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RESEARCH PAPER

Differences between professionals in treatment planning for patients with stage III lung cancer using treatment-planning QA software

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ABSTRACT

Background: The quality of treatment planning for stage III non-small cell lung cancer varies within and between facilities due to the different professions involved in planning. Dose estimation parameters were calculated using a feasibility dose-volume histogram (FDVH) implemented in the treatment planning quality assurance software PlanIQ. This study aimed to evaluate differences in treatment planning between occupations using manual FDVH-referenced treatment planning to identify their characteristics.

Materials and methods: The study included ten patients with stage III non-small cell lung cancer, and volumetric-modulated arc therapy was used as the treatment planning technique. Fifteen planners, comprising five radiation oncologists, five medical physicists, and five radiological technologists, developed treatment strategies after referring to the FDVH.

Results: Medical physicists had a higher mean dose at D98% of the planning target volume (PTV) and a lower mean dose at D2% of the PTV than those in other occupations. Medical physicists had the lowest irradiation lung volumes (V5 Gy and V13 Gy) compared to other professions, and radiation oncologists had the lowest V20 Gy and mean lung dose. Radiological technologists had the highest irradiation volumes for dose constraints at all indexes on the normal lung volume.

Conclusions: The quality of the treatment plans developed in this study differed between occupations due to their background expertise, even when an FDVH was used as a reference. Therefore, discussing and sharing knowledge and treatment planning techniques among professionals is essential to determine the optimal treatment plan for each facility and patient.

Key words: stage III non-small cell lung cancer; PlanIQ; treatment planning quality; volumetric-modulated arc therapy

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Introduction

In conventional 3-dimensional conformal radiotherapy (3D-CRT), the planner sets beam parameters such as the irradiation field, gantry angle, and the ratio of each irradiation field to the prescribed dose to calculate the dose distribution. The optimal dose distribution is then obtained through repeated trial and error of beam parameter settings. On the other hand, volumetric-modulated arc therapy (VMAT) employs a treatment planning method called inverse planning [1]. In inverse planning, the treatment planner calculates the irradiation required to create an ideal dose distribution. Specifically, the optimal beam can be synthesized by instructing the treatment planning system with the mathematical values of the radiation dose to the three-dimensional contour information of the tumor and organs at risk (OARs) [1].

However, because the optimization calculation is considerably affected by the planner's experience and working time variations, differences in the treatment planning quality among planners pose a problem [2–4]. Recently, tools such as RapidPlan (Varian Medical Systems, Palo Alto, CA, USA) [5], a knowledge-based treatment planning system, and PlanIQ (Sun Nuclear, Melbourne, FL) [6], a treatment planning quality assurance (QA) software, have been developed to solve this problem and have been used in clinical applications.

RapidPlan is a tool that predicts the achievable dose-volume histogram (DVH) range for targets and OARs in new cases, with minimal intervention by the treatment planner. It achieves this by building models using the treatment plans from previous cases [5]. Therefore, this tool is expected to improve both the variability and quality of treatment plans by reducing the differences in plans between different planners or facilities, as compared to conventional tools. In contrast, PlanIQ is a tool that can predict in advance the achievable dose reduction for each OAR based on computed tomography (CT) images and contour data [6]. Also, PlanIQ, a commercial treatment-planning QA software provided by Sun Nuclear (Melbourne, FL), has a crucial advantage because it does not require a patient database [7].

PlanIQ allows the calculation of the feasibility dose-volume histogram (FDVH), which is a dose estimation parameter [8]. The FDVH tool automatically predicts the dose distribution, assuming that the prescribed dose is uniformly administered up to the planning target volume (PTV) limbus and that the dose is ideally reduced [8].

In PlanIQ, the f-value is defined as a parameter indicating the feasibility of the DVH. The f-value is assigned as $f = 0–0.9$ according to the difficulty of achieving FDVH and dividing the DVH region of the OAR into four areas: impossible (red, $f = 0$), difficult (orange, $0 < f \leq 0.1$), challenging (yellow, $0.1 < f \leq 0.5$), and probable (green, $0.5 < f \leq 0.9$) (Fig. 1) [8-10]. If the DVH of the treatment-planned OAR was < 0, the prescribed dose was insufficient for the PTV.

Previous studies have reported that confirming the FDVH for OARs calculated using PlanIQ before treatment planning can help reduce the variation in quality from one treatment plan to another [9–11].

Shimizu et al. reported that $f \leq 0.22–0.26$ is an acceptable f-value for normal lung dose in stage III non-small cell lung cancer VMAT [12]. In Japan, treatment planning is performed by personnel qualified as radiation oncologists, medical physicists, or radiological technologists, considering the individual situation because the number of staff, equipment, and cases vary significantly from facility to facility. The quality of treatment planning may vary within and between facilities owing to the different occupations of the planners, which may be problematic. Furthermore, clinical and medical-physical knowledge may differ according to the occupation of the professionals planning treatment. Therefore, in this study, each planner manually performed treatment planning to achieve an f-value of 0.26 or less based on previous studies regarding the FDVH. This study aimed to evaluate and characterize the differences in treatment planning among professional groups of radiation oncologists, medical physicists, and radiological technologists. While there have been studies on inter-professional contouring [13], no reports are currently available on inter-professional inter-observer errors during treatment planning.

Materials and methods

Patients

Ten patients diagnosed with stage III non-small cell lung cancer who underwent treatment with

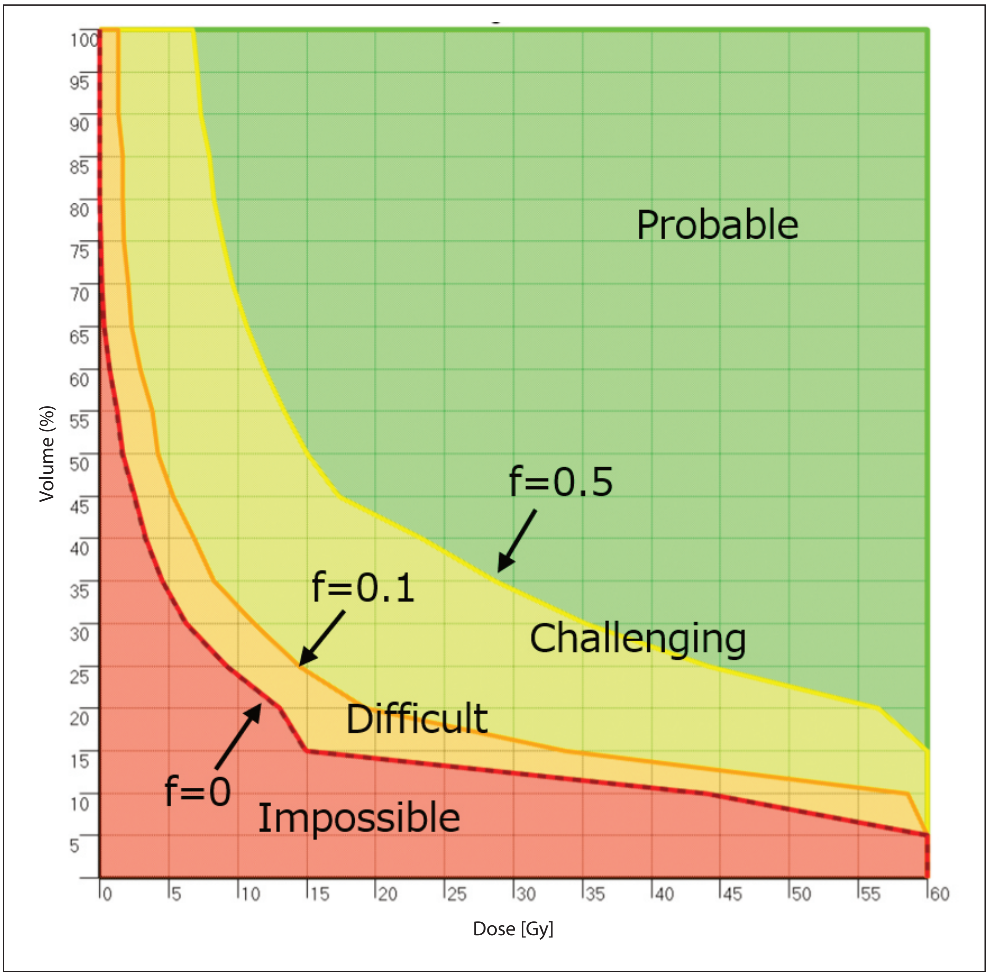

Figure 1. The f-value is defined as a parameter indicating feasibility dose volume histogram (FDVH) in PlanIQ. The f-value is assigned according to the difficulty of achieving the FDVH with f = 0 to 0.9, and the organ at risk (OAR) DVH region is divided into four regions: impossible (red, f = 0), difficult (orange, 0 < f ≤ 0.1), challenging (yellow, 0.1 < f ≤ 0.5), and probable (green, 0.5 < f ≤ 0.9)

3D-CRT at our hospital between April 2018 and December 2020 were included in this study.

Equipment

Computed tomography (CT) imaging in treatment planning was performed using Optima CT580W (General Electric Medical Systems, Waukesha, WI, United States). Linear accelerator TrueBeam (Varian Medical Systems, Palo Alto, CA, United States) with an X-ray energy of 6 MV was used for radiation therapy. The treatment planning system used was Eclipse version 16.1 (Varian Medical Systems, Palo Alto, CA, United States), and PlanIQ version 2.2 (Sun Nuclear) was used for treatment plan evaluation. In PlanIQ, FDVH (a dose reduction estimation tool for OARs) was used.

Treatment planning

CT images were taken during three phases to determine the treatment plan: resting inspiration, resting expiration, and free breathing. The gross tumor volume (GTV) for the primary lesion and metastasis to regional lymph nodes were identified in these three phases and combined to create the internal GTV (iGTV). A 5 mm margin was added to the iGTV to create the planning target volume (PTV). The organs at risk (OARs) used in this study were the lung-iGTV, esophagus, heart, spinal cord, and planning OAR volume (PRV) of the spinal cord (spinal cord+PRV). The lung-iGTV was defined as the contour of the lung minus the iGTV area, whereas the spinal cord+PRV was defined as the contour of the spinal canal enlarged by 2 mm. The prescribed dose was 60 Gy/30 fractions, com-

Table 1. Patient characteristics

Case	Primary tumor position	Clinical stage	PTV [cm³]	Lungs-iGTV [cm³]	Supraclavicular node involvement
1	Right	T4N2M0	586	3771	–
2	Right	T4N2M0	501	2943	–
3	Right	T4N2M0	455	2420	–
4	Left	T4N2M0	645	2345	–
5	Right	T4N2M0	206	3475	–
6	Right	T2aN3M0	682	3478	Yes
7	Left	T2bN3M0	189	3110	–
8	Right	T1cN3M0	552	2202	Yes
9	Right	T1cN3M0	1315	4994	Yes
10	Left	T2bN3M0	312	3992	–

PTV — planning target volume; iGTV — internal gross tumor volume

Table 2. Dose constraint

Structure	Dosimetric parameter	Dose constraint
PTV	D98 %	> 50 Gy (*54.0–57.6 Gy)
	D2 %	< 72 Gy (*67 Gy)
Lungs-iGTV	V5 Gy	< 65% (*60%)
	V13 Gy	< 40%
	V20 Gy	< 37% (*35%)
	Mean dose	< 20 Gy
Esophagus	Maximum dose	< 66 Gy
	Mean dose	< 34 Gy
Heart	V30 Gy	< 45%
	V50 Gy	< 25%
Spinal cord	Maximum dose	< 45 Gy
Spinal cord + PRV	Maximum dose	< 50 Gy (*46 Gy)

PTV — planning target volume; iGTV — internal gross tumor volume; PRV — planning organ at risk volume; *If possible

prising 95% of the PTV volume (D95%). The dose constraints are listed in Table 2. The planner was instructed to ensure that the dose constraints for the PTV, spinal cord, and spinal cord+PRV were satisfied.

The 15 planners consisted of five radiation oncologists (with more than ten years of treatment planning experience in clinical practice), five medical physicists (with more than seven years of treatment planning experience in clinical practice), and five radiological technologists (with less than two years of treatment planning experience in clinical practice) (RO1-5, MP1-5, and RT1-5, respectively). For radiological technologists to gain a good understanding of the purpose of this study, a test case was used to explain the treatment planning process, including contour definition, dose constraint, and optimization for a stage III non-small cell lung cancer patient, and the radiological technologists were provided hands-on experience.

The CT images, target, and OAR contour information were imported into PlanIQ. FDVHs for the lung-iGTV, esophagus, heart, spinal cord, and spinal cord+PRV were generated using 6 MV X-rays and a dose grid size of 2.5 mm. The planner used these FDVHs to optimize the treatment plan for each case. The treatment planning time was limited to 1 hour, allowing for an average of two treatment plans, considering the maximum time that could be spent on one patient in our clinical practice. In this study, 3D-CRT was used to treat the patients, and X-ray irradiation at angles of

60–120° and 240–300° were excluded to limit irradiation to both upper extremities. The planner was allowed to set a maximum of three arcs, and there were no restrictions on the gantry rotation angle or the collimator angle, except for restricting irradiation to both upper limbs. Other treatment planning parameters, such as the isocenter position, were standardized among the planners. The grid size for dose calculation was 2.5 mm × 2.5 mm × 2.5 mm, and the dose calculation algorithm used was AcurosXB. A photon optimizer was used as the optimization algorithm.

The evaluation methods used included measuring the D2% and D98% doses of the PTV, lung-iGTV, esophagus, heart, spinal cord, and spinal cord+PRV parameters. Finally, the treatment planning time determined by each planner was measured and compared.

Results

Results of PTV

Table 3 presents the number of arcs and whether a full or partial arc was selected as part of each planner's treatment plan set-up parameters. All the planners, except the medical physicists, adopted full-arc treatment plans. Medical physicists selected partial arcs in nine out of ten cases.

The mean ± standard deviation of the D98% and D2% PTV doses for each planner are listed in Table 4. However, the D2% dose constraint was not met by six planners in RO1-5 and RT3 (72.03–72.46 Gy). Four planners included duplicate cases, so 12 treatment plans exceeded the dose constraints.

The mean D98% PTV of the radiation oncologists' treatment plans was 57.7 Gy, which was lower than that of the other professionals. The mean D98% of the PTV for medical physicists was 58.5 Gy, which was higher than that of the other occupational groups. Medical physicists had the lowest standard deviation for treatment plans, whereas radiation oncologists had the highest standard deviation.

The mean D2% of the PTV for the medical physicists' treatment plans was 65.7 Gy, which was lower than that of the other professions. The mean D2% of the PTV for radiation oncologists was 70.4 Gy, which was higher than that of the other groups. The standard deviation of the medical physicists' treatment plans varied the least, whereas that of the radiological technicians varied the most.

Results of OARs

Table 5 shows the mean ± standard deviation of each dose index for each planner's OAR. The percentage of treatment plans that exceeded the dose constraints for each index of lung-iGTV was lower for radiation oncologists, medical physicists, and radiological technologists, in that order. Also, at V13 Gy for lung-iGTV, all indexes exceeded the dose constraints in cases 1, 6, and 8. Furthermore, at V20 Gy for lung-iGTV, none of the cases exceeded the dose constraints for all planners.

The characteristics of lung-iGTVs in inter-professional treatment planning are described. Medical physicists had the lowest irradiation volumes of V5 Gy and V13 Gy compared to other professions. Radiation oncologists had the lowest V20 Gy and mean lung dose compared to other professionals. Radiological technologists had the highest irradiation volumes for dose constraints at all indexes on the lung-iGTV. Radiological technologists had the lowest standard deviation for V5 Gy, and radiation oncologists had the lowest variation for V13 Gy, V20 Gy, and the mean lung dose. Next, medical physicists had the greatest variation in V5 Gy and V13 Gy, while radiological technologists had the greatest variation in V20 Gy and the mean lung dose.

The treatment plans that exceeded the dose constraint for the maximum esophageal dose were 100.0, 72.0, and 92.0% for radiation oncologists, medical physicists, and radiological technologists, respectively. Also, for the mean esophageal dose, the dose constraint was exceeded in cases 6, 8, 9, and 10 in all situations, and 44.0% of the treatment plans exceeded the dose constraint at all indexes.

The characteristics of the esophageal treatment plan during inter-professional treatment planning are described. Medical physicists had the lowest irradiation volume compared to other professionals for dose constraints at all indexes in the esophagus. Radiation oncologists had the highest irradiation volume compared to other professionals for dose constraints at all indexes. Medical physicists had the lowest standard deviation for dose constraints at all indexes. Radiological technologists had the greatest variation in the maximum dose, where-

Table 3. Number of beams (full or partial arc)

	RO1	RO2	RO3	RO4	RO5	MP1	MP2	MP3	MP4	MP5	RT1	RT2	RT3	RT4	RT5
Case 1	2/full	2/full	2/full	2/full	2/full	2/partial	2/partial	2/partial	2/partial	2/partial	2/full	2/full	2/full	2/full	2/full
Case 2	2/full	2/full	2/full	2/full	2/full	2/partial	2/partial	2/partial	2/partial	2/partial	2/full	2/full	2/full	2/full	2/full
Case 3	3/full	2/full	2/full	2/full	2/full	2/partial	2/partial	2/partial	2/partial	2/partial	2/full	2/full	2/full	2/full	2/full
Case 4	3/full	2/full	2/full	2/full	2/full	2/partial	2/partial	2/partial	2/partial	2/partial	2/full	2/full	2/full	2/full	2/full
Case 5	2/full	2/full	2/full	2/full	2/full	3/partial	2/partial	2/partial	2/partial	2/partial	2/full	2/full	2/full	2/full	2/full
Case 6	3/full	2/full	2/full	2/full	2/full	3/partial	2/full	2/full	2/full	2/full	2/full	3/full	2/full	2/full	2/full
Case 7	3/full	2/full	2/full	2/full	2/full	2/partial	2/partial	2/partial	2/partial	2/partial	2/full	2/full	2/full	2/full	2/full
Case 8	3/full	2/full	2/full	2/full	2/full	3/full	2/full	2/full	2/full	2/full	2/full	3/full	2/full	2/full	2/full
Case 9	2/full	2/full	2/full	2/full	2/full	3/partial	2/partial	2/partial	2/partial	2/partial	2/full	2/full	2/full	2/full	2/full
Case 10	2/full	2/full	2/full	2/full	2/full	2/partial	2/partial	2/partial	2/partial	2/partial	2/full	2/full	2/full	2/full	2/full

Table 4. Results of planning target volume (PTV)

Structure	Dosimetric parameter	Mean ± standard deviation														
		RO1	RO2	RO3	RO4	RO5	MP1	MP2	MP3	MP4	MP5	RT1	RT2	RT3	RT4	RT5
PTV	D98 % (Gy)	57.3 ± 0.9	57.4 ± 0.3	57.4 ± 0.3	58.0 ± 0.4	58.2 ± 0.6	58.4 ± 0.4	58.4 ± 0.4	58.6 ± 0.5	58.6 ± 0.6	58.6 ± 0.5	57.9 ± 0.5	58.5 ± 0.4	58.1 ± 0.5	58.2 ± 0.5	58.4 ± 0.6
	D2 % (Gy)	70.8 ± 1.6	70.1 ± 1.4	70.0 ± 1.4	70.6 ± 1.5	70.4 ± 1.5	65.4 ± 1.5	65.4 ± 1.0	65.9 ± 1.3	65.8 ± 1.4	65.9 ± 1.3	69.8 ± 1.1	67.1 ± 1.4	70.8 ± 1.3	67.8 ± 2.1	69.6 ± 2.4

Table 5. Results of organs at risk (OARs)

Structure	Dosimetric parameter	Mean ± standard deviation														
		RO1	RO2	RO3	RO4	RO5	MP1	MP2	MP3	MP4	MP5	RT1	RT2	RT3	RT4	RT5
Lungs-iGTV	V5 Gy (%)	56.0 ± 15.8	56.8 ± 14.9	56.3 ± 14.6	57.0 ± 14.8	56.5 ± 14.9	53.1 ± 16.5	51.7 ± 15.9	54.0 ± 16.2	55.3 ± 18.4	54.7 ± 17.2	58.0 ± 15.0	57.3 ± 15.0	61.2 ± 13.1	57.5 ± 15.4	58.5 ± 14.4
	V13 Gy (%)	36.7 ± 11.8	39.0 ± 10.8	39.7 ± 12.3	40.3 ± 11.4	39.9 ± 11.3	36.4 ± 11.1	36.3 ± 13.8	38.4 ± 14.3	38.3 ± 13.6	38.3 ± 13.6	41.6 ± 12.8	42.0 ± 12.3	45.0 ± 11.6	41.6 ± 13.0	42.6 ± 12.2
	V20 Gy (%)	25.2 ± 6.9	28.4 ± 7.7	29.3 ± 9.0	29.6 ± 8.1	29.1 ± 8.4	29.0 ± 8.4	29.4 ± 11.5	29.5 ± 9.3	29.4 ± 9.2	29.4 ± 9.2	32.7 ± 11.6	32.7 ± 10.2	34.4 ± 11.4	32.7 ± 11.3	33.1 ± 11.0
	Mean dose (Gy)	14.7 ± 3.8	15.3 ± 4.2	15.4 ± 4.5	15.6 ± 4.2	15.3 ± 4.1	15.4 ± 4.1	15.4 ± 5.0	15.6 ± 5.0	15.3 ± 4.6	15.5 ± 4.8	16.2 ± 4.9	15.9 ± 4.6	16.7 ± 4.6	16.5 ± 5.2	16.3 ± 5.1
Esophagus	Max dose (Gy)	71.1 ± 2.4	71.5 ± 1.7	71.1 ± 2.2	72.0 ± 2.5	71.6 ± 2.0	66.8 ± 1.7	66.6 ± 1.6	67.1 ± 1.9	67.0 ± 1.7	67.0 ± 1.4	69.6 ± 2.9	67.7 ± 2.0	70.4 ± 2.3	68.3 ± 2.9	69.2 ± 2.7
	Mean dose (Gy)	30.5 ± 13.1	29.3 ± 13.3	29.3 ± 13.3	30.6 ± 12.2	30.6 ± 12.2	28.9 ± 11.3	28.6 ± 11.7	28.9 ± 12.1	29.2 ± 11.9	29.1 ± 12.0	30.2 ± 12.3	29.8 ± 11.9	29.4 ± 11.3	30.0 ± 12.1	29.7 ± 11.6
Heart	V30 Gy (%)	13.1 ± 11.7	6.9 ± 5.8	6.7 ± 5.6	15.0 ± 15.6	11.4 ± 9.2	13.9 ± 13.4	13.1 ± 11.9	14.1 ± 16.1	16.9 ± 16.4	15.9 ± 15.7	12.3 ± 12.9	15.1 ± 16.4	12.5 ± 12.5	15.4 ± 16.7	14.8 ± 14.3
	V50 Gy (%)	3.2 ± 2.5	2.3 ± 2.1	2.7 ± 2.4	4.0 ± 4.2	3.5 ± 2.7	3.5 ± 3.9	3.2 ± 2.9	2.7 ± 2.7	2.8 ± 3.5	2.6 ± 3.2	2.8 ± 2.7	2.3 ± 2.1	2.4 ± 2.2	3.6 ± 3.6	2.8 ± 2.6
Spinal cord	Max dose (Gy)	44.5 ± 2.4	42.8 ± 3.4	42.5 ± 4.5	37.9 ± 4.4	42.3 ± 4.2	38.1 ± 3.0	41.2 ± 2.1	40.7 ± 4.1	41.5 ± 3.2	41.1 ± 3.5	41.5 ± 4.4	41.7 ± 1.9	41.2 ± 3.7	40.9 ± 3.3	42.1 ± 4.1
Spinal cord + PRV	Max dose (Gy)	49.2 ± 2.4	48.8 ± 5.9	48.8 ± 6.1	44.4 ± 3.0	49.8 ± 5.1	44.8 ± 1.8	45.6 ± 2.0	46.2 ± 3.3	47.3 ± 4.1	46.8 ± 4.3	46.4 ± 2.8	46.1 ± 2.7	46.6 ± 3.5	46.8 ± 3.3	47.1 ± 3.4

as radiation oncologists had the greatest variation in the mean dose.

The characteristics of the heart treatment plan during inter-professional treatment planning are described. Radiation oncologists had the lowest volume of radiation at V30 Gy in the heart, and medical physicists had the highest volume of radiation compared to other professions. In terms of the standard deviation at V30 Gy, radiation oncologists showed less variation than the other professionals, whereas medical physicists showed more variation. For V50 Gy, radiological technologists had the lowest irradiation volume, and radiation oncologists had the highest irradiation volume compared to other professions. The standard deviation at V50 Gy was less variable for radiological technologists and more variable for medical physicists than for other professionals.

The percentages of treatment plans that exceeded the dose constraints for the spinal cord and the spinal cord+PRV were 20.0, 0.0%, and 10.0% for radiation oncologists, medical physicists, and radiological technologists, respectively. Medical physicists had the lowest maximum dose for the spinal cord and spinal cord+PRV, while radiation oncologists had the highest maximum dose compared to the other professions. In terms of the standard deviation, medical physicists showed less variation than other professions, whereas radiation oncologists showed more variation.

Comparison of treatment planning time among planners

The mean treatment planning time for radiation oncologists was 26 minutes and 22 seconds, which was shorter than that of other occupations. Radiological technologists had a mean treatment planning time of 50 minutes and 23 seconds, which was longer than that of the other occupational groups. The standard deviation of the treatment planning time varied the least among radiological technologists and the most among radiation oncologists.

Discussion

In this study, the quality of the treatment plans by 15 planners was standardized by referring to the FDVH in advance when planning the treatment. We evaluated the occupational differences in dose restraints at our hospital.

Medical physicists had a higher mean dose at D98% of the PTV and a lower mean dose at D2% of the PTV than those in other occupations. Compared to other professions, medical physicists gave higher priority to the PTV and used three optimization ring contours around the PTV to improve dose concentration and uniformity; D98% of the PTV is a measure of minimum dose, and D2% is a measure of maximum dose. Therefore, it is conceivable that medical physicists drafted the concept to create a dose distribution that was uniformly irradiated within the PTV but steeply outside the PTV.

Shimizu et al. reported an improved evaluation of VMAT for stage III non-small lung cancer using FDVH, similar to that in the present study [12]. In their report, medical physicists with five years of treatment planning experience developed all treatment plans [12]. The mean D98% of the PTV for treatment planning by medical physicists in the present study was 58.5 Gy, whereas the D95% of the PTV in the study by Shimizu et al. was 57.7 Gy [12]. The D98% dose used in this study was higher than that reported in the previous study.

The mean V5 Gy and V13 Gy of the lung-iGTV for medical physicists were lower than those for other professionals, and the treatment planning parameters shown in Table 3 indicate that medical physicists used partial arcs in many cases. For tumors unevenly distributed on either side, limiting the beam to the side with no tumor was considered to reduce the low lung-iGTV dose. The treatment planning times shown in the average treatment planning time was shorter for RO3 and RO4 than that for the other planners. Compared with other planners, RO3 and RO4 did not reduce the dose to the OAR for FDVH, suggesting that further improvements in treatment planning techniques are desirable.

The mean volumes of V5 Gy, V13 Gy, and V20 Gy of the lung-iGTV were higher for radiological technologists than for other occupations. We believe that the high volume of lung-iGTV could be ameliorated by further training in the treatment planning methodology, as ring contours were not used for priority setting or optimization of dose reduction for FDVH.

The standard deviations of V20 Gy and the mean dose for lung-iGTV varied more among radiological technologists than among other occupational groups. The radiological technologists in this study had fewer years of experience in treatment planning; therefore, it is predicted that they planned treatment only with dose constraints and FDVH in mind. Therefore, they may not yet be able to plan treatment considering the relationship between the PTV location, OAR location, and dose distribution. For example, in cases where the PTV and OAR are adjacent to each other, it is necessary to achieve both sufficient doses for the PTV and dose reduction for the OAR, and either the PTV or the OAR should be prioritized. The need for appropriate irradiation methods and prioritization for each case has resulted in a large variation in treatment plans from case to case. In general, it is necessary to set appropriate dose values for the PTV and OAR by assuming a limit of achievable dose reduction for the OAR in each case. However, the fact that the treatment planning time was longer than that of other professionals suggests that they planned their patients' treatments by trial and error to determine a feasible dose reduction.

Sasaki et al. showed that treatment planning quality is affected by differences in the planner's technique, even when the FDVH is referenced [10]. In this study, the same factors may be responsible for the fact that radiological technologists with less experience in treatment planning could not achieve dose reduction for lung-iGTV compared to other professionals and for the variation in the quality of the treatment plans.

The mean maximum esophageal dose in the treatment plans of radiation oncologists was higher than that of other occupations. In all cases, the treatment plans of the radiological technologists exceeded the dose constraint for the maximum dose to the esophagus. Instead of increasing the dose to the esophagus, radiation oncologists sought to reduce the low to intermediate dose to the lungs by avoiding the left-to-right spread of the intermediate dose distribution. This suggests that radiation oncologists gave less priority to esophageal dose reduction than other professionals.

In contrast, the mean maximum dose in the esophagus for medical physicists was lower than that for other occupations. Medical physicists created a highly concentrated dose distribution for the PTV using ring contours. Therefore, medical physicists should reduce the dose to the esophagus near the PTV.

However, the mean dose to the esophagus showed less inter-professional variability than the maximum dose. Because the esophagus is a long organ in the head-tail direction, some areas of the PTV are included in the irradiation field, while others are not. Therefore, the ease of reducing the mean dose to the esophagus varies depending on the head-tail direction in which the PTV is located. In some cases, the esophagus was included in the PTV, depending on the position of the PTV in the left-right direction. Therefore, the mean dose to the esophagus depends on the positional relationship between the PTV and esophagus. In cases where the esophagus was included in the PTV, it was difficult to reduce the mean dose, whereas in cases where the esophagus was not included, the mean dose could be easily reduced. In cases where dose reduction was easy to achieve, all planners were able to reduce the dose, whereas in cases where dose reduction was not easy to achieve, all planners had difficulty focusing on the dose. Therefore, we believe that was little variation between the planners.

In cases 6 and 8–10, the mean dose to the esophagus exceeded the dose constraint for all planners. This may be because the esophagus was included in the PTV in cases 6 and 8–10, and the mean dose to the esophagus could not be reduced if the treatment plan was designed to ensure dose uniformity in the PTV.

In the radiation oncologists' treatment plans, the mean V30 Gy of the heart was lower than that in other occupations. In particular, RO2 and 3 had a high priority in the low-dose area of the heart. However, the dose constraint was strongly set at the low-dose area of the esophagus, which may have resulted in a lower dose value of D98% for the PTV.

In the treatment plans of the medical physicists, the mean maximum dose for the spinal cord and spinal cord+PRV was lower than that for other occupations. Medical physicists consider the spinal cord as a serial organ and a compliant object; therefore, they reduced the dose by restricting the irradiation direction, prioritizing the object, and optimizing ring contours around the PTV. Other professionals optimistically considered that the GTV often shrinks in stage III non-small lung cancer, and their treatment plans were based on the assumption that the maximum dose to the spinal cord and spinal cord+PRV could be reduced at the time of re-planning.

Radiation oncologists may have more clinical knowledge than other professionals but less medical-physical knowledge than medical physicists. Therefore, the need for treatment planning techniques based on medical-physical knowledge to reflect medical expertise in treatment planning makes it difficult to reduce the dose to the low-dose range of V5 Gy and V13 Gy for the lung-iGTV. Medical physicists have less clinical knowledge than radiation oncologists but more knowledge than radiological technologists. Medical physicists also have a high degree of expertise in medical-physical knowledge and understand the treatment-planning technique more than other professionals. Therefore, the results of this study suggest that when treatment planning is conducted regarding FDVH, it leads to stability in the quality of treatment planning. Radiological technologists have less clinical and medical-physical knowledge than other professionals because of their fewer years of experience; therefore, their treatment planning tended to be inferior to that of other professionals in this study.

Conclusions

The quality of treatment plans developed in this study varied among occupations in terms of background expertise, even when a FDVH was used as a reference. In Japan, treatment planners differ according to the situation at each facility. Therefore, it is essential to discuss and share knowledge and treatment-planning techniques among different professionals to determine the optimal treatment plan for each facility and patient.

Conflict of interest

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