International Journal of Medical Physics, Clinical Engineering and Radiation Oncology, 2023, 12, 17-27
https://www.scirp.org/journal/ijmpcero
ISSN Online: 2168-5444
ISSN Print: 2168-5436

Dosimetric Study of the Effect of Calypso-Compatible Couch Top for Spine Stereotactic Body Radiation Therapy

Ahmad Amoush[1*], Long Huang[2]

[1]Department of Radiation Oncology, Mount Sinai Beth Israel, New York, USA
[2]Department of Radiation Oncology, Cleveland Clinic, Florida, Braathen Center, Weston, USA
Email: *ahmad.amoush@mountsinai.org

How to cite this paper: Amoush, A. and Huang, L. (2023) Dosimetric Study of the Effect of Calypso-Compatible Couch Top for Spine Stereotactic Body Radiation Therapy. *International Journal of Medical Physics, Clinical Engineering and Radiation Oncology*, **12**, 17-27.
https://doi.org/10.4236/ijmpcero.2023.121003

Received: November 21, 2022
Accepted: February 19, 2023
Published: February 22, 2023

Abstract

Purpose: To study the effect of the Qfix kVue Calypso-compatible couch top on the dosimetry of Spine Stereotactic Body Radiation Therapy (SBRT). **Methods and Materials:** The computed tomography (CT) data set for Qfix kVue Calypso-compatible couch top with rails were imported into the treatment planning system (TPS). Nine patients who underwent spine SBRT were selected for this study. The inclusion criteria included patients who were treated on a stereotactic linear accelerator with 5 fractions or less from 2016 to 2017 without the couch model. Seven patients were treated with static intensity-modulated radiation therapy (IMRT) fields and two patients were treated using volumetric modulated arc therapy (VMAT) technique. The dose was recalculated for 1) couch top and rails setup (CR) 2) couch-top no rails setup (CNR), and then compared to 3) no couch no-rails setup (NCNR). Dose to 100% of the target volume (D100%), Dose to cover 99% of the target volume (D99%), Dose to cover 95% of the target volume (D95%), Dose to cover 90% of the target volume (D90%), volume receiving 100% of the prescription dose (V100%), conformity index (CI), dose gradient index (DGI), and spinal cord threshold and maximum dose were compared to the plan with NCNR. **Results:** The average D100% was 77.89% ± 11.78%, 74.51% ± 12.24%, and 75.83 ± 12.67% for NCNR, CR, CNR ($p = 0.84$), respectively. The average D99% was 91.64% ± 9.57%, 89.93% ± 9.48%, and 91.15% ± 9.55% for NCNR, CR, CNR ($p = 0.98$), respectively. The average D95% was 99.14% ± 9.96%, 95.23% ± 9.76, and 96.78% ± 9.84% for NCNR, CR, CNR ($p = 0.047$), respectively. The average D90% was 101.3% ± 0.65%, 97.11% ± 2.48%, and 98.75% ± 2.12% for NCNR, CR, CNR ($p = 0.0004$), respectively. The maximum dose to the spinal cord was 1750.79 ± 41.84, 1672.90 ± 40.90, and 1709.91 ± 41.35 (cGy) for NCNR, CR, CNR ($p = 0.97$), respectively. In all cases, the spinal

cord threshold dose was far below the tolerances and the differences were insignificant. Average CI was 1.18 ± 0.16, 0.53 ± 0.39, and 0.86 ± 0.24 for NCNR, CR, CNR ($p = 0.0002$), respectively. **Conclusions:** The study investigated the dosimetric impact of Qfix kVue Calypso-compatible couch top on the quality of the spinal SBRT treatment using static IMRT or VMAT techniques. IMRT plans showed more sensitivity to the couch being in the plan than the VMAT plans.

Keywords

SBRT, Couch, TPS

1. Introduction

External devices to the patient such as the couch top and immobilization devices act primarily as attenuators and scatterers so they can increase the skin dose, reduce the target coverage, and alter the isodose line distribution. Modern couch tops are made of carbon fiber material to increase the mechanical strength and reduce the imaging artifacts. These carbon fiber couch tops increase the skin dose and dose attenuation compare to the older tennis racket inserts [1]. The dosimetric effect of the couch tops was ignored in the old days to reduce dose calculation complexity but with the modern treatment planning systems (TPS), introducing a couch top into dose calculation became much easier. American Association of Physicists in Medicine Task group 76 (AAPM-TG76) [2] reviewed the literature and found increasing interest in the effect of couch tops on dose calculations. Since 2000, AAPMTG-76 identified 53 papers on this subject, 25 of them being published in 2009-2011. It is clear that couch top can influence the dose especially for Intensity modulated radiation therapy (IMRT) and Volumetric modulated arc therapy (VMAT) where a significant portion of the target dose is delivered through the couch top.

Impact on the skin dose was studied by many authors and showed that the skin dose can increase significantly when beams travel through the couch tops at either normal or oblique angles [3]-[9]. The depth of basal cell layer is used for skin dose measurements. This depth is reported as 0.07 mm but 0.1 mm can be used as the reference depth of the basal cell layer [10]. Skin toxicity due to the passage of beams through couch tops and immobilization devices has been reported in the literature [11] [12] [13]. Kulmala and Seppala [1] reported that the surface dose for 10×10 cm^2 field increased, depending on the type of couch top, by 26% - 37.4% (absolute) for 6 MV and 20% to 43.5% (absolute) for 15 MV photons. Photon beam attenuation is another concern for the couch tops. Attenuation increases with decreasing photon energy and angle of incidence. Several authors reported that the couch attenuation can increase 4-fold as the beam angle ranges from 0˚ to 70˚ [14] [15] [16] [17]. For carbon fiber couch tops, attenuation of up to 15% for certain parts of the couch top was reported. For VMAT

and IMRT plans, the measured dose at isocenter was reported to be 2% to 3% lower than the calculated dose when the couch and rails were ignored [15] [16] [17] [18]. Pulliam *et al.* showed that ignoring the couch components can reduce the tumor control probability (TCP) by about 8% [15]. Manually correcting the dose may lead to an overdose or underdose in regions of the patients so it is recommended to include the couch model into the treatment planning system for optimization.

In this study, QFix kVue Calypso-compatible couch top with the rails was modeled into Eclipse treatment planning system v 11.0 (Varian Medical Systems) to study the effect of the couch and rails on the dosimetry of Spine Stereotactic Body Radiation Therapy (SBRT).

2. Materials and Methods

2.1. Couch Top

The Varian Edge system (Varian Medical Systems, CA, USA) was installed with four energies (6 MV, 10 MV, 6 MVFFF, and 10 MVFFF), optical surface monitoring system, calypso system, and advanced imaging package. Calypso system is used for accurate tumor tracking in real time based on the system's detection of electromagnetic signals generate by markers called Beacon transponders. To ensure system accuracy, the system must be used with a nonconductive Calypso kVue couch top (QFix Systems). The couch top measures 132.5 cm in length, 51.4 cm in width, and 2.8 cm in thickness [19]. The rails were designed to reduce the imaging artifacts. **Figure 1** shows the couch top along with the rails. The couch three-dimensional (3D) computed tomography (CT) images, contours, and assigned CT numbers were adopted from Gardner *et al.* [20]. The CT scan for the couch with the rails was performed with 1.0 mm slice thickness using Philips scanner (Philips Brilliance Big Bore; Philips Healthcare, Andover, MA).

The 3D-CT image data was imported into Eclipse v. 11. (Varian Medical Systems). In Eclipse 11.0, couch was divided into couch interior, couch surface, couch right rail, couch left rail with assigned CT values of −930 HU, −500 HU, 250 HU, and 250 HU, respectively.

2.2. Model Verification

To verify the couch model in Eclipse 11.0, the methods proposed by Gardner *et al.* [20] were adopted. For attenuation verification, point dose measurements using a slimline miniature ion chamber (Exradin A1SL REF 92722, 0.057 cc collecting volume, Standard Imaging, WI, USA) was used. Measurements were performed with rails-in using three energies (6 MV, 6 MVFFF, and 10 MV), and three field sizes (2×2 cm^2, 4×4 cm^2, and 10×10 cm^2). Dose rates were 600 MU/min for 6 MV and 10 MV, and 1400 MU/min for 6 MVFFF. The number of gantry angles was 54 with a resolution of 2.5˚ for the oblique angles and 10˚ for the rest of the angles. **Figure 2** shows the couch model, solid water phantom and beam arrangements.

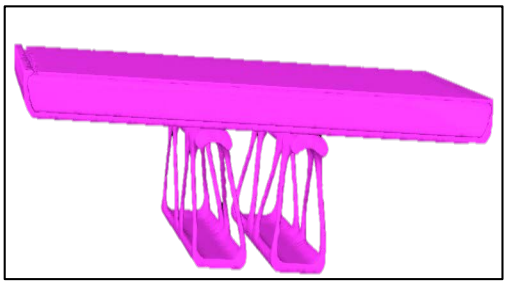

Figure 1. Calypso kVue couch top with rails (QFix Systems).

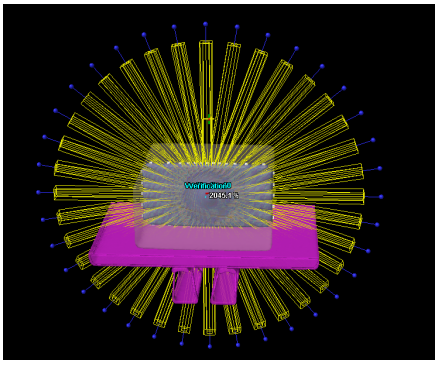

Figure 2. Calypso couch model with solid water phantom to measure beam attenuation using a slimline miniature chamber.

2.3. Couch Modeling

Calypso kVue couch top model is not available in Eclipse 11.0 so in order to include the couch into the optimization and dose calculations, the couch CT image data was imported into Eclipse manually. Then, a rigid registration was performed between each patient's CT and the Calypso CT data sets. Calypso couch top was aligned manually to replace the CT simulation couch top. The structures from the Calypso couch top were copied into the patient's structure set. Structures include couch interior, couch surface, couch rail right, and couch rail left with density override values of −930 HU, −500 HU, 250 HU, and 250 HU, respectively. The type of the couch structures was set to support in order to include the couch into the dose calculation without modifying the body contour.

2.4. Patient Selection

Nine patients who underwent spine SBRT from 2016 to 2017 were selected for this study. The patients were treated initially on stereotactic linear accelerators with no couch model. Seven patients were treated with static IMRT fields and two patients were treated with VMAT technique. The treatment sites ranged from T4 to L5 and the volume ranged from 1.83 cc to 100 cc. **Table 1** summarizes the patient data. Patients were treated following the recommendations of Task Group 101 of the American Association of Physicists in Medicine (AAPM-TG 101) [21].

Table 1. Spine SBRT patient data.

Patient #	Technique	Volume (cc)	Prescription Dose
1	IMRT-9 Beams	1.83	30 Gy (6 Gy, 5 factions)
2	IMRT-9 Beams	16.3	30 Gy (6 Gy, 5 factions)
3	IMRT-9 Beams	25.47	14 Gy (1 fraction)
4	IMRT-9 Beams	36.7	18 Gy (1 fraction)
5	IMRT-9 Beams	60.63	40 Gy (8 Gy, 5 fractions)
6	IMRT-9 Beams	92.3	15 Gy (5 Gy, 5 fractions)
7	IMRT-9 Beams	100.15	18 Gy (1 fraction)
8	VMAT-2 Arcs	24.76	30 Gy (6 Gy, 5 factions)
9	VMAT-2 Arcs	50.5	30 Gy (6 Gy, 5 factions)

2.5. Treatment Planning

Patients were initially treated on Varian trilogy linac (Varian Medical Systems, CA, USA) with plans designed on Eclipse 11.0 without the couch model. In order to study the effect of the Calypso kVue couch, three plans with three different setups were designed for each patient on Varian Edge machine. The setups are 1) no couch no rails (NCNR), 2) couch and rails (CR), and 3) couch with no rails (CNR). Optimization with the NCNR setup was performed using Eclipse Dose Volume Optimizer algorithm (DVO version 11.0) for IMRT plans and Progressive Resolution Optimizer algorithm (PRO version 11.0) for VMAT plans. Final dose calculation was done with Analytical Anisotropic Algorithm (AAA version 11.0). For CNR and CR setups, dose was recalculated with the same number of monitor units (MUs) without optimization to study the effect of the couch top and rails.

In order to insert the Calypso couch model into the plan, a verification plan was created with Calypso's CT and registered to the patient's CT. Densities for calypso couch structure were overridden as shown in section C. Two plans were created, one with CR and another plan with CNR. Dose was recalculated without any optimization and compared to NCNR. Dose covering 100% of the target volume (D100%), Dose covering 99% of the target volume (D99%), Dose covering 95% of the target volume (D95%), Dose covering 90% of the target volume (D90%), volume receiving 100% of the prescription dose (V100%), conformity index (CI) defined as the volume closed by the prescription isodose surface divided by the target volume (22), dose gradient index (DGI) defined as the volume closed by 50% isodose surface divided by the volume closed by 100% isodose surface (23), and spinal cord threshold and maximum doses were compared to the initial plan with NCNR. A single factor analysis of variance (ANOVA) is used because there are more than two variables. ANOVA compares variation between groups to determine whether the observed differences are significant or not.

3. Results

3.1. Couch Model Verification

Couch model was verified for 6 MV, 6 MVFFF, and 10 MV using point dose measurements. Figure 3 shows the measured dose versus the calculated dose with and without the couch model. For gantry angles between 100˚ and 260˚, the average difference between the measured dose and calculated dose without the couch model were 0.32% ± 0.75%, 0.32% ± 0.91%, and 0.24% ± 1.03% for 2 × 2 cm^2, 4 × 4 cm^2, and 10 × 10 cm^2, respectively. For this range of angles, the couch has minimum influence on dose measurements.

For oblique angles ranging from 110˚ - 180˚ and 250˚ - 190˚, the average difference between the measured dose and the calculated dose without the couch model for 6 MV was 7.64% ± 3.98% (ranging from 3.34% to 15.09%), 6.96% ± 3.16% (ranging from 3.18% to 12.64%), and 6.33% ± 2.72% (ranging from 2.63% to 11.22%) for 2 × 2 cm^2, 4 × 4 cm^2, and 10 × 10 cm^2, respectively. Accordingly, for 6 MVFFF, the average difference was 6.94% ± 2.72% (ranging from 3.53% to 14.25%), 6.66% ± 2.56% (ranging from 3.61% to 13.65%), and 6.50% ± 2.45% (ranging from 1.94% to 12.67%). For 10 MV, the average difference was 4.51% ± 1.71% (ranging from 2.41% to 9.53%), 4.66% ± 1.70% (ranging from 1.17% to 9.24%), and 4.82% ± 1.58% (ranging from 1.74% to 8.68%).

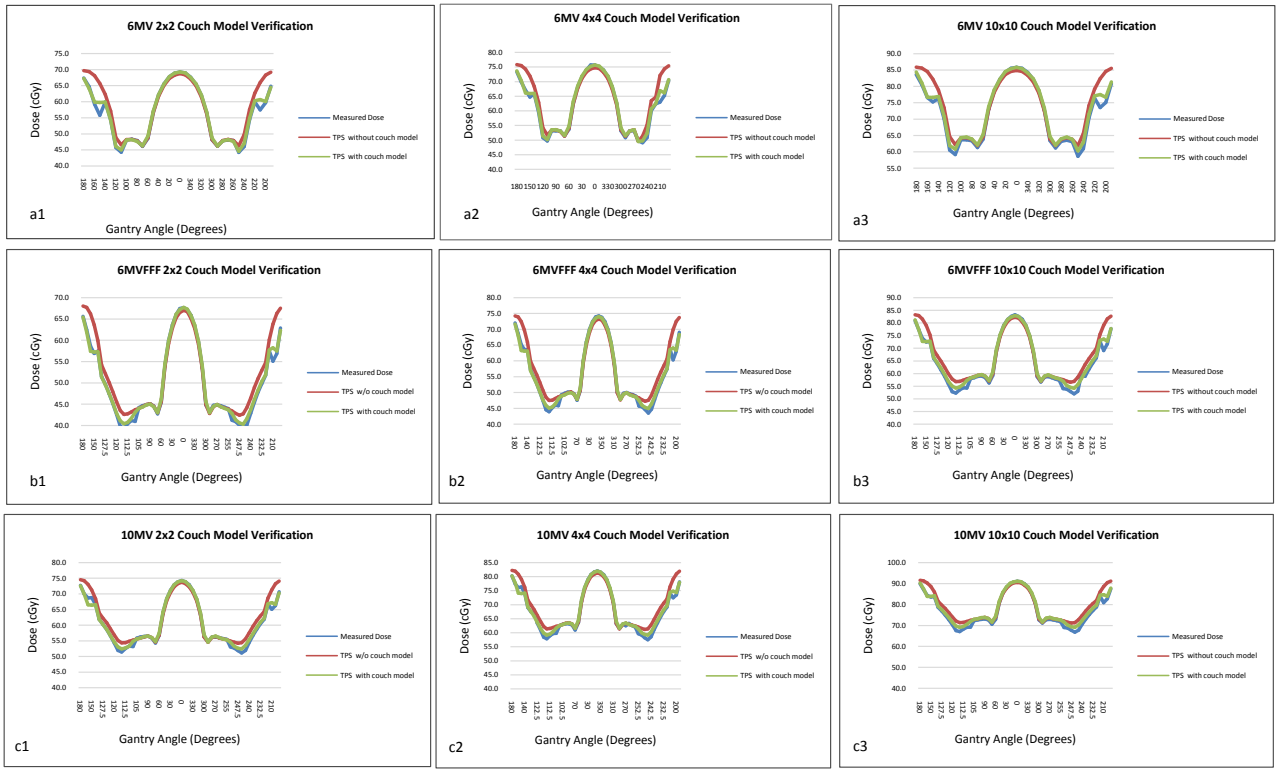

Figure 3. Couch Model Verification using a chamber point dose for (a1) 6 MV 2 × 2 cm^2, (a2) 6 MV 4 × 4 cm^2, (a3) 6 MV 10 × 10 cm^2, (b1) 6 MVFFF 2 × 2 cm^2, (b2) 6 MVFFF 4 × 4 cm^2, (b3) 6 MVFFF 10 × 10 cm^2, (c1) 10 MV 2 × 2 cm^2, (c2) 10 MV 4 × 4 cm^2, (c3) 10 MV 10 × 10 cm^2. Blue lines represent the measured dose, red line represents the planning system calculated dose without the couch model, and the green line represents the planning system calculated dose with the couch model.

On the other hand, for the oblique angles, the difference between the measured dose and the calculated dose with the couch model for 6 MV was 1.27% ± 2.18% (ranging from −0.89% to 6.71%), 1.16% ± 1.65% (ranging from −1.41% to 5.85%), and 1.70% ± 1.30% (ranging from 0.19% to 5.12%) for 2 × 2 cm^2, 4 × 4 cm^2, and 10 × 10 cm^2, respectively. Accordingly, for 6 MVFFF, the average difference was 1.19% ± 1.75% (ranging from −2.04% to 5.37%), 0.96% ± 1.91% (ranging from −2.9% to 5.84%), and 1.87% ± 2.08% (ranging from −2.96% to 6.14%). For 10 MV, the average difference was 0.67% ± 1.57% (ranging from −3.62% to 3.16%), 0.90% ± 1.60% (ranging from −3.11% to 3.09%), and 1.74% ± 1.27% (ranging from −0.66% to 4.47%). These differences may be due to the uncertainties in chamber and phantom positions relative to the couch rails.

3.2. DVH Analyses

A single factor analysis of variance (ANOVA) was used to test whether the means of the three setups (NCNR, CR, and CNR) are different. The average D100%, D99%, V50% were equivalent in the three setups with no significant differences. The average D95% was 99.14% ± 9.96%, 95.23% ± 9.76%, and 96.78% ± 9.84% for NCNR, CR, CNR ($p = 0.047$), respectively. The average D90% was 101.3% ± 0.65%, 97.11% ± 2.48%, and 98.75% ± 2.12% for NCNR, CR, CNR ($p = 0.0004$), respectively. The reduction in the average D95% and D90% were significant when the couch and rails added to the plans ($p = 0.047$, $p = 0.0004$, respectively). The reduction in the average V100% was significant with a p value of 0.0008. Table 2 summarizes the average Dose-volume metrics for the three setups.

Conformity index (CI) dropped from 1.18 for the NCNR to 0.53 and 0.86 for CR and CNR, respectively with a p-value of 0.0002. Dose gradient index (DGI) was insignificant among the three setups with a p-value of 0.16. The change in the cord maximum dose was lower when the couch and rails setup was introduced into the plan but insignificant ($p = 0.96$). Table 3 shows the CT, DGI, and cord maximum dose.

For IMRT plans only, the D90%, V100%, and CI were significant among the three setups but for VMAT plans, only D95% was significant. In clinical practice, it is challenging to maintain the rails and the patient at the same relative position so it is recommended to use the CNR setup. Comparing the CNR with CR, showed that CI and V100% are barely statistical significant with p-value of 0.0475 and 0.047, respectively. If the CNR setup is chosen over the CR setup, then it is recommended to perform dry run to avoid any beams going through the rails. Figure 4 shows the dose distributions for IMRT and VMAT plans with the three setups.

4. Discussion

The importance of couch top and rails on skin dose, isodose distribution, dose attenuation, and target coverage were discussed in AAPM-TG76 [2]. Couch tops

Table 2. Average Dose-volume metrics for no-couch-no-rails (NCNR) setup, couch-no-rails (CR) setup, and couch-no-rails setup for spinal SBRT patients planned with and without Calypso kVue couch.

	NCNR	*CR*	*CNR*	p-value
D100%	77.89% ± 11.78%	74.51% ± 12.24%	75.83% ± 12.67%	0.84
D99%	91.64% ± 11.73%	89.93% ± 7.07%	90.97% ± 9.55%	0.98
D95%	99.14% ± 9.96%	95.23% ± 9.76%	96.78% ± 9.84%	0.047
D90%	101.3% ± 0.65%	97.11% ± 2.48%	98.75% ± 2.12%	0.0004
V100%	94.38% ± 1.4%	48.01% ± 33.68%	76.07% ± 19.99%	0.0008
V50%	248.73% ± 163.98%	232.66% ± 154.43%	237.11% ± 153.56%	0.97

Table 3. Conformity index (CI), dose gradient index (DGI), and cord maximum dose for no couch no rails setup (NCNR), couch rail setup (CR), and couch no rails setup (CNR).

	NCNR	*CR*	*CNR*	p-value
CI	1.18 ± 0.16	0.53 ± 0.39	0.86 ± 0.24	0.0002
DGI	4.52 ± 1.00	11.63 ± 12.03	5.82 ± 4.75	0.16
Cord Max Dose (*Gy*)	17.51 ± 41.84	16.73 ± 40.90	17.10 ± 41.35	0.97

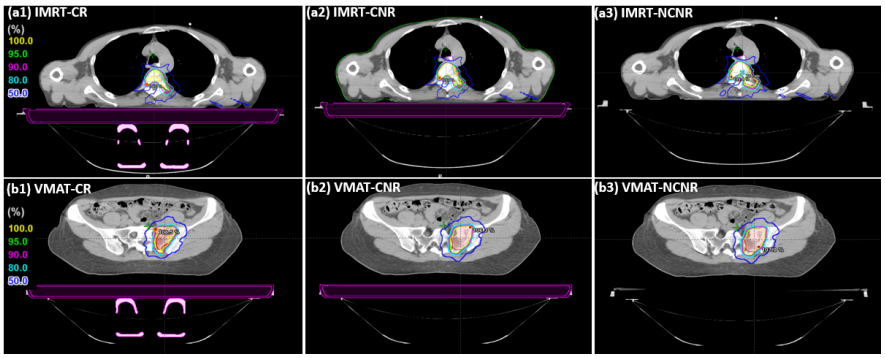

Figure 4. Isodose line distribution for (a1) IMRT plan with CR setup, (a2) IMRT plan with CNR setup, (a3) IMRT plan with NCNR setup, (b1) VMAT plan with CR setup, (b2) VMAT plan with CNR setup, and (b3) VMAT plan with NCNR setup.

increase the skin dose and dose attenuation; which can be significant when the treatment plan is designed with posterior beams. Spine SBRT is usually delivered using either IMRT or VMAT techniques. In both techniques, a significant portion of the radiation is delivered posteriorly but with VMAT technique, the treatment plan can be designed with full or half arcs so some radiation can be delivered anteriorly. Pulliam *et al.* [15] studied the impact of the Varian Exact Couch on dose, volume coverage to targets and critical structures, and tumor control probability (TCP) using IMRT and arc therapy for prostate patients. They reported that the couch caused average prescription dose losses (relative to plans that ignored the couch) to the prostate of 4.2% and 2.0% for IMRT with the rails out and in, respectively, and 3.2% and 2.9% for RapidArc with the rails out and in, respectively. On average, the percentage of the target covered by the

prescribed dose dropped to 35% and 84% for IMRT (rails out and in, respectively) and to 18% and 17% for RapidArc (rails out and in, respectively). The TCP was also reduced by as much as 10.5% (6.3% on average).

Varian Edge radiosurgery system uses the nonconductive Qfix kVue Calypso-compatible couch top with rails. In this study, the couch was modeled into Eclipse treatment planning system with rails. Nine spine SBRT patients treated in the past at our department were selected for this study. Three plans were designed for each patient with 1) NCNR setup, 2) CNR setup, and 3) CR setup. Optimization was done only on NCNR setup. For CNR and CR setups, dose was only recalculated to investigate the influence of the couch and rails. Skin dose was ignored in this study due to the fact that radiation was delivered from many angles to avoid any skin toxicity. The average D100%, D99%, V50% were equivalent in the three setups. The reduction in the average D95% and D90% were significant when the couch and rails were added to the plans with p-values of 0.047 and 0.0004, respectively. The reduction in the average V100% was significant with a p value of 0.0008.

In clinical practice, posterior IMRT beams or two half arcs are used to deliver dose to the spine using SBRT technique so significant portion of the radiation travels through the couch and rails. Results showed that D95%, D90%, V100%, and CI are significant as shown in Table 2 and Table 3. For IMRT plans, the D90%, V100%, and CI were significant among the three setups. For VMAT plans, only D95% was significant so VMAT is less susceptible to the couch top and rails presence. In clinical practice, it is a challenge to maintain the rails and the patient at the same relative position so we recommend in this study to avoid the CR setup and use the CNR setup. In IMRT, rails can be avoided by moving them either in or out during treatment so no beams can go through them. For VMAT, it is recommended to push the rails in during treatment and avoid them when designing the arcs on the treatment planning system.

5. Conclusion

AAPM TG 176 summarized the dosimetric effects caused by couch tops and immobilization devices. Many authors reported that ignoring the couch components can impact the skin dose, reduce the tumor control probability, and change the dose distribution (2, 3, 4, 5, 6, 7, 9). Manually correcting the dose may lead to an overdose or underdose in regions of the patients so it is recommended to include the couch model into the treatment planning system for optimization. In this study, we investigated the influence of the Qfix kVue Calypso-compatible couch top with rails on the treatment of spine using SBRT technique. The treatment for Spine SBRT can be delivered via static IMRT technique or using VMAT technique. For IMRT technique, a significant portion of the treatment is delivered posteriorly through the couch and rails so adding the couch structure and rails during optimization are significant as shown in the results section. For VMAT technique, radiation is delivered continuously around the patient so the effect of the couch and rails is less compared to the IMRT technique. In conclu-

sion, the couch structure should be added during plan optimization.

Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

References

[1] Seppälä, J.K.H. and Kulmala, J.A.J. (2011) Increased Beam Attenuation and Surface Dose by Different Couch Inserts of Treatment Tables Used in Megavoltage Radiotherapy. *Journal of Applied Clinical Medical Physics*, **12**, 15-23. https://doi.org/10.1120/jacmp.v12i4.3554

[2] Olch, A.J., Gerig, L., Li, H., Mihaylov, I. and Morgan, A. (2014) Dosimetric Effects Caused by Couch Tops and Immobilization Devices: Report of AAPM Task Group 176. *Medical Physics*, **41**, Article ID: 061501. https://doi.org/10.1118/1.4876299

[3] De Ost, B., Vanregemorter, J., Schaeken, B. and Van den Weyngaert, D. (1997) The Effect of Carbon Fibre Inserts on the Build-Up and Attenuation of High Energy Photon Beams. *Radiotherapy and Oncology*, **45**, 275-277. https://doi.org/10.1016/S0167-8140(97)00118-7

[4] Higgins, D.M., Whitehurst, P. and Morgan, A.M. (2001) The Effect of Carbon Fiber Couch Inserts on Surface Dose with Beam Size Variation. *Medical Dosimetry*, **26**, 251-254. https://doi.org/10.1016/S0958-3947(01)00071-1

[5] Court, L., Urribarri, J. and Makrigiorgos, M. (2010) Carbon Fiber Couches and Skin Sparing. *Journal of Applied Clinical Medical Physics*, **11**, 3241. https://doi.org/10.1120/jacmp.v11i2.3241

[6] McCormack, S., Diffey, J. and Morgan, A. (2005) The Effect of Gantry Angle on Megavoltage Photon Beam Attenuation by a Carbon Fiber Couch Insert. *Medical Physics*, **32**, 483-487. https://doi.org/10.1118/1.1852792

[7] Spezi, E. and Ferri, A. (2007) Dosimetric Characteristics of the Siemens IGRT Carbon Fiber Tabletop. *Medical Dosimetry*, **32**, 295-298. https://doi.org/10.1016/j.meddos.2006.11.006

[8] Berg, M., Bangsgaard, J.P. and Vogelius, I.S. (2009) Absorption Measurements on a New Cone beam CT and IMRT Compatible Tabletop for Use in External Radiotherapy. *Physics in Medicine & Biology*, **54**, N319-N328. https://doi.org/10.1088/0031-9155/54/14/N04

[9] Butson, M.J., Cheung, T. and Yu, P.K. (2007) Megavoltage X-Ray Skin Dose Variation with an Angle Using Grid Carbon Fibre Couch Tops. *Physics in Medicine & Biology*, **52**, N485-N492. https://doi.org/10.1088/0031-9155/52/20/N03

[10] ICRU (1991) Recommendations of the International Commission on Radiological Protection. *Annals of the ICRP*, **21**, 1-201. https://doi.org/10.1016/0146-6453(91)90067-Q

[11] Hoppe, B.S., Laser, B., Kowalski, A.V., *et al.* (2008) Acute Skin Toxicity Following Stereotactic Body Radiation Therapy for Stage I Nonsmall-Cell Lung Cancer: Who's at Risk? *International Journal of Radiation Oncology, Biology, Physics*, **72**, 1283-1286. https://doi.org/10.1016/j.ijrobp.2008.08.036

[12] King, S.C., Acker, J.C., Kussin, P.S., *et al.* (1996) High-Dose, Hyperfractionated, Accelerated Radiotherapy Using a Concurrent Boost for the Treatment of Nonsmall Cell Lung Cancer: Unusual Toxicity and Promising Early Results. *International Journal of Radiation Oncology, Biology, Physics*, **36**, 593-599.

https://doi.org/10.1016/S0360-3016(96)00353-7

[13] Lee, N., Chuang, C., Quivey, J.M., *et al.* (2002) Skin Toxicity Due to Intensity-Modulated Radiotherapy for Head-and-Neck Carcinoma. *International Journal of Radiation Oncology, Biology, Physics*, **53**, 630-637. https://doi.org/10.1016/S0360-3016(02)02756-6

[14] Mihaylov, I.B., Corry, P., Yan, Y., *et al.* (2008) Modeling of Carbon Fiber Couch Attenuation Properties with a Commercial Treatment Planning System. *Medical Physics*, **35**, 4982-4988. https://doi.org/10.1118/1.2982135

[15] Pulliam, K.B., Howell, R.M., Followill, D., *et al.* (2011) The Clinical Impact of the Couch Top and Rails on IMRT and Arc Therapy. *Physics in Medicine & Biology*, **56**, 7435-7447. https://doi.org/10.1088/0031-9155/56/23/007

[16] Teke, T., Gill, B., Duzenli, C. and Popescu, I.A. (2011) A Monte Carlo Model of the Varian IGRT Couch Top for RapidArc QA. *Physics in Medicine & Biology*, **56**, N295-N305. https://doi.org/10.1088/0031-9155/56/24/N01

[17] Li, H., Lee, A.K., Johnson, J.L., *et al.* (2011) Characterization of Dose Impact on IMRT and VMAT from Couch Attenuation for Two Varian Couches. *Journal of Applied Clinical Medical Physics*, **12**, 23-31. https://doi.org/10.1120/jacmp.v12i3.3471

[18] Van Prooijen, M., Kanesalingam, T., Islam, M.K. and Heaton, R.K. (2010) Assessment and Management of Radiotherapy Beam Intersections with the Treatment Couch. *Journal of Applied Clinical Medical Physics*, **11**, 128-139. https://doi.org/10.1120/jacmp.v11i2.3171

[19] QFix (2013) kVue couchtop [Brochure]. OFix, Avondale. https://qfix.com/catalog/radiotherapy-couch-tops/kvue-calypso-compatible-couch-top

[20] Gardner, S.J., Gulam, M., Song, K., *et al.* (2015) Generation and Verification of QFix kVue Calypso-Compatible Couch Top Model for a Dedicated Stereotactic Linear Accelerator with FFF Beams. *Journal of Applied Clinical Medical Physics*, **16**, 163-180. https://doi.org/10.1120/jacmp.v16i4.5441

[21] Benedict, S.H., Yenice, K.M., Followill, D., *et al.* (2010) Stereotactic Body Radiation Therapy: The Report of AAPM Task Group 101. *Medical Physics*, **37**, 4078-4101. https://doi.org/10.1118/1.3438081