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Clinical Impact of the Couch Top and Rails on IMRT and Arc Therapy

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Abstract

The clinical impact of the Varian Exact Couch on dose, volume coverage to targets and critical structures, and tumor control probability (TCP) has not been described. Thus, we examined their effects on IMRT and arc therapy. Five clinical prostate patients were planned with both, 6-MV 8-field IMRT and 6-MV 2-arc RapidArc using the Eclipse treatment planning system (TPS). These plans neglected treatment couch attenuation, as is a common clinical practice. Dose distributions were then recalculated in Eclipse with the inclusion of the Varian Exact Couch (imaging couch top) and the rails in varying configurations. The changes in dose and coverage were evaluated using the DVHs from each plan iteration. We used a tumor control probability (TCP) model to calculate losses in tumor control resulting from not accounting for the couch top and rails. We also verified dose measurements in a phantom. Failure to account for the treatment couch and rails resulted in clinically unacceptable dose and volume coverage losses to the target for both IMRT and RapidArc. The couch caused average 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). Dose and volume coverage losses for IMRT plans were primarily due to the rails, while the imaging couch top contributed most to losses for RapidArc. Both the couch top and rails contribute to dose and coverage losses that can render plans clinically unacceptable. A follow-up study we performed found that the less attenuating unipanel mesh couch top available with the Varian Exact couch does not cause a clinically impactful loss of dose or coverage for IMRT but still causes an unacceptable loss for RapidArc. Therefore, both the imaging or mesh couch top and the rails should be accounted for in arc therapy. The imaging couch top should be accounted for in IMRT treatment planning or the mesh top can be used, which would not need to be accounted for, and the rails should be moved to avoid the beams during treatment.

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Keywords

beam attenuation; treatment couch; IMRT; arc therapy; VMAT treatment planning

1. Introduction

There is an assumption in external beam radiation therapy that the treatment couch (comprised of both the couch top and, for some models, movable support rails) is a radiotranslucent, nonattenuating structure because of its low-density carbon fiber composition (De Ost *et al* 1997, Meara and Langmack *et al* 1998). As such, it is not generally taken into account during treatment planning, even for posterior fields. However, numerous studies have demonstrated that various treatment couch tops induce non-negligible beam attenuation, ranging from 4 to 9% (McCormack *et al* 2005, Njeh *et al* 2009, Mihaylov *et al* 2008, Gerig *et al* 2010). In addition, the support rails found on some couch models may attenuate the beam, and are denser than the couch top. Studies evaluating attenuation due to the rails (Vieira *et al* 2003, Myint *et al* 2006, van Prooijen *et al* 2010) have found that they alone may attenuate the beam by up to 17%. Knowing the large potential attenuation by the rails, some clinics move the rails out of the beam path during IMRT treatments; however, this is far from universal practice. Furthermore, the rails cannot be moved during arc therapy treatments. Failure to account for dose attenuation of the rails, or failure to move the rails out of the beam path, may compromise the effectiveness of therapy by introducing unacceptable changes between the planned and delivered doses.

Despite the fact that treatment couch tops and rails are known to cause beam attenuation, data about the clinical impact of these attenuations on treatment plan quality are lacking, particularly in terms of typical clinical parameters such as dose-volume histograms (DVHs) and tumor control probability (TCP). Additionally, further investigation is needed to develop clinically feasible methods to correct for couch-induced attenuation. Studies by Myint *et al* (2006), Mihaylov *et al* (2008), and Gerig *et al* (2010) have investigated the effects of couch structures by directly importing computed tomography (CT) images of couches into their treatment planning systems and then evaluating those systems' ability to predict the measured attenuation. All the studies found that measured and predicted attenuation in phantoms agreed to within 1.4–2%; however, none of the studies investigated the impact on plan quality using actual patient cases.

Recently, studies began to fill this need by investigating the impact of couch structures on treatment plan quality. A study by Vanetti *et al* (2009) evaluated the impact of treatment couch modeling on RapidArc using six prostate cancer patient CT data sets. Using the Eclipse model of the IGRT treatment couch, they compared the mean dose differences to target and normal tissue structures between plans that included the IGRT couch and those that did not. They found mean differences of 1.3 ± 0.3 Gy, 0.6 ± 0.2 Gy, and 0.6 ± 0.2 Gy to the PTV, rectum, and bladder, respectively for 6-MV plans with a single 360 degree arc. While this study represents a thorough and complete investigation of the impact of the IGRT couch, this treatment couch does not include the movable rails found on other Varian couch models and, as the author noted, “beam attenuation through these rails could be significantly bigger than what was shown in this study” (Vanetti *et al* 2009). To date, no study in the

literature has evaluated the impact of the Varian couches that include these highly attenuating rails for arc therapy deliveries.

One study did evaluate the impact of the Varian Exact couch with movable rails on IMRT plan quality. A study by van Prooijen *et al* (2010) investigated the impact on five clinical IMRT treatment plans; they found losses of 3% and 1% in coverage of the planning target volume (PTV) and clinical target volume (CTV), respectively, as defined by 95% of the prescription dose, when they imported CT images of the couches and rails. However, the differences between the five patients' disease sites, prescriptions, beam arrangements, and couch structures were not described, so it is difficult to apply their findings to specific types of treatments. Also, although van Prooijen *et al* incorporated the rails into their treatment planning system, they did so for one couch rail model by representing the rails as an structure of uniform density that did not take into account inhomogeneities in the rails, which might have caused errors in assessing the dosimetric effects.

Therefore, we undertook this study to further describe the impact of couch top and rail structures for IMRT and arc therapy in clinical terms such as DVH data and TCP predictions. Planning was done using the Eclipse v 8.6 treatment planning system (Varian Medical Systems), which includes models of several Varian Exact treatment couch components. The treatment planning system couch models were tested for accuracy and then used to calculate dose magnitude and dose coverage losses to target and normal tissue structures using clinical treatment plans for five prostate cancer patients.

2. Methods and materials

2.1 Treatment plans

Five prostate cancer patients were randomly selected for the study from our clinical database. All patients were planned using the prostate volume as the CTV. The PTV was generated with a 7 mm expansion in all directions with the exception of a 5 mm posterior expansion per treatment planning protocol at The University of Texas MD Anderson Cancer Center. Using the patients' original planning CT images, we created new treatments using the Eclipse v 8.6 treatment planning system, one a clinical 6-MV, 8-field IMRT plan (dynamic multileaf collimator delivery with fields 35° apart with the first field at 35° and the last field at 330°) and the other a 6-MV, 2-arc RapidArc plan (360° gantry rotation for each arc with collimators at 30° and 330°). All plans met the clinical planning criteria for target dose and coverage (98% of the CTV (prostate) and 95% of the PTV receiving at least 76 Gy) with a maximum hotspot to the CTV and PTV of 105% and 106% of prescription dose, respectively. The mean CTV and PTV volumes for these patients were 51 and 150 cm³, respectively. Additionally, normal tissue DVH constraints for the rectum and bladder (less than 20% of the rectum and bladder receiving a dose of 70 Gy; the other dose-volume constraints are shown in the results) were met. The mean rectum and bladder volumes for these patients were 91 and 187 cm³, respectively. Per clinical practice, these plans did not include the couch top and rail structures and are referred to as the clinical scenario or no-couch plans.

Each of the clinical scenario plans was then copied, and the Varian Exact Treatment Couch structures were inserted in the following configurations:

1. Imaging insert (this couch top is commonly used on Varian linear accelerators with on-board imagers (OBI) and is shown as a model in figure 2) with rails in the out position (referred to as the “rails-out” plan), representing a scenario in which the rails are not moved during treatment
2. Imaging insert with the rails in the in position (referred to as the “rails-in” plan), also representing a scenario in which the rails are not moved
3. Imaging insert only (referred to as the “couch top-only” plan), representing a scenario where the rails are moved to avoid the beam during IMRT delivery (this scenario is not clinically achievable in arc therapy but was evaluated for RapidArc to assess the effect of the couch top and rails individually).

The couch was inserted such that the patient was centered laterally on the couch, and the dose distributions were then recalculated with the same monitor units (MUs) as the no-couch plans. Each patient therefore had a total of 4 IMRT and 4 RapidArc plans, yielding a total of 40 plan configurations for the patient group as a whole.

2.2 Eclipse Couch Model Validation

The Varian Exact Treatment Couch model included in Eclipse was validated by comparing an absolute point dose measured in an IMRT quality assurance (QA) phantom (IBA Dosimetry, Bartlett, TN) with the calculated point dose obtained by copying the patient plans onto the QA phantom in the treatment planning system (i.e., hybrid patient plans). The plans for each patient were delivered (both IMRT and RapidArc) to the phantom with the rails out and with the rails in. Doses were measured at a point in the phantom with a CC04 ionization chamber (IBA Dosimetry) for each of the 20 irradiations. These measurements were compared to the calculated doses for the same rail configurations. The calculated dose in the hybrid plans was calculated as the average dose over a region of interest corresponding to the active volume of the ionization chamber in the phantom.

Varian sets the CT HU's of the couch components to default values determined by both CT analysis of the couch components and measurement data (200 HU for the rails, -1000 HU for the couch filling, and -300 for the couch top shell). However, a recent study by Wagner *et al* 2011 suggested the values be changed to 225 HU for the rails, -995 HU for the couch filling and, substantially different, -750 HU for the couch shell for the Exact couch. Another study by Vanetti *et al* (2009) found similar results for the couch shell of a different Varian couch model in Eclipse. To determine which set of HU values to use, comparison between TPS calculated point doses and measurements were made with both the Varian default and Wagner *et al* HU numbers. Based on our results, the Varian manufacturer default values were used in this study.

2.3 Clinical evaluation

The measured doses for the couch positions detailed in the previous section were also compared to the calculated values for the clinical scenario (no-couch) hybrid plans. In this

case, the measured and calculated doses were not expected to agree. Rather, the dose difference represents clinical reality when the couch is ignored in treatment planning but exists during dose delivery.

Next, the dosimetric impact of the couch top and rails on the patient treatment plans was compared with the current standard (i.e., no-couch plans) by examining dose and target coverage as shown by DVHs. The impact of the couch top and rails on doses to the prostate (CTV) and PTV were evaluated by determining the mean dose loss to each structure in the plans with the couch top and/or rails as compared to the respective structure in the clinical scenario (no-couch) plan for both IMRT and RapidArc. The relative volume coverage for the prostate and PTV was evaluated by calculating the relative volume of the structure covered by the prescribed dose (76 Gy). Additionally, the normal tissue structures of most concern clinically, the rectum and bladder, were evaluated for dose-volume losses at clinical DVH planning constraint doses.

2.4 Tumor control probability

The TCP for each plan was calculated using a script (Gay and Niemierko 2007) based on a clinically implementable TCP model previously developed by Niemierko and Goitein (1993) for an inhomogeneously irradiated tumor derived from principles of mechanistic cell kill and Poisson statistics. The script used the following equation (1) to calculate the TCP using a differential DVH:

$$TCP = \frac{1}{1 + \left(\frac{TCD_{50}}{EUD} \right)^{4\gamma_{50}}} \quad (1)$$

TCD_{50} is the dose to the tumor needed to control 50% of the tumor cells when it is homogeneously irradiated, γ_{50} is a unitless parameter that describes the slope of the dose-response curve, and EUD is the biologically equivalent dose that, if given uniformly, will lead to the same cell kill in the tumor volume as the actual nonuniform dose distribution. Equation (2) represents the formula for calculating EUD using DVH input data.

$$EUD = \left(\sum_{i=1} V_i D_i^a \right)^{1/a} \quad (2)$$

Where 'a' is a unitless parameter that is specific to the tumor of interest and that describes the dose-volume effect and V_i is the i th partial volume receiving a dose of D_i . User inputs included the DVH information. Additionally, a value for 'a', TCD_{50} , and γ_{50} , the α/β ratio, and the dose fractionation of the plans used to derive these values were needed. We took our parameters for these values from a study by Levegrun *et al* (2001) that fit the dose-response data of 103 prostate cancer patients to the Niemierko model to obtain values for the radiobiological parameters of interest. Assuming an intermediate-risk patient population, we used a TCD_{50} of 67.75 Gy, with a corresponding γ_{50} of 3.6, an α/β of 10, and fractions of 2 Gy. The value for 'a' of -10 was taken from a study evaluating prostate cancer cases with this model (Wu *et al* 2002).

3. Results

3.1 Couch model validation

The first column of data in table 1 shows the average percentage differences between the measured doses and planning system-calculated doses with the Wagner *et al* recommended HU values for the Exact couch model in Eclipse. The second column in table 1 shows the same comparison except with the Varian default HU values for the couch model used to compare with measurements. Comparing the results in these columns shows that for each treatment modality and rail position, the Varian default HU values agreed better with measured values (1.2% vs 0.6% averaged over all measurements for Wagner and Varian default, respectively). From these results, it was decided that the Varian Exact couch model with default HU values was valid and was subsequently used for the remaining parts of this study.

The third column of table 1 shows the average percentage differences between the measured doses with the different rail configurations and the calculated doses without the couch and rails taken into account (clinical scenario) as IMRT QA is commonly performed. Unlike the data in the first two columns, these data were expected to show disagreement by the amount the couch attenuated the dose at the ion chamber. The disagreement was as large as 6.2% for one patient's IMRT treatment delivered with the rails out. The magnitude of this disagreement was sufficiently large that, on average, the plans delivered with the rails out for IMRT, or with either configuration for RapidArc, failed or nearly failed to meet the common clinical IMRT QA agreement criterion of $\pm 3\%$.

3.2 DVH Analysis

Cumulative DVH's for all 5 patients averaged together are shown in figure 1 for IMRT and RapidArc with all plan iterations (no couch, rails out, rails in, and couch top only). The outer-most set of lines are the target structures for both the IMRT and RapidArc clinical scenario plans (i.e., the no-couch plans). The effects of the couch and rails are shown as the inner sets of lines on the DVH; each represents a loss in coverage and dose due to attenuation by the couch and rail structures. For the IMRT plans (figure 1a), the greatest loss was observed in the rails-out plan because both the couch top and the rails were traversed by beams in this arrangement. The target DVH lines for the rails-in and couch top-only plans represent more moderate losses of dose and coverage, and overlap completely. When the rails were in, they were not traversed by the posterior fields in our IMRT beam arrangement, and thus, both plans resulted in dose losses from the couch top alone.

The pattern of dose and coverage loss was different for the RapidArc plans (figure 1b). The approximately equal losses seen for the rails-out and rails-in plans were greater than the losses seen for the couch top-only plan. The rails-out and rails-in plans exhibited similar losses in target coverage because both the couch top and the rails were traversed completely in both configurations with our field arrangement. In general, the magnitude of coverage losses in RapidArc were intermediate between the IMRT coverage losses, with less loss than the IMRT rails-out plan and more loss than the IMRT rails-in plan.

Figures 2a, b, c, and d show distributions of dose differences between no-couch and other scenarios overlaid on the planning images for one patient, obtained by using the plan subtraction feature in Eclipse. These depictions of beam attenuation effects are consistent with the results of DVH analysis and show the spatial areas of dose loss around the prostate/CTV target. As with the IMRT DVH in figure 1a, the rails-out plan had a greater loss of dose (in excess of 3 Gy) than the rails-in plan, and the losses were entirely in the direction of the posterior fields. The RapidArc subtractions (figure 2c, d) were similar in magnitude (also in excess of 3 Gy), as was expected on the basis of the DVH in figure 1b, but the path of dose loss was different and was a function of rail position.

The average dose losses by target structures are shown in table 2 for the IMRT and RapidArc plans. On average, 4.2% of the dose to the prostate was lost because of the effects of both the couch top and the rails for the rails-out IMRT beam arrangement, with a maximum loss of 5.1% seen in one patient. Approximately half as much (mean 2%) was lost with the rails in, and that loss was due to the couch top. The dose losses for the RapidArc plans were 3.2% and 2.9% with the rails-out and with the rails-in, respectively, and a maximum of 4% lost for one plan. The couch top alone contributed most of the dose loss (mean 2%).

Another planning criterion, the volume of targets covered by the prescribed dose, was evaluated as shown in table 3 for both the IMRT and RapidArc plans. All plans met the planning criteria when the couch and rails were not accounted for, but when they were included for IMRT plans, coverage of the prostate dropped from a clinically acceptable 100% to 35% and 84% for the rails-out and rails-in plans, respectively. Even more dramatically, the coverage of the prostate with the RapidArc plans dropped from 99% to 18% and 17% for the rails-out and rails-in plans, respectively.

The results of the DVH analysis for the normal rectum and bladder tissue are shown in table 4 for the IMRT plans. We observed less volume of these normal tissues receiving every dose level, including high doses, in the plans with the couch and rails compared with the no-couch plans. Similar results (not shown) were observed for the RapidArc plans. While these results do not negatively impact the clinical acceptability of these plans, they are important to note as they are involved in treatment planning optimization.

3.3 Tumor control probability

The average TCP for each plan iteration is shown in table 5. The biological model used in this study for intermediate risk prostate patients indicated a loss in tumor control of 6.3% on average. Instead of the intended 88–90% tumor control, the presence of the couch and rails reduced this control to a minimum TCP of 80% (a 10.5% reduction) for one IMRT patient. Less TCP reduction occurred in the RapidArc plans (table 5). Inclusion of the couch and rails resulted in a minimum TCP of 78%, which was 8% less than the TCP predicted by the no-couch scenario for that patient.

4. DISCUSSION

Our measurement results using the IMRT QA phantom demonstrated two things: First, the Eclipse couch model accurately described the dose perturbations due to the presence of the patient support devices used. Second, the couch introduced substantial perturbations to the delivered dose in the patients to the extent that, on average, the plans were rendered clinically unacceptable.

The ability of the treatment planning system to account for the perturbations from the couch and rails is consistent with data in the literature. Mihaylov *et al*, Myint *et al*, Gerig *et al*, and Prooijen *et al* found agreement within 2% between calculated and measured doses when they incorporated the appropriate couches into their planning system using CT data sets of the couch components. Our agreement with measurement of within 0.7% or less validates Eclipse's ability to accurately account for dose perturbations by the couch and rails.

There is debate about the accuracy of the CT numbers of parts of the couch model as defined by Varian (Vanetti *et al*, Wagner *et al*). However, Varian continues to recommend use of the default HU values. Additionally, when we compared point dose calculations with each set of HU values (Wagner *et al* and Varian default) to measured values, we found better agreement using the default HU values in Eclipse (1.2% vs 0.6% Wanger *et al* and default HU values, respectively). For all but three of the twenty measurements, the Wagner *et al* calculated point doses resulted in a higher predicted dose than measured, meaning that use of these HU values would underestimate the impact of the couch and rails. Use of the Varian recommended default values therefore both agreed better with our measurements and may represent a more conservative assessment of the couch impact. A potential cause for the discrepancy between the Wagner *et al* findings and ours could be in methodology: Wagner *et al* used open, static fields ($10 \times 10 \text{ cm}^2$ and 100 MU) to arrive at their HU values whereas our study used actual treatment plans for couch model verification. The correct assignment for HU values for the Eclipse couch models represents an ongoing discussion in the literature, but for this study, in contrast to Wagner *et al*, we found best agreement using the default HU values.

The evaluation of the patient DVH data demonstrated a substantial inconsistency between expected dose deliveries (as described by the clinical scenario plans) and actual dose deliveries through the couch and rails. When the treatment couch with imaging insert and rails were not accounted for in treatment planning, there were, on average, clinically unacceptable losses of dose and coverage to target structures for both treatment modalities and both rail configurations. This loss of dose in patient plans was, on average, consistent with the loss of dose measured with our IMRT QA protocol. The largest difference between IMRT QA measurement and DVH expectation was observed in one patient with a 6.2% dose loss to the ionization chamber and a 4.1% loss to the CTV from DVH information. While our clinical IMRT QA protocol seemed to reasonably predict the loss of dose we observed with our DVHs, such an assessment provided no information about the spatial distribution of the dose loss or coverage loss.

Importantly, this study highlighted the need for consistency between the QA protocol and treatment delivery. If the rails are moved out of the path of the beam during IMRT QA, the resulting dose perturbation was 1.7%, and within $\pm 3\%$ tolerance. However, if similar care is not taken during patient treatment (e.g., patients treated with the rails out or otherwise not moved during treatment) it could result in a dose loss of 4.8%. As such, the plans considered acceptable by IMRT QA would, in reality, be unacceptable in clinical delivery.

On average, the losses in coverage to the target CTV and PTV structures were clinically unacceptable regardless of rail position or treatment modality, even if the rails were not intersected by the beam. The structure most responsible for the loss, however, differed between IMRT and RapidArc. As shown in table 2, the majority of the coverage loss was due to the rails when they were traversed for IMRT, but were due to the couch top for RapidArc.

The possible impact of these dose losses is depicted by the average TCP reduction of 6.3%. This reduction in tumor control is sizable, and suggests that substantial effort should be put into clinical management of the couch and rails. Naturally, the exact percent reduction in TCP is dependent on the model and associated parameters. Many of the input parameters to the model (e.g., γ_{50} , TCD₅₀, α) are dependent upon clinical data that are related to patient outcome, which can cause variance in the TCP values. In addition to the normal variance of outcomes in patient populations, these clinical parameters may be subject to a further systematic skewing since the dosimetric data used to correlate with the patient outcomes did not account for the effects of the treatment couch. Also, there is the further complication of life expectancy in typical prostate cancer patients, whose typical age at diagnosis is 68 years and who have an average life expectancy of 75.4 years (National Center for Health Statistics 2011); this relatively short post-treatment lifespan may prevent manifestations of recurrences on the order predicted by the TCP modeling. Nevertheless, couch and rail attenuation may represent a serious detriment to patient outcome if not appropriately managed.

One possible approach to managing the dosimetric impact of the treatment couch is to use a different, less attenuating couch insert. The Varian Exact Treatment Couch comes with two types of removable couch top inserts: the imaging insert often used with on-board imaging linear accelerators that was evaluated in this study, and the unipanel mesh top insert commonly used on non-on-board imaging units (units not generally capable of delivering RapidArc treatments). To compare the effects of the two couch tops, we validated the mesh top couch model by comparing measurements and TPS-calculated point doses in the IMRT QA hybrid phantom. Using the default HU values, we found agreement between TPS calculations and measurements of 0.4% on average. The couch tops were compared for dose, coverage loss, and normal tissue dose-volume constraints in tables 6 and 7. Note that these analyses did not consider the impact of the rails, whose impact would be identical to their contributions in tables 2 and 3. The dose loss was much lower for both modalities with the mesh top than with the imaging insert, and the results show that magnitude of loss may not be clinically impactful from the couch-top alone (i.e., assuming the rails do not intersect the beam). In addition to the dose loss, the coverage loss to the target structure for IMRT was also, on average, not clinically impacted and all plans would be delivered within

planning criteria limits if the rails were moved from the beams' path. These conclusions do not hold true for RapidArc. Although much less coverage was lost with the mesh top than with the imaging insert, the target coverage was made clinically unacceptable simply from the presence of the mesh top. For both IMRT (rails out) and RapidArc, if the rails were not moved during delivery the expected losses would be clinically unacceptable (2.4% dose loss and an associated unacceptable coverage loss to the prostate for IMRT, and 1.6% dose loss and an associated unacceptable coverage loss for RapidArc).

Two further issues should be considered when using a couch model in the planning system in a clinical setting: the lateral patient position and possible incorrect rail position for plans that include the rail structures. Plans that include the rails in treatment planning will increase MU's through fields that intersect the rails to compensate for attenuation. If the patient is not positioned at the same lateral position, portions of the patient would receive an unintended increased dose through those posterior fields. This problem can be avoided for IMRT by moving the rails out of the beam for each posterior field, but since this cannot be avoided for RapidArc, lateral position indexing is an additional important step for treatment set-up. Another form of this error would occur if, for example, a patient's treatment plan assumed the rails would be in the out position, but treatment was done with the rails in. This would lead to regions of underdose and overdose within the patient that could be substantial.

Consideration of the couch and rails in treatment planning has an additional interesting implication: The results from the DVH analysis of the normal tissues demonstrated greater sparing of the bladder and rectum at higher doses. While normal tissue sparing is clinically desirable, DVH constraints that are used in the clinic are set based on toxicity data from previous patients whose dosimetric data likely did not account for the treatment couch (Michalski *et al* 2010). If normal tissues receive lower doses than originally thought, dose constraints may not match reality as these structures may not have been receiving the dose that was expected when treatments involved posterior fields. Thus, the clinical constraints may need to be re-evaluated by examining patient outcomes with the couch and rails taken into account.

5. CONCLUSIONS

The attenuation of the posterior treatment fields by the Varian Exact Treatment Couch with the imaging insert and support rails for IMRT and RapidArc plans caused clinically unacceptable losses of dose and coverage to the target structures associated with prostate cancer treatment when the support structures were not taken into account in treatment planning. The magnitude of the losses of target coverage and dose was clinically impactful to the extent that ignoring the couch and rail structures resulted in plan failure, on average, for all IMRT and RapidArc couch and rail positions. This finding is important because it indicates a clinically unacceptable difference between what we may think a plan will deliver to a patient and what is really delivered for prostate radiotherapy cancer treatments.

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(a)

(b)

Figure 1.

DVH averaged over all patients (relative volume vs. high dose component of absolute dose) for IMRT (a) and RapidArc (b) delivery to target and normal tissue structures for all plan iterations (no couch, rails-out, rails-in, and imaging couch top only). The averaged PTV, CTV, rectum, and bladder are shown in black, red, green, and yellow, respectively.

Figure 2.

Representative IMRT and RapidArc dose differences between the no-couch scenario and other plan iterations ((a) IMRT rails-out, (b) IMRT rails-in, (c) RapidArc rails-out, and (d) RapidArc rails-in) showing spatially the areas of dose loss due to the couch and rails. Differences of 1, 2, and 3 Gy are shown. The outer most line is 1 Gy, the next line interior is the 2 Gy line and the inner most lines represent 3 Gy. The prostate/CTV is shown in solid colorwash.

Table 1

Magnitude of average percentage differences between measured and calculated doses for hybrid plans that included the couch and rails, and for plans that did not include these structures (per common IMRT QA protocol). Wagner HU values from Wagner *et al* 2011.

Treatment modality and configuration	Difference with Wagner HU couch and rail values	Difference with Varian default HU couch and rail values	Difference excluding couch and rails (normal delivery)
IMRT			
Rails out	1.5%	0.6%	4.8%
Rails in	0.9%	0.4%	1.7%
RapidArc			
Rails out	1.4%	0.7%	3.1%
Rails in	1.0%	0.7%	2.7%

Table 2

Average percentage prescription dose losses to target structures for IMRT and RapidArc plans.

Treatment modality and target	Mean dose loss (relative to clinical scenario)		
	Rails-out	Rails-in	Imaging couch top only
IMRT			
CTV	4.2%	2.0%	2.0%
PTV	4.1%	1.9%	1.9%
RapidArc			
CTV	3.2%	2.9%	2.0%
PTV	3.2%	3.1%	2.1%

Table 3
Average volume coverage of target structures at the prescribed dose for IMRT and RapidArc plans.

Treatment modality and target	DVH Constraints	Clinical Scenario	Rails-out	Rails-in	Imaging couch top only
IMRT					
CTV	76 Gy	100%	35%	84%	84%
PTV	76 Gy	97%	39%	79%	79%
RapidArc					
CTV	76 Gy	99%	18%	17%	40%
PTV	76 Gy	97%	27%	26%	57%

Table 4

Average volumes of critical structures receiving clinical DVH constraint doses for IMRT plans.

Critical structure	DVH constraints	Clinical Scenario	Rails-out	Rails-in	Imaging couch top only
Rectum	40 Gy < 60%	45%	42%	44%	44%
	45 Gy < 50%	38%	35%	36%	36%
	60 Gy < 40%	21%	19%	20%	20%
	70 Gy < 20%	13%	10%	12%	12%
	75.6 Gy < 15%	7%	4%	4%	4%
Bladder	78–80 Gy < 5%	1%	0%	0%	0%
	70 Gy < 20%	12%	11%	11%	11%

Table 5

Average TCP values for IMRT and RapidArc plans.

Treatment modality	Clinical Scenario	Rails-out	Rails-in
IMRT TCP	90%	82%	87%
RapidArc TCP	88%	81%	81%

Table 6

Average percentage prescribed dose losses and volume coverage of target structures for IMRT and RapidArc with imaging insert only and mesh insert only plans (no rail contribution).

Treatment modality and target	Mesh Couch Top Only		Imaging Couch Top Only	
	Mean Dose Loss	Volume Coverage	Mean Dose Loss	Volume Coverage
IMRT				
CTV	0.3%	100%	2%	84%
PTV	0.3%	96%	2%	79%
RapidArc				
CTV	0.6%	91%	2%	40%
PTV	0.6%	92%	2%	57%

Table 7

Average volumes of critical structures receiving clinical DVH constraint doses for IMRT plans that included the mesh couch top and imaging couch tops only.

Critical structure	DVH constraints	Clinical Scenario	Mesh couch top only	Imaging couch top only
Rectum	40 Gy < 60%	45%	45%	44%
	45 Gy < 50%	38%	38%	36%
	60 Gy < 40%	21%	21%	20%
	70 Gy < 20%	13%	13%	12%
	75.6 Gy < 15%	7%	7%	4%
	78–80 Gy < 5%	1%	1%	0%
Bladder	70 Gy < 20%	12%	12%	11%