Physica Medica 46 (2018) 153–159

Contents lists available at ScienceDirect

Physica Medica

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

Original paper

Evaluation of a commercial automatic treatment planning system for liver stereotactic body radiation therapy treatments

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ARTICLE INFO

Keywords:
Automatic planning
SBRT
Auto-Planning
Pinnacle

ABSTRACT

Purpose: Automated treatment planning is a new frontier in radiotherapy. The Auto-Planning module of the Pinnacle[3] treatment planning system (TPS) was evaluated for liver stereotactic body radiation therapy treatments.

Methods: Ten cases were included in the study. Six plans were generated for each case by four medical physics experts. The first two planned with Pinnacle TPS, both with manual module (MP) and Auto-Planning one (AP). The other two physicists generated two plans with Monaco TPS (VM). Treatment plan comparisons were then carried on the various dosimetric parameters of target and organs at risk, monitor units, number of segments, plan complexity metrics and human resource planning time. The user dependency of Auto-Planning was also tested and the plans were evaluated by a trained physician.

Results: Statistically significant differences (Anova test) were observed for spinal cord doses, plan average beam irregularity, number of segments, monitor units and human planning time. The Fisher-Hayter test applied to these parameters showed significant statistical differences between AP e MP for spinal cord doses and human planning time; between MP and VM for monitor units, number of segments and plan irregularity; for all those between AP and VM. The two plans created by different planners with AP were similar to each other.

Conclusions: The plans created with Auto-Planning were comparable to the manually generated plans. The time saved in planning enables the planner to commit more resources to more complex cases. The independence of the planner enables to standardize plan quality.

1. Introduction

In the last few decades radiotherapy has evolved significantly and there has been a steady increase in the number of patients, especially for treatments such as IMRT (intensity modulated radiotherapy treatments) and VMAT (volumetric modulated arc therapy). Radiation treatment planning has become increasingly complex both for the software and calculations required and user capability. It is rapidly becoming more and more automated or semi-automated in order to relieve the planner from tasks that can be easily carried out by computers, such as auto-segmentation and optimization [1]. After having obtained the anatomical information required for planning purposes using various imaging modalities, most of the steps required for generating an optimal treatment plan can be automated. In particular, the automation of optimization process could reduce human variability thus allowing similar treatment plan quality.

The Italian Association of Medical Physics (AIFM) established a work group dedicated to the study of the dosimetric aspects of the stereobody radiation therapy (SBRT) technique. A multicentre treatment planning comparison was carried out for prostate [2], lung [3] and liver [4] SBRT treatments. A wide spread dose distribution to target and organs at risk (OARs) was observed. Esposito et al. reported that the human factor and the constraints imposed to the target volume have a greater dosimetric impact than treatment planning and radiation delivery technology in the stereotactic treatment of liver metastases [4].

Radiation therapy has historically had a limited role in the treatment of liver primary and secondary tumours due to the risk of radiation-induced liver disease (RILD) [5]. Thanks to the development of SBRT, external beam radiation therapy has become a treatment option

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https://doi.org/10.1016/j.ejmp.2018.01.016
Received 20 October 2017; Received in revised form 3 January 2018; Accepted 24 January 2018
Available online 08 February 2018

for unresectable liver tumours, like transarterial chemoembolization (TACE), radio frequency ablation (RFA) and radioembolization (TARE) [5,6]. Furthermore, SBRT has also been used as bridging or down-staging treatments for patients awaiting liver transplants [7,8]. In order to avoid treatment-related toxicity, a liver SBRT planner must take care not to harm a healthy liver and avoid damaging other relevant OARs such as bowel, kidneys and great vessels. In some cases where there may be more than one lesion and/or the planning target volume is large in respect to the liver and/or it is located in the center of it, it is difficult to respect all OARs dose constraints. In these situations, efficient user capability is essential and an automatic treatment planning system may be useful.

Currently, there are only two available commercial automatic treatment planning systems. One is the Varian's RapidPlan (Varian Medical Systems, Palo Alto, CA, USA) which uses a database of previously treated plans (knowledge-based); the other is the Auto-Planning module (AP) of Pinnacle^3 (Philips Medical System, Fitchburg, WI) which is based on a progressive optimization algorithm.

The aim of this study was to evaluate and compare treatment plans generated with Auto-Planning module with human-driven plans generated with various treatment planning systems (TPS) for liver SBRT.

2. Materials and methods

Ten liver SBRT cases, previously treated at our department, were included in the study (Table 1). The delivered dose range was from 36 to 48 Gy in 3 fractions, two cases 40 Gy in 5 fractions, prescribed on 80% isodose. For each case, four expert medical physicists (at least 5 years experience in clinical IMRT treatment planning) generated six plans. The first two planned with Pinnacle^3 TPS using the SmartArc technique, both with manual module (MP: MP1 and MP2) and with Auto-Planning one (AP: AP1 and AP2); the other two physicists generated two VMAT plans with Monaco TPS (VM: VM1 and VM2) (version 5.0, Elekta AB, Stockholm, Sweden) based on the Monte Carlo algorithm. All of the plans were generated for an equal generalized equivalent uniform dose (gEUD) to planning target volume (PTV) and following dose constraints recommended in the report published by the American Association of Physicists in Medicine task group 101 (AAPM TG101) [9]. All of the plans were planned for an Elekta Axesse™ linear accelerator, with a specific Beam Modulator (with 4 mm leaf width at isocenter) which was employed to achieve the desired beam fluence. The geometrical approach consisted of a single 180°–220° arc and planners could choose the arc width and the starting angle.

In the Auto-Planning module, the user defines the beams, dose prescriptions for PTV and threshold doses for each OAR. The AP engine then attempts to meet the target goal while lowering the dose to OARs with minimal compromise to the PTV coverage by multiple optimization iterative loops and automatic creation of objectives and optimization functions on additional structures. The contours automatically generated by the AP engine include: body structures used to control body dose, residual OARs structures where overlaps between target are removed, residual target structures where overlaps between non compromised (priority to OARs respect to target coverage) OARs are removed, PTV rings to manage dose fall-off, structures to manage target uniformity and structures to enforce high priority max and min dose goals that are not met in the last optimization. The progressive optimization algorithm involves six loops where target, OARs and hot/cold spot objectives are added, fine-tuned with one another and optimized. The optimizer continues working after meeting clinical goals in order to maximize target coverage and OARs sparing.

Table 1
Features of the ten liver SBRT cases included in the study.

N°	Dose [Gy] (80% isodose)	Number of fractions	Number of lesions	Total liver volume (cc)	Planning Target Volume (cc)
1	36	3	1	1526.1	488.9
2	48	3	1	1127.8	80.7
3	48	3	2	987.0	84.9
4	36	3	1	829.0	191.0
5	40	5	1	1678.7	18.6
6	48	3	1	1181.4	120.0
7	48	3	2	1212.8	72.7
8	48	3	2	2139.7	192.5
9	36	3	2	919.6	94.8
10	40	5	1	1014.7	90.9

The manual IMRT planning module in the Pinnacle^3 system includes both biological (target EUD, minimum EUD, maximum EUD) and physical (minimum and maximum dose, minimum and maximum DVH, uniform dose and uniformity) objective functions. The user can decide to use only one "kind" of function or both of them simultaneously. The Pinnacle^3 dose calculation algorithm is a collapsed cone algorithm, while Monaco TPS uses a X-ray Voxel Monte Carlo (XVMC) dose algorithm and its plan optimization is based on biological objective functions (target EUD, serial, parallel).

The plans were compared in terms of dosimetric parameters, total monitor units, number of plan segments, plan complexity metrics and human resource planning time. Homogeneity index (HI), conformity index (CI) and gradient index (GI) were calculated according to Paddick's formulas [10,11]. For parallel organs, volumes below threshold doses were evaluated according to Scorsetti et al. [12] for healthy livers and to AAPM TG101 [9] for kidneys. Instead, maximum dose (defined at 0.035 cc) and dose to maximum critical volume for serial tissues (rib, spinal cord, heart, bowel, stomach, great vessel) indicated in AAPM TG101 [9] were considered. The critical volume value at threshold dose was not considered since the maximum dose was often lower.

In order to determine plan complexity, we used the metrics proposed by Du et al. [13]: plan average beam area (PA), plan average beam irregularity (PI) and plan average beam modulation (PM). These parameters were determined with a homemade MATLAB (MathWorks, Natick, MA) code. The average beam area of treatment plans is measured in cm^2 and is the sum of the areas of all segments weighted for monitor units for all beams of the plan:

$$PA = \frac{\sum_i (BA_i \cdot MU_i)}{MU_p} \quad (1)$$

with

$$BA_i = \frac{\sum_j (MU_{ij} \cdot AA_{ij})}{MU_i} \quad (2)$$

wher BA_i is the area of beam i, MU_i are monitor units of beam i, MU_p total monitor units in the plan, MU_{ij} monitor units of segment j of beam i and AA_{ij} is the area of segment j of the beam i. Average beam irregularity is indicative of segment aperture narrowness: PI is equal to 1 if the aperture is a perfect circle and greater than 1 otherwise. The greater the PI value, the narrower the aperture. Similarly to Eqs. (1) and (2), PI is computed using BI_i (beam irregularity) and AI_{ij} (segment aperture irregularity) instead of BA_i and AA_{ij}, calculated as $AI_{ij} = \frac{AP_{ij}^2}{4\pi \cdot AA_{ij}}$ where AP_{ij} is the aperture perimeter of segment j of beam i. Average beam modulation is defined as:

$$PM = \frac{\sum_i (BM_i \cdot MU_i)}{MU_p} \quad (3)$$

with

$$BM_i = 1 - \frac{\sum_j (MU_{ij} \cdot AA_{ij})}{MU_i \cdot U(AA_{ij})} \quad (4)$$

where $U(AAij)$ is the union area of all apertures of beam i. PM ranges from 0 to 1 and is equal to 0 when the plan is not modulated (i.e. 3D-