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ORIGINAL ARTICLE

Current Status of Stereotactic Radiotherapy in Türkiye: Turkish Society for Radiation Oncology Stereotactic Radiotherapy Study Group 10-006 Survey

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OBJECTIVE

Stereotactic radiotherapy (SRT)/Stereotactic body radiotherapy (SBRT) constitutes extensively employed therapeutic modalities for various cancer types in our country, offering precise and conformal delivery of high radiation doses. This survey aims to analyze the current status of SRT/SBRT in our country.

METHODS

A total of 34 questions were asked by an online survey through Google Forms (SurveyMonkey) in October 2021. This nationwide survey focused on the demographic information of participants, SRT application techniques, treatment planning, and the utilization of SRT in clinical practice.

RESULTS

The survey was completed by a total of 106 respondents. A predominant number of participants belonged to the 40–50 age group, with <10 years of experience. Linear accelerators (92%) were the most common devices used for SRT, followed by CyberKnife (27%), Gamma Knife (5%), and Magnetic resonance imaging-Linac (3%). Combined kilovolt/megavolt portal imaging with cone-beam computed tomography (CBCT) was the most commonly used imaging verification method (58%). Treatments typically began within 2–7 days (76%) after simulation. The number of patients treated with SRT/SBRT over the past year varied in a wide range, with a median of 50 (range: 0–1000) patients. SRT/SBRT was applied in many cancer types including mostly brain (98%), lung (89%), bone (89%), adrenal (64%), liver (47%), prostate (42%), head and neck (41%), pancreas (35%), and other tumors (3%).

CONCLUSION

SRT/SBRT applications in our country vary in terms of number, experience, and treated tumor groups. These results are crucial for understanding the current status of SRT, treatment indications, challenges, and diversity in application approaches in our country.

Keywords: Cancer; stereotactic body radiotherapy; stereotactic radiotherapy; survey.

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INTRODUCTION

The significant progress in radiation therapy technology, encompassing the utilization of multiple imaging modalities and advanced computer technology in treatment planning, coupled with the advancements in linear accelerator capabilities, has significantly enhanced the accuracy of radiation delivery. Stereotactic radiotherapy (SRT)/Stereotactic body radiotherapy (SBRT) is an advanced and precise technique for treating small targets using numerous treatment beams.[1] SRT/SBRT utilizes highly conformed high-dose volumes shaped by multiple beams, often achieving excellent local control rates with minimal complications.[2]

The introduction of stereotactic radiosurgery (SRS) for the treatment of arteriovenous malformations was undertaken by Leksell in 1951.[3] Initially developed for intracranial tumors, SRT utilized the Gamma Knife, but nowadays, most centers employ conventional linear accelerators (Linacs) for intracranial SRT. Since 1995, SBRT has been employed to treat small primary or metastatic tumors outside the brain, predominantly in the lungs and liver.[4,5]

Modern Linacs integrate advanced 2–D and 3–D imaging technologies, providing superior image quality for precise daily patient set-up using bony structures, fiducials, or the target itself.[6] Kilovoltage X–ray capabilities enhance soft-tissue contrast, while cone-beam computed tomography (CBCT) reconstruction offers high-resolution imaging for direct target alignment. These advancements, combined with software-assisted registration and error calculation, have made image-guided radiotherapy (IGRT) the standard, reducing uncertainties related to target movement and improving treatment accuracy.[7] To address the challenge of target motion during radiotherapy (RT) in the thorax and upper abdomen, a 4–D CT scan with simultaneous respiratory registration is often used for treatment planning.[8,9] Other techniques, such as active breathing or applying pressure on the upper abdominal wall, have been effective in minimizing respiratory motion, reducing internal target movement by up to 50%. Ongoing developments involve tracking the target using continuous modulation of the multi-leaf collimator in conjunction with real-time imaging during treatment delivery. Currently, the CyberKnife, a robotic arm-mounted linear accelerator that synchronizes with respiration, is the sole commercially available beam-tracking RT system.[4,10–12]

Due to the considerable variation observed in SRT utilization among the radiation oncology community concerning the devices, application methods, motion management, and clinical use in daily practice, related to experience and other factors, we aimed to present a comprehensive survey encompassing a detailed analysis of the workflow, technological aspects, indications, and limitations of SRT/SBRT among participants from various regions across Türkiye. To the best of our knowledge, this is the first survey assessing the use of SRT/SBRT among Turkish radiation oncologists, although nationwide surveys of SBRT have been recently conducted in a few other countries.[13–21]

MATERIALS AND METHODS

In late 2021, October, a national survey was conducted to evaluate the current state of SRT/SBRT in Türkiye. The survey specifically targeted radiation oncologists who were actively engaged in the practice of SRT/SBRT and who were also members of the Turkish Society for Radiation Oncology (TSRO). For the execution of the survey, an online survey platform (www.surveymonkey.com) was employed, and a comprehensive questionnaire consisting of 34 specific items was meticulously developed.

The distribution of the survey among TSRO members was carried out through email notifications, and a link, also through WhatsApp, accompanied by a request to complete it within the subsequent 2 weeks. Respondents were assured that the survey would take maximum 5 min to complete. Before initiating the data collection process, the study obtained ethical approval from the Ankara University Scientific Research Ethics Board.

The initial segment of the survey was dedicated to gathering demographic information and work-related data from participating physicians. This included details such as age, type of hospital they practiced, and their respective professional titles. Hospital categories were classified into university hospitals, state training and research hospitals, public/city hospitals, and private hospitals. Regarding professional designations, they were divided into professor, associate professor, radiation oncology specialist, and radiation oncology resident.

In the second section of the survey, seven questions were presented to explore general clinical information. These questions covered topics such as the educational background before starting SRT practice, multidisciplinary assessment practices, the type of device, clinical protocols, and communication with other centers, SRT experience in years, and the regularity of reports on SRT treatment results.

The third section of the survey comprised 15 questions concerning simulation techniques, simulation tools, imaging fusion, treatment planning, treatment verification methods, and tumor tracking systems, real-time imaging, 6D coach, and surface-guided RT.

Finally, the fourth part of the questionnaire consisted of five questions related to the clinical application of SRT. This section aimed to gather information on the number of patients treated with SRT in the previous year, SRT indication rates, the cancer types, and the reasons of unable to perform SRT.

The collected data were analyzed in the online platform and also imported into the SPSS 23.0 package program to obtain further descriptive analysis. Because respondents could choose more than one answer for certain questions, the overall percentage for selected questions did not reach or sometimes exceeded 100%.

RESULTS

Our survey was responded to by 106 radiation oncologists. The age distribution of the participants was as follows: 12.3% <30 years; 26.4% 30–39 years; 37.7% 40–49 years; 21.7% 50–59 years; 1.9% ≥ 60 years. The respondents were working at university hospitals, state training and research hospitals, public/city hospitals, and private hospitals with the following rates of 40.6%, 37.7%, 4.7%, and 17%, respectively. Academic affiliations of the respondents were as follows: 21.7% professors, 13.2% associate professors, 50% radiation oncology specialists, and 15.1% radiation oncology residents, respectively. Figure 1 represents the demographic characteristics of participants (first 4 questions) and Tables 1 and 2 demonstrate the remaining questions and response rates.

The majority of participants were in the 40–50 age group and 84% of them had already completed their training. Most of the respondents (64.2%) had more than 5 years of experience. In majority (76.4%) of the respondents, a multidisciplinary council decision was required for SRT. Moreover, 74.5% of respondents followed their written protocols, and 59.4% collaborated with other experienced centers.

Linear accelerators (92.4%) were the most commonly used devices for SRT, followed by CyberKnife (27.4%), Gamma Knife (4.7%), and Magnetic resonance imaging -Linac (2.8%). Various immobilization methods were employed, including head frames and thermoplastic masks (88.7%), vacuum bags (77.4%), T board (48.1%), and abdominal compression body frame (34%). Respiratory motion management was provided by mostly four-dimensional computed tomography (4DCT) with respiratory gating (71.7%), followed by breath-hold techniques (58.5%), abdominal compression (28.3%), and fiducial tracking (25.5%), respectively. Surface tracking was used in only 20.8% of cases.

Regarding image fusion during treatment planning, 79.2% of participants utilized deformable registration, with 97.2% reassessing the quality of fusion. Concerning treatment, 67.9% of them had systems to integrate old and new plans for second fractionation. Treatments typically commenced within 2–7 days (75.5%) after simulation. Combined kilovolt/megavolt (kV/mV) portal imaging with CBCT was the most commonly used imaging method (57.6%), primarily performed before each fraction (73.6%). Six-dimensional table correction was used in 57.5% of cases, while real-time imaging was not widely implemented (70%). The real-time imaging modalities varied among respondents depending on their therapy device.

The number of patients treated with SRT/SBRT over the past year was reported as a median of 50 (range: 0–1000) among 103 of 106 respondents (97.1%). Among these respondents, the distribution of treated patients over the past year was as follows: 0–49 patients by 51 individuals (49.5%), 50–199 patients by 41 individuals (39.8%), 200–499 patients by 7 individuals (6.8%), and 500–1000 patients by 4 individuals (3.9%). Only one person indicated that no SRT/SBRT patient had been treated yet. The proportion of patients who received SRT/SBRT constituted a median 12% (1–80%) of all patients they treated that year according to 103 of 106 respondents. Among these respondents, 4 (3.7%) of them stated that treatment with SRT accounted for more than 50%, 40 (37.4%) of them between 20% and 50%, and 59 (55.1%) of them <20% of the whole group, respectively.

SRT was applied to various tumor groups, including brain (98.1%), lung (88.7%), bone (88.7%), adrenal (64.2%), liver (47.2%), prostate (41.5%), head and neck (40.6%), pancreas (34.9%), and other tumors (2.7%). In cranial tumors, SRT was most applicable to metastatic lesions (99.1%) after malign tumors (74.5%) following benign (56.6%) tumors. In lung SBRT cases, SBRT was mostly applied to peripheral tumors (98%), followed by central (72.4%), and ultracentral tumors (27.6%). The reasons for not treating certain tumor groups were issued by respondents as mostly the absence of fiducial tracking systems (55.6%) or lack of suitable devices and ancillary equipment (48.1%). For lung (63.2%), brain (60.4%), adrenal (31.1%), prostate (27.4%), liver (22.6%), bone (22.6%), head and neck (20.8%), and pancreas (16%) tumors, as well as re-irradiation cases (3.2%), alternate-day SRT was the preferred treatment approach.

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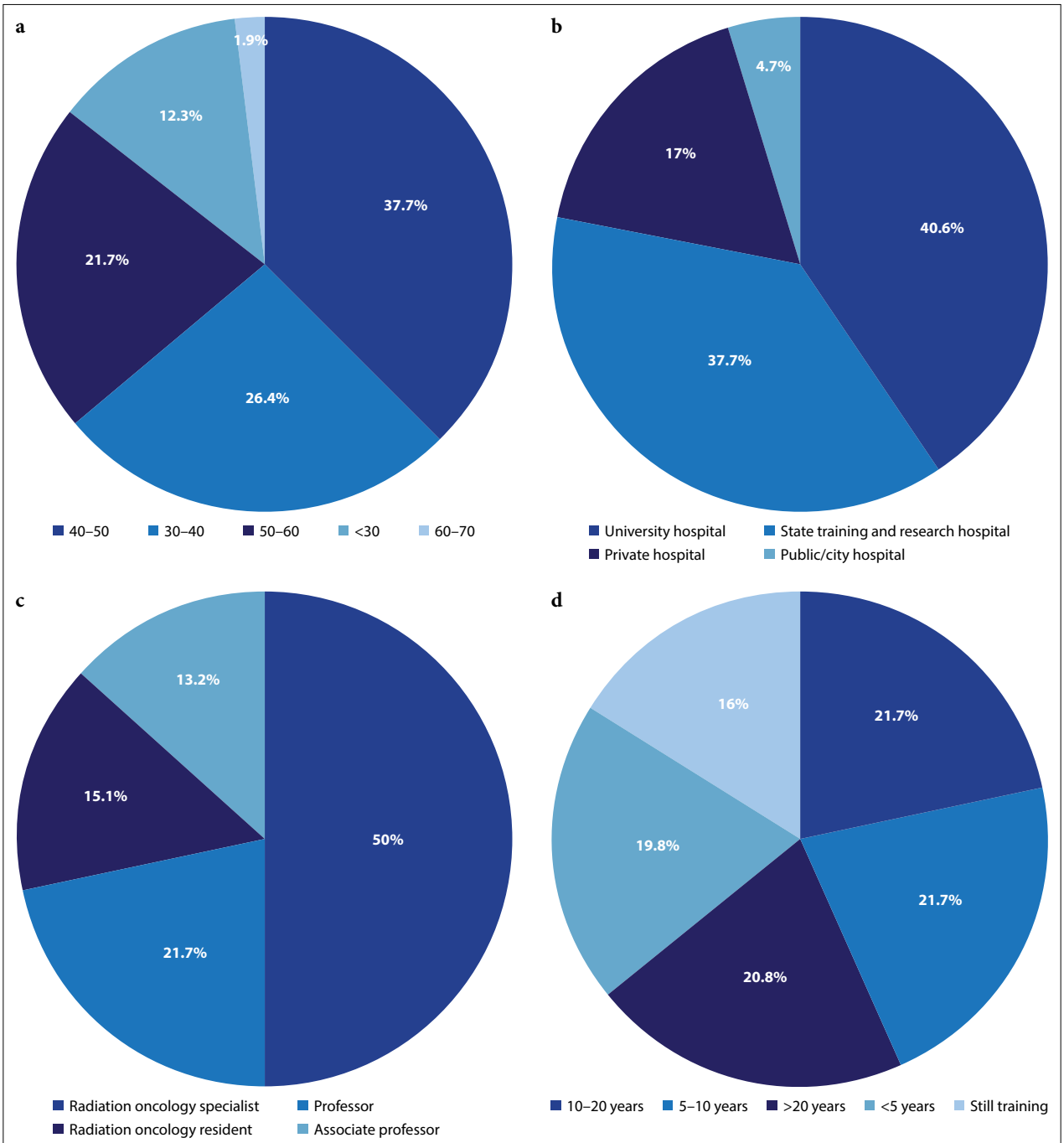

Fig. 1. Demographic characteristics of participants; (a) age, (b) institution, (c) academic affiliation, (d) training completion duration.

DISCUSSION

This nationwide comprehensive survey provides a detailed insight into the workflow, technological nuances, indications, and constraints associated with SRT/SBRT for the management of various cancer types. The adoption of SRT in Türkiye commenced within the past two decades and has exhibited a progressive increase over time. Notably, there has been a noteworthy surge in the utilization of SBRT in recent years. Nonetheless, it is important to note that SRT/SBRT accounts for <20% of all treated patients with-

Table 1 Clinical-technical information about SRT/SBRT

Questions	n	%
5. What is your education before you started utilization of SRT/SBRT?**		
a. I attended a training (course) dedicated to SRT/SBRT.	55	51.9
b. I attended a course dedicated to SRT/SBRT sponsored by the company.	27	25.5
c. I received training in a center with intensive SRT/SBRT experience.	52	49.1
d. I was supervised by someone with SRT/SBRT experience	30	28.3
6. Is the SRT/SBRT decision taken after being evaluated in multidisciplinary councils at your institution?		
a. Yes	81	76.4
b. No	25	23.6
7. Do you have written protocols that you follow for your SRT applications?		
a. Yes	79	74.5
b. No	27	25.5
8. Does your center cooperate with another center for SRS-SRT treatments?		
a. Yes	43	40.6
b. No	63	59.4
9. What type of device do you use for SRT?**		
a. Linac based devices (linear accelerators, tomotherapy)	97	92.4
b. MRI linac	3	2.8
c. Cyberknife	8	7.5
d. Gamaknife	5	4.7
10. How long has SRT been applied in your institution?		
a. <1 year	9	8.5
b. 1–3 years	28	26.4
c. 3–5 years	17	16
d. >5 years	52	49.1
11. Do you regularly report your SRT/SBRT treatment results? (publications, presentations at congresses, in-center self-evaluation).		
a. Yes	46	43.4
b. No	60	56.6

**: More than one answer available. SRT: Stereotactic radiotherapy; SBRT: Stereotactic body radiotherapy

in pertinent centers, based on the responses from more than half of the participants.

The survey primarily drew participation from radiation oncologists, predominantly affiliated with university hospitals and training and research institutions equipped for SRT/SBRT implementation. A considerable proportion of respondents, nearly half, reported possessing a 5 year or longer experience in SRT/SBRT practice. While this level of experience surpasses that reported in other national surveys conducted in countries such as India [21] and Korea,[19] it does indicate relatively less experience compared to counterparts in the United States [14] and numerous European countries.[20]

In terms of training, the survey revealed variability in the education received by respondents before engaging in SRT applications. A similar observation was made in a European survey conducted across selected countries, including England, Netherlands, Belgium, Denmark, Germany, and Austria.[20] Participants in both Türkiye and Europe acknowledged the absence of standardized training protocols and the lack of participation in specific educational programs. A noteworthy parallel between Türkiye and European countries is the tendency for more than half of the respondents to collaborate with more experienced clinics. In daily practice, our survey respondents predominantly adhere to their clinical protocols or relevant guidelines.[20] This practice closely aligns with the approach reported in other contexts.

Türkiye possesses a broad perspective regarding its treatment device portfolio. According to the 2019 report, Türkiye housed 9 Gamma Knife units, 11 CyberKnife systems, and 2 Novalis platforms dedicated exclusively to SRS/SRT treatments.[22] However, contemporary trends, similar to findings observed in surveys conducted in other nations, indicate that SRT is now predominantly administered through Linac-based devices.[21] Our survey reveals that initial applications in the form of SRS/SRT have bestowed considerable ex-

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Table 2 Details in SBRT simulation, planning, and treatment

Questions	n	%
12. Which immobilization tools and methods do you use to apply SRT?**		
a. Vacuum bag	82	77.4
b. Alpha cradle	27	25.5
c. Head frame-thermoplastic mask	94	88.7
d. Abdominal compression-body frame	36	34
e. T board (wingboard)	51	48.1
13. Do you use 4DCT as a simulation tool?		
a. Yes	76	71.7
b. No	28	28.3
14. How do you provide respiratory control for tumors that vary depending on respiratory movement? **		
a. Breathhold technique	62	58.5
b. Abdominal compression	30	28.3
c. Tumor tracking (fiducial)	27	25.5
d. Respiratory gating with 4DCT	76	71.7
15. Do you apply surface guided RT (with surface tracking)?		
a. Yes	22	20.8
b. No	84	79.2
16. Do you use deformable registration in the fusion of pre-contouring images (MRI, PET-CT)?		
a. Yes	84	79.2
b. No	22	20.8
17. Do you re-evaluate the quality of the fusion performed?		
a. Yes	103	97.2
b. No	3	2.8
18. How many days is the average time between the CT simulation and the beginning of the treatment?		
a. Same day		0
b. 1 day	23	21.7
c. 2–7 days	80	75.5
d. >7 days	30	2.8
19. Do you employ software that integrates prior treatment plan information with the new plan for secondary serial irradiations?		
a. Yes	72	67.9
b. No	34	32.1
20. Which imaging verification method do you use during treatment?		
a. Only kv/ mv portal display	10	9.4
b. kv/ mv CBCT only	31	29.2
c. kv/ mv portal imaging and CBCT together	61	57.6
d. MRI	4	3.8
21. How often do you use imaging verification during SRT?		
a. Before each fraction	78	73.6
b. Before and after each fraction	4	3.8
c. Before, within and after each fraction	24	22.6
22. Do you use six-dimensional couch corrections?		
a. Yes	61	57.5
b. No	45	42.5
23. Do you conduct verification imaging once more following repositioning?		
a. Yes	96	90.6
b. No	10	9.4
24. Do you perform real time imaging?		
a. Yes	31	29.2
b. No	75	70.8
25. Which technique do you use for real time imaging?		

Table 2 Cont.

Questions	n	%
26. Do you use fiducial tracking?		
a. Yes	30	28.3
b. No	76	71.7
27. How many SRT/SBRT patients have you treated in the last year?	103	median 50 (0–1000)
28. What percentage of all your patients does this rate represent?	103	median 12%
29. What are the tumor groups that you apply SRT/SBRT? **		
a. Brain	104	98.1
b. Head-neck	43	40.6
c. Lung (a- peripheral b- central/ultracentral)	94	88.7
d. Surrenal	68	64.2
e. Liver	50	47.2
f. Bone	93	87.7
g. Pancreas	37	34.9
h. Prostate	44	41.5
ı. Other	3	2.7
30. Which subgroups do you apply SRT in brain tumors?**		
a. Malignant	79	74.5
b. Benign	60	56.6
c. Metastasis	105	99.1
31. Which localizations in lung tumors do you apply SBRT?**		
a. Peripheral	96	98
b. Central	71	72.4
c. Ultracentral	27	27.6
32. Which tumor group you cannot apply SRT/SBRT?**		
a. Brain	6	5.7
b. Head-neck	24	22.6
c. Lung	9	8.5
d. Surrenal	22	20.8
e. Liver	35	33
f. Bone	7	6.6
g. Pancreas	36	34
h. Prostate	34	32.1
ı. Other	2	1.8
33. What is your reason for not being able to apply SRT/SBRT?**		
a. Lack of suitable devices and auxiliary equipment	26	48.1
b. Lack of trained personnel (physicists, technicians, etc.)	8	14.8
c. Inadequate imaging method	16	29.6
d. Absence of respiratory monitoring system (ABC, RPM etc.)	18	33.3
e. Failure to place fiducial marker	30	55.6
34. What are the tumor groups that you treat every other day?**		
a. Brain	64	60.4
b. Head-neck reirradiation	22	20.8
c. Lung	67	63.2
d. Surrenal	33	31.1
e. Liver	24	22.6
f. Bone	24	22.6
g. Pancreas	17	16
h. Prostate	29	27.4
ı. Other (reirradiation)	4	3.6

**: More than one answer avaliable. SBRT: Stereotactic body radiotherapy; SRT: Stereotactic radiotherapy; 4DCT: Four-dimensional computed tomography; MRI: Magnetic resonance imaging; PET-CT: Positron emission tomography and computed tomography; CBCT: Cone-beam computed tomography; ABC: Active breathing control; RPM: Real-time position management

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perience, particularly in treating intracranial tumors, over an extended period. With regard to SBRT, our findings align with surveys carried out in Japan, the United States, Korea, and European countries.[13,14,19,20] Lung tumors emerge as the most frequent targets for SBRT, as documented in these surveys; however, in contrast to the majority of other countries, liver tumors are superseded by bone and adrenal tumors in Türkiye.

In the context of immobilization techniques during planning CT, our survey highlights the prevalent utilization of head frames and thermoplastic masks (88.7%), vacuum bags (77.4%), T boards (wingboards) (48.1%), and abdominal compression body frames (34%). On the contrary, in Korea, the prevailing immobilization techniques primarily consisted of alpha cradle/vacuum-lock methods (16 institutions, 42%), followed by the utilization of stereotactic body frames (10 institutions, 26%) and wingboards (10 institutions, 26%).[19] It is worth noting that surveys conducted in the United States and Europe did not incorporate this particular immobilization data.[14,20]

4DCT emerged as the prevailing method for SBRT planning, consistent with analogous national surveys conducted in the United States, Korea, and European countries.[14,16,17,19,20] Regarding motion control strategies, respiratory gating with 4DCT and active breath-hold techniques were predominantly favored in Türkiye, while abdominal compression and tumor tracking systems were employed to a lesser extent. In Korea, similar to our observations, respiratory gating with 4DCT constituted the primary approach, with abdominal compression as the subsequent choice. Conversely, in Europe, abdominal compression held precedence following respiratory gating. In the United States, addressing respiratory-induced motion in lung and liver tumor patients primarily involved respiratory gating[23,24] and abdominal compression.[9,25] Techniques such as breath-hold[26] and real-time tracking[27,28] were less commonly employed, which mirrored the Japanese lung SBRT survey highlighting the prevalence of abdominal compression.[13,14]

While SRT historically relied on external coordinates for guidance, contemporary practices predominantly emphasize IGRT for enhanced geometric precision, expedited delivery, and resource optimization.[7] For target localization, the predominant verification method in Türkiye involved a combination of kV/mV portal imaging and CBCT, typically performed before each treatment fraction. Fiducials, used sparingly in Türkiye as well as in Korea and Europe, are infrequently employed as auxiliary localization tools.[19,20] In Korea, cone-beam CT emerged as the chief verification method before each treatment, supplemented by orthogonal kilovoltage radiography, orthogonal megavoltage localization imaging, and fluoroscopy.[19] These outcomes paralleled findings in European surveys.[20] Notably, the nascent verification approach of surface-guided RT remains underutilized in numerous countries, including Türkiye.

In our survey, liver and prostate tumors emerged as the predominant types of cancer for which many centers could not administer SBRT. The primary reasons cited by non-SBRT users were predominantly attributed to the absence of suitable devices and ancillary equipment, mirroring findings documented in other national surveys.[20] Pertaining to the annual caseload, we observed a wide range of patient numbers treated per year across centers in our survey, likely influenced by factors such as clinical experience, equipment availability, patient demographics, and socio-economic status.

An inherent limitation of this study pertains to our inability to analyze participating centers in terms of regional disparities, which could have shed light on variations in patient volume and diagnoses on a center-specific basis. In addition, not every center was represented by a singular respondent due to the option for multiple participants from each center to contribute to the survey. Furthermore, this survey lacked comprehensive information on dose and prescription specifics with respect to different cancer types, as well as insights into treatment outcomes and the cost associated with SRT/SBRT. Despite governmental health insurance approval for reimbursement in numerous centers, excluding private hospitals, our survey lacked detailed data in this regard.

CONCLUSION

In conclusion, this survey delineates the status of SRT/SBRT practices in our country as of 2021, highlighting variations in terms of experience, treatment modalities, and schedules. Our findings underscore Türkiye's diverse array of available equipment for SRT/SBRT applications, yet concurrently underscore a dearth of standardization in clinical approaches. This survey lays the groundwork for potential future endeavors aimed at enhancing SRT/SBRT utilization and fostering nationwide standardization in areas encompassing training, treatment techniques, application protocols, and treatment outcomes.

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