Japanese Journal of
Oncology and Clinical Research

Research Article Open Access

Improving Radiotherapy Plan Quality Through Independent Physics Pre-Review

Yan LL, Huang P, Xu YJ, Men K, Ma P, Tian Y, Fu Q, and Dai JR*

Department of Radiation Oncology, National Cancer Center/National Clinical Research Center for Cancer/Cancer Hospital, Chinese Academy of Medical Sciences and Peking Union Medical College, Beijing, 10021, China

***Corresponding author** : Dai JR, Department of Radiation Oncology, National Cancer Center/National Clinical Research Center for Cancer/Cancer Hospital, Chinese Academy of Medical Sciences and Peking Union Medical College, Beijing, 100021, China, Tel: 8601087787637 Email: dai_jianrong@cicams.ac.cn

Received Date: May 04, 2022 **Accepted Date:** May 30, 2022 **Published Date:** June 01, 2022

Citation: Yan LL, Huang P, Xu YJ, Men K, Dai JR, et al. (2022) Improving Radiotherapy Plan Quality Through Independent Physics Pre-Review. JJ Oncol Clin Res 3: 1-13

Abstract

Background and Purpose: To improve plan quality, a new step, independent physics pre-review, was added to treatment planning process in our department. This study was to investigate how independent physics pre-review affects plan quality and planning time.

Materials and Methods: Independent physics pre-review takes place after a treatment plan is newly designed. If the reviewing physicist considers the plan quality is hard to improve further, physicist will approve the plan, otherwise will disapprove and give advice on how to improve the plan. After revision, the plan will be reviewed by the same reviewing physicist. This loop will continue till the plan is approved. The data of plans related to pre-review was collected from February 2021 to June 2021. For plans disapproval, their corresponding disease types, techniques used of IMRT, VMAT, TOMO, CA, CRT and Electron, problems and causes for disapproval and planning time were statistically analyzed.

Results: Totally 1447 plans were pre-reviewed, where 95.44% of plans were directly approved and 4.56% of plans were not. The three diseases with highest percentage of problem plans were lung cancer (16.67%), breast cancer (13.64%), and liver cancer (10.61%). The most frequent problem was unreasonably high dose to organs at risk. The most frequent cause leading to this problem was improper settings of optimization conditions. For example, compared to disapproved plans of lung cancer, approved plans reduced the V_5, V_{20} and D_{mean} of lung statistically (p <0.05). In addition, 50% plans can be revised and passed physics review within 5.57 working hours, 95% plans can be finished within 11.83 working hours.

Conclusions: Independent physics pre-review plays an important role in assuring the quality of treatment plan, and most independent physics pre-review can be finished within acceptable time.

Keywords: Treatment Planning, Independent physics pre-review, Plan Quality

Introduction

Review of treatment plans is a key step in the radiotherapy process that determines the characteristics of the plan selected for treatment and consequently how patients are treated [1-3,4]. However, the review is not easy since there are many aspects to be considered [5-7]. Not only it should include reviewing dose distribution and dose-volume histograms (DVHs) of target volumes and organs at risks (OARs), but also should reviewing plan parameters, such as, gantry angle, optimization conditions, and control points [8-10].

Currently there are two types of plan review, physician review and physics review [3,11-14]. Physician review is performed by the physician(s) in charge of the patient. This review is to see whether the treatment plan meets clinical requirements [15]. Physics review is performed by a physicist after the treatment plan been transferred to the treatment management system. This review is to make sure there are no errors in the treatment plan and during plan transfer, i.e., to check the safety of the treatment plan [16-19]. However, neither review involves the quality control of plan design [20]. After a treatment plan completed, all parameters affecting plan quality, especially beam arrangement and optimization conditions, should be checked [21-25] as early in the workflow as possible and not rely solely on physics review at the end of treatment planning. In addition, if a problem was found after the plan been transferred to the treatment management system, there would require a lot of rework. For these reasons, a review step by a well-experienced medical physicist right after the plan is designed should be established. It can be called independent physics pre-review, which is different from physician review and physics review afterwards. This study was to investigate how independent physics pre-review affects plan quality and planning time.

Materials and Methods

In this study four senior medical physicists participated in the independent physics pre-review. The requirements for senior medical physicists were good at external treatment planning, at least 15 years clinical working experience and have senior professional title. Once enrolled on the study, all participants would receive the same pre-review items, which can be seen in appendix part.

Independent physics pre-review takes place after a treatment plan is newly designed by a qualified dosimetrist or physicists, which were showed in Fig. 1. If the reviewing physicist considers the plan quality is satisfactory and is hard to improve further, physicist will approve the plan, and the plan will enter next step, physician review. Otherwise, reviewing physicist will disapprove the plan, and give advice to the dosimetrist/physicist on how to improve the plan. The latter will modify the plan per advice. After revision, the plan will be reviewed by the same reviewing physicist again. This loop will continue till the plan is approved.

Items of independent physics pre-review

The items of independent physics pre-review were determined through discussion among physicists in our department. The items for IMRT, VMAT, TOMO, CA, CRT and electron techniques are listed in the appendix of Table A1-6. The clinical techniques for different sites are listed in the appendix of Table A7.

Table A1 Independent physics pre-review items of IMRT treatment plan

Pre-review Items	Problems of plan
Settings of gantry angle	Fields did not follow the principle of parallel to the longest side of target volumes.
	The angle between adjacent fields too small.
	Fields did not follow the principle of nearby target volumes.
	The opposite fields set up.
	For the thorax tumor, the field not limited to a certain angle range in the anterior-posterior direction.
Settings of optimization condition	Optimization conditions omitted.
	Improper settings of optimization conditions.
	The pseudo organs missed.
	Pseudo organs drawn wrongly or unreasonably.
Dose distribution	Unmet target prescription dose.
	Dose to OAR too high.
	Improper conformity of target volumes.
	Improper homogeneity of target volumes.
	Improper maximum dose.
	Slow dose fall-off outside target volumes.
Control point	Improper position of opening control point.
	Improper size of opening control point.
Other items	Please give detail problems.

Table A2 Independent physics pre-review items of VMAT treatment plan

Pre-review Items	Problems of plan
Settings of gantry angle	Unreasonable range of arc.
	Unreasonable number of arc.
	Round-trip arcs not used.
Settings of optimization condition	Optimization conditions omitted.
	Improper settings of optimization conditions.
	The pseudo organs missed.
	Pseudo organs drawn wrongly or unreasonably.
Dose distribution	Unmet target prescription dose.
	Dose to OAR too high.
	Improper conformity of target volumes.
	Improper homogeneity of target volumes.
	The position of maximum dose was improper.
	Slow dose fall-off outside target volumes.
Control point	The position of opening control point improper.
	The size of opening control point improper.
Other items	Please give detail problems.

Table A3 Independent physics pre-review items of TOMO treatment plan

Pre-review Items	Problems of plan
Settings of optimization parameter	Unreasonable field width.
	Unreasonable modulation factor.
Settings of optimization condition	Optimization conditions omitted.
	Improper settings of optimization conditions.
	The pseudo organs missed.
	Pseudo organs drawn wrongly or unreasonably.
Dose distribution	Unmet target prescription dose.
	The dose to OAR was too high.
	Improper conformity of target volumes.
	Improper homogeneity of target volumes.
	Improper maximum dose.
	Slow dose fall-off outside target volumes.
Other items	Please give detail problems.

Table A4 Independent physics pre-review items of CA treatment plan

Pre-review Items	Problems of plan
Settings of gantry angle	Unreasonable range of arc.
	Unreasonable number of arc.
	Round-trip arcs not used.
Dose distribution	Unmet target prescription dose.
	Dose to OAR was too high.
	Improper conformity of target volumes.
	Improper homogeneity of target volumes.
	Improper maximum dose.
	Slow dose fall-off outside target volumes.
Other items	Please give detail problems.

Table A5 Independent physics pre-review items of CRT treatment plan

Pre-review Items	Problems of plan
Settings of gantry angle	Fields did not follow the principle of parallel to the longest side of target volumes. Small angle between adjacent fields. Fields did not follow the principle of nearby target volumes.
Dose distribution	Unmet target prescription dose.
	Dose to OAR was too high.
	Improper conformity of target volumes.
	Improper homogeneity of target volumes.
	Improper maximum dose..
	Slow dose fall-off outside target volumes.
Other items	Please give detail problems.

Table A6 Independent physics pre-review items of Electron treatment plan

Pre-review Items	Problems of plan
Settings of field	Improper energy used.
	Improper angle of field.
Dose distribution	Unmet target prescription dose.
	Dose to OAR was too high.
	Improper conformity of target volumes.
	Improper homogeneity of target volumes.
	Improper maximum dose.
	Slow dose fall-off outside target volumes.
Other items	Please give detail problems.

The clinical site specific technique would have had more impact in improving the plan quality, a list of recommended clinical treatment techniques for different clinical sites can be found as following:

Table A7: Clinical treatment techniques for different sites

Disease species	First recommended treatment technique	Second recommended treatment technique
Brain oligo-metastatic tumor	VMAT	IMRT
Multiple brain metastasis	TOMO	VMAT
Whole brain irradiation	VMAT	IMRT
Whole-brain irradiation and Hippocampus protection	TOMO	VMAT
Whole-brain irradiation and simultaneous integrated boost brain metastasis	TOMO	VMAT
Whole brain and spinal cord	TOMO	VMAT
Nasopharyngeal carcinoma (T1T2)	VMAT	IMRT
Nasopharyngeal carcinoma (T3T4)	TOMO	VMAT
Oropharynx cancer	VMAT	IMRT
Paranasal sinus tumor	VMAT	IMRT
Lung cancer	VMAT	IMRT
Esophageal cancer	VMAT	IMRT
Sarcoma tumor	VMAT	IMRT
Whole breast irradiation	IMRT	CRT
Whole breast and supraclavicular irradiation	VMAT	IMRT
Chest wall and supraclavicular irradiation	VMAT	VMAT/IMRT+E
Liver cancer	VMAT	IMRT
Stomach cancer	VMAT	IMRT
Prostate cancer	VMAT	IMRT
Bladder cancer	VMAT	IMRT
Gynecological tumor	VMAT	IMRT
Lymphoma cancer	VMAT	IMRT
Limb tumor	VMAT	IMRT
Bone metastasis	VMAT	IMRT

The pre-review items mainly include settings of gantry angle, settings of optimization conditions, dose distribution, control point and so on.

Data collection

For this study, plans by independent physics pre-review from February 2021 to June 2021 were collected. For plans disapproval, their corresponding disease types, techniques used, problems and causes for disapproval and planning time were counted. The homogeneity [24] and conformity [26] of target volumes and dose to OARs between disapproved and approved plans were statistically analyzed.

Data analysis

To determine whether there is a significant difference of dosimetric parameters between disapproved and approved plans, a Chi square test was performed. The threshold for statistical significance was set at $p < 0.05$ (two-tailed). All statistical analyses were performed using SPSS Version 19.0 (SPSS Inc., Chicago, IL).

Results

Statistics of independent physics pre-review plans

From February 2021 to June 2021, for three months, there were 1447 plans involved into pre-reviewed, including 138 IMRT, 1233 VMAT, 53 TOMO, 3 CA, 10 CRT and 10 Electron plans, which were showed in Fig. 1. The ratio of the number of IMRT, VMAT, TOMO, CA, CRT and Electron plans to total pre-reviewed plans is 9.54%, 85.21%, 3.67%, 0.21%, 0.69% and 0.69%, respectively. VMAT is the most used technique. Therefore, the independent physics pre-review results related to the VMAT techniques will be mainly presented and discussed in the paper.

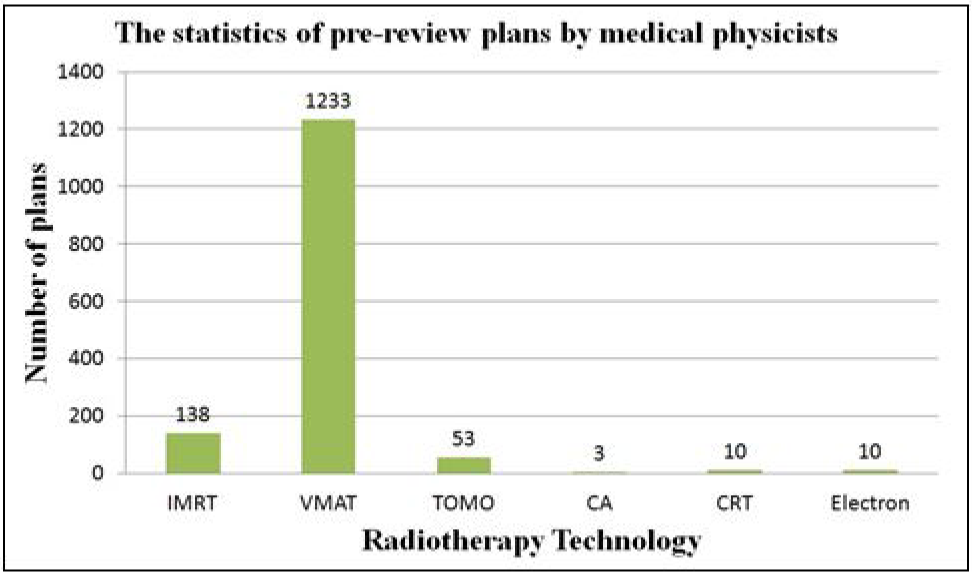

Figure 1: The statistics of pre-review plans by medical physicists for three months

Statistics of problem plans found by independent physics pre-review

Table 1 shows the statistics of problem plans found by independent physics pre-review. From the table, it can be seen that the ratio between the number of problem plans and total pre-reviewed plans is 4.56%. For TOMO, VMAT and IMRT technique, this rate is 9.43%, 4.79%, and 1.45%, respectively.

Table 1: The statistics of problem plans found by independent physics pre-review

Radiotherapy Technique	Number of problem plans found by independent physics pre-review	Number of total plans by independent physics pre-review	Proportion
IMRT	2	138	1.45%
VMAT	59	1233	4.79%
TOMO	5	53	9.43%
CA	0	3	0.00%
CRT	0	10	0.00%
Electron	0	10	0.00%
Total	66	1447	4.56%

Figure 2 shows the percentage of problem plans classified by diseases. The top three diseases with highest percentages of problem plan were lung cancer, breast cancer and liver cancer, of which problem plans account for 16.67%, 13.64% and 10.61%, respectively, of total problem plans found by independent physics pre-review.

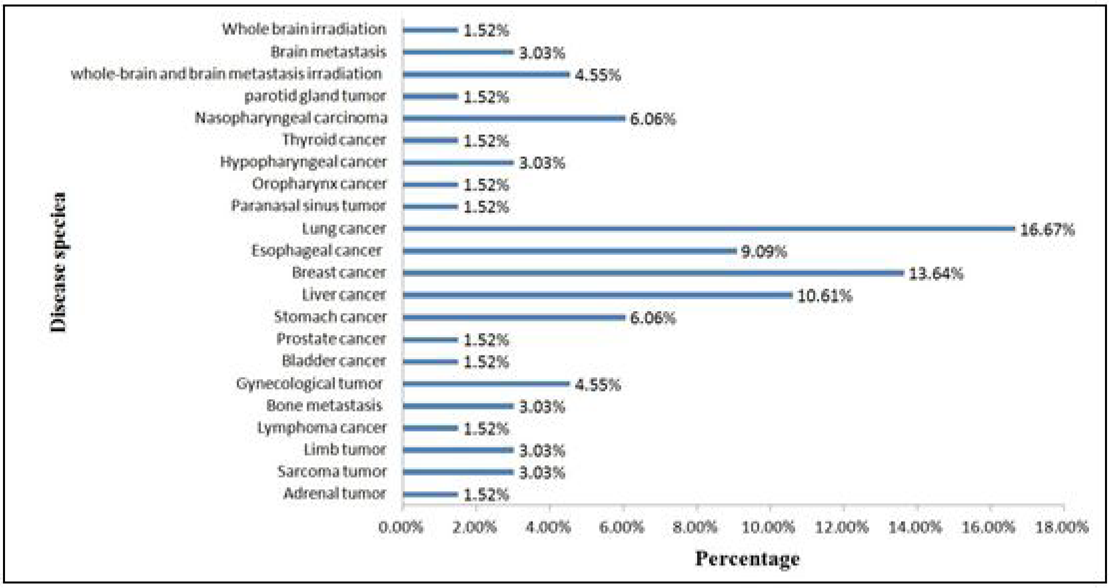

Figure 2: Percentage of problem plans classified by diseases

Statistics of problems found by independent physics pre-review

Figure 3 displays the statistics of problems for VMAT plans found through independent physics pre-review. The top problem found by independent physics pre-review was dose distribution improper. Example disapproval and approved dose distributions by independent physics pre-review for plans of sarcoma tumor were showed in Fig. 4(a) and 4(b), respectively. After revision, the dose of normal tissue in Fig. 4(b) was significantly less than that of Fig. 4(a). The secondary problem was the improper setting of gantry angle. Example setting of disapproval and approved gantry angles by independent physics pre-review for plans of lung cancer were showed in Fig. 5(a) and 5(b), respectively. After adjustment, the setting of gantry angle in Fig. 5(b) was more reasonable than that of Figu 5(a), because modified gantry angle was more limited to longest side of target volumes, and less normal tissue was penetrated.

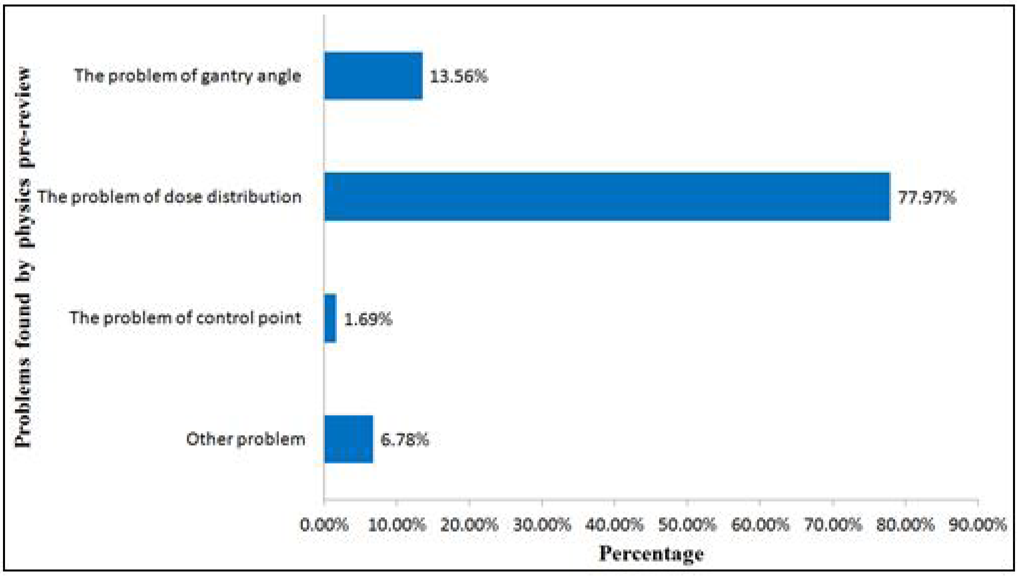

Figure 3: Percentage of problem for VMAT plans found by independent physics pre-review

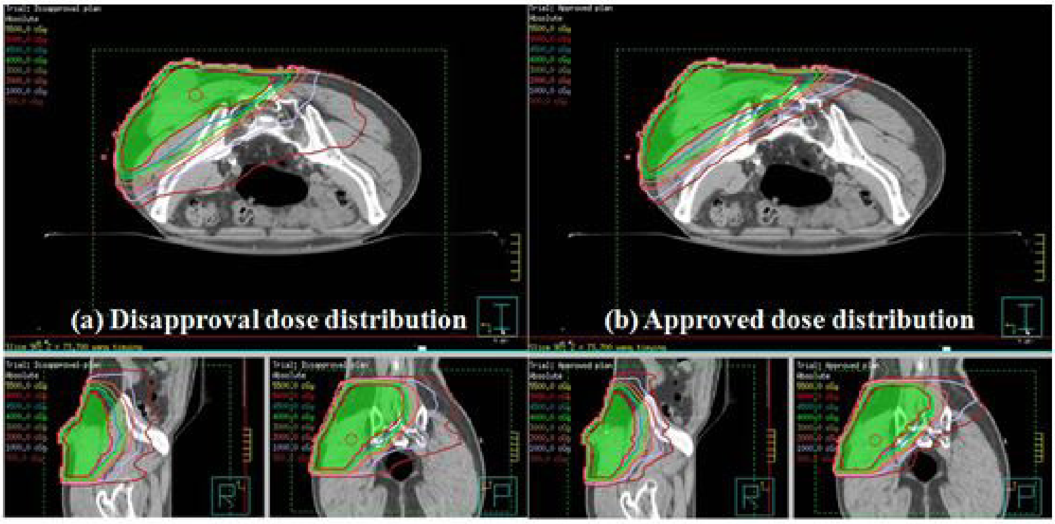

Figure 4: Example dose distribution of independent physics pre-review planning for sarcoma tumor. (a) Disapproval dose distribution; (b) Approved dose distribution

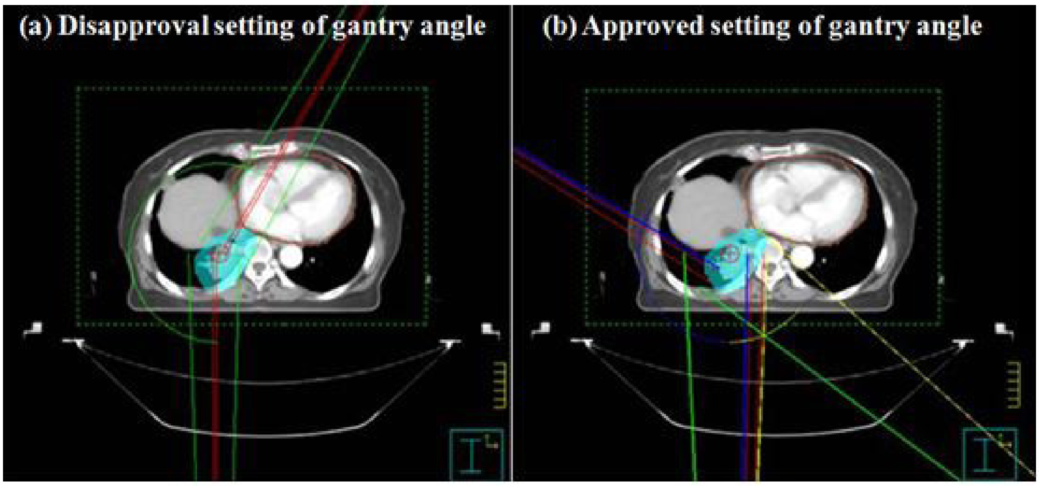

Figure 5: Example setting of gantry angle by independent physics pre-review planning for lung cancer. (a) Disapproval setting of gantry angle; (b) Approved setting of gantry angle

The dose distribution problems include unmet target prescription dose, dose to OARs too high, improper conformity of target volumes, improper homogeneity of target volumes, improper maximum dose, and slow dose fall-off outside target volumes. Detail problem percentages of unreasonable dose distribution are displayed in Fig. 6. The top three problems were dose to OARs too high, improper homogeneity of target volumes, and unmet target prescription dose, of which number of plans account for 67.57%, 18.92%, and 8.11%, respectively, of all plans with dose distribution problems.

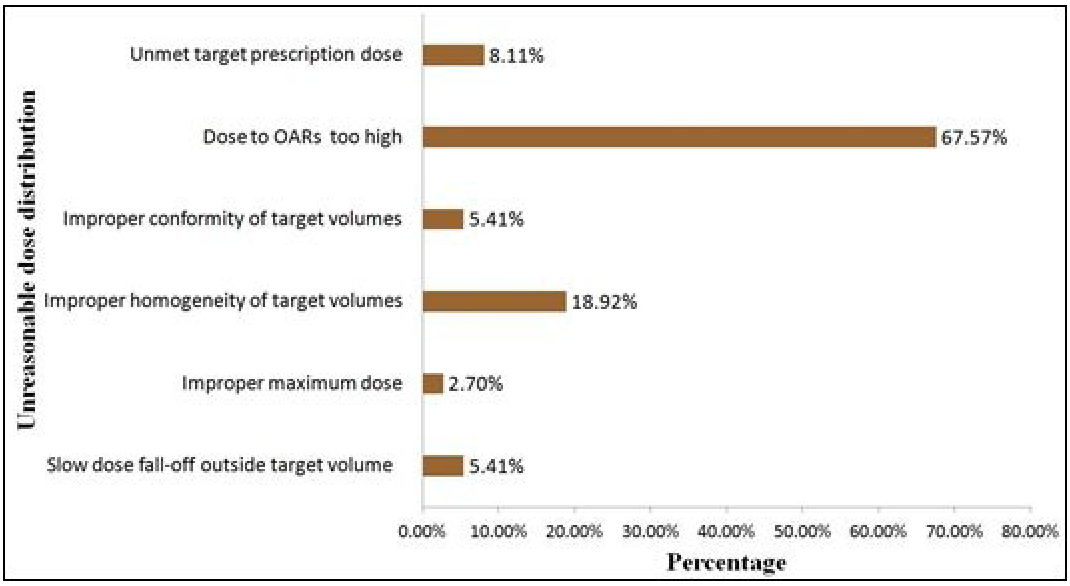

Figure 6: Problem percentages of unreasonable dose distribution

Cause analysis of problem plans

The percentage of causes for VMAT plans are displayed in Fig. 7. The top three causes were improper setting of optimization conditions, pseudo organs drawn wrongly or unreasonable, and unreasonable arc range. These three causes resulted in 67.71%, 13.56% and 13.56% problem plans, respectively.

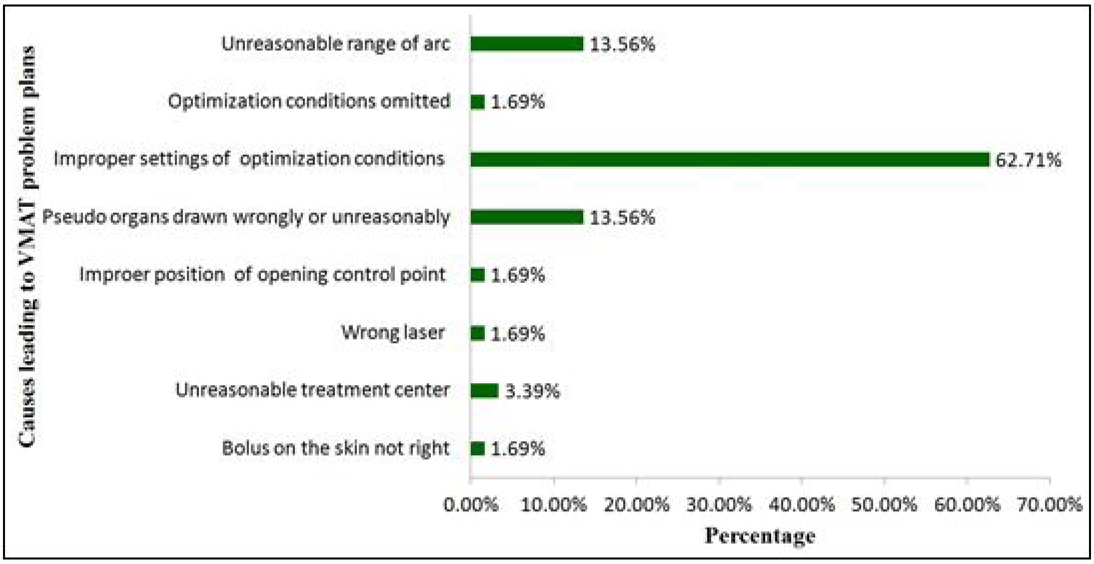

Figure 7: Percentage of causes leading to VMAT problem plans found by independent physics pre-review

Dosimetric difference between disapproval and approved plans

The treatment plans of lung cancer, with highest percentage of problem, as an example, the dosimetric difference between disapproval and approved plan by independent physics pre-review were shown in Table 2. The forth column in the table lists the p-values. A p-value of < 0.05 is considered clinically significant. As shown in Table 2, compared to disapproval plans, approved plans statistically provide significant decrease in lung all V_5, V_{20} and D_{mean}, and no significant reduction in Cord D_{max} and Cord PRV D_{max}. These comparisons show that independent physics pre-review can effectively ensure the quality of treatment plan.

Table 2: The dosimetric statistics between disapproval and approved plans of lung cancer by independent physics pre-review

Parameters	Disapproval plan	Approved plan	P-value
HI	0.23±0.08	0.23±0.08	0.824
CI	0.76±0.08	0.74±0.06	0.171
D_{max}(Cord)	32.10±11.80	31.29±12.01	0.224
D_{max}(Cord PRV)	37.07±13.21	37.55±13.34	0.468
V_5(%)(Lung all)	31.16%±13.26%	29.11%±13.29%	0.006
V_{20}(%)(Lung all)	15.85%±6.83%	15.24%±6.91%	0.049
V_{30}(%)(Lung all)	12.05%±5.35%	11.81%±6.83%	0.064
D_{mean}(Lung all)	9.22±3.67%	8.87±3.72%	0.013
V_{30}(%)(Heart)	17.39%±15.51%	16.06%±15.31%	0.298
V_{40}(%)(Heart)	10.57%±9.18%	10.66%±10.44%	0.925
D_{mean}(Gy)(Heart)	11.48 ±9.10	11.26±9.30	0.526
MU	811.71±178.30	823.14±200.94	0.428

Planning time of modifying the disapproval plans

The statistics of planning time of modifying disapproval plans were showed in Fig. 8. From disapprovement to approvement, 50% plans can be revised and passed physics review within 5.57 working hours, 95% plans can be finished within 11.83 working hours, and the longest time for passing independent physics pre-review was 26.6 working hours.

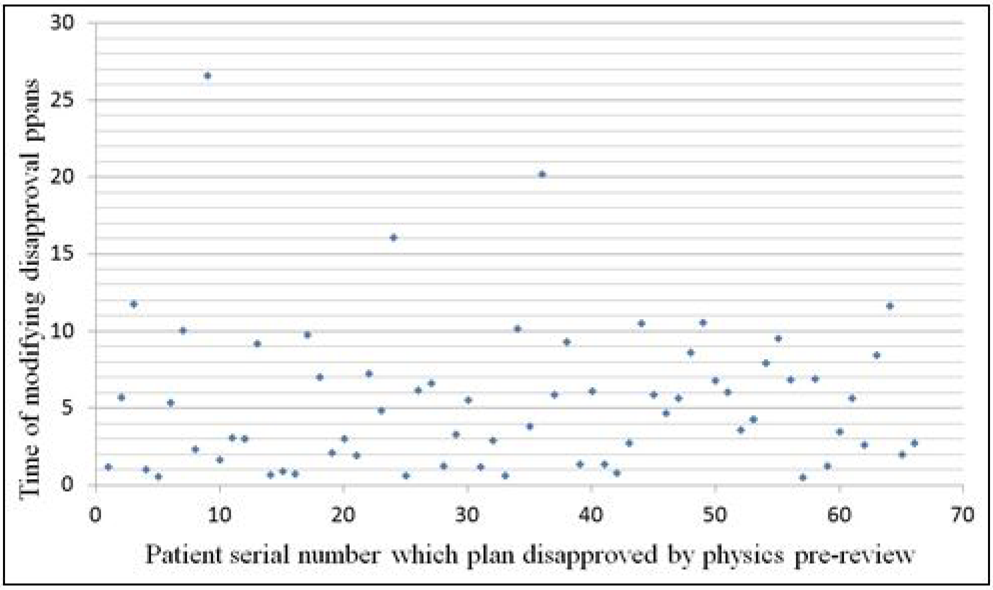

Figure 8: Statistics of planning time of modifying disapproval plans

Discussion

The results of Fig. 1 and Table 1 display the statistics of pre-reviewed plans and rate of problem plan found by independent physics pre-review. IMRT, VMAT and TOMO plans account for 98% of total reviewed plans. Approximately, 4.79% of VMAT plans were disapproved by independent physics pre-review and this value was in line with disapproval rate of all plans. 9.43% of TOMO plans were disapproved in independent physics pre-review, and this value was higher than the results of other techniques. This may be because TOMO technique was often used to design more complex treatment plans. The complexity increases the difficulty of the plan design, which requires more experienced, knowledge and skilled ability of dosimetrist/physicist.

Figure 2 show that plan of lung cancer has the highest percentages of problem plan. The main problem was the low dose of lung not strictly restricted caused by the improper setting of optimization condition or by pseudo organs drawn unreasonably. This indicates that for low dose of lung, it needs more attention by dosimetrist/physicist. For plans of breast cancer, the secondary percentages of problem plan, its main problem was no strictly protections of OARs, including the high dose to thyroid or humeral head, too much low dose to the lung, heart or contra-lateral breast.

The proper setting of optimization conditions was very important in plan design, which was displayed in Fig. 7. In addition to the reasonable arrangement of the field, setting of optimization condition largely determined the quality of the plan. If settings of optimization condition were no proper, they would most likely cause the problem of dose to OARs too high, followed by problem of dose homogeneity, which were displayed in Fig. 6. Independent physics pre-review found that even if some OARs meet the clinical requirements, their dose can be further reduced by reasonable setting of optimization conditions.

Independent physics pre-review is a critical step in ensuring the plan quality. Whether the setting of field/arc reasonable and whether settings of optimization conditions reasonable, and whether control point reasonable were all involved in independent physics pre-review. Independent physics pre-review could eliminate suboptimal treatment plans. It can review whether threatment plan has optimization space, that is, whether the dose of OARs is as low as possible on the premise of ensuring the prescription dose of target volumes.

Face-to-face communication between reviewing physicist and planning dosimetrist/physicist helps the dosimetrist/physicist really understand the causes leading to the problems and how to make timely and effectively modification to the plan. The statistics of planning time for modifying disapproval plans was displayed in Fig. 8. The planning time only include working time, excluding the weekends and holidays. It can be counted that the average time of physics review from disapprovement to approvement was 5.51 working hours. 50% plans can be revised and passed physics review within 5.57 working hours. 95% plans need more than 11.83 working hours to finish. The longest time for passing independent physics pre-review was 26.6 working hours, and the corresponding plan was a design of protecting hippocampus plan in whole-brain irradiation with simultaneous integrated boost to metastatic tumors. The complexities of the plan lead to a long optimization time, which increased the time for the plan from disapprovement to approvement. Such time cost is considered to be acceptable in our department.

Despite the benefits described above, the independent physics pre-review also has limitation, and its evaluation efficiency is not as high as the automatic evaluation software. This may increase the waiting time from designing plan to treatment for a patient. Therefore, further work to develop intelligent physical pre-review software is necessary.

Conclusions

This study shows that independent physics pre-review can improve plan quality, and most independent physics pre-review can be finished within acceptable time.

Conflict of Interest Statement

The authors have no relevant conflicts of interest to disclose.

References

1. Van der Scheuren E, Horiot JC, Leunens G, et al. (1993) Quality assurance in cancer treatment. Eur J Cancer 29: 172-181.

2. Kalapurakal JA, Zafirovski A, Smith J, et al. (2013) A comprehensive quality assurance program for personnel and procedures in radiation oncology: Value of voluntary error reporting and checklists. Int J Radiat Oncol Biol Phys 86: 241-248

3. Ford E, Conroy L, Dong L, et al. (2020) Strategies for effective physics plan and chart review in radiation therapy: Report of AAPM Task Group 275. Med Phys 4: 236-272.

4. Cho Y, Cho YJ, Chang WS, Kim JW, Choi WH and Lee IJ (2019) Evaluation of optimal treatment planning for radiotherapy of synchronous bilateral breast cancer including regional lymph node irradiation. Radiat Oncol 14: 56.

5. Kutcher GJ, Coia L, Gillin M, et al. (1994) Comprehensive QA for radiation oncology: report of AAPM Radiation Therapy Committee Task Group 40. Med Phys 21: 581-618.

6. Fraass B, Doppke K, Hunt M, et al. (1998) American Association of Physicists in Medicine Radiation Therapy Committee Task Group 53: Quality assurance for clinical radiotherapy treatment planning. Med Phys 25: 1773-1829.

7. Halvorsen PH, Das IJ, Fraser M, et al. (2005) AAPM Task Group 103 report on peer review in clinical radiation oncology physics. J Appl Clin Med Phys 6: 50-64.

8. Hernandez V, Hansen CR, Widesott L, et al. (2020) What is plan quality in radiotherapy? The importance of evaluating dose metrics, complexity, and robustness of treatment plans. Radiother Oncol 153: 26-33.

9. Nascimento A, Falzon P (2012) Producing effective treatment, enhancing safety: Medical physicists' strategies to ensure quality in radiotherapy. Appl Ergon 43: 777-784.

10. Abdellatif A, Gaede S, Control point analysis comparison for 3 different treatment planning and delivery complexity levels using a commercial 3-dimensional diode array. Med Dosim. 2014; 39: 174-179.

11. Siochi RA, Balter P, Bloch CD, et al. (2021) Report of Task Group 201 of the American Association of Physicists in Medicine: Quality management of external beam therapy data transfer. Med Phys 48: e86-e114.

12. Xia P, Sintay BJ, Colussi VC, et al. (2021) Medical Physics Practice Guideline (MPPG) 11.a: Plan and chart review in external beam radiotherapy and brachytherapy. J Appl Clin Med Phys 22: 4-19.

13. Gopan O, Zeng J, Novak A, Nyflot M, and Ford E (2016) The effectiveness of pretreatment physics plan review for detecting errors in radiation therapy. Med Phys 43: 5181-5187.

14. Lack D, Liang J, Benedetti L, Knill C, Yan D (2018) Early detection of potential errors during patient treatment Planning. J Appl Clin Med Phys 19: 724-732.

15. Wilke L, Andratschke N, Blanck O, et al. (2019) ICRU report 91 on prescribing, recording, and reporting of stereotactic treatments with small photon beams: Statement from the DEGRO/DGMP working group stereotactic radiotherapy and radiosurgery. Strahlenther Onkol 195: 193-198

16. Siochi RA, Pennington EC, Waldron TJ, Bayouth JE (2009) Radiation therapy plan checks in a paperless clinic. J Appl Clin Med Phys 10: 43-62.

17. Xu H, Zhang B, Guerrero M, Lee SW, Lamichhane N, Chen S, Yi B (2021) Toward automation of initial chart check for photon/electron EBRT: the clinical implementation of new AAPM task group reports and automation techniques. J Appl Clin Med Phys 22: 234-245.

18. Gopan O, Smith WP, Chvetsov A, et al. (2018) Utilizing simulated errors in radiotherapy plans to quantify the effectiveness of the physics plan review. Med Phys 45: 5359-5365.

19. Huq MS, Fraass BA, Dunscombe PB, et al. (2016) The report of Task Group 100 of the AAPM: Application of risk analysis methods to radiation therapy quality management. Med Phys 43: 4209-4262.

20. Nelms BE, Robinson G, Markham J, et al. (2012) Variation in external beam treatment plan quality: An inter-institutional study of planners and planning systems. Pract Radiat Oncol 2: 296-305.

21. Bzdusek K, Friberger H, Eriksson K, et al. (2009) Development and evaluation of an efficient approach to volumetric arc therapy planning, Med Phys 36: 2328-2339.

22. Masi L, Doro R, Favuzza V, Cipressi S, Livi L (2013) Impact of plan parameters on the dosimetric accuracy of volumetric modulated arc therapy. Med Phys 40: 071718.

23. Moore KL, Schmidt R, Moiseenko V, et al. (2015) Quantifying Unnecessary Normal Tissue Complication Risks due to Suboptimal Planning: A Secondary Study of RTOG 0126. Int J Radiat Oncol Biol Phys 92: 228-235.

24. Commission on Radiation Units and Measurements. Measurements. Report 83. Prescribing, recording, and reporting photon-beam intensity-modulated radiation therapy (IMRT). Oxford University Press; 2010.

25. Salomons G, Nakonechny K, Neath C, Chin L, Keller H, Chan GH (2021) Medical physics external beam plan review: what contributes to the variability? Phys Medica 89: 293-302.

26. Van't Riet A, Mak AC, Moerland MA, Elders LH, van de Zee W (1997) A conformation number to quantify the degree of conformality in brachytherapy and external beam irradiation: Application to the prostate. Int J Radiat Oncol Biol Phys 37: 731-736.