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Research Article

A review of kilovoltage radiotherapy treatment in the United Kingdom: quality control, radiation dosimetry, treatment equipment, and workload

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Abstract

Objectives: To survey kilovoltage (kV) radiotherapy in the United Kingdom, updating a 2016 study, focussing on radiotherapy physics, including equipment quality control (QC) and radiation dosimetry, with information on installed equipment and clinical activity.

Methods: All UK radiotherapy physics departments ($n = 68$) were invited to complete a comprehensive survey. An analysis of the installed equipment base, patient numbers, clinical activity, QC testing, and radiation dosimetry processes were undertaken.

Results: 91% of centres ($n = 62$) responded to the survey. kV radiotherapy was available in 70% of UK radiotherapy departments, with a wide variation in workload; 7-436 patients/centre annually. There has been an increase in centres using treatment calculation software rather than manual methods, up from 36% in 2016 to 50% currently. Only 50% of centres use an independent calculation check method. There was an increase in the use of the addendum to the UK dosimetry code of practice, enabling medium energy calibration in-air rather than at depth in phantom, citing "clinical relevance." Appropriate levels of QC testing were being conducted at UK centres, with Institute of Physics and Engineering in Medicine (IPEM) Report 81 cited as a primary source of guidance. Good consensus for the frequency and tolerance values used for QC was seen across UK centres.

Conclusions: A comprehensive review of consensus practice for QC and dosimetry in kV radiotherapy across the United Kingdom is presented, with supporting information on equipment installation and clinical use.

Advances in Knowledge: Updated data are presented on kV radiotherapy treatment in the United Kingdom, with focus on physics aspects of QC and dosimetry.

Keywords: kV radiotherapy; quality control; radiation dosimetry; survey; United Kingdom.

Introduction

This study reviews aspects of the current status of kilovoltage (kV) radiotherapy across the United Kingdom, with particular focus on physics aspects of quality control (QC) testing and radiation dosimetry. This snapshot of practice is valuable for individual departments to evaluate their own practice against UK consensus. The survey was commissioned on behalf of the Institute of Physics and Engineering in Medicine (IPEM) Radiotherapy Special Interest Group (RT-SIG) and IPEM Interdepartmental Dosimetry Audit Group (IDA). A total of 91% of Radiotherapy Physics Departments across the United Kingdom responded to the survey, with the majority answering all questions. This provided a robust data set to update the results of a similar survey conducted during 2015-2016.[1] The second edition of IPEM Report 81,[2] providing recommendations for QC in radiotherapy, was issued after the previous survey and may have subsequently affected practice. A similar study of kV radiotherapy conducted in Australia and New Zealand demonstrated the usefulness of establishment of consensus practice.[3]

Methods

All radiotherapy centres in the United Kingdom were contacted by email in January 2024 to request their contribution to the study, with collation and analysis of responses taking place during March to April 2024. Centres were asked to complete a detailed on-line questionnaire, using Microsoft

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Forms 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's introductory text to allow for any required clarification of survey questions.

Results

All UK centres ($n = 68$) were invited to participate in the survey of kV treatment radiotherapy, with 91% ($n = 62$) responding. A fully completed response was received by 81% ($n = 55$), with 10% ($n = 7$) providing a partially completed survey.

kV equipment profile in the United Kingdom

From the survey responses across the United Kingdom, 29% of centres had no kV unit, 66% had 1 kV unit, and 5% had 2 kV units. Most machines (86%) were either Xstrahl (Xstrahl Medical, Camberley, United Kingdom) or their predecessor company, Darpac or Gulmay (Gulmay Ltd, Byfleet, United Kingdom). The remaining centres were split relatively equally between manufacturers with electronic brachytherapy devices including 2 Papillon units (Ariane Medical Systems, Derby, United Kingdom), 1 Intrabeam (Zeiss Surgical, Oberkochen, Germany), and 1 Grenz Ray (Progressus Medica, Sweden). The 25 centres with no kV unit were asked for the reasons of not having this treatment modality available. The majority of centres (45%, $n = 14$) cited alternative modalities of electrons or high dose rate (HDR) brachytherapy as the main reason for not using kV, other reasons included: patients referred elsewhere (16%), low patient numbers (16%), decommissioned (13%), and never used (10%).

The age distribution of kV units across the country has changed since the last survey.[1] The data for the 39 centres responding to this question are summarized in Fig. 1. The majority of units, 65% ($n = 26$), have been installed in the last 10 years. Thirty percent ($n = 12$) between 10 and 20 years old and 5% ($n = 2$) older than 20 years. In terms of planned replacement, the majority, 67%, of responding centres ($n = 32$) had no planned replacement date. Nineteen percent ($n = 9$) had a planned replacement within 5 years and the remaining 14% of centres ($n = 7$) within 10 years. As expected, there was a direct correlation between age of unit and plans for replacement. For those who gave information regarding the location of their unit, the majority, 84%, were located in a dedicated room, while 16% ($n = 5$) were in a room shared with another treatment unit.

The lowest and highest commissioned energies were 45 and 300 kV, respectively, with a median energy of 120 kV. From the 38 centres that provided energy data, the very low energy dosimetry range <1 mm Al was used in 4 centres (11%). The low energy range (1-8 mm Al) was used in 38 centres (100%), and medium energy (0.5-4 mm Cu) was used in 27 centres (71%).

Table 1 provides a summary of applicator data across responding centres. Papillion has been separately listed due to its standard applicator set-up. Most applicators available for use in the low to medium energy range were open-ended (92%). For the medium energy range, the majority of responding centres only used closed applicators (78%).

kV clinical workload in the United Kingdom

Of the 62 respondents, 43 had kV treatment units and of those, 35 supplied clinical activity data. An additional 2 centres reported having kV treatment units delivering only breast inter-operative radiotherapy (IORT) or other dermatological treatments but not cancer, so they were considered separately from the 35 sites with clinical data.

There was a large range in the reported kV treatment workload, between 7 and 436 patients per year per centre, delivering between 48 and 2261 fractions. The median number of patients per centre was 89.5 (mean 113.1, IQR 80.3), and the median number of fractions was 634.0 (mean 729.3, IQR 278.0). Note, these data are not corrected or scaled for size of population being served by a centre. Figure 2 presents a histogram of the number of patients treated at centres across the United Kingdom. It shows that the most common frequency is in the 50-100 patient range with 12 centres falling in this bracket. There were 10 centres with less than 50 patients per year.

Analysis of the ratio of patients treated with kV compared to MV in each centre gave a median value of 3.0% (mean 4.1%, IQR 3.6%). Where electrons are also used at a centre, there was a median ratio of 2.2% (mean 3.3%, IQR 2.3%) kV compared to MV activity. There was a clear inverse proportional relationship between kV and electron utilization.

Analysis of kV energies used to treat patients showed the "low energy" range, defined by the kV Code of Practice (CoP)[4,5] as 1-8 mm Al, was the most used accounting for 83.8% of all treatments. "Very Low energy," <1 mm Al, accounted for 2.6%, with the "medium energy," 0.5-4.0 mm Cu, contributing 13.6%; 13.4% of energies clinically available were unused in individual centres in the previous year.

Figure 3 shows a breakdown of treatment indications performed in the United Kingdom in 2023. Conditions treated

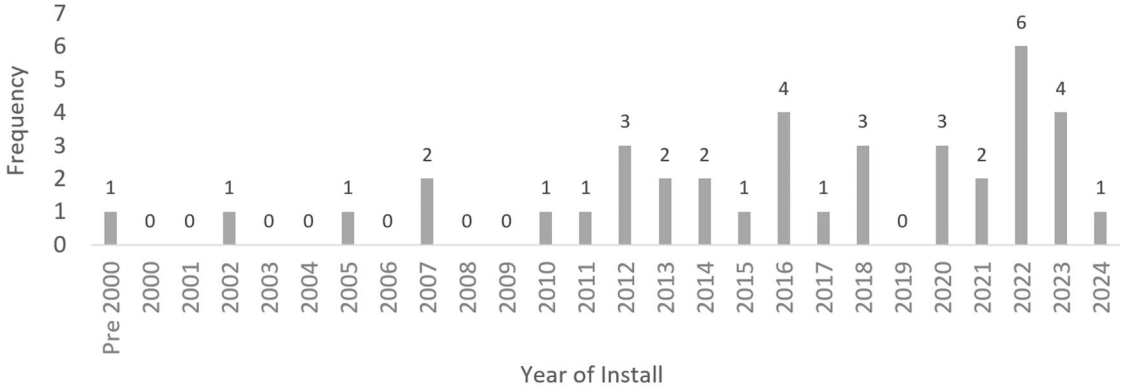

Figure 1. Install date of kV treatment units in centres across the United Kingdom. kV = kilovoltage.

Table 1. Summary of kV unit specifications across the United Kingdom, in terms of HVL, FSD, and available applicators.

HVLs	0.04-10.38 mm Al		0.36-3.34 mm Cu
Number of units	2 Papillon	36 Other manufacturers	27
FSD range (cm)	2.9-3.8	15-30	15-50
Applicator end-type	3 open	32 open, 4 both open and closed	21 closed, 3 open, 3 both open and closed
Diameter range (cm)	2.2 - 3.0	1.0-20	2.0-20.0

Abbreviations: kV = kilovoltage, HVL = half-value layer, FSD = focus to surface distance.

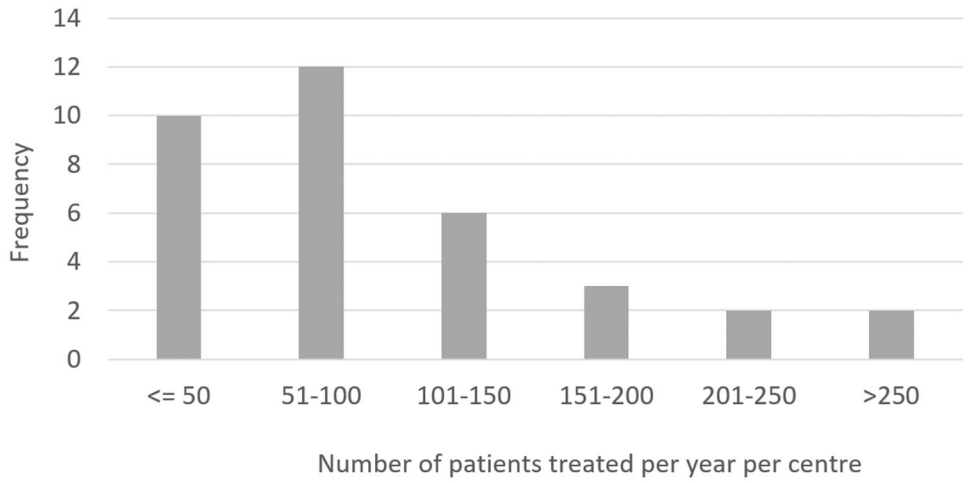

Figure 2. Number of kV patients treated per year in centres across the United Kingdom. kV = kilovoltage.

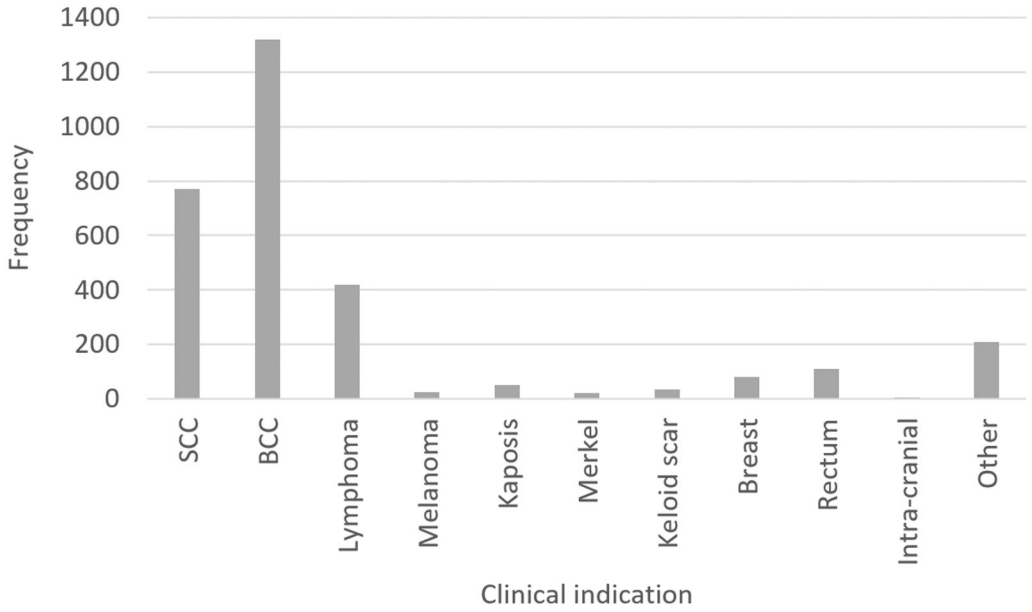

Figure 3. kV treatments by clinical indication in centres across the United Kingdom. kV = kilovoltage.

with kV are predominately Basal Cell Carcinoma (BCC) and Squamous Cell Carcinoma (SCC) with all centres that had a traditional kV unit and supplied data treating these conditions. BCC accounted for 43% and SCC 25% of all indications treated with kV. Lymphoma accounted for 14% of treatments nationally, being treated at 12 centres. The most common other indications treated across centres were melanoma and keloid scar with these being treated with kV at 12 centres. Other common indications were Merkel cell carcinoma and bone metastases (included under Other in Fig. 3), treated at 7 centres. Two centres treated rectum patients with Papillon. One centre treated breasts with IORT and another centre provided dermatological treatments including eczema and psoriasis with a Grenz ray treatment unit.

A review of the fractionation patterns for definitive or adjuvant BCC and SCC treatments show UK centres are generally following RCR guidelines,[6] with 45 Gy in 10# (72% of responding centres) and 32.5-35 Gy in 5# (79%) being the most prevalent. Other common prescriptions used from the guidelines are 55 Gy in 20# (45%) and 18-20 Gy in 1#

(38%). A common prescription in use but not covered under current RCR guidelines is 40 Gy in 10# (38%), often offered in conjunction with 45 Gy in 10#, subject to local clinical practice. One centre uses 42 Gy in 10# but is moving to the RCR guideline prescription of 45 Gy in 10#. Where centres have a difference in dose prescription locally for BCC and SCC, SCC will have a higher dose, for example BCC protocol will be 32.5 Gy in 5# and SCC will be 35 Gy in 5#. Most centres (63% of respondents) restrict clinical treatment hours on kV units. This can depend on staffing and preference at the centre. It can be restricted by weekday, or mornings-only or afternoons-only and several other variations.

kV treatment planning in the United Kingdom

Treatment planning data

Thirty-five centres provided partial information regarding their data used for treatment planning calculations, but not all centres provided responses to all questions. Table 2 indicates the source of plan calculation data used at UK centres. Fifty-one percent of all centres who completed the survey use chamber correction factors taken from the relevant CoP. An additional 14% compare CoP values to measured values and values obtained from BJR 25.[7] In 77% of responding centres, the applicator factors are derived from measurement with 17% derived from a combination of measurement, IPEM CoP, and BJR 25. Exceptions are for those machines that use manufacturers' data. Depth dose data are derived from BJR 25 in 51% of responding centres and from measurement in 31% of centres. Inverse square corrections for stand-off and stand-in are made from measurement in 36% of centres, and 52% of respondents used an Inverse square law (ISL) formula or a combination of measurements to validate published data. Two centres reported that they do not allow stand-in due to uncertainties. For centres with open-ended applicators, stand-off correction factors are derived from using a calculation formula in 54% of centres, primarily using ISL alone or using a combination of ISL and verification by measurement. Correction made from measurement alone is performed in 34% of centres; 6% (2 centres) use data from BJR 25, whilst the remaining 2 centres do not use stand-off correction factors due to machine type.

For centres that treat with closed-ended applicators, 78% of centres use a chamber measurement to help validate stand-off correction factors. The most common method is to use a chamber measurement to either validate ISL, create a polynomial equation to use in treatment planning, or to calculate an effective source position to use in a calculation formula (65% of centres). Of the remaining centres, 17% use measured values alone, and 1 centre using stand-off values quoted in Gräfe et al. 2014[8] but are considering measuring their own data if time permits.

There were fewer responses for data used for stand-in corrections, with 11 centres stating not applicable, whilst 2 of these stated not allowed due to uncertainties. Of the centres that allow stand in corrections, 38% of centres use ISL calculation formula, 30% use a measured value, and 21% use a combination of measured and calculated values with 2 centres using data from BJR 25. Backscatter factors are taken from a relevant CoP in 49% of centres, 34% from BJR 25, with 3% using measured data.

Treatment planning processes

Of the responding centres, 81% provided information on their processes for kV treatment calculations. Almost 66% of centres that responded said that primary calculations are performed by treatment radiographers, 20% used a combination of radiographers, physicists, and dosimetrists dependent on the complexity of the calculation, whilst 14% indicated that clinical scientists alone undertook the primary dose calculation. All centres perform a secondary dose calculation using the same staff groups who undertook the primary calculation in over 90% of responses. The monitor unit (MU) calculations are primarily done using a manual calculation from tables in just over half of all centres with 29% using a commercial TPS, 3 centres use spreadsheets and 2 centres have an in-house TPS. Half of all centres use a different calculation method for the second check, for example use of a commercial TPS for the primary calculation and another TPS, spreadsheet, or manual calculation from tables for the second check. A third MU check is performed by 25% of responding centres.

All but 1 centre, and excluding those with Papillon, Progressus medical, and Intrabeam, use custom cut outs for lead shielding. These cut-outs are selected from an existing set supplemented by those made in the mould room in 65% of centres.

Regarding the use of Record and Verify (R&V) systems, the kV unit has its own R&V system in 60% of centres who provided information (35 centres). All but 1 centre use this system. The kV unit is only integrated with the main R&V unit in 31% of centres. However, 66% of centres indicated that there is a need for integration.

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

Parameter used in calculations	Source of treatment calculation data						
	Local measurement	BJR 25	IPEM code of practice (CoP)	Combination of measurement, BJR 25 and IPEM CoP	Calculation formula	Manufacturer data	N/A
Chamber correction factors	3%		51%	14%			32%
Applicator factors	77%	3%		17%			3%
Depth doses	31%	51%		9%		3%	6%
Backscatter factors	3%	34%	49%	8%			6%
Inverse square corrections	36%	6%			52%		6%

For clarity, the most common reported frequencies in the current survey are indicated underlined, with the most common from the previous (2016) survey in bold type. (Chamber correction factor data were not considered in the 2016 survey).
Abbreviation: IPEM = Institute of Physics and Engineering in Medicine.

kV QC tests

Information on QC test frequencies and tolerances was received from 37 centres. Table 3 summarizes the frequency with which the QC tests have been implemented by the survey respondents, in comparison to the previous survey (2016)[1] and the recommendations in IPEM Report 81.[2]

The most common QC test frequencies in the current survey are consistent with those of the 2016 survey for all tests, except "applicator integrity" that was most commonly tested monthly but is now tested daily, the latter now in line with the recommendations of IPEM Report 81. All the QC test frequencies most commonly used are consistent with IPEM Report 81 except "radiation field size," which is tested annually in the majority of centres but recommended as monthly in the report. "Focal spot size" is now most often measured annually rather than at commissioning only, as in the previous survey. Three tests were not assessed in the previous survey but are in widespread use: angular dependency of output (results given from 36 centres), end effect consistency (35 centres), and definitive calibration (37 centres).

Table 4 summarizes the QC test performance limits in use across the responding 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, the reported Notify and Suspend limits were identical.

The tolerance values in the current survey are largely consistent with those of the 2016 survey except for the following: Dose "output constancy" now has a most common notify level of 1%-2% compared with 2%-3% previously, with the suspend level remains at 2%-3%. The "output measurement" suspend level has moved from 2%-3% to 1%-2% for most centres. The "HVL constancy" notify level has changed from 1%-2% to 4%-5% but the suspend level remains at 5%-10%. The "full HVL measurement" levels are unchanged. Field uniformity suspend level is now most commonly 4%-5%, changing from 5% to 10% previously. Tolerance levels for 4 tests not included in the 2016 survey are also included in the table.

For some tests, a wide range of acceptable limits were defined across the responding centres, such as "end effect consistency" defined in percentage, time and MU, and "backup treatment termination," which also included various percentage, time and MU, as well as responses of "no set level" and "confirm functional." Only survey limits specified in mm or percentage are included in the table, being the most common descriptors. The basic functional checks (interlocks, fixture, and filter tests) were universally associated with simple pass/fail criteria.

kV QC and dosimetry methods

For half-value layer (HVL) measurements, the required purity of metal is stated as 99.9%.[2] Of the responding centres, 65% stated that the aluminium they used for HVL measurement had at least 99.9% purity, with 35% stating a value below this level, which was generally given as 99.0% purity. For copper, 78% of responding centres stated at least 99.9% purity, with 22% giving a value less than this, generally 99 or 98% purity. Most centres (63%) did not respond to this question, and 8% stated they did not know the purity of their metal.

The most common method of measuring HVL constancy (at 64% of responding centres) involved placing a Farmer-type ion chamber at a fixed distance from the source with metal sheets, of one or a few thicknesses, at a fixed distance between the source and the chamber. The next most common method involving a Farmer-type chamber (16% of centres) utilized the ratio of measurements in solid water or Perspex blocks at 2 fixed depths. A 2D array device under 2 fixed build-up depths was used by 20% of centres. The popularity of these methods is consistent, within a couple of percent, of the data from the 2016 survey.[1]

For absolute HVL measurements, all respondents used a Farmer-type chamber positioned in air at a fixed distance, usually 100 cm, from the source with a narrow beam geometry, with a range of metal sheet thickness at the mid-point, as recommended in the kV CoP.[4] There was no response from 7% of centres to this question. The responses were consistent with the 2016 survey.

For dose output constancy checks, the preferred devices were either an electronic 2D array or a suitably large ion chamber check device, for very low, low, or medium energy kV energies, as recommended in the kV CoP.[4,5] Of the respondents, 87% preferred using a 2D array device for all kV energies. For absolute output measurements, all centres preferred using ion chambers with calibrations traceable to national standards laboratories, consistent with the methods described in the kV CoP.[4,5]

For focal spot measurements, 85% of centres use a dedicated pin-hole applicator with film, whilst the remaining centres use their smallest applicator with film. One centre used a device called PAICH, associated with the Zeiss Intrabeam, for focal spot testing.

There were mixed responses to QC methods used for field uniformity checks: 32% of centres used radiochromic films in contact with the applicator and analysed results qualitatively; 24% of centres used film with ImageJ or Python script for quantitative analysis; 32% of centres used a 2D array device to measure profiles, which were then compared with profiles taken at commissioning to check the field uniformity. The remaining 2 centres that responded to the question tested uniformity only at the time of commissioning with 3D scanning water tank, and diode detectors.

kV QC practices in the United Kingdom

Of the responding kV centres, 79% reported on their QC scheduling. Figure 4 summarizes the time taken for each department to perform the various QC sessions throughout the year. Only 41% and 32% of centres reported performing weekly and quarterly QC, respectively. Annual QC sessions were spread throughout the year in 64% of centres.

Almost all centres reported performing QC tests with frequencies of daily, monthly, or annual tests. Only 2 centres did not perform monthly QC. The mean (and interquartile range) of quoted hours to complete QC sessions was: daily 0.4 h (0.25-0.75 h), weekly 0.6 h (0.25-0.75 h), monthly 2.2 h (1.5-3.0 h), quarterly 2.2 h (1.5-3.0 h), and annually 3.2 (3.0-4.0 h). Three centres reported annual QC times of under 1 h as they spread out parts of their annual QC across the year into monthly sessions. If these are excluded, the mean time to perform annual QC tasks was 3.5 h. Two of the centres reported not performing annual QC at all. The survey did not separate daily warm-up time from QC session time. For example, the Xstrahl 200 has a warm-up time of 17.5 min;

Table 3. kV unit QC test frequencies at responding UK radiotherapy centres: percentage of centres using stated frequency, with comparison to Report 81.[2]

Parameter	Daily or treatment days	Weekly	Two-weekly	Monthly	Quarterly	Six-monthly	Annually	Commissioning only	When require/ post-service or repair	Never	N/A	Previous UK survey (2016)[1] most frequently used value	IPEM Report 81[2] recommended frequency
Interlocks	**94**	3							3			Daily	Daily
Applicator integrity	46	11		**34**		3			6			Monthly	Daily and monthly
Filter/applicator interlocks	**51**	9		20		3	3	3	6		6	Daily	Daily and weekly
Dose output Constancy	**94**			6								Daily	Daily
Output absolute measurement	11	9	3	**74**		3						Monthly	Monthly
Timer accuracy	6			**63**	9	3	3	6	3		11	Monthly	Monthly
Linearity				**49**	14	11	14				11	Monthly	Monthly
Dose control reproducibility	6	6		46	11	6	9	11	3		3	Not included	Monthly
Mechanical fixtures	20	6		**54**		3	3		11			Monthly	Monthly
Back-up treatment termination	17	3	3	**54**				6	3	6	9	Monthly	Monthly
Focal spot size and alignment				6	6	3	43	**29**	9	3	3	Commissioning only	Annually
Radiation field size				26	3	3	**49**	6	11		3	Annually	Annually
HVL constancy				**63**	3	6	14		3	9	3	Monthly	Monthly
HVL full					3	6	**54**	14	3	3		Annually	Annually
Uniformity	3			11	6	6	**60**	9	3	3		Annually	Annually
Applicator factors				11	3	6	**66**	9	6			Annually	Annually
Angular dependency of output				3	3	6	49	26	3	14		Not included	Annual
End effect consistency (effect of ramp up)			3	37	6	6	3	20	3	17	6	Not included	Monthly
Definitive calibration						3	37		**66**			Not included	Annual

For clarity, the most commonly reported frequencies in the current survey are indicated underlined, with the most common from the previous (2016) survey in bold typeface.
Abbreviation: kV = kilovoltage; QC = quality control.

Table 4. Notification and suspension limits for QC tests: percentage of responding UK radiotherapy centres using the specified limits, with comparison to IPEM Report 81[2] tolerances.

		Percentage of UK centres using specified tolerance value (x), % or mm								Previous UK survey (2016)[1] most frequently used value	IPEM Report 81[2] recommended "action limit"
QC test	Limit type	$x \leq 1$	$1 < x \leq 2$	$2 < x \leq 3$	$3 < x \leq 4$	$4 < x \leq 5$	$5 < x \leq 10$	$10 < x \leq 15$	$15 < x$		
Dose output constancy	Notify	3	58	**35**		3				$2 < x \leq 3$	3%
	Suspend	3	10	39	10	23	3			$2 < x \leq 3$	–
Output measurement	Notify	10	74	16						$1 < x \leq 2$	2%
	Suspend		42	**35**	13	3				$2 < x \leq 3$	–
Timer	Notify		23			3	3			$1 < x \leq 2$	–
	Suspend	3	29	3						$1 < x \leq 2$	–
Monitor chamber linearity	Notify	**32**	48							$x \leq 1$ and $1 < x \leq 2$	2%
	Suspend									$1 < x \leq 2$	–
Focal spot size and applicator alignment	Notify	39	6	3		3	3			$x \leq 1$	*1 mm*
	Suspend	29	13	3			6			$x \leq 1$	–
Radiation field size	Notify	6	48	3						$1 < x \leq 2$	2 mm
	Suspend	6	35	23	3					$1 < x \leq 2$	–
HVL constancy	Notify	10	**16**			35	3			$1 < x \leq 2$	5%
	Suspend	3	13		10	16	29			$5 < x$	–
HVL measurement	Notify	3	10			29	16			$4 < x \leq 5$	5%[a]
	Suspend		3			19	23	6	3	$5 < x$	–
Field uniformity	Notify		3	16		32	3			$4 < x \leq 5$	5%
	Suspend		3		3	39	**6**	3		$5 < x$	–
Applicator factors	Notify	13	29	19						$1 < x \leq 2$	2%
	Suspend	3	32	32	6	3				$2 < x \leq 3$	–
Dose control reproducibility	Notify	32	16							*Not included*	2%
	Suspend	29	13	6						*Not included*	–
End effect consistency	Notify	3	13							*Not included*	*0.02 min*
	Suspend		6	3	3					*Not included*	–
Definitive calibration	Notify	26	29							*Not included*	2%
	Suspend	16	35	6						*Not included*	–
Angular dependence of output	Notify	16	39	6						*Not included*	2%
	Suspend	10	13	32	3	3				*Not included*	–

[a]IPEM Report 81 Table 10.1 states 10%, but is given as 5% in the text of Section 10.4.1.
For clarity, the most commonly reported frequencies in the current survey are indicated underlined, with the most common from the previous (2016) survey in bold typeface. (Only those centres responding with % or mm are included, for alternative descriptors, see text).
Abbreviation: QC = quality control; HVL = half-value layer.

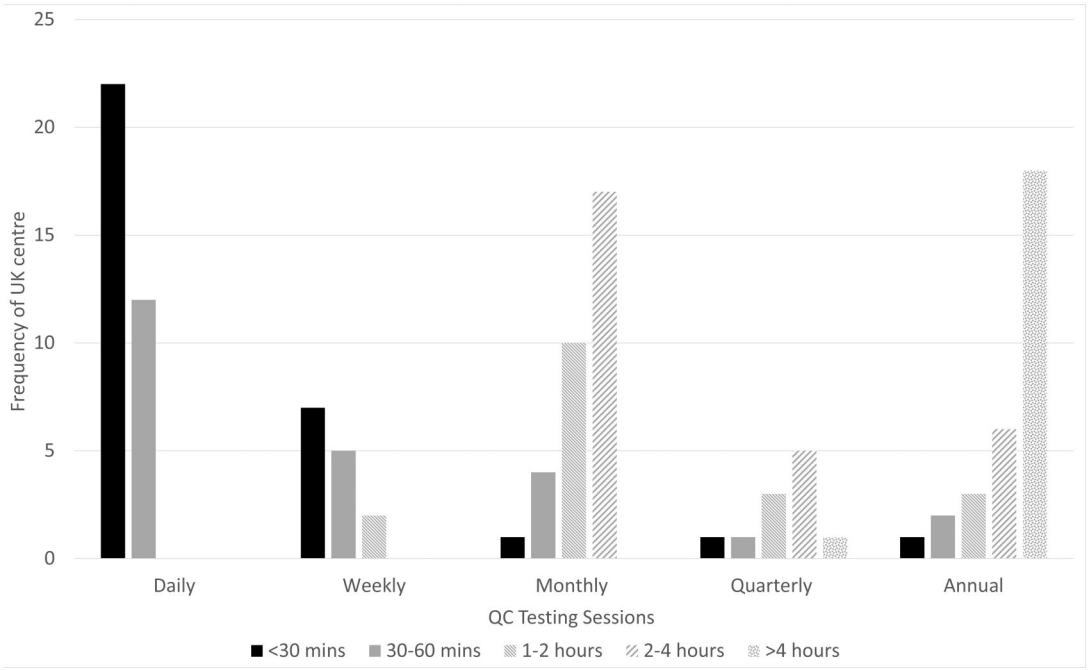

Figure 4. Duration of QC sessions at the responding kV centres for daily to annual QC. kV = kilovoltage; QC = quality control.

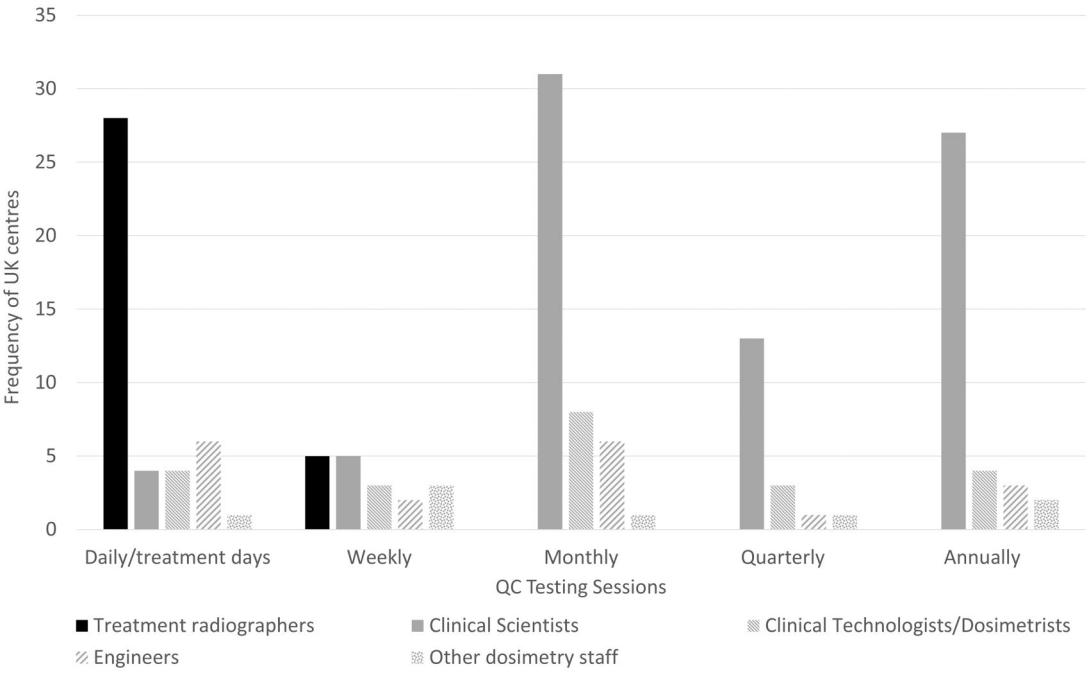

Figure 5. Staff group performing daily to annual QC session type. QC = quality control.

therefore, the average daily QC session time could be significantly lower.

Figure 5 shows the staff groups involved in performing each QC session type. Twenty-two out of 33 centres that responded reported that commissioning was performed by clinical scientists, with engineers performing some commissioning tasks in 2 centres.

kV treatment unit commissioning times were most commonly 1 month in duration, reported by 46% of centres, with 7% reporting commissioning taking just 2 weeks. Seventeen percent took 2 months, 13% 3 months, and 17% a longer duration. It would have been preferable to survey the total number of hours spent on commissioning, but these data are still valuable, indicating the overall periods taken by UK centres, accounting for other workload pressures. There is no clear correlation in the time taken to commission a kV unit and the number of energies to commission. However, the 2 centres who reported spending less than 2 weeks commissioning only had 1 kV energy. No trend was identified in regards to manufacture of kV unit and commissioning time.

Additionally, there was no relationship seen between commissioning time and dose calculation method.

kV radiation dosimetry

Thirty-six centres provided responses on questions related to kV radiation dosimetry, corresponding to 84% of kV radiotherapy centres in the United Kingdom. All radiotherapy centres were using the IPEM CoP and its addendum.[4,5] Four (11%) centres were using the "very low energy" range, 33 (91%) were using the "low energy" and 25 (66%) were using the "medium energy" range. For those centres using the medium energy range, 8 (33%) were using the original 1996 CoP measuring at 2 cm depth, and 16 (67%) were using the 2005 addendum for the CoP, measuring in-air. Of those using the original CoP and retaining an in-phantom measurement at medium energy, 3 (38%) centres stated the reason as "clinical relevance" as the main reason, 1 (13%) said "ease of setup," but 5 (63%) said for "historic reasons." This contrasted with the centres using the 2005 CoP, where 10 (63%) centres said "clinical relevance," 3 (19%) said "setup uncertainty," 8 (50%) said "ease of set up," and 5 (31%) said the "inherent accuracy of the code." All centres were asked to expand on their reasons for this question, but not all centres completed this question. For the 1996 CoP, 4 centres responded: 3 centres said it was historic, but said they will probably change when they get new machines. One said they recently had a new tube and took the additional measurements to switch codes so may change soon. One centre said they only treat ribs with their medium energy, so believe the 1996 CoP offers a more clinically relevant prescription point. Nine centres gave reasons for the 2005 CoP, with 8 centres saying it was because they prescribe to the skin, with some going further to say it is more accurate on the newer code. One centre said it is the latest guidance.

The ionization chambers used in radiotherapy centres as secondary standards (calibrated at a standards lab, including the National Physical Laboratory [NPL] in the United Kingdom) and field instruments (cross-calibrated against secondary standards in local centres and used for routine dosimetry measurements), at each energy range, are shown in Table 5. The NE2611 chamber was most common as a secondary standard at medium and low energies, with a few centres using the NE2561 and NE2611B chambers. Farmer-type chambers were exclusively used (with the exception of 3 blank answers for low energies) for field chambers, mostly of the NE2505/2503/2571/2781 types. For the very low energies, the PTW 23341 was used as secondary standard in all centres, with the PTW23342/PTW23344 used as field instrument.

There was evidence that interdepartmental audit is well established in most centres. Fifteen (42%) centres have had an audit in the last year, with a further 6 centres having audits in the last 3 years. However, 6 centres have not had an audit for 5-8 years. Three centres have never had an audit—one of these is an Intrabeam, and one is a Grenz ray unit, both of which are unique units, so they are hard to audit. The third is an XStrahl 200, and an audit has been requested for 2024. Overall, 58% of centres have received an external dosimetry audit in the last 3 years. Twenty-nine (81%) centres reported that dosimetry audits are scheduled according to the regional audit group schedule, 1 centre reported that they were scheduled annually, and 23 centres (59%) have an audit when commissioning a new machine. Three centres (8%) have an audit every 5 years. Four centres (11%) reported other reasons for an audit, 1 centre tries to do a TLD audit with an external audit performed annually in the department 1 one saying an audit has been requested in 2024 (this is the centre that has never had an audit).

Figure 6 shows a histogram of the consistency of host and auditor outputs for the most recent interdepartmental dosimetry audits undertaken. The range of output agreement is wide from −1.5% to 4%, with a mean output difference of 0.9 ± 1.6%. Fifty-eight percent ($n=21$) of all centres reported output differences of less than 2%, whilst 19% ($n=7$) reported differences between 2% and 3%. One centre reported a difference greater than 4%.

Discussion

kV equipment profile in the United Kingdom

Based on the survey responses, kV radiotherapy is used at 71% of UK centres, which is consistent with the 2016 survey (73%), the difference between surveys could be attributed to

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

Energy range	Secondary standard of field instrument	Chamber type or model number	Number of centres	Percentage of treatment units (%)
Very low	Secondary standard	PTW23342	4	100
		PTW23344	0	0
	Field instrument	PTW23342/PTW23344	4	100
Low	Secondary standard	NE2561	2	6.4
		NE2611	27	87.2
		NE2611B	2	6.4
	Field instrument	Farmer-type (NE2505/2503A/2571/2581);	24	70.6
		Farmer-type (Exradin A12/A19)	1	3
		Farmer-type (PTW30001/02, 30010/11/12/13, IBA FC65, etc.)	6	17.6
		No data provided	3	8.8
Medium	Secondary standard	NE2561	1	4.7
		NE2611	1	4.7
		NE2611B	19	90.6
	Field instrument	Farmer-type (NE2505/2503A/2571/2581);	21	80.7
		Farmer-type (PTW30001/02, 30010/11/12/13, IBA FC65, etc.)	5	19.3

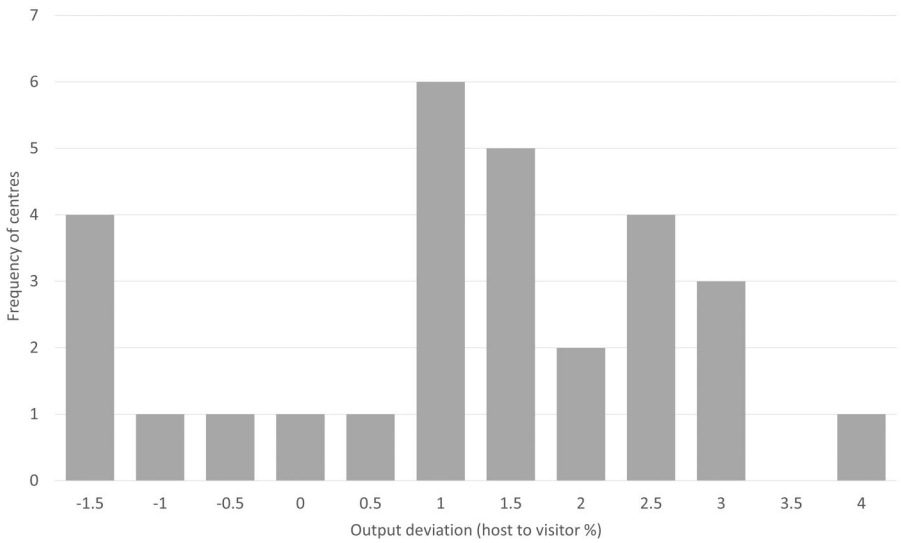

Figure 6. Consistency of host and independent dosimetry auditor kV output measurements for the most recent reported dosimetry audits undertaken at centres in the United Kingdom. kV = kilovoltage.

a difference in responding centres. Of the centres that do not use kV, 16% of respondents send their patients elsewhere; up from a figure of 3% (2 centres) from the previous survey.

In terms of manufacturer, most centres are using XStrahl systems (86%, 38 centres). The major change from previous manufacturer installed base is due to equipment replacement, with Gulmay (one across responding centres compared with 19 previous) machines being replaced by Xstrahl (37 up from 22 in 2016). This aligns with the replacement profile across the United Kingdom when compared to the previous survey, with only 24 installs having occurred since 2016. The majority of these are XStrahl installations replacing Gulmay units, resulting in a more recent age profile for machines.

kV clinical workload in the United Kingdom

kV treatment units make up an average 4.1% (range 0.1%-14.1%, IQR 1.9%-5.5%) of patient radiotherapy treatment at centres with kV units in the United Kingdom. This shows a decrease in activity from 5.0% in 2016. Comparing to treatment activity from the 2016 survey, it is noticeable that some centres treating less than 50 patients have decommissioned their kV units. This would make sense that reviewing service needs with a lack of demand or usage of a service, a service is closed. A Grenz ray unit has entered United Kingdom practice treating dermatological conditions.

There is some limited data presented showing that centres with more electron treatments treat less kV treatments and vice versa. These data are weakly correlated, and several factors not included in this survey would influence practice at a centre such as clinician experience and preference, and modalities available such as brachytherapy. Brachytherapy activity was not included in the survey and centres without kV units would not have completed the survey in detail to indicate how superficial treatments were carried out at their centre. There is scope to develop an audit to investigate this separately.

Treatment by energy is similarly proportioned between very low, low, and medium energy compared to the 2016 survey. However, the percentage of unused energies has decreased. This would be expected since several quieter centres have closed their kV service, and these would include a larger proportion of unused energies. The number of energies in this survey with less than 10 patients treated in a year was 30% of all clinical energies. Removing unused or low-use energies from clinical use would save QA time and improve maintainability of the service.

The broad range of clinical prescriptions recorded in this survey for BCC and SCC reflects a survey in 2014 by McPartlin et al.,[9] which identified similar, frequently used recommended prescriptions by RCR guidelines. They reported in that study a "large degree of variation in non-standard fractions proposed with significant potential differences in radiobiological effect." This has been evident in this study, with 40 Gy in 10# found to be in common use whilst not being covered under the RCR guidelines.

kV treatment planning

Data for use in treatment calculations at UK radiotherapy centres have been generated from several sources, primarily local measurement, BJR 25, relevant codes of practice, and manufacturers data. It was recommended in the 2016 survey that where possible, these sources of data should be cross-checked against each other at commissioning and then a decision as to the best data source to use can be made by each individual centre for all treatment planning calculations. This is still our recommendation. Responses from this survey suggest that only 17% of centres are using combined data sources for applicator factors and 9% for depth doses. Data regarding backscatter factors in particular indicated that the IPEM CoP was used where possible, but additional data were sought from BJR 25 or AAPM report 61[10] where necessary, with effects of non-standard FSD managed by comparison with data in Grosswendt[11] (1990). A further discussion regarding appropriate measurement mediums and appropriate detectors for use in measurements can be found in the 2016 survey.

The calculation of treatment MUs using software rather than manual calculation, has increased from 36% to 50% between the 2016 and 2024 surveys, which is still a relatively low percentage of centres. All centres perform a second check, and 50% of centres use a different calculation method for this check. We would recommend that all centres use 2

independent methods, with MU calculation software desirable, and that in-house action levels are established for agreement between the primary and secondary calculation if a second calculation method is used. All data sources must be properly commissioned and robust.

R&V integration

There has been an increase in kV units having their own R&V systems since the 2016 survey. This can be attributed to newer units being installed, which now have their own software for this functionality. Typically, only the units over 10 years old now do not have their own R&V systems. Integration into the main radiotherapy R&V software has increased to 31% of centres, up from 16% in the 2016 survey, which is still quite a low uptake, as 66% of centres indicated that there is a need for integration. There has been some interest from manufacturers in this development, and we recommend that further investment is necessary. Centres should include in their business case any additional licencing costs from both the kV and the third-party R&V supplier to implement integration as part of any new equipment tendering process.

kV QC methods and schedules

The most reported frequencies for performing QC tests were in general agreement with the recommendations of the second edition of Report 81[2] and the previous survey from 1996[1] for the majority of tests, although there was some variability across the United Kingdom.

In line with the previous survey, we defined a "notify" level as prompting further action while continuing clinical treatments, and a "suspend" level where operating performance would lead to the removal of a unit from clinical use. The UK survey data are presented using these terms in this report. We found these terms to be less ambiguous than the "tolerance" and "action" terms used in IPEM Report 81[2] Chapter 2, which 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," and performance outside the action level is unacceptable and demands further immediate action to remedy the situation.

The survey results presented in this report reflect a snapshot of QC activity across the United Kingdom from the responding centres. 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, for example Canadian Partnership for Quality Radiotherapy, CPQR,[12] and EU document RP 162.[13] The data presented here provide an updated consensus of opinion on actual QC practice across the United Kingdom, over and above the guidance set out in Report 81.

kV QC practice

There was no correlation seen between kV unit commissioning periods and other factors such as equipment manufacturer, or dose calculation method, and associated beam data collection. This could suggest that the dominant factor in commissioning time are other variables such as staffing availability, familiarity with the equipment, or local expertise. The duration required by a specific centre is dependent on local factors, and appropriate time must be allowed, with the data presented here only an indication of practice elsewhere. The survey did not collect total hours of commissioning time, but the overall period within which UK centres achieved readiness for clinical use.

kV radiation dosimetry in the United Kingdom

In the 2016 survey, half of all centres were using the 1996 CoP[4] for medium energies and half were using the 2005 addendum.[5] In this updated survey, this has changed to two-thirds of centres using the update, with a corresponding reduction in centres using only the original 1996 CoP. The reasons for maintaining the original CoP have changed; in the 2016 survey,[1] two-thirds of respondents said they used the 1996 CoP for clinical relevance, this was only cited by 38% of users in this survey with 63% of users saying they used it for historical reasons (not a reason given on the 2016 survey). Meanwhile the reasons for using the 2005 addendum have also changed; in the 2016 survey, the most common reason was "ease of setup," now the most common reason was "clinical relevance" at 63%, which is broadly in line with the 2016 survey. The previous most common reason for using the original 2005 code was "ease of setup" at 86% of respondents; this has fallen to 50% but is still high. Inherent accuracy of the code was not quoted at all for the 1996 CoP, but was quoted by 31% of respondents for the 2005 addendum, but this was higher than setup uncertainty.

There were no changes in terms of the chambers used for dosimetry since the 2016 survey, with all chambers still using the NE2561/2611/2611B as secondary standards and numerous variants of a Farmer-type chamber as field chamber for low and medium energies. Similarly, for very low energies, the same chambers as per the 2016 survey are used. This is consistent with the recommendations of the IPEM kV CoP.[4,5]

It is accepted in the United Kingdom that external dosimetry audits should take place regularly,[14] approximately every 3 years for each modality, or after a major change in equipment or processes.[15] However, there has been a fall in the number of centres receiving an audit in the last 3 years, from 64% to 58%, and an increase in the number of centres not having an audit in the last 5 years, only 2 centres in the 2016 survey, increasing to 6 centres in the current study. It is likely this is due to restriction of interdepartmental auditing during the covid pandemic. Forty-two percent of centres have been audited in the past year, which does suggest a recent improvement in dosimetry auditing. Fifty-nine percent of centres reported having an audit for a new treatment machine, which is similar to the previous survey (56%), which asserted the recommendation that an external audit should form part of the quality assurance of all new radiotherapy equipment installations.

The reported results of interdepartmental dosimetry show an improvement on the previous survey. Previously, half of all centres gave <2% agreement between host and auditor, compared to 58% in the current study. There is also an improvement reported in this survey at the 3%-5% agreement level, with the previous survey reporting 27% and the current survey only 19%. Only 1 centre reported a greater than 3% dose difference, compared to the previous survey, which reported 4 centres.

Conclusions

Ninety-one percent of UK centres ($n = 62/68$) responded to this survey of kV radiotherapy. The modality continues to make an important contribution to treatment options, available in approximately 70% of centres, treating a mean value of between 50 and 100 patients per year per centre, with the most common treatment being BCC used for a total of 1300 patients per year across the United Kingdom. Thirty-five percent of clinical treatment units are currently over 10 years old, an improvement on the previous survey from 8 years ago.

The survey data provide a good representation of current consensus practice for QC and dosimetry across the United Kingdom. This provides a useful resource for individual centres' assessment of QC and dosimetry needs in determining their practice and schedules. The contents of this report must not be interpreted as professional advice as to QC requirements and are presented as a UK benchmark only for comparison.

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Conflicts of interest

No authors have any conflict of interest to declare.

Cover statement

We are pleased to provide an update to the 2016 survey of kV use in the United Kingdom, which has been useful as a comparative benchmark for physics departments. An update is needed to reflect changes in practice. This work has been undertaken on behalf of the Institute of Physics and Engineering in Medicine (IPEM) Radiotherapy Physics Special Interest Group (RT-SIG) and the IPEM Interdepartmental Dosimetry Audit Sub-committee (IDA).

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