Journal of Medical Imaging and Radiation Sciences xx (2016) 1-12

Journal of Medical Imaging and Radiation Sciences

Journal de l'imagerie médicale et des sciences de la radiation

www.elsevier.com/locate/jmir

# Analysis of Influence of Errors in Angular Settings of Couch and Collimator on the Dosimetric and Radiobiological Parameters in VMAT Plans

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## ABSTRACT

**Objective:** To evaluate the impact of couch and collimator angular variations on dose volume histogram (DVH), tumour control probability (TCP), and normal tissue complication probability (NTCP) of the volumetric-modulated arc therapy (VMAT) plans.

**Methods:** Stereotactic radiosurgery and stereotactic body radiation therapy VMAT plans were generated for three different hypothetical planning target volumes (PTVs) that mimic brain metastases, single brain lesion, and single spine lesion. Thirty routine VMAT plans (10 prostate, 10 head and neck, and 10 brain cases) treated in our clinic were also selected for this study. The plans were generated using an Eclipse Treatment Planning System and delivered using a Clinac iX linear accelerator equipped with a Millennium 120 multileaf collimator. All the plans were generated using two complementary full arcs (with gantry angle from 179° to 181° and collimator rotation of 30° and 330°) except the brain tumour cases, which used single full arc with collimator rotation of 30°. In all the cases, the couch angle was zero. Impact of the angular variations in the collimator and couch was studied by varying the collimator and couch angular settings by 1°, 2°, and 3°, and creating six erroneous plans corresponding to the original plans. The variation due to these errors on different DVH and radiobiological parameters (TCP, equivalent uniform dose (EUD), and NTCP) of the PTVs and organs-at-risk (OARs) were observed. The relative percentage of difference in these parameters (ΔD, ΔTCP, ΔEUD, and ΔNTCP) were analysed, and statistical significance was tested.

**Results:** The variation due to collimator misplacement was observed to be larger than the couch misplacement. Furthermore, in both cases, the variation increased as the degree of error increased. Among the DVH parameters, $D_{98\%}$, $D_{95\%}$, and $V_{95Gy}$ were affected more by the errors than $D_{2\%}$, $D_{5\%}$, and $D_{50\%}$, in both hypothetical and clinical PTVs. In the clinical PTVs, the TCP showed the most variation among all parameters. The ΔNTCP of the bladder and brain OARs were zero, whereas for head and neck OARs, it was high.

**Conclusions:** The couch and collimator angular variation has different effects on different planning situations and different parameters. The outcome produced by the errors is specific to the treatment sites.

## RÉSUMÉ

**Objectif :** Évaluer l'effet des variations angulaires de la table d'examen et du collimateur sur l'histogramme dose-volume (DVH), la probabilité de contrôle de la tumeur (TCP) et la probabilité de complication des tissus normaux (NTCP) des plans de VMAT.

**Matériel et méthodologie :** Des plans de VMAT pour la radiochirurgie stéréotactique (SRS) et la radiothérapie stéréotactique (SBRT) ont été produits pour trois volumes cibles de planification (PTV) hypothétiques différents, imitant des métastases au cerveau, une lésion unique du cerveau et une lésion unique de la colonne. De plus, 30 plans VMAT de routine (10 cas pour la prostate, 10 pour la tête et le cou et 10 pour le cerveau) traités dans notre clinique ont aussi été retenus pour cette étude. Les plans ont été générés à l'aide d'Eclipse TPS et administrés au moyen d'un LINAC Clinac ix équipé d'un collimateur multicouches Millennium 120. Tous les plans ont été générés en utilisant deux arcs complets complémentaires (avec un angle de statif entre 179 et 181 et une rotation du collimateur de 30 et 330), sauf pour les cas de tumeur au cerveau, pour lesquels on a utilisé un arc complet unique et une rotation du collimateur de 30. Dans tous les cas, l'angle de la table d'examen était de zéro. L'effet des variations angulaires du collimateur et de la table d'examen a été étudié en faisant varier les réglages angulaires de la table d'examen et du collimateur de 1, 2 et 3 et en créant six plans erronés correspondant aux plans originaux. Les variations résultant

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1939-8654/$ - see front matter 
http://dx.doi.org/10.1016/j.jmir.2016.10.012

de ces erreurs sur différents DVH et paramètres radiobiologiques (TCP, dose équivalente uniforme (EUD) et NTCP) des PTV et des OAR ont été observés. Le pourcentage relatif des écarts dans ces paramètres (ΔD, ΔTCP, ΔEUD et ΔNTCP) a été analysé et l'importance statistique a été testée.

**Résultats :** On a observé que les variations attribuables au mauvais emplacement du collimateur étaient plus élevées que celles attribuables au mauvais emplacement de la table d'examen. De plus, dans les deux cas, l'écart augmente avec le degré d'erreur. Parmi les paramètres de DVH, D98%, D95%, V95 Gy a été davantage affecté par les erreurs que D2%, D5% et D50%, dans les PTV hypothétiques comme dans les PTV cliniques. Dans les PTV cliniques, le TCP affiche les plus grandes variations parmi tous les paramètres. Le ΔNTCP des OAR de la vessie et du cerveau étaient de zéro tandis qu'il était élevé pour les PTV de la tête et du cou.

**Conclusions :** Les variations angulaires de la table d'examen et du collimateur ont des effets différents sur des situations de planification différentes et sur des paramètres différents. Le résultat produit par les erreurs est spécifique au site de traitement.

*Keywords:* VMAT; collimator error; couch error; NTCP; TCP; EUD; DVH

## Introduction

The field of radiation delivery has undergone many innovative developments over the past few years. Volumetric-modulated arc therapy (VMAT) is one of the modern techniques that have become an indispensable part of the radiotherapy department. The VMAT is a highly advanced rotational intensity-modulated radiation therapy (IMRT) technique based on the concept of Otto [1]. It has the ability to produce complex dose distribution in a single rotation of gantry and become quite popular because of its ability to produce highly conformal dose distribution in a shorter time than IMRT. VMAT plans are now being used for almost all tumour sites [2–5]. In VMAT, the plans are produced by the modulation of gantry speed, dose rate, and the position of the multileaf collimator (MLC). A real-time correlation between these parameters plays a key role in the dose delivery. Any error in these parameters raises potential changes in the delivered dose from that of the planned one. RapidArc is the commercial implementation of VMAT on the Varian linear accelerator (LINAC). RapidArc uses progressive resolution optimizer algorithm, where the optimisation starts with a few number of control points and as the process progress, and the number of the points get increased. The final single arc plan, with gantry control points, is sampled approximately every 2°. A continuous and real-time interpolation between the control points, used by the treatment planning system (TPS) for the optimisation process, is also required during the delivery [6].

In both VMAT and IMRT, there always exist a sharp dose gradient between the planning target volume (PTV) and the organ-at-risk (OAR) than that found in conventional three-dimensional conformal radiotherapy techniques. Any positional error in the MLC or small calibration errors in the angular settings of the collimator, couch, or gantry can create an underdose on the tumour or an overdose on the critical structure [7–13]. This is especially important when the complex nature of the VMAT is considered. More investigation is needed to be performed in these areas to study how the delivery errors affect the dose volume histogram (DVH) parameters and how these errors significantly change the tumour control probability (TCP) and the normal tissue complication probability (NTCP).

The MLC plays a vital role in the treatment delivery in dynamic treatment techniques like VMAT and IMRT. Several investigations have been performed to study the effects of systematic and random positional errors of the MLC on VMAT and IMRT plans. IMRT is more prone to the delivery errors than the VMAT plans [14]. Systematic errors in the MLC leaf bank position produce a 2%–4% higher dose difference in sliding window IMRT than in VMAT plans [14]. The gantry error also has a greater effect on the sliding window-IMRT compared with the latter [14]. Mu et al [7] reported that random MLC positional error up to 2 mm has only a negligible effect on the dosimetric parameters in the head and neck (HN) IMRT plans, whereas systematic MLC error of 1 mm produces a significant impact. It created a 4% and an 8% variation in the dose received by 95% of PTV volume in simple and complex IMRT plans, respectively [7]. Another study reported that a 1.5 mm random error in MLC or back up jaws in IMRT plan delivery can produce a 5% dose difference in the plan, whereas a systematic error of $\pm$0.5 mm is enough to produce a significant dose variation [8].

Rangel and Dunscombe [9] also reported that a 2-mm random error in dynamic MLC for prostate and HN IMRT plans led to negligible dose difference, but in order to limit the target dose change within 2%, the systematic error needed to be less than 0.3 mm. Similar studies have also been performed for VMAT plans. Oliver et al [11] have investigated the effect of MLC position errors on the VMAT plans in HN cases. They studied the systematic and random errors in the MLC and their impact on the equivalent uniform dose (EUD) and reported that the correlation between all MLC error types and the EUD was linear. The EUD dose sensitivities with random, systematic shift, systematic close, and systematic open MLC errors for the PTV were $-0.2$, $-0.9$, $-2.8$, and 1.9 Gy/mm, respectively [11].

Several collimator and couch angular settings are used in both IMRT and VMAT plans, depending on the complexity of the plan. The VMAT planning technique is now being used for the stereotactic radiosurgery (SRS) and stereotactic