Physica Medica 65 (2019) 6–14

Contents lists available at ScienceDirect

Physica Medica

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

Original paper

A national survey on technology and quality assurance for stereotactic body radiation therapy

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ARTICLE INFO

Keywords:
Stereotactic body radiation therapy (SBRT)
Survey
Quality assurance (QA)
Technology

ABSTRACT

Purpose: Stereotactic body radiation therapy (SBRT) for early stage solid tumors and metastases is increasing worldwide. In 2013, the Italian Association of Medical Physicists (AIFM) created a working group in order to standardize the SBRT dosimetric aspects (AIFM/SBRT-WG). The aim of this study was to investigate the current status of technology and quality assurance (QA) as regards SBRT in Italy. Clinical evaluation of SBRT was beyond the scope of the present study.

Methods: A pre-questionnaire was designed by three medical physicists expert in SBRT. It contained questions on 4 main aspects: technology, image-guidance solutions (IGRT), treatment planning system commissioning and QA. In early 2018, all the centers involved in the AIFM/SBRT-WG were invited to complete the online questionnaire.

Results: The survey was undertaken by 45 centres (83% of them involved in the AIFM/SBRT-WG). The most available delivery system was conventional linacs with VMAT modality; 6MV and 6MV-FFF were the most common energies; robotic couch was available in 56% of centers; CBCT/MVCT was the most used IGRT technique (58% of centers) and 40% of centers adopted respiratory management during treatment delivery. The smallest measured field size for lateral beam profiles was $\leq 1 \times 1\ \text{cm}^2$ in 79% of linac-based centers. Great heterogeneity in terms of protocols and guidelines for QA were found. A large number of centers (51%) felt the need to upgrade their dosimetric QA devices dedicated to SBRT.

Conclusion: This survey on SBRT is a starting point in standardizing the dosimetry of SBRT verification and to improve the QA procedure.

1. Introduction

Modern radiotherapy is evolving towards a reduction in the number of fractions. Stereotactic body radiotherapy (SBRT) is a radiation therapy approach in which high doses are delivered in few fractions to small extra-cranial tumors with rapid dose fall-off outside the target. In particular, SBRT is becoming the elective therapy in several anatomic site, both for primitive tumors and metastatic lesions [1–5]. The success of SBRT can be largely attributed to technological advances in linac devices, treatment planning systems (TPS), image-guidance radiotherapy (IGRT) solutions, and advanced dosimetric quality assurance (QA) procedures [6]. Initial clinical experiences were usually performed in university hospitals within controlled clinical trials [7]. However, SBRT is now no longer limited to highly-qualified academic centers but is routinely adopted in smaller and non-academic centers, too [8]. Therefore, the sharing of knowledge by centers with different experiences is useful in SBRT implementation. For this reason in 2013, the Italian Association of Medical Physics (AIFM) set up a working group focusing on the physics and technical aspects of SBRT (AIFM/SBRT-WG) [3,4,9–22].

To the best of our knowledge, the few countries that have conducted nationwide surveys of SBRT, have done so mainly to evaluate the

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https://doi.org/10.1016/j.ejmp.2019.07.025
Received 29 March 2019; Received in revised form 26 July 2019; Accepted 30 July 2019
Available online 05 August 2019
1120-1797/

clinical aspects of SBRT and not specifically to assess the technology, dosimetry and quality assurance dedicated to SBRT [7,23–28]. A very comprehensive survey was launched by the UK stereotactic ablative body radiotherapy Consortium with the aims of ascertaining the progress being made towards the implementation of SBRT, of obtaining details of current practice and forecasting future provision [29]. The survey covered several areas such as simulation, motion management techniques, treatment planning, image-guidance and QA methods. A survey has been performed in UK by Dimitriadis et al. [30] to analyze the clinical and dosimetric aspects of cranial stereotactic treatment.

In this study, a questionnaire-based survey was conducted to clarify the technologies currently used in SBRT treatments focusing on dosimetric aspects of TPS commissioning and quality controls. Clinical evaluation of SBRT was beyond the scope of the present study.

2. Materials and methods

A pre-questionnaire was designed by three medical physicists expert in SBRT. It contained questions on 4 main aspects of SBRT: technology, IGRT solutions, TPS commissioning and QA. The pre-questionnaire was sent to 7 AIFM/SBRT-WG board members and their suggestions were included in the final survey. All 54 centers involved in the AIFM/SBRT-WG were contacted by mail in early 2018 and invited to complete the online questionnaire. The survey was collected using Google Form.

The questionnaire consisted of 29 multiple choice questions. For each query, a free text was available covering every aspect of the working reality of all the participants. The full questionnaire list is reported in Appendix A.

Answers were analyzed using basic descriptive statistics. Further sub-stratifications were performed to analyze trends.

3. Results

Physicists from 45 centers (83% – total: 54 centers) completed the survey. A detailed summary of the survey is reported below.

The national geographic distribution of the responses was: 51%, 31%, and 18% from north, center and south of Italy, respectively. This almost corresponds to the percentage of inhabitants in the three areas: 47% (north), 33% (center), 20% (south) (https://www.istat.it/it/popolazione-e-famiglie). At the time of the survey, 78% of the centers (35/45) had > 2 years' experience of SBRT treatments. It should be noted that in a previous internal survey, not published, performed when the AIFM/SBRT-WG was established in 2013, the percentage of centers with > 2 years' experience and assuming at least 50 patients treated with SBRT per year was < 50%, showing that the use of SBRT has grown in the last few years.

3.1. Technology

Fig. 1 shows the systems dedicated to SBRT and the delivery techniques. Fifty-five machines dedicated to SBRT from the 45 centers were identified, that is, 78% (35/45), 20% (9/45), and 2% of the centers (1/45) claimed, respectively, one, two, or three (or more) machines for SBRT. Linac was the most commonly available delivery system (69% of machines – 38/55), while dedicated systems, such as Cyberknife (Accuray, USA), Tomotherapy (Accuray, USA) and Vero (Mitsubishi Heavy Industries, Ltd., Japan and BrainLAB AG, Feldkirchen, Germany) represented a percentage of 11% (6/55), 15% (8/55), and 5% (3/55), respectively.

Of the linac treatments, many centers declared to adopt different delivery techniques on the same machine. In detail, Volumetric Modulated Arc Therapy (VMAT) was the most used delivery technique (89% – 34/38 Linacs), followed by dynamic arc (24% – 9/38 Linacs) and Intensity Modulated Radiation Therapy (IMRT) (21% – 8/38 Linacs).

The most used energy was 6MV, flattening filter beam (available in 73% of the centers, 33/45) and Flattening Filter Free (FFF) beam (available in 44% of the centers, 20/45); maximum energy was 10 MV. More than one energy was adopted for SBRT treatments in around half of the centers.

It is interesting to note that robotic couch (i.e. repositioning based on 6 dimensions, 3 translations + 3 rotations) was available in 56% of the centers (25/45), most of them with linacs (52% – 13/25).

Multileaf collimator (MLC) was available in 96% of the centers (43/45). Two centers with Cyberknife adopted only cylindrical cones. MLC width at the isocenter was 5 mm or less in 81% of cases (35/43 centers). Ten centers (23% – 10/43) had MLC width of 2.5 mm.

3.2. IGRt

Forty-four centers (98% – 44/45) used online daily IGRT before treatment delivery. In particular, computed tomography, either cone beam (CB)-CT or Mega Voltage (MV)-CT, was used by 26 centers (58% – 26/45). Three centers of these (11% – 3/26) performed 4D-CBCT before treatment. Single or stereoscopic X-ray imaging with kilo Voltage (kV), Mega Voltage (MV), and simultaneous kV/MV were used in 20% (9/45), 17% (8/45) and 5% (2/45) of the centers respectively. Four centers (9% – 4/45) used surface optical localization, while one center (2% – 1/45) adopted GPS localization and one center (2% – 1/45) used ultrasound for repositioning. The majority of the centers performed daily IGRT before treatment only (56% – 25/45), 27% (12/45) performed it also during treatment (in terms of verification performed between arcs/fields), 13% (6/45) acquired images also at the end of the treatment and the remaining 4% (2/45) performed IGRT pre- during- and post-treatment.

Fig. 2 shows the tumor motion management during the simulation CT and the delivery. As shown, respiratory correlated four dimensional CT (4DCT) for accurate target definition and motion assessment was used in the majority of the centers (60%). Forty percent of the centers used active motion management techniques (breath hold, gating or

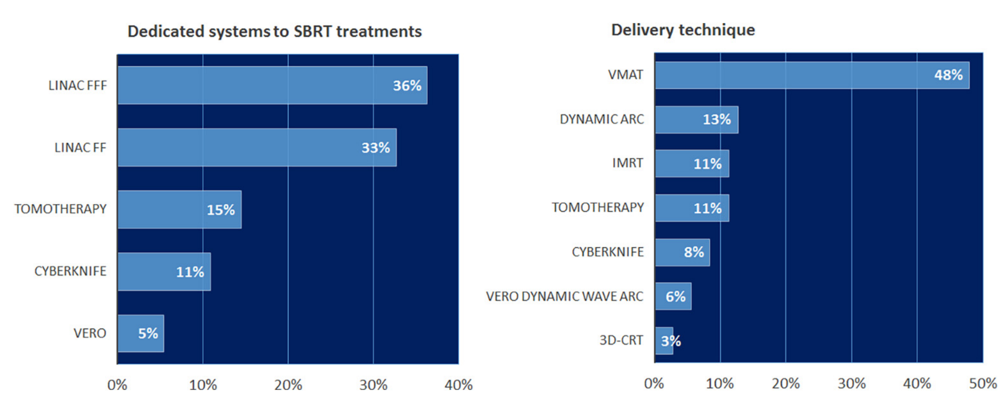

Fig. 1. Percentage of machines dedicated to SBRT (55 machines in total) (left) and percentage of delivery techniques available in all centers (right).

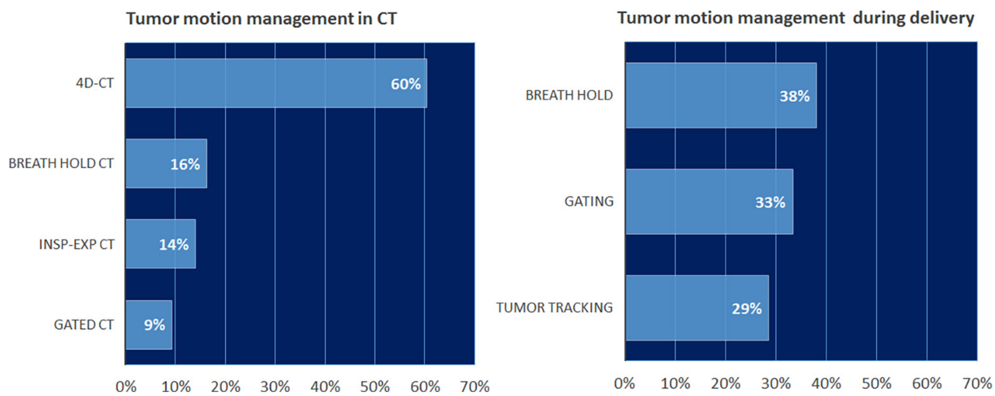

Fig. 2. Tumor motion management during CT simulation (left) and delivery (right).

tracking) during treatment delivery, while only 3 centers used abdominal compression.

3.3. Treatment planning system

The detectors used for TPS commissioning were: micro-ionization chambers with active volume < 0.05 cm^3 (72% – 32/45 centers), diodes (56% – 25/45 centers) and diamond detectors (38% – 17/45 centers).

Table 1 shows data on dose calculation algorithms, calculation grid size, minimum measured and commissioned output factor (OF) and profile. The majority of the linac-based centers (79% – 30/38 Linacs) measured OF and lateral beam profiles down to field size ≤10 × 10 mm^2, probably as a consequence of the multicenter studies on small fields carried out within the AIFM/SBRT-WG [10,13–17]. In these multi-center studies, square field sizes as low as 5 mm were measured with 3 detectors: micro-diamond PTW-60019 (PTW, Freiburg, Germany), optical fiber W1 (Standard Imaging, Middleton, USA) and stereotactic semiconductor Razor (IBA dosimetry, Schwarzenbruck, Germany). However, it is interesting that only 49% (18/38 Linacs) of the centers entered the smallest measured beam into the TPS for the dose calculation. Furthermore, the majority of the centers that entered fields ≤10 × 10 mm^2 into the TPS, had 2 or more measurement devices dedicated to small field dosimetry. The table shows that there is great heterogeneity in dose calculation algorithms and settings. According to Knöös et al. classification [31], type-c model-based dose calculation algorithms, such as Monte Carlo techniques and deterministic solvers (currently Acuros AXB, Varian), were used only in just over 30% of cases (14/45 centers). Half of the centers adopted a calculation grid size of 2 mm (47% – 21/45), while grid size > 3 mm was adopted in 7% of the centers (7/45).

3.4. Quality assurance

Regarding the SBRT commissioning and QA program, the centers followed different reference protocols; the majority of the centers followed AAPM reports 54, 101, 119, 135, 142, 148, 178 or ICRP documentations 83, 91, or NCS 24. The lack of standardized reference protocols also led to multiple approaches in pre-treatment patient-specific verification management, both in terms of devices dedicated to QA and gamma agreement index (GAI) passing rate criteria. It is therefore necessary to standardize the minimal requirement reference documents.

Table 2 reports data on pre-treatment QA procedures. Ion chambers and diode arrays were the most used devices dedicated to SBRT patient specific QA: cylindrical matrix was used in 38% of the centers (17/45), while planar matrix was used in 22% of the centers (10/45). EPID and Gafchromic films were adopted by, respectively, 22% (10/45) and 18% of the centers (8/45). Regarding detector arrays, the minimum distance between detectors was > 4.1 mm in all cases. It is important to highlight that more than half of centers (51% – 23/45) felt the need to upgrade their dosimetric devices dedicated to SBRT QA.

Patient specific QA was performed in all patients before the start of the first fraction in 67% of the centers (30/45); 20% (9/45) performed it only for selected cases; 11% (5/45) adopted a random approach; one institute (2% – 1/45) did not perform any patient specific QA program at all.

Sixty-three percent of the centers (28/45) adopted GAI (2 mm, 2%) as acceptance criteria (i.e. distance to agreement, DTA = 2 mm and dose difference, DD = 2%), using local or maximum approaches for DD estimation. It should be noted that, some centers evaluated a DTA = 2 mm with equipment having an intrinsic spatial resolution > 4 mm. Many centers adopted a two-step gamma criteria and passing

Table 1
Details of dose calculation algorithms and TPS commissioning for SBRT.

Dose calculation algorithm		TPS calculation grid size (mm)		Minimum measured OF (mm)		Minimum OF commissioned in TPS (mm)		Minimum measured profile (mm)		Minimum profile commissioned in TPS (mm)	
Monte Carlo	24%	1	11%	< 10 × 10	45%	< 10 × 10	15%	< 10 × 10	33%	< 10 × 10	13%
PB	15%	1.25	13%	10 × 10	27%	10 × 10	29%	10 × 10	38%	10 × 10	29%
CCC	34%	1.5	9%	16 × 16	2%	16 × 16	7%	16 × 16	2%	16 × 16	7%
AAA	30%	2	47%	20 × 20	13%	20 × 20	27%	20 × 20	14%	20 × 20	25%
ACUROSXB	7%	2.5	11%	30 × 30	2%	30 × 30	9%	30 × 30	2%	30 × 30	11%
		3	7%	40 × 40	2%	40 × 40	2%	40 × 40	2%	40 × 40	2%
				Tomo (400 × 10)	2%	50 × 50	2%	Tomo (400 × 10)	2%	50 × 50	4%
				Tomo (400 × 25)	7%	Tomo (400 × 10)	2%	Tomo (400 × 25)	7%	Tomo (400 × 10)	2%
						Tomo (400 × 25)	7%			Tomo (400 × 25)	7%

Legend: TPS = treatment planning system, PB = Pencil Beam algorithm, CCC = Collapsed Cone Convolution algorithm, AAA = Analytical anisotropic algorithm, OF = output factor.

Table 2
Patient specific pre-treatment QA characteristics.

SBRT QA		SBRT verification devices		N° QA devices for center		N° QA Evaluations		QA Evaluation method		Gamma evaluation threshold		Gamma passing rate		In-vivo dosimetry	
Yes, for all patients	67%	EPID	19%	1	58%	1	71%	Local Gamma	46%	3%/3 mm	43%	98%	2%	Yes	13%
Yes, for selected cases	20%	Gafchromic	15%	2	35%	2	24%	Global Gamma	34%	3%/2 mm	4%	95%	43%	No	87%
Yes, random	11%	Planar array	19%	3	7%	3	5%	DVH	5%	3%/1 mm	4%	90%	43%		
No	2%	Cylindrical array	33%					Other	14%	2%/2 mm	43%	85%	8%		
		Ion Chamber for point dose	14%							2%/1 mm	4%	80%	4%		
										1%/2 mm	2%				

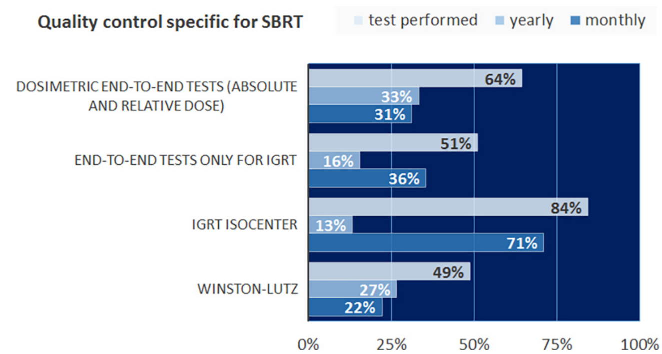

Fig. 3. Specific quality controls performed with relative frequency.

rate. An initial very restrictive threshold was used to evaluate whether the plan quality could be defined as “ideal” (GAI (2 mm, 2%) > 95%); otherwise a less restrictive threshold was adopted to define the plan quality as “acceptable” (GAI (3 mm, 3%) > 90%). However, there was no general and standardized threshold for all the centers, showing the need for common guidelines.

The majority of the centers (51% – 23/45) did not performed the Winston Lutz test, of those who did, 22% (10/45) did it once a month, 27% (12/45) once a year.

Specific IGRT isocenter verification was performed monthly or annually by 71% (32/45) and 13% (6/45) of the centers, respectively. IGRT end-to-end tests were performed monthly by 36% (16/45) and annually by 16% (7/45) of the centers. Worth noting that IGRT plus absolute/relative dosimetric end-to-end tests were performed monthly or annually in 31% (14/45) and 33% (15/45) of the centers, respectively (see Figs. 3 and 4).

4. Discussion

This survey falls within the framework of the Italian working group on the technical and dosimetric aspects of SBRT. The principal aim of this paper was to provide a snapshot of SBRT technology and dosimetric procedures for TPS commissioning and QA nationally. The authors would like to underline the fact that no feedback was given to the centers. This survey was to be used to harmonize SBRT dosimetry QA at a national level and to define minimum requirement guidelines for a safe SBRT implementation from a technical and dosimetric point of view. To the best of our knowledge, nationwide surveys of SBRT have been conducted in only a few countries [7,23–29], and all of them focused on the clinical use of SBRT, including technology, IGRT, dose regimens and disease sites. The survey presented in our work focused more on the technical and dosimetric aspects of SBRT related to TPS commissioning and QA.

In 2014 Dahele et al. [7] reported that the preferred delivery method was fixed conformal beams (61%), while VMAT was used in only 16% of centers. More recently, Bae et al. [28] gave the same percentage of centers using VMAT (16%), while the majority of centers delivered SBRT with static field IMRT (76%). Our findings, obtained in 2018, showed VMAT to be the first choice for the majority of centers (67%). This is probably because of the rapid development of VMAT technology all over the world in the last few years. This can also explain why SBRT is no longer limited to highly-qualified academic centers but is routinely adopted in smaller and non-academic centers, too [8]. In this paper, Aznar et al. [8] referred to lung SBRT, however we believe that this could be referred to SBRT in general. In fact, Bae et al. [28] reported that the number of institutions using SBRT has shown a gradual increase year by year and 76% of SBRT users planned to increase its use. Pan et al. [24] suggested that the technology has become accessible to the broader radiation oncology community. Our findings confirmed this trend. To note that Dahele et al. [7], in 2014, reported

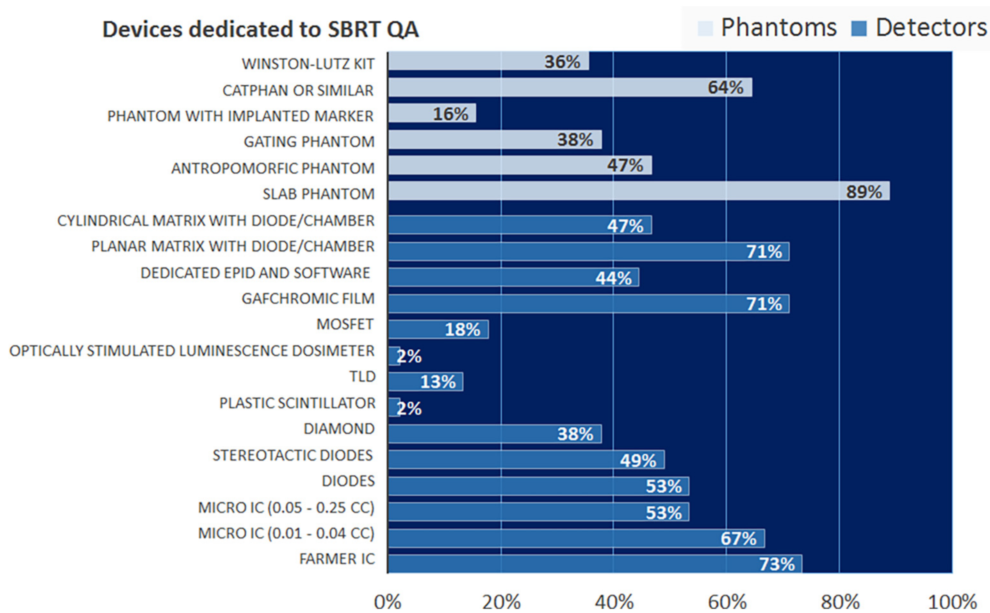

Fig. 4. Devices dedicated to SBRT QA.

that 69% of experts interviewed believed that SBRT should be limited to experienced centers treating a lot of patients. Dahele et al. [7] also reported that 33% of centers had MLC leaf width of 10 mm. In our survey, only one center delivered SBRT with MLC leaf width of 10 mm at the isocenter distance, reflecting the recent upgrade of the equipment dedicated to SBRT.

Small field dosimetry was harmonized in Italy with the help of AIFM/SBRT-WG multicenter studies involving a large number of sites and by sharing the results with the aim of standardizing procedures. As a consequence, the majority of the linac-based centers in this study measured OFs and lateral beam profiles down to field size $\leq 1 \times 1\text{cm}^2$ with proper detectors. However, accurate experimental determination of OFs in small fields is only one component in the accurate dose calculation of the TPS. The other aspect is the implementation or modelling of these OFs in the TPS, which is critical for dose calculation accuracy. Recently [32], a multinational audit showed that the OFs for small fields calculated by TPSs were generally larger than measured reference data. These deviations increased with decreasing field size with 30% of the calculated OFs for $2 \times 2\,\text{cm}^2$ field exceeding the action limit of 3%. This is probably the reason why only 49% of the centers involved in the present study included the smallest measured beam into the TPS for dose calculation.

As regards the TPS calculation grid size, our findings were consistent with the ICRU 91 [33] and AAPM TG-101 report [6] recommendations to adopt an isotropic grid size of 2 mm or finer for SBRT planning. Type-b algorithms are superior to type-a methods of dose calculation in electron disequilibrium regions and are adequate for conventional clinical SBRT application. ICRU 91 Report recommended the use of type-c model based dose calculation algorithms for small field dose calculation for situations involving small fields and tissue heterogeneity, The use of such algorithms are preferable and must be encouraged at a national level especially with higher beam energy because the impact of lateral electron scatter becomes more significant as the lateral range of the secondary electrons increases.

As far as tumor motion management during imaging is concerned, 4D CT for accurate target definition and motion assessment was adopted in 60% of centers, 14% used only the inspiration and expiration phases (Cyberknife). Our results are in agreement with the findings of surveys conducted in Korea [28], United States [26], and Germany and Austria [7,27] where the most common CT planning method was 4D CT.

Regarding IGRT, our survey confirmed volumetric imaging such as CBCT or MV CT (Tomotherapy) to be the most common procedure adopted for SBRT. Bae et al. [28] and Dahele et al. [7] reported the use of CBCT in 87% and 56% of centers respectively.

Bae et al. [28] reported that the two most commonly used techniques were respiratory-gated radiotherapy (63%) and forced shallow breathing with abdominal compression (34%). In a survey of SBRT practice in six selected European countries, Dahele et al. [7] reported the use of motion reduction or compensation techniques in 24/30 centers, 9 using abdominal compression, 8 gating, 4 tumor tracking and 3 forced breath hold. In comparison, in our study we found that 40% of the centers used active motion management techniques (breath hold, gating or tracking) during treatment delivery, while only 3 centers used abdominal compression.

Although we did not include in our survey a question on treated tumor sites, being the survey specifically designed to investigate technical and dosimetric aspects of SBRT, we can reasonably assume that most of the SBRT treatments performed by the centers are for lung tumors, while the rest for liver and abdominal lesions. Indication of tumor sites will be included in a future more general survey on SBRT clinical practice which will allow us to. This data will allow us to correlate the motion management techniques and relative quality assurance procedure with the tumor site.

A recent Japanese paper reported a large survey over 490 institutions on operational situations, treatment planning and processes, and quality assurance with relevance to SBRT, IMRT, and IGRT [34]. Authors reported that medical physicists were engaged in the quality assurance procedure only in 65% of the institutions. Authors concluded that a manpower shortage should be corrected for high-precision radiotherapy, especially in the field of quality assurance. In our study, all centers had medical physicists expert in radiation physics available and a large number of centers indicated the need to improve the equipment dedicated to SBRT, especially as far as QA is concerned.

In a survey on planar IMRT QA analysis with 2D diode array devices, Nelms and Simon [35] found that 64% of centers used a field-by-field method with different values of DD and DTA and 58% performed absolute dose analysis. Our study revealed heterogeneity in the use of GAI criteria, most of the centers using 2%/2mm, which agrees with the results obtained in other surveys [30]. A possible explanation is the heterogeneity in the QA instrumentation that would induce different GAI criteria.

A possible limitation of this study was that the survey was sent to physicists belonging to the AIFM-SBRT working group, that is to those experienced in SBRT. Different results could be obtained with a larger dataset including non-SBRT oriented centers.

In conclusion, this survey has revealed general heterogeneity in the dosimetry of SBRT and QA procedures. It could allow us to define minimum requirements for SBRT dosimetry and to improve the QA procedure. A comprehensive survey in collaboration with radiation oncologists that includes clinical aspects of the SBRT is warranted to have a clear picture of SBRT use in Italy and possibly to define national guidelines covering all the different aspects of SBRT with the final aim of a safe broad implementation of this technique.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Acknowledgements

The authors would like to thank all the physicists who answered the questionnaire, most of whom are involved in the AIFM/SBRT-WG and Miss Verlie Jones, dosimetrist at the European Institute of Oncology, for her editorial assistance in English.

Appendix A Questionnaire

Technology

1) Experience in SBRT treatments
   o < 1 year
   o 1–2 years
   o 2 years
   o Next implementation
2) *Dedicated systems to SBRT treatments* (Indicate one or more technologies)
   o TOMOTHERAPY
   o CYBERKNIFE
   o MITSUBISHI – VERO LINAC SYSTEM
   o VARIAN 600CD
   o VARIAN UNIQUE PERFORMANCE
   o VARIAN 2100
   o VARIAN 2300
   o VARIAN TRILOGY
   o VARIAN TRUEBEAM
   o VARIAN EDGE
   o ELEKTA COMPACT
   o ELEKTA PRECISE
   o ELEKTA SYNERGY
   o ELEKTA INFINITY
   o ELEKTA AXESSE
   o ELEKTA VERSA HD
   o SIEMENS
3) *Robotic couch*
   o Yes
   o No
4) *Model of Robotic couch, if available*
   o Elekta HexaPOD Varian PerfectPitch
   o Tema Protura
   o BrainLab ExacTrac
   o CyberKnife
   o BrainLab (Vero)
   Additional information__________________
5) *MLC dimension at isocenter* (Indicate the smallest available thickness in the central part of MLC)
   o 2.5 mm
   o 4 mm
   o 5 mm
   o 6.25 mm
   o 10 mm
   o Other
6) *Energy used for SBRT treatments*
   o 6MV
   o 6MV-FFF
   o 10MV
   o 10MV-FFF
   o Other
7) *Delivery technique*
   o VMAT
   o IMRT
   o Dynamic Arc
   o 3D-CRT
   o Cyber
   o Tomo
   o Vero Dynamic Arc
   o Vero Dynamic Wave Arc
   o Other

Image-guided solution (IGRT)

8) *IGRT technique* (Select one or more used techniques)
   o CBCT or MV CT (Tomo)
   o 4D-CBCT
   o MRI
   o KV
   o MV KV/MV
   o Ultrasound
   o Surface Optical localization
   o Electromagnetic localization
   o Other
   Additional information__________________
9) *Tumor motion management in CT*
   o Gated CT
   o 4DCT
   o Breath hold CT
   o Free-breathing CT
   o Insp-Exp CT
   o Nothing
   o Any clarifications
10) *Respiratory management during delivery*
   o Gating
   o Breath hold
   o Tumor tracking
   o Free-breathing
   o Nothing
   o Other
   Additional information__________________
11) *Timing for IGRT (SBRT)*
   o Pre-Treatment
   o Post-Treatment
   o During Treatment
   o Other
   Additional information__________________

Treatment planning system commissioning

12) *TPS*
   o Monaco
   o Eclipse
   o RayStation
   o RayPlan

o Pinnacle
o Multiplan
o MasterPlan
o TomoPlan
o iPlan RT
o Other

13) *Calculation algorithm for SBRT*
o CCC
o Monte Carlo
o AAA
o Acuros XB
o PB
Additional information___________________

14) *Calculation grid size for SBRT*
o 1.00 mm
o 1.25mm
o 1.50 mm
o 2.00 mm
o 2.25mm
o 2.50 mm
o 3.00 mm
o Other

15) *Lowest output factor measured (cm)*
o < 1 × 11 × 1
o 1.6 × 1.6
o 2 × 2
o 2.4 × 2.4
o 2.6 × 2.6
o 3 × 3
o 3.2 × 3.2
o 4 × 4
o 4.2 × 4.2
o 5 × 5
o Tomo (40 × 2.5)
o Other
Additional information___________________

16) *Lowest output factor inserted in the TPS (cm)*
o < 1 × 1
o 1 × 1
o 1.6 × 1.6
o 2 × 2
o 2.4 × 2.4
o 2.6 × 2.6
o 3 × 3
o 3.2 × 3.2
o 4 × 4
o 4.2 × 4.2
o 5 × 5
o Tomo (40 × 2.5)
o Other
Additional information___________________

17) *Lowest profile measured (cm)*
o < 1 × 1
o 1 × 1
o 1.6 × 1.6
o 2 × 2
o 2.4 × 2.4
o 2.6 × 2.6
o 3 × 3
o 3.2 × 3.2
o 4 × 4
o 4.2 × 4.2
o 5 × 5
o Tomo (40 × 2.5)
o Other
Additional information___________________

18) *Lowest profile inserted in the TPS (cm)*
o < 1 × 1
o 1 × 1
o 1.6 × 1.6
o 2 × 2
o 2.4 × 2.4
o 2.6 × 2.6
o 3 × 3
o 3.2 × 3.2
o 4 × 4
o 4.2 × 4.2
o 5 × 5
o Tomo (40 × 2.5)
o Other
Additional information___________________

Quality assurance

19) *Reference protocols used for SBRT commissioning and QA program*
o AAPM TG 142
o AAPM TG 101
o AAPM TG 54
o AAPM TG 135
o AAPM TG 178
o AAPM TG 119
o AAPM TG 148
o NCS 24
o Other
Additional information___________________

20) *Devices dedicated to SBRT QA*
o Farmer Ion Chamber
o Micro Ion Chamber (0.01–0.04 cc)
o Micro Ion Chamber (0.05–0.25 cc)
o Diodes
o Stereotactic Diodes
o Diamond
o Plastic scintillator
o TLD
o OSLD (Optically Stimulated Luminescence Dosimeter)
o Mosfet
o Gafchromic
o Slab phantom
o Antropomorfic phantom
o Gating phantom
o Phantom with marker
o Planar matrix with diode/chamber
o Cylindrical matrix with diode/chamber
o Dedicated EPID and Software
o Catphan or similar
o Winston-Lutz Kit
o Other
Additional information___________________

21) *Resolution of Matrix Diode/chamber dedicated to SBRT*
o < 2 mm
o 2–4 mm
o 4.1–6 mm
o > 6 mm
o Matrix not supplied
Additional information___________________

22) *SBRT Patient Specific QA*
o Yes, for all patients
o Yes, only for selected cases
o Yes, but with a random approach
o No
o Other

23) *Device dedicated to SBRT Patient Specific QA*

o Planar matrix
o Cylindrical matrix
o EPID
o Gafchromic films
o Other
Additional information__________________
o *SBRT patient Specific QA evaluation* Global analysis
o Local analysis
o DVH
o Other
Additional information__________________

24) *Gamma analysis parameters*
o 1%/1mm
o 1%/2mm
o 2%/1mm
o 2%/2mm
o 3%/1mm
o 1%/3mm
o 3%/2mm
o 2%/3mm
o 3%/3mm
o Other
Additional information__________________

25) *Gamma passing rate*
o 80%
o 85%
o 90%
o 95%
o 98%
o Other
Additional information__________________

26) *In vivo dosimetry availability*
o No
o Yes (specify the name of used system)

27) *Monthly QC specific for SBRT*
o Winston-Lutz
o IGRT isocenter
o End-to-End only for IGRT
o Dosimetric End-to-End (absolute and relative dose)
Additional information__________________

28) *Annual QC specific for SBRT*
o Winston-Lutz
o IGRT isocenter
o End-to-End tests only for IGRT
o Dosimetric End-to-End tests (absolute and relative dose)
Additional information__________________

29) *Do You feel the necessity to upgrade your dosimetric QA device dedicated to SBRT?*
o Yes
o No
o Other
What would you like to buy? _________________

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