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FULL PAPER

Current status of kilovoltage (kV) radiotherapy in the UK: installed equipment, clinical workload, physics quality control and radiation dosimetry

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Objective: To assess the status and practice of kilovoltage (kV) radiotherapy in the UK.

Methods: 96% of the radiotherapy centres in the UK responded to a comprehensive survey. An analysis of the installed equipment base, patient numbers, clinical treatment sites, quality control (QC) testing and radiation dosimetry processes were undertaken.

Results: 73% of UK centres have at least one kV treatment unit, with 58 units installed across the UK. Although 35% of units are over 10 years old, 39% units have been installed in the last 5 years. Approximately 6000 patients are treated with kV units in the UK each year, the most common site (44%) being basal cell carcinoma. A benchmark of QC practice in the UK is presented, against which individual centres can compare their procedures, frequency of testing and acceptable tolerance values. We propose the use of internal "notification" and

"suspension" levels for analysis. All surveyed centres were using recommended Codes of Practice for kV dosimetry in the UK; approximately the same number using in-air and in-water methodologies for medium energy, with two-thirds of all centres citing "clinical relevance" as the reason for choice of code. 64% of centres had hosted an external dosimetry audit within the last 3 years, with only one centre never being independently audited. The majority of centres use locally measured applicator factors and published backscatter factors for treatments. Monitor unit calculations are performed using software in only 36% of centres.

Conclusion: A comprehensive review of current kV practice in the UK is presented.

Advances in knowledge: Data and discussion on contemporary kV radiotherapy in the UK, with a particular focus on physics aspects.

INTRODUCTION

Kilovoltage (kV) X-rays were the first modality of radiotherapy, used within a year of their discovery 120 years ago.¹ Superficial (approximately 50–150 kV) and orthovoltage (approximately 150–300 V) units have since become an established section of clinical departments and are recommended by the International Atomic Energy Agency (IAEA) for inclusion in even a basic clinic [alongside megavoltage (MV) teletherapy and high dose rate (HDR) units].² More recently, electronic brachytherapy devices have been developed, which are miniature kV X-ray sources that mimic traditional radioactive sources.³ The 2014 survey of clinical practice for skin cancer in the *British*

Journal of Radiology (BJR) showed wide variation in workload, energies and non-standard fractionation regimes.⁴ Publication of more data on local outcomes was suggested to improve consistency of prescribing. Similarly, for benign conditions such as keloid scars, a wide range of prescription doses and techniques have been used.⁵

This study reviews the current status of kV radiotherapy treatments in the UK, with particular focus on radiotherapy physics aspects of QC and dosimetry, but also includes clinical activity workload, treatment sites and equipment installed base. It is over 20 years since a comprehensive review has been undertaken of physics aspects of quality

control (QC) and dosimetry practice in the UK: reproduced in the Institute of Physics and Engineering in Medicine (IPEM) Report 81 “Physics aspects of quality control in radiotherapy”.⁶ The IPEM guidance on QC for radiotherapy is currently being revised, and it is therefore timely to undertake a repeat benchmark exercise of current UK radiotherapy physics practice for kV radiotherapy. Similar contemporary studies have been undertaken for MV and brachytherapy activity.^{7,8} The publication of a comprehensive assessment of current QC and dosimetry practice has several potential benefits for individual radiotherapy departments: centres may be reassured that their QC systems are in-line with accepted practice; alternatively, centres may identify discrepancies against standards of practice. Following investigation, this may lead to either reduction of tests or frequencies and hence efficiency savings, or resolution of deficiencies and potential improvements in safety and quality. However, the details of QC tests presented here should not be interpreted as guidelines or recommendations, but as a “snapshot” of current UK practice. An update of IPEM Report 81 is expected in 2017, which will provide further guidance on QC. It is important to be aware that specific QC testing is a local decision, based on many local factors, and should ideally be based on risk assessment approaches.

The present survey aimed to assess the status and practice of kV radiotherapy in the UK, specifically reviewing the installed equipment base, patient numbers, clinical treatment sites, QC testing and radiation dosimetry processes. This has been conducted under the auspices of the IPEM Radiotherapy Special Interest Group.

METHODS AND MATERIALS

All radiotherapy centres in the UK were contacted by email in November 2015 to request their contribution to the study, with collation and analysis of responses taking place during December 2015–March 2016. Centres were asked to complete a detailed online questionnaire, using SurveyMonkey® Palo Alto, CA cloud-based online software, on their QC and dosimetry practices, clinical activity and equipment profile. One response from each centre was requested. An email address was provided within the questionnaire introductory text to allow for any required clarification of survey questions.

RESULTS

A total of 64 of 67 radiotherapy centres in the UK that were invited to participate completed the questionnaire, in full or part, providing a robust representation of current UK practice. Additional basic information was collected by contacting the remaining three centres directly to ensure all UK kV units were represented.

Kilovoltage equipment profile in the UK

The number of kV treatment units per radiotherapy centre in the UK, and the proportion by manufacturer, are shown in Figure 1. 73% (49 centres) of those surveyed have at least 1 clinical kV therapy unit, with a total of 58 units between them. The name of the manufacturer was provided for 55 units. The majority of units (75%) are either Xstrahl (Xstrahl Medical, Camberley, UK) or Gulmay (Gulmay Ltd, Byfleet, UK; no longer producing medical equipment). Electronic brachytherapy

devices, such as Papillon (Ariane Medical Systems, Derby, UK) and Intrabeam (Zeiss Surgical, Oberkochen, Germany), represent a significant minority of units (15%). The growth of this sector is likely to increase, because of the ease of use and portability of these machines. However, clinical opinion remains divided on their utility for some indications.³

The 18 centres with no kV units were asked the reason for having no unit, with some centres giving more than 1 answer. Only four centres did not have enough patients, and two centres send patients elsewhere. The remaining use electrons (with or without HDR, 12 centres), HDR only (2 centres) or are awaiting a replacement (2 centres).

The age of units across the country is varied; Figure 2 shows the year of installation for the 51 units for which these data were submitted. 65% (33 units) are 10 years old or less; 88% (45 units) are less than 16 years old. Centres were also asked about any planned replacements, with 73% (37 centres) responding that they have no plans for a replacement. 6% (3 centres) were planning a replacement in the next year, 10% (5 centres) in the next 2–5 years and 12% (6 centres) in 6 years or more. The majority of units, 80%, are located in a dedicated room. 12% (6 units) are in a room shared with either an HDR unit or a clinic and 8% (4 units) are used in theatre.

Commissioned beam energies and applicators for the 51 units received shows that the minimum and maximum energies in routine use across the country are 40 and 300 kV, respectively, with a median energy of 120 kV. The “very low energy” dosimetry range (<1 mm Al) from the Codes of Practice (CoPs)^{9,10} were used in 5 centres (10%), “low energy” range (1–8 mm Al) in 46 centres (92%) and the “medium energy” range (0.5–4 mm Cu) in 31 centres (62%).

Applicator data are varied across centres and have been summarized in Table 1. Data have been split into two groups: energies with HVLs defined by millimetre (mm) Al (range 0.8–10.38 mm) and energies with HVLs defined by mm Cu (range 0.48–3.5 mm). Papillon units have been separated from the others, as they always come with three standard applicators. The other units have been split into first, second and third sets of applicators, as many centres have more than one set used clinically.

With regard to the use of Record and Verify (R&V) systems, the kV unit has its own R&V system in 54% of centres. The R&V system is used by all of these centres. The kV unit is integrated with the main departmental R&V in only 16% of centres. However, 74% of centres indicate there is a need for integration.

Kilovoltage clinical workload in the UK

41 centres submitted data on clinical workload (84% of treating centres), representing 45 treatment units. The mean number of patients treated per year in each centre was 134 patients [range 10–450 patients, interquartile range (IQR) 30–172 patients]. These patients represented on average 5% of the total department workload (range 0.2–25%, IQR 2–6%). 17 departments (41% of submissions) treated <50 patients per year, as shown in Figure 3a.

Figure 1. (a) Frequency of UK centres having none, 1-, 2-, or 3-kV treatment units and (b) the number of kilovoltage units by manufacturer installed in the UK.

Most of the indications treated were basal cell carcinomas, making up 44% of the total number of patients treated (range 0–87% across each centre). The number of patients reported across a range of indications is shown in Figure 3b. The category “other” includes mycosis fungoides, bony metastasis and intraoperative breast and rectal treatments. Almost all units treated a range of different indications, except for the Intrabeam and Papillon units, which only treated these latter two indications, respectively. In total, about 5000 treatments were reported, which when scaled up to the full number of centres suggests about 6000 patients are treated with kV in the UK per year.

When broken down by energy range, the number of patients treated was 2% at “very low energy” (<1 mm Al), 82% at “low energy” (1–8 mm Al) and 15% at “medium energy” (0.5–4 mm Cu). 5% of available kV energies were reported as having not been used to treat any patient and 24% energies were used for <10 patients in the past year.

Most centres had seen no recent change in patient numbers or energies used, but several reported a decrease in patient numbers and only one or two had seen an increase. 35% of responding centres had some restriction on the days or weeks when treatments were performed, usually based on room and staff availability.

Kilovoltage treatment planning in the UK

48 centres provided responses on questions relating to treatment planning, representing 98% of the kV radiotherapy centres in the UK. Table 2 indicates the source of the calculation data used for treatment planning at each centre. In 98% of responding centres, the applicator factors are derived from measurement. The exception is the manufacturer data used for Intrabeam. The depth doses are from measurements in 33% of centres, while 57% use the BJR supplement 25 data.¹¹ Again, the manufacturer data are used for Intrabeam, while Papillon users state depth doses are not applicable. Backscatter factors are taken from the relevant CoP in 44% of centres, 38% from BJR supplement 25, and 7% use measured data. Inverse square corrections are from measurement in 37% of centres, while 46% use the inverse square law formula. Chamber correction factors are taken from the CoP in 67% of centres, while 24% state this as N/A, owing to not being applicable for the section of the code used.

All centres, with the exception of Intrabeam and Papillon users, use custom cut-outs for field shaping. These cut-outs are selected from the existing set of cut-outs in 65% of centres.

The primary and secondary dose calculations are performed by treatment radiographers in 75% of centres, by the planning staff group in 15% of centres and by physics in around 10% of centres. Physics are reported to give advice on complex

Figure 2. Year of installation for the 51 units in the UK for which data were submitted.

Table 1. Summary of kilovoltage applicator data from surveyed centres

HVLs	0.8–10.38 mm Al				0.48–3.5 mm Cu		
Machine type	Papillion	Other 45 centres, mixed manufactures			29 units, mixed manufacturers		
Applicator set	First set	First set	Second set	Third set	First set	Second set	Third set
Number of units	3	45	31	2	3	9	1
FSD range (cm)	2.9–3.8	15–30	20–50	30	15–50	25 or 50	30
Applicator end	3 open	44 open 1 closed	26 open 6 closed	2 open	10 open 19 closed	3 open 6 closed	1 open
Diameter range (cm)	2.2–3.0	1–20	1.5–20	Not provided	1.5–25	4–20	Not provided

FSD, focus to surface distance; HVL, half-value layer.

treatments. All centres have a second check of monitor units (MU) or time, with the exception of Papillon users, where the MU are standardized.

The MU calculations are performed using software in 36% of centres. There is an even split between the software being used as the primary calculation or the secondary check, with this other calculation performed manually. Software is used for both the primary and secondary calculation in 4% of centres. The majority of software are written in-house; there are two users of the commercial RadCalc® LifeLine Software Inc, Austin, TX software.

Kilovoltage quality control practices in the UK

Information on QC test frequencies and tolerances was received for 46 machines. Very few responses were received for intra-cavity (Papillon) or intraoperative (Intrabeam) devices, and QC for these units has been described in detail elsewhere,³ so they are not considered further in this section.

Table 3 summarizes the frequency with which the QC tests specified in Report 81⁶ have been implemented by the survey respondents. Although Report 81 does not specify a frequency for carrying out focal spot alignment checks, 51% of respondents routinely perform this QC test and it has therefore been included in the analysis.

Table 4 summarizes the QC test performance limits in use across UK radiotherapy centres. Centres were asked to define the level at which a treatment unit would be removed from clinical use,

termed “Suspend” limit in the table, and any additional performance level they may use to prompt further action while allowing clinical treatments to continue, termed ‘Notify’ limit in the table. For some tests, Notify and Suspend limits were identical. The basic functional checks (interlocks, fixture and filter tests) were universally associated with simple pass/fail criteria. The QC limits used for timer end error (not shown in Table 2) were very variable across UK centres, both in the methodology of the test and the interpretation of QC result, with no suitable generic analysis possible.

The survey enquired as to the purity, and provenance of, aluminium used in HVL measurements. 51% of respondents stated that they could demonstrate that their aluminium met the 99.8% minimum purity requirement stipulated in Report 81⁶ for use in low-energy beams. 18% of users cited a purity between 99.0 and 99.8%. 31% of respondents were uncertain of the quality of the aluminium they employed. While this finding is not entirely surprising, given the long legacy associated with kV beam radiotherapy, it is a concern that some centres are using a measurement tool with unconfirmed metal purity, at odds with the standards demanded by the modern quality management culture associated with radiotherapy.

The survey sought information on how frequently QC test results are outside of tolerance values. For traditional kV units, 80% of respondents replied “Rarely” or “Never”. The remaining 20% respondents reported the frequency of test results being outside of tolerance exceeded 12 months.

Figure 3. (a) Kilovoltage (kV) treatment workload at UK radiotherapy centres each year and (b) the number of patients treated by clinical indication in the UK each year. BCC, basal cell carcinoma; SCC, squamous cell carcinoma.

Table 2. Source of treatment planning data used at radiotherapy centres in the UK, indicating the % of centres using each specified data source

Treatment planning data	Local measurement	BJR supplement 25 ¹¹	Code of practice	Calculation formula	Manufacturer data	N/A
Applicator factors	98%	–	–	–	2%	0%
Depth doses	33%	57%	–	–	2%	9%
Backscatter factors	7%	38%	44%	–	–	11%
Inverse square corrections	37%	2%	4%	46%	–	11%

For clarity, the highest percentage is indicated in bold.

Kilovoltage radiation dosimetry in the UK

48 centres provided responses on questions relating to radiation dosimetry, representing 98% of the kV radiotherapy centres in the UK. All responding centres were using the recommended CoPs for kV radiation dosimetry in the UK, either the Institute of Physics and Engineering in Medicine (IPEM) 1996 or IPEM 2005 addendum codes.^{9,10} The “very low energy” dosimetry ranges from the CoPs were used in 9 centres (19%), “low energy” range in 43 centres (90%) and the “medium energy” range in 27 centres (56%). Of those using the medium energy range, 13 centres were using the 1996 CoP incorporating an in-water measurement, and 14 centres were using the 2005 CoP incorporating an in-air measurement. Two-third of those using the 1996 CoP and two-third of those using the 2005 CoP cited “clinical relevance” as a reason for using the particular code. This was the most frequently cited reason from those using the 1996 code, whereas “ease of setup” was the most common reason for users of the 2005 CoP, cited by 86% of respondents. “Setup uncertainty” and then “inherent accuracy of the code” were cited least frequently by users of both codes. Other reasons stated for using the 1996 CoP included “inertia”, and for the 2005 CoP “can calibrate all energies at the same time (with the same equipment)”.

The ionization chambers used by radiotherapy centres as secondary standards (generally calibrated at a standards lab, including the National Physical Laboratory (NPL) in the UK) and as field instruments (cross-calibrated against secondary standards at local centres and used for routine dosimetry measurements), at each energy range, are provided in Table 5. For secondary standard calibrations, use of the NE2611 chamber was most common at medium and low energies, then NE2611B. At very low energies, the PTW23342 was used in all but one centre. For field instrument measurements, parallel-plate chambers were used at all centres with very low energies. NE Farmer types were the most common at low and medium energies.

There was evidence of adoption of interdepartmental dosimetry audit practice for kV radiotherapy across the majority of centres in the UK. Figure 4 shows time periods since the last external audit at UK centres (from November 2015 to January 2016). 64% ($n = 30$) of centres had received an external audit within the last 3 years, with 34% ($n = 16$) centres longer than 3 years ago, and 1

centre having never hosted an external audit on their equipment. The four units (at three centres) audited over 10 years ago, and the unit never audited, were all conventional orthovoltage kV treatment units. Comments from centres indicated the majority of audits were conducted *via* local audit network groups in the UK, either as scheduled regional audit programmes, at commissioning of new equipment, or when moving to a new CoP.

The consistency of kV dosimetry between centres was good, indicated by the results of interdepartmental dosimetry audits. Half of all centres, $n = 24$, reported <2% difference between auditor and host measurement of kV dosimetry at their last external audit. 27%, $n = 13$, centres reported 2–3% difference and 8%, $n = 4$, centres reported 3–5% difference, with none >5% difference (4 centres did not provide data). There was no correlation between equipment type and magnitude of difference between host and auditor measurements. The results with largest differences, in the range 3–5%, were for conventional orthovoltage kV treatment units. The very low-energy results were predominantly within 2–3% range with one <2%.

The frequency of hosting external kV dosimetry audits was reported as being determined by the regional interdepartmental audit groups by the majority of centres (81%), with additional audits being conducted by the majority of centres (56%) at the commissioning of new treatment units. 4% of centres ($n = 2$) reported scheduling audits every 2 years, and 4% centres also reported scheduling annual external audits.

DISCUSSION

Kilovoltage equipment profile in the UK

These data show that kV therapy is being used in 73% of UK centres, the majority of which have Xstrahl or Gulmay machines in their own dedicated room. In addition, 2 (3%) centres who responded to this survey said they sent patients elsewhere, still giving these patients access to kV treatments. In a survey by McPartlin et al,⁴ it was found that 81% of respondents had access to kV treatments, although they accepted more than one response per centre and had incomplete coverage from all UK centres, which may explain the difference.

35% of units in the UK are over 10 years old, which is in contrast to MV units, which tend to be replaced after 10 years as recommended by the National Radiotherapy Advisory Group in

Table 3. Kilovoltage unit quality control test frequencies at responding UK radiotherapy centres: percentage of centres using stated frequency, with comparison with Report 81⁶

Parameter	Daily	Weekly	Monthly	Quarterly	Annually	Commissioning only	Never	N/A	IPEM Report 81 recommended
Interlocks	83%	12%	5%	–	–	–	–	–	Daily
Fixtures	33%	5%	43%	7%	5%	5%	–	2%	Daily
Filters	49%	7%	32%	5%	5%	–	–	2%	Daily/weekly
Output constancy	93%	2%	2%	–	–	–	–	2%	Daily
Output	7%	26%	64%	2%	–	–	–	–	Monthly
Timer accuracy	14%	5%	57%	7%	7%	7%	2%	–	Monthly
Linearity	–	–	34%	20%	12%	10%	5%	20%	Monthly
Back-up timer	17%	–	56%	5%	7%	5%	7%	2%	Monthly
Focal spot	–	–	12%	7%	32%	44%	5%	–	Unspecified
Radiation field size	–	2%	26%	12%	38%	19%	2%	–	Monthly
HVL constancy	–	–	62%	12%	14%	–	7%	5%	Monthly
HVL full	–	–	–	7%	62%	29%	2%	–	Annually
Uniformity	–	–	17%	17%	49%	15%	–	2%	Annually
Applicator factors	2%	–	7%	10%	60%	19%	–	2%	Annually

IPEM, Institute of Physics and Engineering in Medicine.
For clarity, the most commonly reported frequencies are indicated in bold.

Table 4. Notification and suspension limits for quality control (QC) tests: percentage of responding UK radiotherapy centres using the specified limits, with comparison with Institute of Physics and Engineering in Medicine (IPEM) Report 81⁶ tolerances

QC test	Limit type	IPEM tolerance	Percentage of UK centres using specified tolerance value (x), % or millimetre					
			$x \leq 1$	$1 < x \leq 2$	$2 < x \leq 3$	$3 < x \leq 4$	$4 < x \leq 5$	$5 < x$
Output constancy	Notify	5%	3%	39%	52%	–	6%	–
	Suspend	–	3%	3%	56%	5%	33%	–
Output measurement	Notify	3%	–	77%	23%	–	–	–
	Suspend	–	–	30%	48%	5%	18%	–
Timer	Notify	2%	35%	65%	–	–	–	–
	Suspend	–	23%	59%	14%	–	5%	–
Monitor chamber linearity	Notify	2%	47%	47%	7%	–	–	–
	Suspend	–	28%	60%	4%	–	8%	–
Radiation field size	Notify	5 mm	6%	94%	–	–	–	–
	Suspend	–	11%	72%	6%	–	11%	–
HVL constancy	Notify	5%	12%	38%	8%	–	19%	23%
	Suspend	–	7%	24%	14%	3%	10%	41%
HVL measurement	Notify	10%	6%	6%	–	–	61%	28%
	Suspend	–	8%	4%	–	–	24%	64%
Field uniformity	Notify	5%	–	–	38%	–	50%	13%
	Suspend	–	–	–	37%	–	21%	42%
Applicator factors	Notify	3%	5%	64%	32%	–	–	–
	Suspend	–	7%	21%	61%	–	11%	–
Focal spot alignment	Notify	Not stated	77%	23%	–	–	–	–
	Suspend	–	50%	44%	6%	–	–	–

For clarity, the most frequently used tolerances are indicated in bold.

2007.¹² However, it is important to note that machines are still being installed across the country, with 20 (39%) units being installed in the last 5 years.

The “low” and “medium” energies are most common, although 10% of centres do have “very low” energies commissioned. There is no consensus on the applicators used, however energies with HVLs defined in mm Al tend to have open applicators (all but one in the centres first group of applicators) while the energies with HVLs defined by mm Cu have a larger variation; 10 open, 19 closed. FSDs range from 15 to 50 cm.

Kilovoltage clinical workload in the UK

kV units still perform a substantial proportion of radiotherapy treatments, averaging 5% of the total department workload (range 0.2–25%, IQR 2–6%), but there is a wide range in the number of patients treated in each centre per year. For brachytherapy, the National Health Service Specification Standard¹³ recommends at least 50 patients per year to maintain clinical competence. Almost half the centres responding to the survey do not meet this level. This value is similar to that reported by McPartlin et al.,⁴ who found that 46% of clinicians surveyed saw <60 patients per year. Therefore, a national

review of resource use and referral patterns may be warranted. Likewise, almost 30% of beam energies were used to treat <10 patients per year; so, a reduction of energies in clinical use could be made. This would save resources on maintenance and QA. About a third of centres already restrict treatments to certain days or weeks, and such economies may be possible in all centres.

Kilovoltage treatment planning in the UK

The survey of the source of treatment planning data demonstrates that a range of resources are used for these data. Where possible, it is suggested that these sources are cross-checked against each other during commissioning. Then, a decision can be made locally as the most appropriate data source to use for all subsequent treatment planning calculations. Care should be taken over the choice of detector and irradiation medium for local measurements.¹⁴ In addition, for backscatter factors, a recent review concluded that there is little evidence that established CoP values will not be applicable to clinical units.¹⁵ Uncertainty in measurement can be high, and reported differences in other studies were within this uncertainty, or related to unrepresentative beam spectra. Local values should only be introduced following specific Monte Carlo modelling of the beams

Table 5. Frequency of ionization chamber type/models used as secondary standard and field instruments, by energy range, at radiotherapy centres in the UK

Energy range [A, B]	Secondary standard or field instrument	Chamber type or model number	Number of centres	Percentage of treatment units (%)
Very low	Secondary standard	PTW23342	7	87.5
		PTW23344	1	12.5
	Field instrument	Parallel plate (PTW23342 or PTW23344)	8	100.0
Low	Secondary standard	NE2561	3	7.1
		NE2611	31	73.8
		NE2611B	8	19.0
	Field instrument	NE Farmer-type (NE2505, NE2503A, NE2571, NE2581)	36	90.0
		Other Farmer-type (PTW30001, PTW30002, PTW3010, PTW3011, PTW3012, PTW3013, IBA FC65, or similar)	4	10.0
Medium	Secondary standard	NE2561	1	4.0
		NE2611	18	72.0
		NE2611B	6	24.0
	Field instrument	NE Farmer-type (NE2505, NE2503A, NE2571, NE2581)	22	91.7
		Other Farmer-type (PTW30001, PTW30002, PTW3010, PTW3011, PTW3012, PTW3013, IBA FC65, or similar)	2	8.3

involved and verification by measurement, but these situations are expected to be rare.

Applicator output factors may be measured in a number of ways: either direct measurement at the water surface, measured at depth and corrected to the surface *via* a depth dose, or measured in air and converted to dose to water *via* a ratio of backscatter factors. There are reports of differences in measured output

factors and those calculated using the ratio of published backscatter factors.¹⁴ It has been recommended that output factors are measured in water¹⁴ and then may be checked against published BJR supplement 25 data.¹¹

Measured depth doses should also be compared against BJR supplement 25 data. As with all commissioning, the appropriate detector should be used for the measurements, and the appropriate methodology should be used for the measurements. Farmer-type chambers are appropriate for relative dose measurements at depth but are not suitable for measurements at the water surface; here, parallel-plate chambers are more appropriate.¹⁴ Discrepancies have been reported between measured depth doses and BJR supplement 25 data at energies below 75 kV (2.6-mm Al HVL),¹⁶ with this being attributed to differences in the detectors, irradiated medium and measurement methodology for the BJR data. The 2001 Report 75 from the American Association of Physicists in Medicine¹⁷ recommends that if it is not possible to identify a suitable detector for relative dosimetry, then the BJR supplement 25 data should be used.

Backscatter factors are taken from published sources in the majority of UK centres, with only 7% of survey responses using measured values. Recent research has shown that backscatter factors may be measured accurately with thermoluminescent dosimeter and Gafchromic film.¹⁴

Figure 4. Period since last external kilovoltage (kV) dosimetry audit for radiotherapy centres in the UK (from November 2015 to January 2016).

MU calculations are performed using software in 36% of centres. This is a relatively low percentage of UK centres, in comparison with MV linear accelerator treatments, where MU check software is standard. We recommend the use of kV MU calculation software, particularly in light of the Edinburgh Cancer Centre incident involving an error in a manual treatment calculation (2015).¹⁸ The software must be properly commissioned and robustly tested.

The kV unit has its own R&V system in 54% of centres and is integrated with the main department R&V system in only 16% of centres. Integration with the main department R&V system is clearly valuable and we would urge manufacturers to invest in this development. This need is confirmed by the survey results, with 74% of centres indicating the R&V systems should be integrated.

Kilovoltage quality control in the UK

The most commonly reported frequencies for performing QC tests were in general agreement with the recommendations of Report 81⁶ for the majority of tests, although there was some variability across the UK. Two tests were measured on average less frequently than Report 81: fixtures checked monthly rather than daily, and radiation field size annually rather than monthly. Centres which find their QC schedules as outliers in the data are encouraged to reassess their chosen frequencies. For example:

- output constancy checks were performed monthly at one centre and weekly at another centre, whereas 93% perform this QC test daily in line with Report 81 recommendations.
- HVL constancy check is performed monthly at 62% of centres in accordance with Report 81, but only quarterly at 12% centres, annually at 14% centres and not at all in 7% of centres.

For conventional kV treatment units, the treatment timer function is to prevent gross errors (perhaps exceeding 10%) resulting from monitor chamber termination failure; hence, a suspend level of perhaps 5% accuracy for the QC check, and a check on functionality of termination if possible, is likely to be appropriate. (For treatment units that rely on a timer as the primary source of exposure determination, an accuracy of the primary timer in line with an MU chamber is required.)

IPEM Report 81⁶ (Chapter 2) makes the distinction between “tolerance” and “action” level. It defines operating within a tolerance level as providing “optimum conditions based on the therapeutically desirable values, although these may not be enforceable or achievable in all circumstances”. Performance within the tolerance level is deemed to be of acceptable accuracy in any situation. Action levels are often set at approximately twice the corresponding tolerance level. Performance outside the action level is unacceptable and demands further immediate action to remedy the situation. There may be instances when it is appropriate to set the tolerance and action levels to the same value. For kV units, Report 81 provided only tolerance level limits. However, it did afford some flexibility in the interpretation of the meaning of tolerance, and this survey indicates that while some users have applied the values given in Report 81 as the

limit at which a machine is immediately suspended from clinical use (or at least proactively risk-managed), others have preferred to take this as the point at which remedial action is required to enable satisfactory performance to be restored as soon as service availability permits.

In 2012, the European Union published guidance on suspension limits for kV therapy units taken from the IPEM Report 81 tolerances. More recent recommendations (2015) from Canadian Partnership for Quality Radiotherapy¹⁹ has developed the two-level approach further. The survey sought to establish to what extent this philosophy had been adopted into UK practice, and respondents were asked to provide the operational limits they used to maintain their equipment. The majority of UK centres have adopted a two-level approach to assessing QC test results. However, use of terms “tolerance” and “action” were considered potentially ambiguous and the survey questions were designed to be explicit as to meaning. We propose the use of a “Notify” level to prompt further action while continuing clinical treatments and a “Suspend” level to remove a unit from clinical use. The UK survey data are presented using these terms in this report.

Centres which find their QC test result acceptability values as outliers in the data are encouraged to reassess their chosen tolerance levels: for example, the majority of UK centres would suspend clinical treatments if output measurements exceeded 3%, with 30% centres allowing only 2% deviation; however, 18% of centres allow up to 5% deviation.

As with the previous report by Palmer et al,⁷ it should be stressed that these survey results reflect currently adopted practice. These results suggest that IPEM Report 81 is still relevant for the majority of kV QC frequency and tolerances, with other bodies also citing the data published in that report (Canadian Partnership for Quality Radiotherapy,¹⁹ European Union 162²⁰). However, given advances in the reliability and stability of currently installed equipment compared with that of those extant in 1991 (when IPEM last carried out a survey into kV QC practices),⁶ it would be appropriate for QC system implementers to re-evaluate how they apply the published tolerance levels. Kapanen et al²¹ reports that for linear accelerator output measurements, tighter limits allow test frequency to be reduced. However, reduced frequency of testing carries a concomitant risk of “skills fade”.²² this will be particularly relevant to kV units, which are usually the only such machines within a department.

Kilovoltage radiation dosimetry in the UK

While there was good consistency in some aspects of dosimetry, all centres were using a recommended UK CoP; there were aspects of inconsistency, including an equal split between those using the 1996 in-water code and those using the 2005 in-air code for the medium energy range. It was recommended in the 2005 CoP addendum¹⁰ that the selection of calibration methodology should be based on whichever the clinical users find most appropriate to them, *i.e.* determined by whether the local oncologist prescription is defined at the surface or at depth. Clearly, there must be consistent practice between oncologists

within a radiotherapy centre. Only two-third of the UK survey respondents cited “clinical relevance” as the reason for selection of either the 1996 or 2005 CoP. Centres are encouraged to re-evaluate their choice of dosimetry code if the relevance of local clinical prescribing practice was not considered, and a discussion between local physicists and doctors is encouraged.

Only one centre reported never having hosted an external kV dosimetry audit, and there were 16 centres that had hosted audits at 4 years or longer ago. It is important that routine quality assurance programmes include interdepartmental dosimetry audits at reasonable frequency, ideally every 3–4 years. It is surprising that only 56% of centres reported hosting an external dosimetry audit at the commissioning of new kV treatment units. It is recommended that external audit should form part of the quality assurance of all new radiotherapy equipment installations. The importance of regional audit groups in the UK is clear, with 81% of centres stating their kV treatment units would be audited externally in line with regional audit group schedules.

CONCLUSION

The survey data analyzed in this report, compiled from responses returned by the majority of radiotherapy centres in the

UK, provide a good representation of current practice and infrastructure for kV radiotherapy. The majority of radiotherapy centres in the UK have access to kV treatment modality, the most common treatment indication being basal cell carcinomas. One-third of the treatment units are currently over 10 years old.

A benchmark data set of kV treatment unit QC and dosimetry testing is provided. Local assessment of QC and dosimetry needs is essential in determining practice and schedules, rather than simple reliance on the “majority view” across the UK. However, comparison with generally accepted practice is a good starting point for local review. The contents of this report must not be interpreted as professional advice as to QC requirements and are presented as a benchmark only for comparison. Local decisions on QC testing must be made based on full risk assessment, further analysis and local factors.

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