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Questionnaire survey on treatment planning techniques for lung stereotactic body radiotherapy in Japan

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ABSTRACT

This study aimed to obtain details regarding treatment planning techniques for lung stereotactic body radiation therapy (SBRT) employed at each institution in Japan by using a questionnaire survey. An Internet questionnaire survey on SBRT procedures performed in 2016 was conducted by the QA/QC committee of the Japan Society of Medical Physics from April to June 2017. The questionnaire assessed two aspects: the environment for SBRT at each institution and the treatment planning techniques with and without respiratory motion management techniques (RMMT). Of the 309 evaluated responses, 218 institutions had performed SBRT. A total of 186 institutions performed SBRT without RMMT and 139 institutions performed SBRT with RMMT. When respiratory motion was ≥10 mm, 69 institutions applied RMMT. The leading RMMT were breath holding (77 institutions), respiratory gating (49 institutions) and real-time tumor tracking (11 institutions). The most frequently used irradiation technique was 3D conformal radiotherapy, which was used in 145 institutions without RMMT and 119 institutions with RMMT. Computed tomography (CT) images acquired under free breathing were mostly used for dose calculation for patients treated without RMMT. The usage ratio of IMRT/VMAT to SBRT is low in Japan, compared to elsewhere in the world (<20% vs ≥70%). Among the available dose calculation algorithms, superposition convolution was the most frequently used regardless of RMMT; however, 2% of institutions have not yet made heterogeneity corrections. In the prescription setting, about half of the institutions applied point prescriptions. The survey results revealed the most frequently used conditions, which may facilitate standardization of treatment techniques in lung SBRT.

Keywords: SBRT; treatment planning; standardization; questionnaire survey

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INTRODUCTION

Stereotactic body radiation therapy (SBRT) is a useful treatment technique for lung cancer, and the treatment outcome of SBRT is reported to be comparable with that of surgery [1–5]. A phase 2 clinical trial for non-small cell lung cancer (NSCLC) showed that this technique has a high primary tumor control rate of 97% and a local control rate of 92% [1, 6]. As a result, SBRT is now becoming a standard therapeutic option for patients with early stage NSCLC.

The treatment approaches employed in SBRT are continually evolving. Among beam delivery techniques, 3D conformal radiotherapy (3DCRT) with non-coplanar beams was used classically with conventional linear accelerators [7]. However, intensity-modulated radiotherapy (IMRT) or volume-modulated arc therapy (VMAT) are being gradually introduced in lung SBRT [8]. Moreover, implementation of Monte Carlo simulation and the clinical use of 4D-CT have substantially improved the dose calculation accuracy within the body. Among dose calculation algorithms, superposition, a grid-based Boltzmann equation solver, and Monte Carlo simulation are clinically available in commercial treatment planning systems (TPSs) [9,10]. Among CT scanners, multi-detector CT scanners have been shown to improve longitudinal resolution and tumor detectability. Furthermore, 4D-CT has been clinically used to evaluate internal target volume (ITV) [11]. The dose distribution in SBRT is known to be dependent on the calculation algorithms and the type of CT images [12, 13]; therefore, differences in the calculation algorithms and the type of CT images used among institutions can result in variations in dose distribution.

In general, the use of various treatment planning techniques, including dose prescription and margins, can make comparison of clinical outcomes difficult among institutions; therefore, standardization of treatment planning techniques is required. As the first step toward standardization of treatment planning techniques in lung SBRT, it is important to survey the techniques currently employed for lung SBRT in various institutions. To achieve this goal in Japan, the QA/QC committee of the Japan Society of Medical Physics instituted a working group that conducted an Internet-based survey. The aim of this survey was to identify the treatment planning techniques for lung SBRT used by institutions in Japan. These data will contribute to the improvement of treatment planning techniques for lung SBRT.

MATERIALS AND METHODS

From April to June 2017, a questionnaire survey was carried out via the Internet to investigate the environment and the treatment planning techniques for lung SBRT at each institution in Japan. We did not set any criteria for facility selection. We asked representatives who were involved in treatment planning and quality assurance (QA) for lung SBRT to answer the questionnaire. The questionnaire contained two parts: the first part evaluated the environment for lung SBRT, while the second part assessed the treatment planning techniques with and without respiratory motion management techniques (RMMT) in lung SBRT. In this survey, RMMT included respiratory gating, breath holding and real-time tumor tracking. The abdominal compression technique was not included as an RMMT in this survey. We did not collect patient-identifiable information in this survey.

Part 1 consisted of seven questions characterizing the SBRT environment at each institution as follows.

ENVIRONMENT RELATED TO LUNG SBRT

1–1. Whether to perform SBRT.
1–2. Number of patients treated with SBRT in 2016.
1–3. Number of treatment machines at each institution.
1–4. Available modality for image-guided radiotherapy (IGRT) before beam delivery.
1–5. Number of terminals for TPSs at each institution.
1–6. Respiratory motion management techniques.
1–7. Target movement criteria for implementation of RMMT.

Part 2 consisted of 11 questions on the treatment planning techniques without and with RMMT as follows.

TREATMENT PLANNING TECHNIQUES WITH AND WITHOUT RMMT

2–1. Acquisition of CT images at simulation.
  2–1-1. Device used to reduce respiratory motion.
  2–1-2. Thickness of CT slices.
  2–1-3. Method used to determine ITV.
2–2. Definition of beams.
  2–2-1. Irradiation techniques.
  2–2-2. Photon energy.
  2–2-3. Setup margins.
  2–2-4. Multi-leaf collimator (MLC) margins for 3DCRT.
2–3. Parameters for dose calculation.
  2–3-1. CT images for dose calculation.
  2–3-2. Grid size for dose calculation.
  2–3-3. Dose calculation algorithm.
  2–3-4. Dose prescription.
  2–3-5. Combination of the algorithm and CT datasets for dose calculation.

RESULTS

Characteristics at each institution

Whether to perform SBRT

Evaluable responses were received from 309 institutions. The institution categories that answered the survey were as follows: university hospitals 23.3%, cancer centers 5.5%, national hospital organizations/public hospitals 33.3%, red cross/labors/public welfare/social welfare corporation/public interest incorporated association/corporations/mutual association hospitals 19.1% and private/medical corporation/medical association/others hospitals 18.8%. Of 309 institutions, 218 performed lung SBRT and 91 institutions did not. Staff- and equipment-related issues were the two main reasons why institutions did not perform SBRT. Among the staff-related reasons, 47 and 34 institutions selected a lack of occupational expertise and limited staff numbers, respectively. Among equipment-related reasons, 47 and 12 institutions selected lack of performance of the treatment machine and TPS, respectively.

Number of patients treated with SBRT in 2016

The number of patients treated with SBRT from April to March in 2016 was collected from each institution that performed SBRT (a denominator of 218): 106 (48.6%) institutions treated <10 patients, 55 (25.2%) treated 10–19 patients, 36 (16.5%) treated 20–39 patients, 11 (5.0%) treated 40–59 patients, 4 (1.8%) treated 60–79 patients, 3 (1.4%) treated 80–99 patients and 3 (1.4%) treated ≥100 patients.

Number of treatment machines at each institution

Among the 218 institutions that performed lung SBRT, 94 (43.1%) had one treatment machine, 82 (37.6%) had two machines, 40 (18.3%) had three to five machines, and 2 (0.9%) had more than five machines.

Among the 91 institutions that did not perform lung SBRT, 85 (93.4%) had one treatment machine, 4 (4.4%) had two machines, 2 (2.2%) had three to five machines and 0 (0%) had more than five machines.

Available functions of IGRT before beam delivery

Among the 218 institutions that performed lung SBRT, 215 (98.6%) had treatment machines that could be used to perform IGRT. A total of 198 (90.8%) institutions had machines that could perform soft tissue IGRT. Three (1.4%) institutions had machines that did not perform any functions of IGRT. Among the 91 institutions that did not perform lung SBRT, 64 (70.3%) institutions had treatment machines that could be used to perform IGRT, while 27 (29.7%) had treatment machines that could not perform IGRT.

Number of TPS terminals at each institution

Among the 218 institutions that performed lung SBRT, 22 (10.1%) had one TPS, 40 (18.3%) had two TPSs, 93 (42.7%) had three to five TPSs and 63 (28.9%) had more than five TPSs.

Among the 91 institutions that did not perform lung SBRT, 55 (60.4%) had one TPS, 24 (26.4%) had two TPSs, 12 (13.2%) had three to five TPSs and no institutions had more than five TPSs.

Respiratory motion management techniques

Among institutions that performed SBRT, 107 performed SBRT with and without RMMT and 32 performed SBRT only with RMMT. Seventy-nine institutions did not use any RMMT. Among the 139 institutions that used RMMT, 49 (35.3%) used respiratory gating, 77 (55.4%) used breath holding, 11 (7.9%) used real-time tumor tracking and 2 (1.4%) did not provide specific details.

Target movement criteria for implementation of RMMT

A total of 107 institutions performed SBRT with and without RMMT. Of these, 15 (14.0%) and 11 (10.3%) institutions applied RMMT for targets moving ≥5 mm in any direction and the 3D vector, respectively. Thirty-five (32.7%) and 34 (31.8%) institutions employed RMMT when a tumor moved ≥10 mm in any direction and the 3D vector, respectively. Twenty-six (24.3%) institutions applied an implementation standard of 5-mm respiratory motion for RMMT. Seventy-one (66.4%) institutions applied an implementation standard of 10-mm respiratory motion for RMMT. The remaining 12 institutions did not have clear criteria for the implementation of RMMT.

Treatment planning techniques with and without RMMT

Except in subsections MLC margins for 3DCRT and Combination of the algorithm and CT datasets for dose calculation, in this section, the following numbers of institutions were used as the denominators: 186 for non-RMMT, 49 for respiratory gating, 77 for breath holding and 11 for real-time tumor tracking.

Acquisition of CT images at simulation

Device used to reduce respiratory motion. Figure 1(a) shows the respiratory suspiration methods employed in each RMMT. A total of 138 (74.2%) institutions used various respiratory suspiration approaches. Abdominal compression, vacuum system and shell system were used in 53 (28.5%), 16 (8.6%), and 69 (37.1%) institutions, respectively. Thirty (61.2%), 42 (54.5%), and 9 (81.8%) institutions did not use any methods for respiratory suspiration in respiratory gating, breath holding and real-time tumor tracking, respectively.

Thickness of CT slices. The thickness of CT slices used in each RMMT is shown in Figure 1(b). Thickness values of <3 mm and ≥2 mm were the most frequently used, except in real-time tumor tracking. Six institutions (3.2%) acquired CT images with thickness ≥3 mm in non-RMMT. In real-time tumor tracking, thickness <2 mm was the most frequent, in 7 (63.6%) institutions.

Method used to determine ITV

Figure 1(c) shows whether each institution used 4D-CT for setting the ITV. A total of 110 (59.0%), 37 (35.1%), 45 (89.8%) and 8 (72.7%) institutions used 4D-CT for setting ITVs for non-RMMT, breath holding, respiratory gating and real-time tumor tracking, respectively. In addition, 21 (11.3%), 4 (8.2%), 10 (13.0%) and 0 (0.0%) institutions used fluoroscopy for non-RMMT, respiratory gating, breath holding and real-time tumor tracking, respectively. One of the 11 tumor tracking facilities did not determine the ITV.

Figure 1(d) shows whether each institution used breath hold CT images for setting the ITV. Fifty-seven (74.0%) institutions used breath hold CT images for setting the ITV. Sixty-five (34.9%), 10 (20.4%) and 2 (18.2%) institutions used breath hold CT images for non-RMMT, respiratory gating and real-time tumor tracking, respectively.

Definition of beams

Irradiation techniques. Figure 2(a) shows the treatment techniques with and without RMMT. The number of institutions in which 3DCRT was used without and with RMMT was 145 (78.0%) and 114 (82.0%), respectively. The number of institutions using IMRT or VMAT without and with RMMT was 32 (17.2%) and 17 (12.2%), respectively, where CyberKnife (Accuray, Inc., Sunnyvale, CA, USA) is included in IMRT.

Photon energy. Figure 2(b) shows the treatment techniques in each RMMT. An energy level of 6 MV was used most frequently, followed by 6 MV flattening filter free (FFF). Some institutions used 10 MV combined with 4 MV.

Setup margins. Figure 3 shows the setup margin used in each RMMT. Setup margins of ≤3 mm were more frequently used than others in real-time tumor tracking. The most frequent setup margin was 5 mm. The numbers of institutions selecting 5 mm as the setup margin in the left–

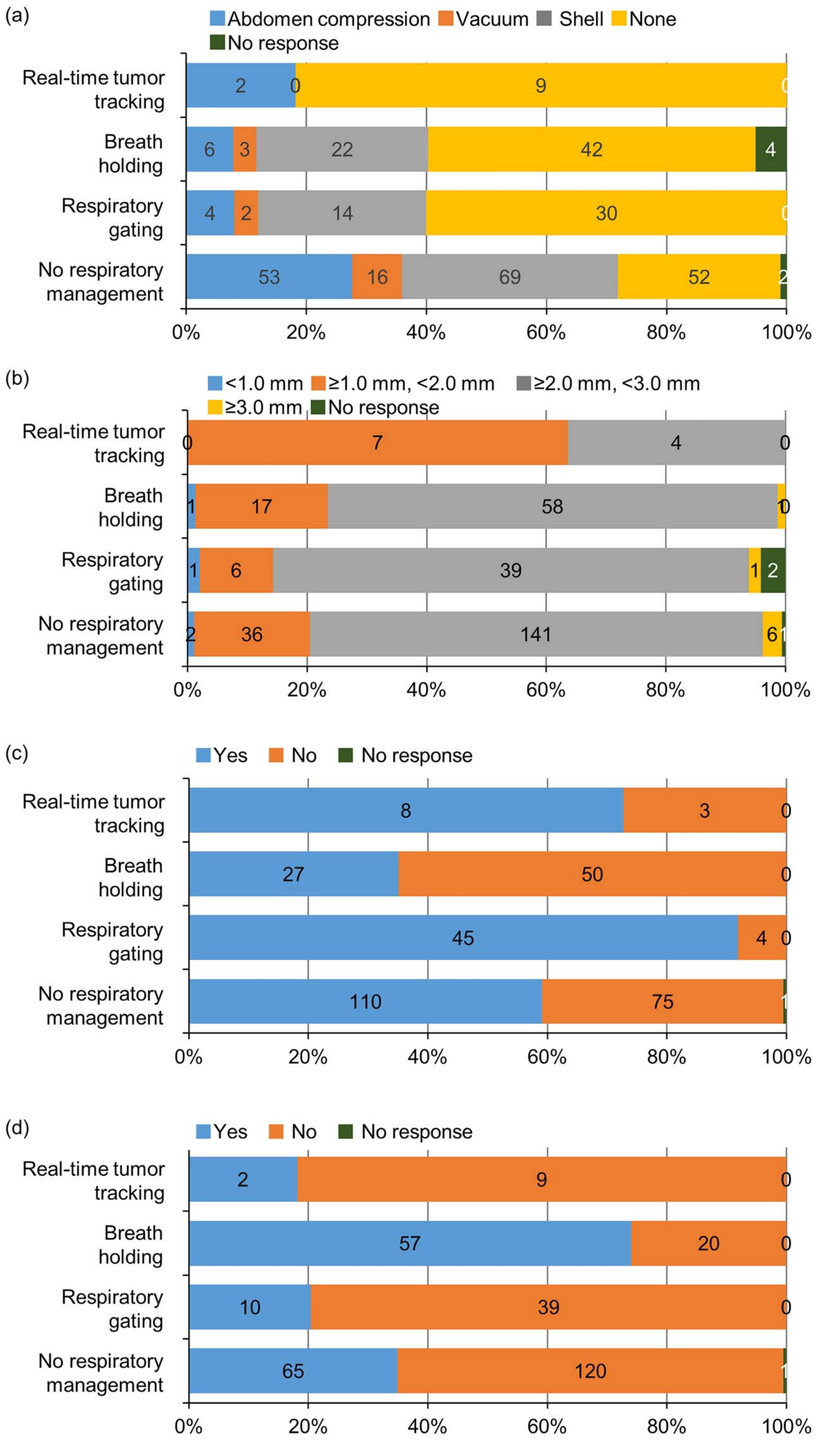

Fig. 1. Each graph shows the institution numbers corresponding to CT simulation conditions in each RMMT. Each horizontal axis represents the percentage for each item. 100% shows the total institution number in each RMMT. In each graph, the bottom-most bar represents institutions without RMMT, the second bar represents institutions using respiratory gating, the third bar represents those using breath holding and the top-most bar represents those using real-time tumor tracking. (a) Methods of respiratory suspiration. (b) Thickness for CT images. (c) and (d) CT images used for setting the ITV. (c) Represents whether 4D-CT images used for setting ITV. (d) Represents whether breath-hold CT images were used for setting ITV. Each color represents each item shown above each graph.

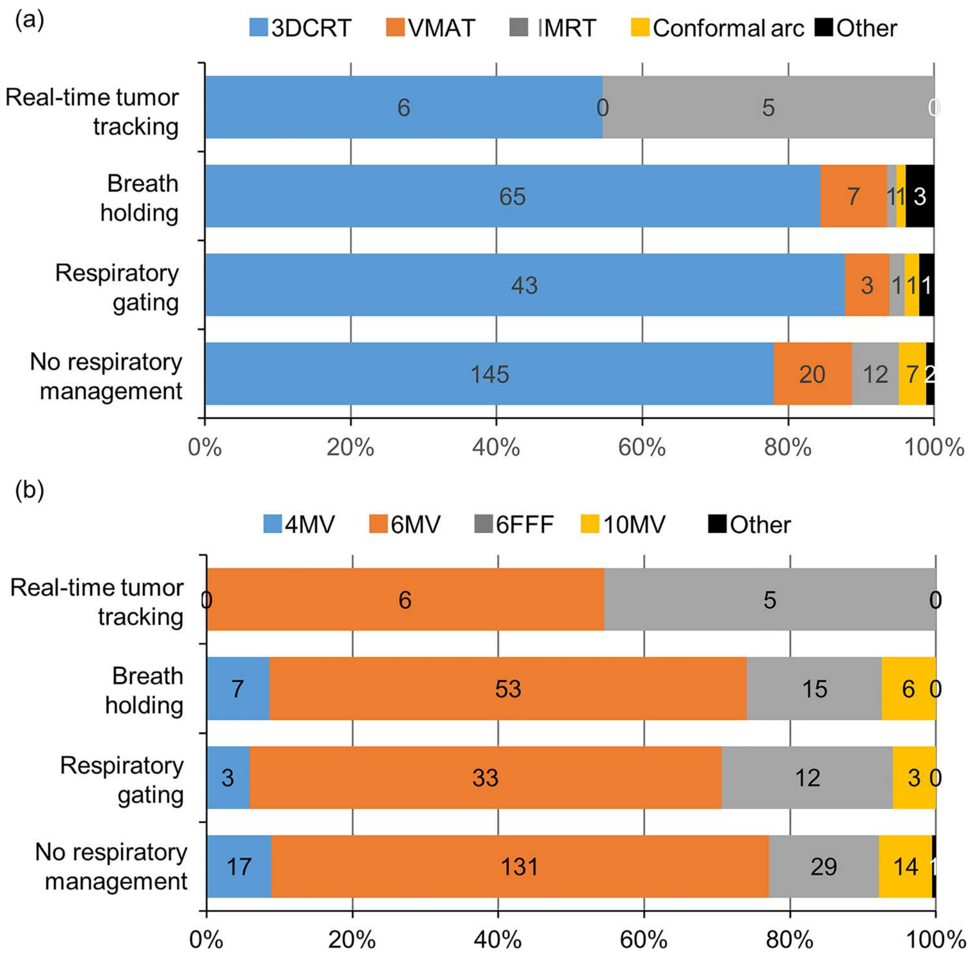

Fig. 2. Each graph shows the institution number for conditions related to irradiation methods and beam energy. Each horizontal axis represents the percentage for each item. 100% shows the total institution number in each RMMT. In each graph, the bottom-most bar represents institutions without RMMT, the second bar represents institutions using respiratory gating, the third bar represents those using breath holding and the top-most bar represents those using real-time tumor tracking. Each color represents each item shown above each graph. (a) Irradiation technique and (b) photon energy.

right (LR), anterior–posterior (AP) and cranial–caudal (CC) directions are shown in Table 1. In institutions without and with RMMT, 23 (12.4%) and 13 (9.4%) institutions used larger margins for the CC directions than the other directions, respectively.

Among institutions using 4D-CT for the ITV setting, 13 (9.2%), 14 (9.9%) and 25 (17.7%) institutions used setup margins of >5 mm in the LR, AP and CC directions, respectively. Among institutions not using 4D-CT for the ITV setting, on the other hand, 10 (22.7%), 10 (22.7%) and 12 (25.0%) institutions used setup margins of >5 mm in the LR, AP and CC directions, respectively. The Mann-Whitney U test (SPSS 8.0; SPSS, Inc., Chicago, IL), however, showed no significant difference between these groups in this survey ($P = 0.29$, 0.31 and 0.08 for the LR, AP and CC directions, respectively).

MLC margins for 3DCRT. Institutions selecting IMRT and VMAT in question 2–2-1 were excluded for this analysis. The most frequent portal margin was also 5 mm. In institutions without and with RMMT, the number of institutions selecting 5 mm for MLC margins is shown in Table 1. Figure 4 illustrates the MLC margin used in each RMMT. Thirteen (7.0%), 4 (8.2%) and 9 (11.7%) institutions selected a 0 mm MLC margin in each direction in non-RMMTs, respiratory gating and breath holding.

Parameters for dose calculation

CT images for dose calculation. Figure 5(a) shows CT images for dose calculation in each RMMT. A total of 135 (71.5%) institutions used CT images, such as slow scan CT, free breathing CT, whole-phase average intensity projection (AIP) and whole-phase maximum intensity projection, in non-RMMT. On the other hand, 33 (67.3%) and 61 (79.2%) institutions used CT images, such as specific-phase 4D-CT and breath hold CT, in respiratory gating and breath holding, respectively.

Grid size for dose calculation. The grid sizes in a plane for dose calculation are shown in Figure 5(b). In non-RMMT, respiratory gating, breath holding and real-time tumor tracking, 147 (79.0%), 42 (85.7%), 62 (80.5%) and 4 (36.4%) institutions used a grid size of <3 mm

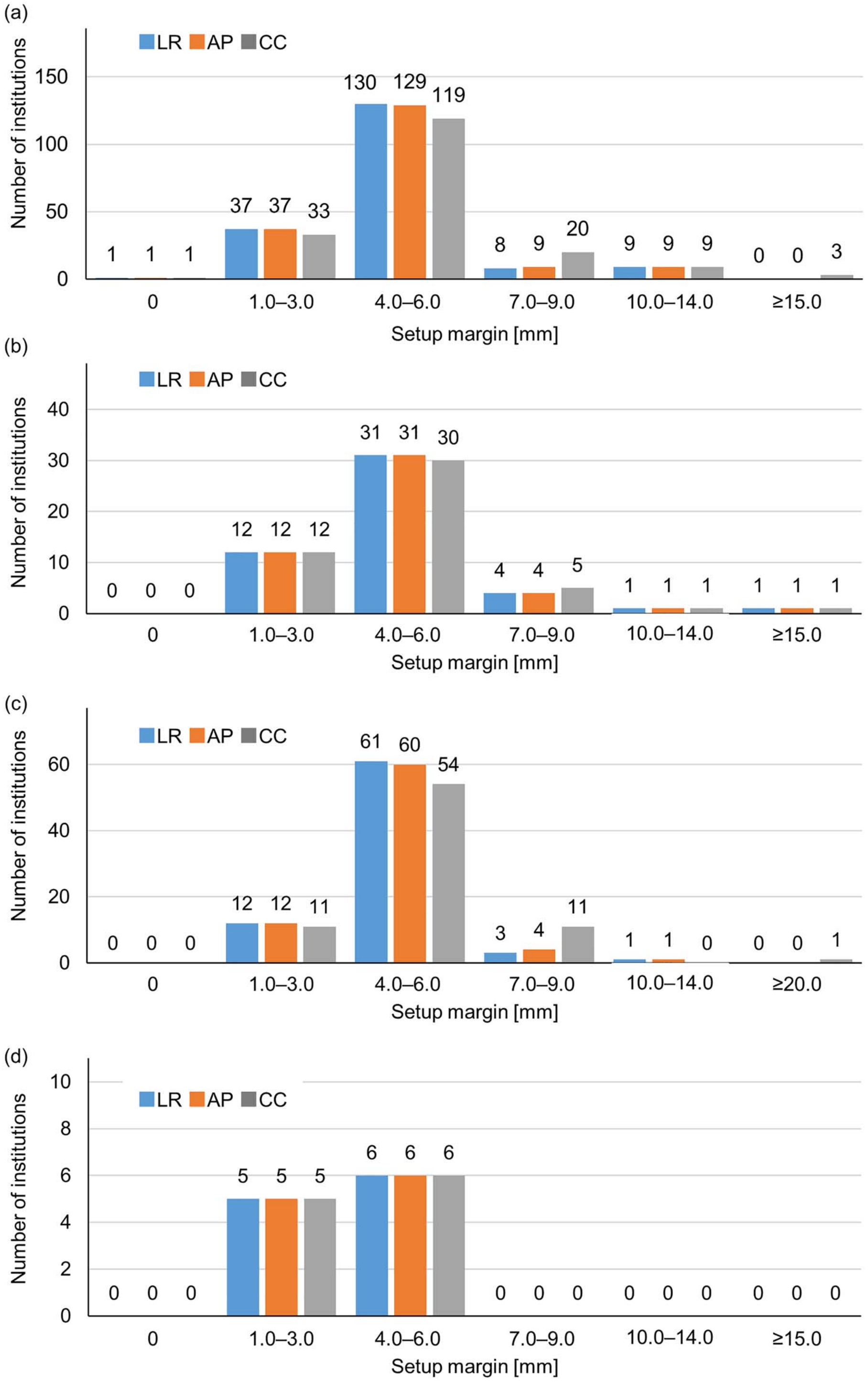

Fig. 3. The setup margins in each direction and RMMT. Each color bar represents the institutional number for each direction: blue, left–right (LR); orange, anterior–posterior (AP); and gray, cranio–caudal (CC). (a) Without RMMT, (b) respiratory gating, (c) breath holding and (d) real-time tumor tracking. The maximum value for the vertical axis is the total number in each RMMT.

Table 1. Number of institutions selecting a 5.0 mm margin for setup and portal margin

Setup margin			
	LR	AP	CC
Without RMMT	118 (63.4%)	117 (62.9%)	109 (58.6%)
With RMMT	91 (65.5%)	89 (64.0%)	82 (59.0%)
Portal margin			
	LR	AP	CC
Without RMMT	73 (39.2%)	73 (39.2%)	73 (39.2%)
With RMMT	65 (51.6%)	65 (51.6%)	66 (52.4%)

and ≥2 mm, respectively. On the other hand, only in real-time tumor tracking was a grid size of <2 mm used most frequently.

Dose calculation algorithm. The classification suggested by Knöös *et al.* [9] was used. Type 'a' includes all the pencil beam convolution (PBC) algorithms, such as Pencil Beam iPlan and Pencil Beam Convolution, which do not consider the changes in electron transport. The type 'b' class includes algorithms that can consider the changes in electron transport, including the anisotropic analytical algorithm, Superposition, Adaptive convolve and Collapsed Cone Convolution. The last category of algorithms, named type 'c' involved implementation of the Monte Carlo in commercial TPS to yield algorithms presenting the same degree of accuracy in dose estimation as the Linear Boltzmann Transport Equation solver, such as the Acuros XB [10]. Type 'c' included X-ray Voxel Monte Carlo, the linear Boltzmann transport equation and Monte Carlo.

Figure 5(c) shows the algorithms used in each RMMT. For respiratory gating, breath holding and non-RMMT, 133 (71.5%), 37 (75.5%) and 60 (77.9%) institutions used type 'b' algorithms, respectively. Some reports recommended using type 'b' or 'c' algorithms for dose calculation in the lung, where electron equilibrium is not established [14]. In real-time tumor tracking, type 'c' algorithms were the most frequent. Heterogeneity corrections were applied to 98% of institutions in each RMMT. The remaining 2% of the institutions have not yet made heterogeneity corrections.

Dose prescription. The volumes for the prescriptions are shown in Figure 6(a). The most frequently used volume for the prescription was the PTV in each RMMT. A total of 166 (89.2%), 45 (91.8%), 70 (70.7%) and 9 (81.8%) institutions used the PTV for the prescription in non-RMMT, respiratory gating, breath holding and real-time tumor tracking, respectively. The methods used for the prescriptions are shown in Figure 6(b). In non-RMMT, respiratory gating and breath holding, 84 (45.2%), 23 (46.9%) and 37 (48.1%) institutions used the point prescription method, respectively, and 102 (54.8%), 26 (53.1%) and 40 (51.9%) institutions used the volume prescription method, respectively. There were slightly more institutions using volume prescription than those using point prescription. In real-time tumor tracking, point prescription was not used in any institution, and volume prescription was used in all institutions. The $D_{95\%}$, which was defined as the dose to 95% of the volume, prescription was the most frequently used among the volume prescriptions in all RMMT.

The leading dose fractionation was 48 Gy in four fractions, for 96 (51.6%) institutions, followed by 50 Gy in four fractions and 60 Gy in eight fractions in non-RMMT. Thirty-four types of fraction schedules were used in this survey. Among institutions without RMMT, 70 institutions have different fraction schedules in the peripheral region and central region. In the central region, the leading dose fractionation was 60 Gy in eight fractions for 30 (16.1%) institutions, followed by 60 Gy in ten fractions and 56 Gy in seven fractions. Twenty-four types of fraction schedules were used in this survey.

Combination of the algorithm and CT datasets for the calculation. Figure 7 shows combination of the algorithm and CT datasets for dose calculation with and without RMMT. In this part, the following number of institutions was used as the denominator: 8 for type 'a', 133 for type 'b' and 44 for type 'c' in non-RMMT. In RMMT, the following number of institutions was used as the denominator: 6 for type 'a' 98 for type 'b' and 33 for type 'c' Various CT datasets were used for the calculation regardless of the types of algorithms. In non-RMMT, four, seven and six types of CT datasets were used in types 'a', 'b' and 'c', respectively. In RMMT, breath holding CT was mostly used, followed by 4D specific-phase CT regardless of the type of algorithm. Dose calculation was performed on breath holding CT or 4D specific-phase CT with type 'a', 'b' and 'c' in 83.3%, 70.4% and 93.9% of the institutions, respectively.

DISCUSSION

In this study, the details of treatment planning methods for SBRT at each institution in Japan were investigated via a survey. According to the Japanese Structure Survey of Radiation Oncology in 2013 (2nd report), 329 institutions performed SBRT [15]. Thus, 66.3% (218/329) of the institutions identified in that survey responded to our questionnaire; therefore, the results reflect the trends in treatment planning methods for lung SBRT in Japan. As a result, we found that treatment planning methods for lung SBRT varied among institutions.

Most of the institutions used methods recommended in guidelines and previous reports [14, 16–18], some did not. We hope that this study will provide an opportunity to review and improve treatment planning methods for lung SBRT at each institution. In addition, we found that there are various fraction schedules and dose prescription settings. The selection of dose prescription settings and fraction schedule are essentially clinical decisions and must be regulated by the results of clinical trials, not treatment planning techniques.

In an investigation on IGRT techniques in the USA conducted by Nabavizadeh *et al.*, 96% of the institutions had machines that could perform soft tissue IGRT [19]. In lung 3DCRT or IMRT, 78% of the

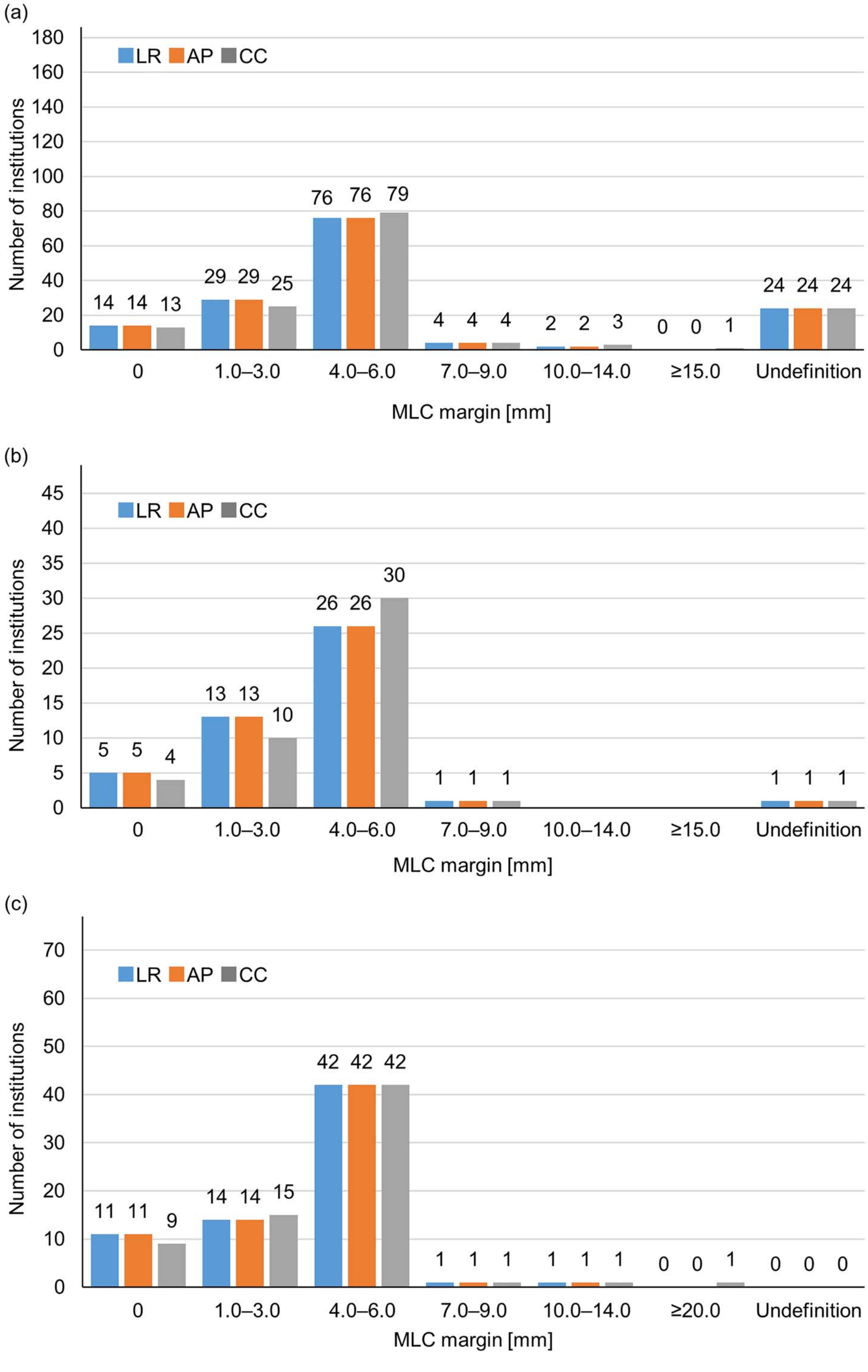

Fig. 4. The multi leaf collimator (MLC) margins in each direction and RMMT. Each color bar represents the number of institutions for each direction: blue indicates left–right (LR); orange, anterior–posterior (AP); and gray, cranio–caudal (CC). (a) Without RMMT, (b) respiratory gating and (c) breath holding. The institutions that selected IMRT or VMAT as irradiation methods were removed from this analysis. The maximum value for the vertical axis is the total number in each RMMT.

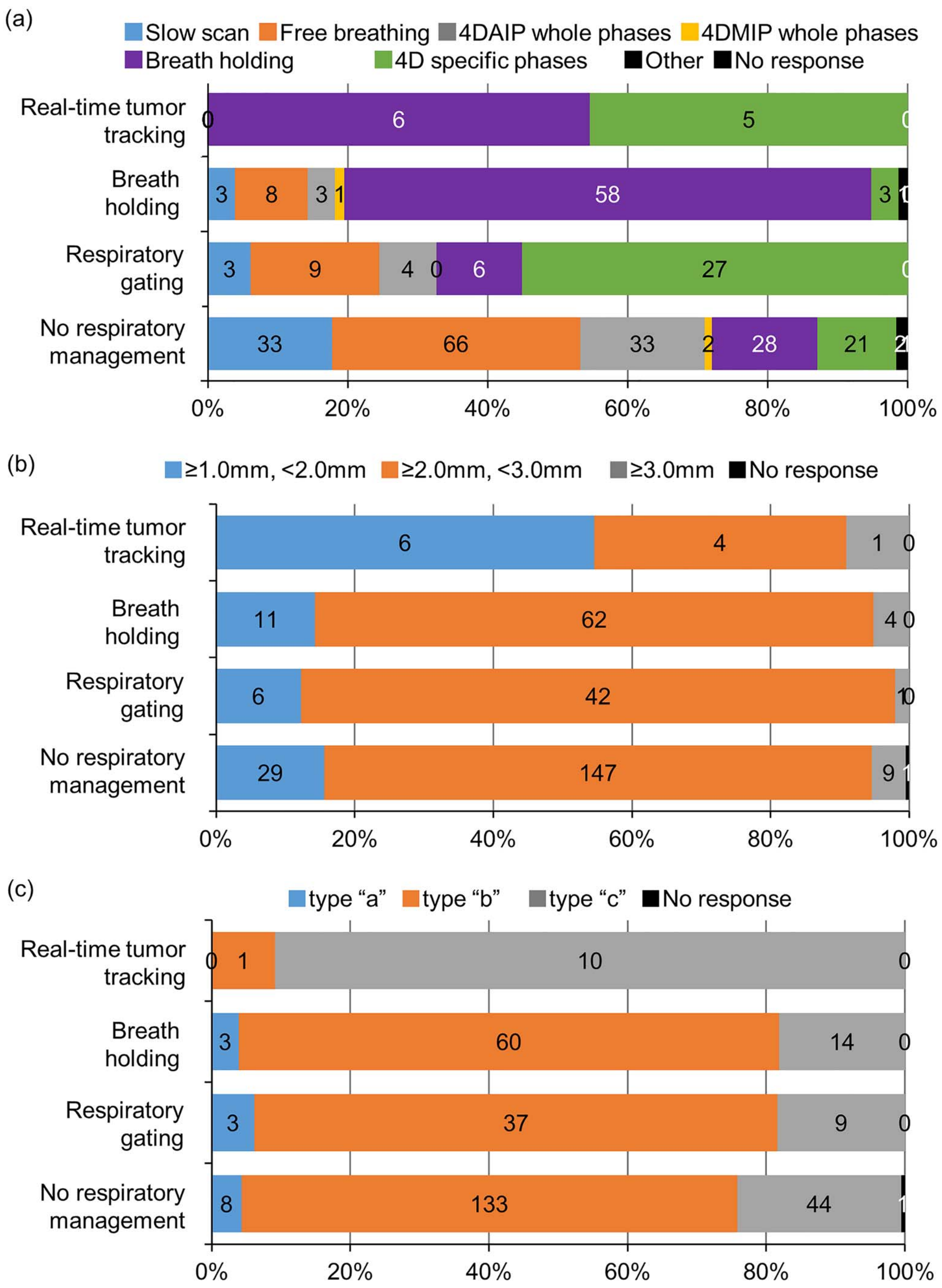

Fig. 5. Institution number for dose calculation methods. (a) The kind of CT images used for calculation, (b) the grid size, and (c) the calculation algorithm. Type 'a' has all the pencil beam convolutions (PBC), such as Pencil Beam iPlan, Pencil Beam Convolution. The type 'b' class includes the anisotropic analytical algorithm, Superposition, Adaptive convolve and Collapsed Cone Convolution. The last algorithm named as type 'c' was the Monte Carlo implemented in the commercial TPS, the Acuros XB. Each horizontal axis represents the percentage for each item. 100% shows the total number of institutions for each RMMT. In each graph, the bottom-most bar represents institutions without RMMT, the second bar represents institutions using respiratory gating, the third bar represents those using breath holding and the top-most bar represents those using real-time tumor tracking. Each color represents each item that is shown above each graph.
AIP = average intensity projection, MIP = maximum intensity projection.

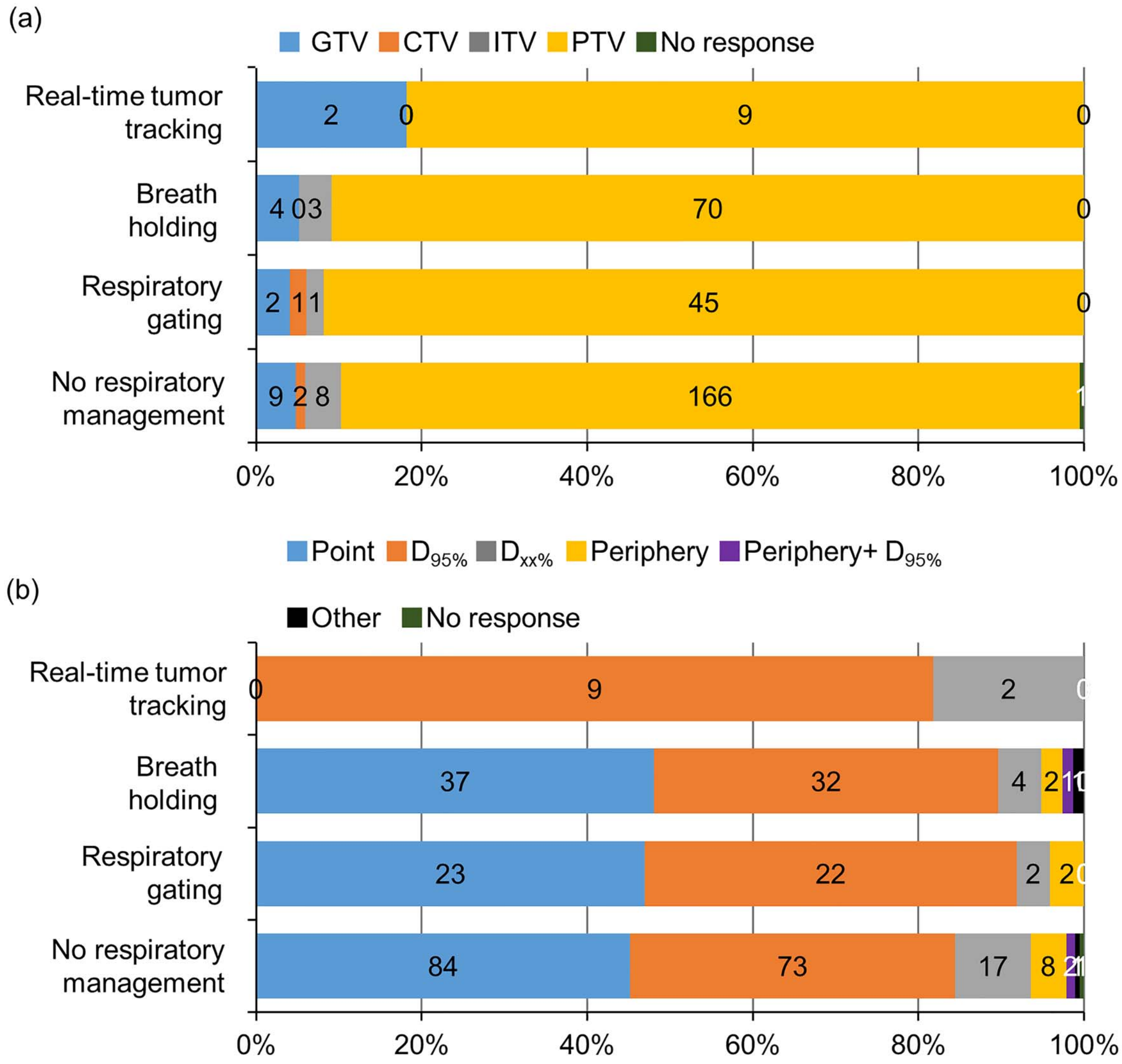

Fig. 6. Number of institutions for the prescription setting. (a) Volume for the prescription and (b) prescription methods. Each horizontal axis represents the percentage for each item. 100% shows the total institution number in each RMMT. In each graph, the bottom-most bar represents institutions without RMMT, the second bar represents institutions using respiratory gating, the third bar represents those using breath holding and the top-most bar represents those using real-time tumor tracking. Each color represents each item that is shown above each graph.
GTV = gross tumor volume, CTV = clinical target volume, ITV = internal target volume, PTV: = planning target volume, $D_{95\%}$ = dose to 95% of the volume, $D_{xx\%}$ = dose to xx% of the volume.

institutions performed soft tissue IGRT using cone-beam CT (CBCT) or CT-on-rails. Only 3% of the institutions did not perform IGRT for lungs in the report. Correspondingly, over 90% of institutions can perform IGRT with soft tissue and 3 (1.4%) institutions did not perform IGRT for lung in this survey. Thus, IGRT with soft tissue is mainly used in Japan and the USA in lung SBRT.

In Japan, institutions that meet the following criteria can demand medical fees for RMMT.

1. The institution should have at least one expert doctor supervising radiation therapy.
2. The institution should have at least one expert radiation therapist who has >5 years' experience.
3. The institution should have at least one expert overseeing quality management of radiotherapy equipment, verification of the treatment planning and support to making treatment plans.
4. There should be two devices as follows:

A) A device that expands the irradiation range necessary to compensate for respiratory movement to <5 mm in each direction for tumors with movement of >10 mm.
B) A device monitoring tumors in the radiation fields during every fraction.

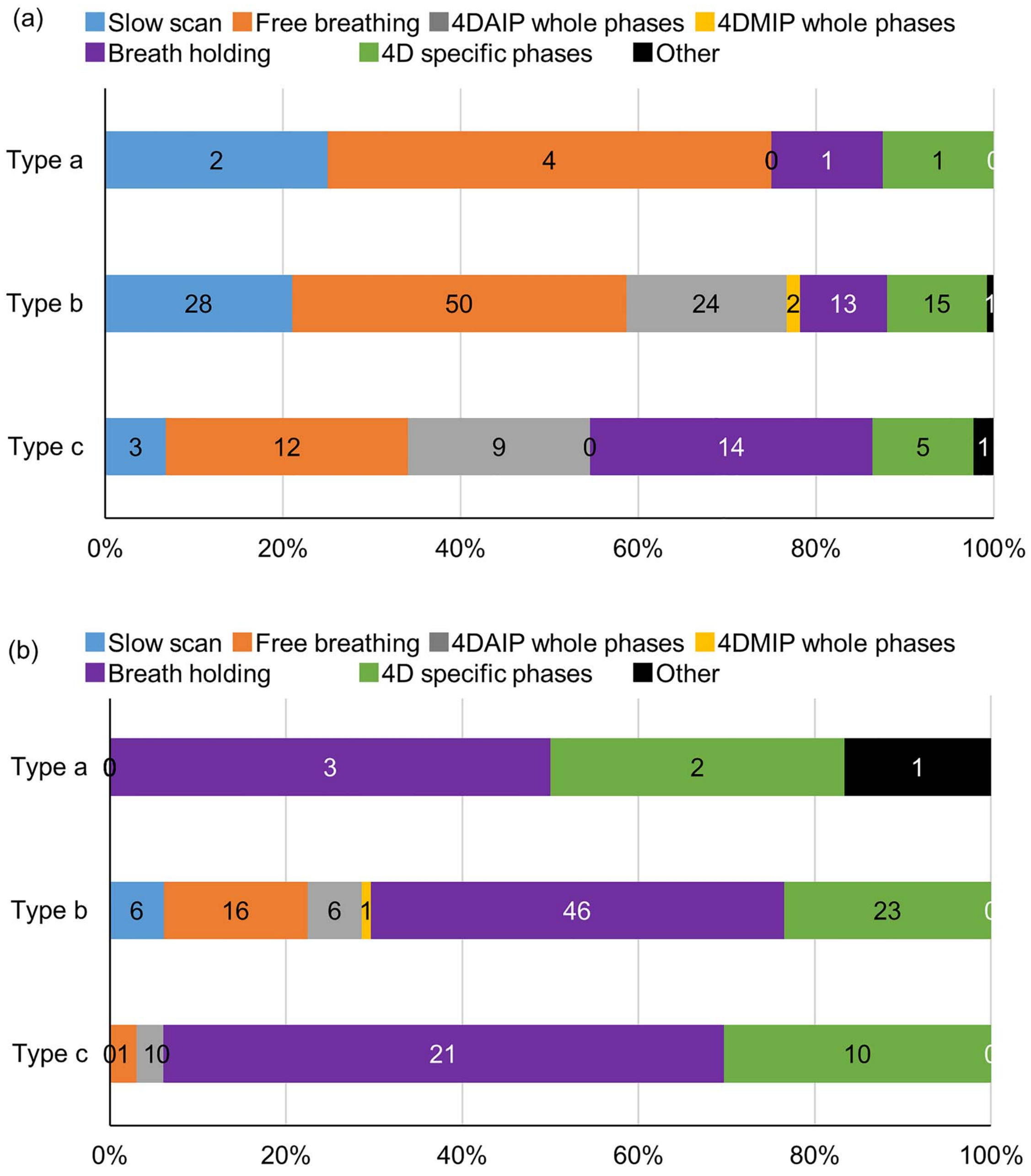

Fig. 7. Combination of the algorithm and images for the calculation. Values in graphs are the number of institutions selecting CT images in each algorithm type. (a) Without RMMT and (b) with RMMT. Each color represents each item that is shown above each graph.

5) Each institution should have implementation and quality management records for RMMT.

Among these criteria, 4A relates to the movement of tumors. A value of 10 mm was primarily used in the criteria for implementation of RMMT. When treating a target moving $\geq$10 mm in the 3D vector, each institution can demand a fee for RMMT in Japan. Thus, the implementation criteria of 10 mm respiratory motion may be applied. However, some institutions would consider 5 mm to be an amplitude value, not a 3D movement length.

In SBRT, various immobilization systems were used for respiratory suspiration and patient immobilization [20, 21]. In non-RMMTs, >70% of institutions used the device used to reduce respiratory motion, such as abdominal compression, vacuum and shell. Abdominal compression reduces the magnitude of tumor motion; therefore, abdominal compression is generally used. Abdominal compression is a significant component of lung SBRT. However, it is preferable to confirm the lung tumor position before beam delivery since abdominal compression can induce unexpected inter-fraction tumor movement [21].

In irradiation techniques, ∼80% of institutions used 3DCRT with and without RMMT. The proportion of institutions using IMRT or VMAT with and without RMMT was <20%. This result was the complete opposite of the result reported by Giglioli *et al.* [22]. In their survey, 95% of institutions used IMRT or VMAT in lung SBRT in Italy. According to studies conducted in 2010, IMRT was available in 87.5% of the institutions surveyed in Canada [23] and 76% of those in the UK [24]. In addition, a survey in New Zealand reported that IMRT/VMAT was available in 100% (7) of institutions [25]. Although these reports did not focus on lung SBRT, IMRT or VMAT would be typically used in lung SBRT since the majority of the institutions were using IMRT. Compared to the other countries, Japanese institutions might be afraid of the impact of interplay effects between lung tumor motion and MLC motion.

International guidelines recommend an energy level of 4 or 6 MV [16] because of the increasing lateral electron transfer in low-density tissue. Recently, treatment machines using 6 FFF have been employed in Japan. A 6 FFF beam has the advantage of delivering the dose within a shorter time with a high dose rate. Purdie *et al.* reported that the mean intrafraction tumor deviation was significantly greater (5.3 mm vs 2.2 mm) when the interval between localization and repeat CBCT imaging exceeded 34 min [26]. Reducing the irradiation time is important for minimizing setup error. Therefore, the frequency of use of 6 FFF will increase in the future.

In the survey conducted by Nabavizadeh *et al.* [19], the usage of 4D-CT for ITV setting depended on expansion of the setup margin. The median setup margin at institutions not using 4D-CT was significantly larger than that in institutions using 4D-CT (median: 10 mm without 4D-CT, 5 mm with 4D-CT). Determination of setup margins is so complicated because setup errors are dependent on immobilization methods, targeting policy, treatment time and so forth. Lung tumors are visible in images obtained with an electronic portal imaging device, CBCT and fluoroscopy. Acquisition of these images during treatment is an effective method for verifying whether the setup margin setting performed by the institution is a suitable institutional method or not [27].

Oku *et al.* [17] investigated the relationship between the peripheral dose and portal margin. In their report, a 0-mm MLC margin was needed to coincide the 60–80% isodose line with the periphery of the PTV. In order to achieve this, the MLC margin should be adjusted to determine the peripheral dose. In this survey, 24 (12.9%) institutions answered ‘undefined MLC margin’ in non-RMMT. It seems that these institutions adjusted the MLC margin by confirming the dose distribution.

A small grid size is suitable for SBRT because small targets should be contoured exactly. According to Mifften *et al.*, a grid size of ∼2 mm is suitable for calculation in the algorithm for superposition [18]. However, nine, one, four and one institutions applying non-RMMT, respiratory gating, breath holding and real tumor tracking used a grid size of ≥3 mm (Figure 5b). We recommend that these institutions should use a smaller grid size for dose calculation.

In this survey, the leading dose fractionation was 48 Gy in four fractions. In non-RMMT, respiratory gating and breath holding, 45–48% of institutions used point prescriptions and 51.9–54.8% used volume prescriptions. From this result, large variations were found in the equivalent dose for targets. Fractionation schedules and prescription setting are quite important because SBRT achieves high local control with limited toxicity when appropriate fractionation schedules are used for tumors [28]. Suzuki *et al.* found that a sufficient dose seems to be crucial, especially for medically fit individuals and for patients with larger tumors in early stage NSCLC treated with SBRT [29]. It is predicted that there may be differences in local control with differences in the PTV dose. For standardization of treatment planning techniques for lung SBRT, new guidelines that mention dose prescription settings and fraction schedules will be required.

Glide *et al.* demonstrated that the use of AIP was an effective strategy for designing treatment plans for moving lung tumors [30]. CT values in the target periphery for the lung were different among various types of CT datasets. Considering these properties for calculations of lung SBRT, it was estimated that the delivered dose to lung tumors differed among institutions. On the other hand, most institutions used breath holding and 4D specific-phase CT images in RMMT. Breath holding and specific-phase CT datasets would have less tumor motion than CT datasets acquired under free breathing.

One limitation of this study is that it is impossible to determine the total number of institutions that received the survey; however, we received responses from ∼66% of institutions performing SBRT in Japan [15]. According to the Japanese Structure Survey of Radiation Oncology in 2013 (2nd report) [15], the institution categories that performed radiotherapy were as follows: university hospitals 15.6%, cancer centers 3.4%, national hospital organization/public hospitals 35.5%, red cross/labors/public welfare/social welfare corporation/public interest incorporated association/corporations/mutual association hospitals 18.7% and private/medical corporation/medical association/others hospitals 21.8%. The institution categories that answered our survey were almost the same as in [15]; therefore, this survey approximately captures the trends in lung SBRT in Japan.

CONCLUSION

In conclusion, this survey revealed numerous combinations of treatment planning techniques for lung SBRT regardless of RMMT. Some institutions selected methods that were not recommended in guidelines and previous reports. In the prescription setting, about half of the institutions applied point prescriptions and the other half applied volume prescriptions. For standardization of treatment planning techniques in lung SBRT, new guidelines that mention dose prescription settings and fraction schedules will be required.

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CONFLICT OF INTEREST

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