests, and annual equipment QC tests recommended by the IAEA and AAPM were not included in the 3rd survey, then these surveys will likely not capture all of the QA activities being performed within a year. QC tests for motion management equipment was not included in the list for the linear accelerator or CT simulator. Finally, the surveys did not include any questions on the possible use of risk assessment [15] or failure modes and effects analysis [16] for devising the local QA program.

The survey forms themselves provide an excellent audit tool for radiotherapy departments in examining the strength of their quality assurance program in the broad areas related to the department, equipment and the patient, and this audit tool is consistent with the IAEA QUATRO audit process [2].

The survey results presented here stand alone as an interesting snapshot of recent worldwide radiotherapy practice. For selected radiotherapy departments, the IAEA's coordinated research project E24017 followed up the surveys with end-to-end dosimetry tests. This was intended to link the quality assurance assessment of the surveys with performance in simulated radiation therapy practice. The results of the end-to-end tests will be presented in a future publication.

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Disclosure statement

No potential conflict of interest was reported by the authors.

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