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The Effect of Respiratory on Dose Distributions in Radiotherapy of Lung Cancer: A Phantom Study

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Abstract: Internal organ motions are one of the most significant obstacles for radiotherapy, especially in the case of motions caused by respiratory during the lung irradiation. There is no any consensus about the margin limit given for the target volume (Clinical Target Volume-CTV, Planning Target Volume- PTV etc.), especially for tumors located moving organs such as lung. Besides, as far as we know, there is no any systematic phantom study showed the effects of respiratory motions on radiotherapy doses depending on PTV margins in the literature. In present study, our aim was to determine the success degree of enlarging the PTV margins on radiotherapy doses during the moving organ irradiations. The study was performed by using GaF-Chromic EBT films placed to a thorax phantom. A cylindrical part within the phantom can move on through craniocaudal direction with a range of 3 cm with 5 sec. period during the irradiation. From the profiles which were obtained from 3 cm moving situations for 3D-Conformal Radiotherapy (3D-CRT), Intensity Modulated Radiotherapy (IMRT) and Volumetric Modulated Arc Therapy (VMAT) with narrow margins, it was observed that PTV cannot get adequate dose. The irradiation was better for CTV with larger margins but there was still inhomogeneity for PTV. As a consequence, enlarging the margins alone is not a sufficient method against the negative effects of organ motions on the radiotherapy doses.

***Key words**:* Radiotherapy, lung movement, respiratory

Akciğer Kanseri Radyoterapisinde Solunumun Doz Dağılımlarına Etkisi: Bir Fantom Çalışması

Özet: Organ hareketleri, özellikle akciğer ışınlamaları sırasında nefes alıp vermeden kaynaklanan hareketler, radyoterapi için en önemli zorluklardandır. Özellikle akciğer gibi hareketli organlarda bulunan tümörler için hedef hacme (Clinical Target Volume-CTV, Planning Target Volume- PTV) verilecek marj sınırı hakkında herhangi bir fikir birliği yoktur. Bunun yanında, literatürde solunum hareketlerinin PTV marjlarına bağlı olarak radyoterapi dozlarına etkisini gösteren sistematik bir fontom çalışması bulunmamaktadır. Bu çalışmada amaç, PTV marjlarının genişlemesinin, organ hareketlerinin radyoterapi dozlarına etkileri üzerindeki başarısını ölçmektir. Çalışma GaF-Chromic EBT filmlerin bir göğüs kafesi fantomuna yerleştirilmesiyle gerçekleştirilmiştir. Fantom içerisindeki bir silindirik bölüm ışınlama sırasında 5 saniyelik periyotlarla, 3 cm genlikle ayak-baş doğrultusunda hareket etmektedir. 3 cm genlikli hareketin olduğu durum için alınan profillerden 3 Boyutlu Konformal Radyoterapi (3D-CRT), Yoğunluk Ayarlı Radyoterapi (IMRT), Yoğunluk Ayarlı Arc Tedavi (VMAT) planları dar marjlar için incelendiğinde, PTV'nin yeterli doz alamadığı gözlemlenmiştir. Işınlama CTV için daha geniş marjlarda iyileşmekte, ancak PTV için inhomojenite devam etmektedir. Sonuç olarak, marjların genişletilmesinin organ hareketlerinin radyoterapi dozları üzerindeki olumsuz etkileri için tek başına yeterli olmadığı gözlemlenmiştir.

***Anahtar kelimeler**:* Radyoterapi, akciğer hareketi, solunum

1. Introduction

The aim of radiotherapy is to deliver lethal dose to the tumor volume while protecting the healthy tissues or organs. Therefore, a sufficient dose must be delivered to the whole target volume to achieve the aim of radical therapy [1]. However, the internal organ motions are one of the most significant obstacles for this aim, especially in the case of motions caused by respiratory during the lung irradiation. While it is suggested that uncertainties should be in very little intervals in radiotherapy such as mm, displacement caused by respiratory motion can reach 3 cm in craniocaudal direction [2-5]. Radiation delivery in the presence of organ motion causes a blurring of dose distribution along the path of the motion. This motion results in a deviation between the prescribed and delivered dose distributions.

Several methods have been proposed to administer organ motions in radiation therapy [6-11]. These methods generally aim; i) to encompass the organ motions by using large irradiation volumes; ii) to control or reduce the magnitude of organ motion; iii) to track the organ motion with moving radiation fields or gating irradiation. The first method mentioned above the oldest strategy to reduce the negative effects of organ motions on the radiotherapy doses. But, there is no any consensus about the margin limit given to the target volume (Clinical Target Volume- CTV, Planning Target Volume-PTV etc.), especially for tumors located moving organs such as lung. In present study, our aim was to determine the success degree of enlarging the PTV margins on radiotherapy doses during the moving organ irradiations. For this aim, a dynamic thorax-lung phantom with a motion range of 3 cm on craniocaudal direction was used and 3D-Conformal Radiotherapy (3DCRT), Intensity Modulated Radiotherapy (IMRT) and Volumetric Modulated Arc Therapy (VMAT) treatment plans were performed for different PTV and block margins. Treatment plans were tested by means of GaF-Chromic EBT films and the dynamic thorax-lung phantom.

2. Material and Method

A dynamic lung phantom, GaF-Chromic EBT dosimetry films, Computerized Tomography, Eclipse treatment planning system and VeriSoft film scanner/analyzer were used in the study. Dynamic lung phantom consists of a thorax region. It has a motor to create the lung motion and it has also an electronic control unit (Figure 1). This thorax phantom was modified for our study. A portable cylindrical structure as shown in the Figure1 (dynamic cylindrical lung part) was constructed by using cork. This cylindrical part has two equal parts and it has a hole filled with beeswax in its center. The beeswax has bigger density compared to the lung tissue and thus, tumor could be simulated by means of using beeswax. This dynamic cylindrical lung part was located into the thorax phantom to simulate the motion of lung caused by respiratory. Cylindrical part can move on through craniocaudal direction with a range of 3 cm with 5 sec. period during the irradiation.

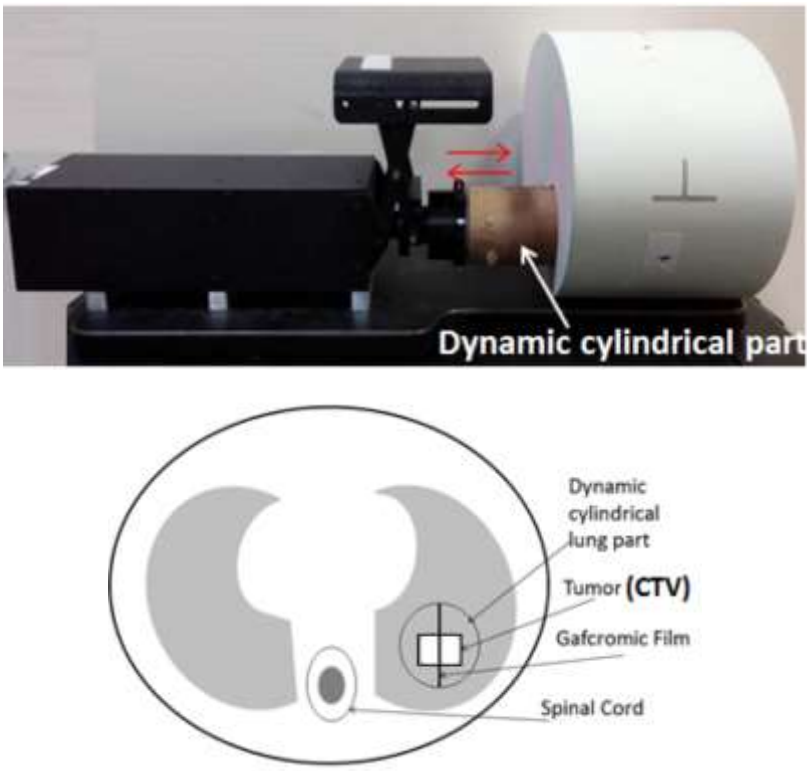

Fig. 1. Dynamic thorax-lung phantom and its schematic representation (axial view). Portable cylindrical structure moves back and forth as indicated with the arrows. Tumor (Beeswax) is accepted as CTV (Clinical Target Volume)

CT images were obtained. Three different treatment plans for the modalities of 3DCRT, IMRT and VMAT were performed in TPS according to the margins shown in the Table 1 for the CT images of the phantom. Plans are given in Figure 2 and the PTV margins and block margins for each plan are given in the Table 1. GaF-Chromic EBT films for each plan were separately located into the center of the moving cylindrical part in the coronal plane at the isocenter level and then phantom were irradiated according to the plans by means of Linac with 6 MV photon beams.

The doses for each plan (3DCRT, IMRT, VMAT) were totally 500 cGy at 90 % isodose level. All of the plans for three treatment modalities were separately repeated for every PTV and block margins in Table 1. Films were calibrated using a dose range of 0-800 cGy. Irradiated films were converted to absolute dose via on calibration curve of GaF-Chromic EBT films.

Table 1. PTV (PTV=CTV + margin) and Block Margins for treatment modalities used in the study

3DCRT	IMRT	VMAT
PTV+Block	PTV+Block	PTV+Block
0.6 cm + 0.6 cm	0.6 cm + 0 cm	0.6 cm + 0 cm
0.8 cm + 0.8 cm	1.0 cm + 0 cm	1.0 cm + 0 cm
1.0 cm + 1.0 cm	1.4 cm + 0 cm	1.4 cm + 0 cm

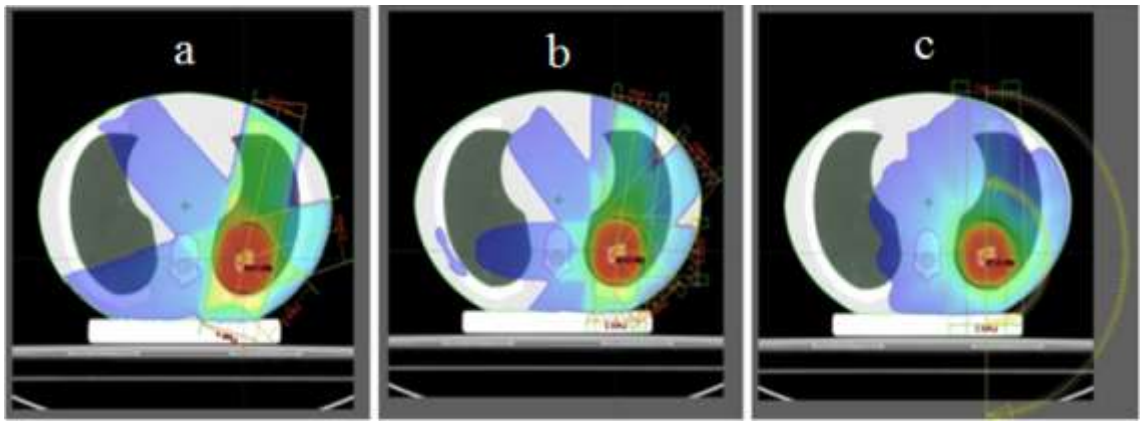

Fig. 2. Treatment fields of plans for (a) 3DCRT has four fields at 15° (8.9 x 4.7 cm^2), 75° (6.4 x 8.9 cm^2), 135° (6.6 x 8.9 cm^2), 195° (8.9 x 6.3 cm^2), (b) IMRT has five fields at 10° (6.6 x 8.1 cm^2), 45° (7.0 x 8.1 cm^2), 90° (6.6 x 8.1 cm2), 140° (7.0 x 8.1 cm^2), 180° (6.6 x 8.1 cm^2) (c) VMAT has a 180° (0° - 179.9°) gantry movement with the fields of 7.1 x 8.1 cm^2, 7.1 x 8.1 cm^2, respectively.

3. Results and Discussion

The aim of radiotherapy is to deliver the maximum dose to the tumor, while protecting the healthy tissues and critical organs. For this aim, when the location and the type of the tumor are considered, some treatment modalities have come up during the development of radiotherapy treatment. In this period, organ movements have become very significant. These movements can be caused by respiratory, skeletal-muscle, hearth and gastrointestinal [2]. Respiratory is the one of the most researched. During the irradiation, movement may lead to changes in the location of the target volume. Because of these changes, mostly the irradiation cannot be performed exactly according to treatment plan, and this prevents the uniform dose distribution on the target volume (PTV, CTV, etc.) [12].

As far as we know, there is no any systematic phantom study showed the effects of respiratory on radiotherapy doses depending on PTV margins in the literature. In a study related to this issue, Booppaty et al. used a handmade phantom with a 2 cm motion on craniocaudal direction and they determined that RapidArc procedures for lung cancer treatment can result in under-dosage of the target volume [13, 14]. They found about 20% uncertainty on PTV dose distributions in craniocaudal direction between static and dynamic arc treatments.

In our study we determined the lung doses in order to obtain the effects of organ motions on the radiotherapy, in the case of moving and without moving situations. In addition to motion effects, we enlarged the margins and examined the effects of magnifying margins on the dose distribution. We gave two films and its isodoses in Figure 3 as an example to show the effects of organ motions on radiotherapy doses. The films (with moving and without moving) irradiated for VMAT plan with 1.4 cm PTV margin and its isodoses obtained in present study and given in Figure 3. It is clearly seen that motion has adverse impacts on the isodose distributions. While the irradiated regions end with sharp lines in the first situation (without moving), the radiation field in the second situation (with moving) seems to expand in craniocaudal direction. The

reason of this is the presence of entering and exiting regions to the radiation field during the respiratory. These comparisons clearly indicated that the tumor motion introduced under-dosing region, especially in the PTV.

For more detailed numerical analysis, we also obtained the dose profiles along craniocaudal direction from all irradiated films. They are given in Figure 4, 5, and 6. From the profiles obtained from 3 cm moving situations for 3DCRT with (0.6 cm + 0.6 cm) PTV+ block margin, it is observed that PTV cannot get adequate dose. With larger margins the irradiation got better for CTV (~ 90%) but there was still inhomogeneity for PTV. Even the largest margin was given, the PTV edge dose decreased to ~ 60%.

When the dose profiles of IMRT plans in Figure 5 were examined, it is seen that a homogeny dose distribution in small margins could not be provided in PTV and CTV in case of 3 cm moving. By means of enlarging the margins, CTV could be irradiated homogeneously within 90 % isodose level. But, at even largest margins (at 1.4 cm PTV margin), PTV could not be homogenously irradiated. PTV doses at edge were dropped to 50%.

On the other hand, the situations in VMAT plans were similar to 3DCRT and IMRT plans. When the VMAT plans were examined in Figure 6, it is observed that little margins are not adequate for CTV doses. But, by means of enlarging the margins to 1.4 cm, CTV doses increased up to 95%. But, even the largest margin was given, the PTV edge doses decreased to 50 %.

4. Conclusion

It is very important to provide a homogeneous irradiation for the PTV to prevent the relapse of the tumors. But, organ movement is one of the biggest problems against to apply a homogeneous dose in radiotherapy. In order to overcome this problem there are so many clinical and technological studies. Nowadays several techniques are used against the respiratory movements. The aim of this technique is to stop the irradiation when the target volume is out of the irradiation region during the organ motion and then start the irradiation when the tumor comes again into the irradiation region. So that CTV and PTV regions can be irradiated with curative doses. On the other hand, enlarging the margins in present study can be an option to irradiate the moving target volumes. It is observed that CTV doses increased up to 90% by means of enlarging PTV margins in our study. But, in terms of PTV, the situation is not as good as CTV. We observed that for three modalities, even at the large margins, the PTV doses dropped to ~ 50% - 60% because of lung movement. As a consequence, enlarging the margins alone is not a sufficient method against the negative effects of organ motions on the radiotherapy doses.

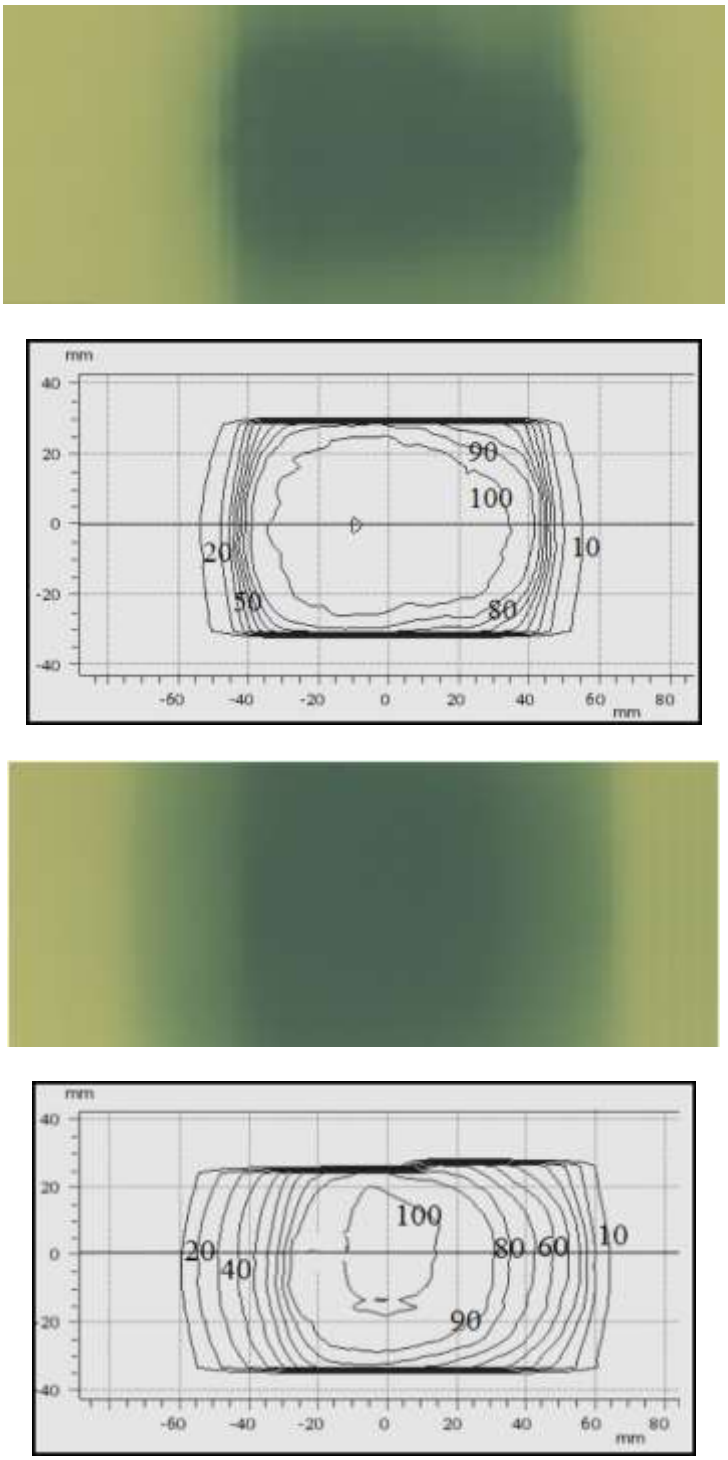

Fig. 3. The film irradiated for VMAT plane created with 1.4 cm PTV margin. (Above; no movement and its isodose. Below; 3 cm movement and its isodose)

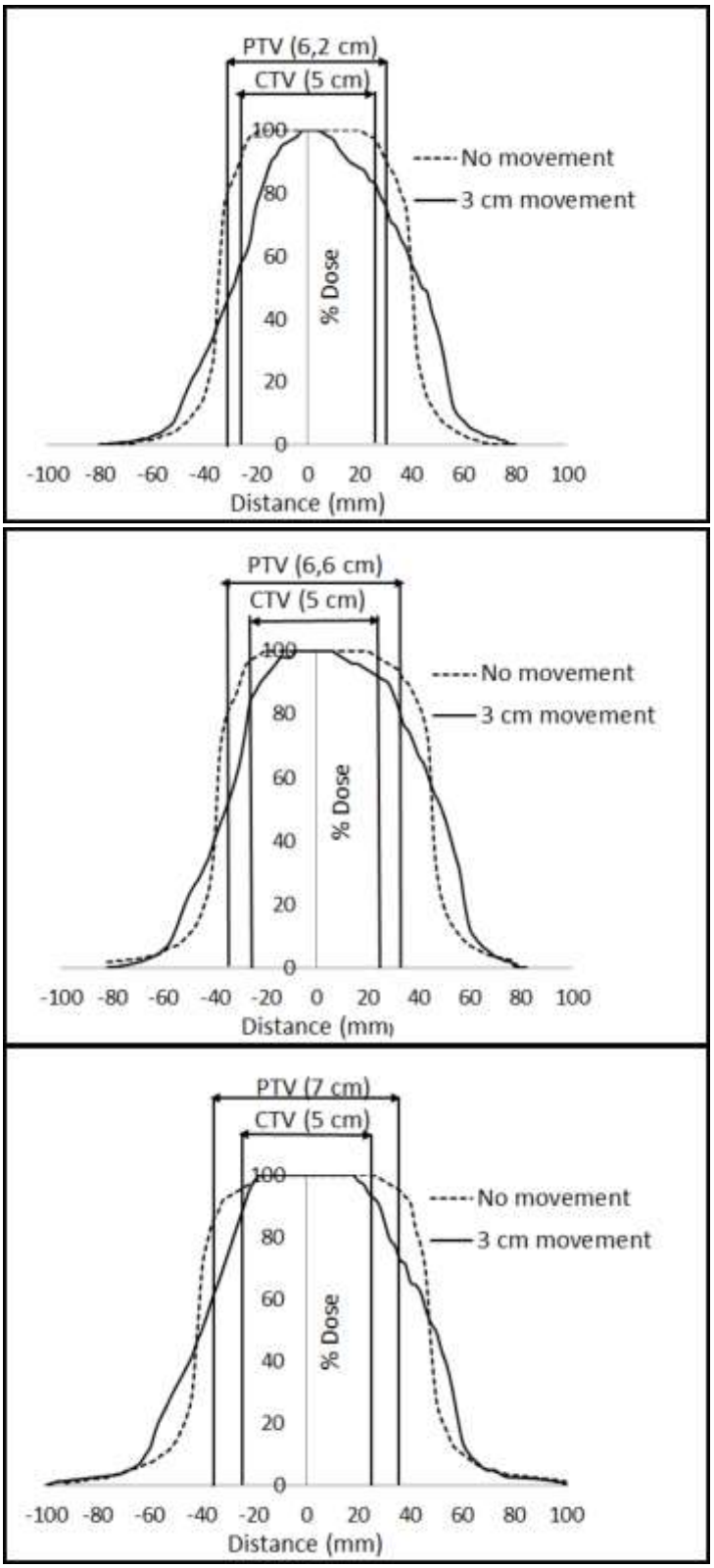

Fig. 4. Dose profiles along craniocaudal direction for 3DCRT plans

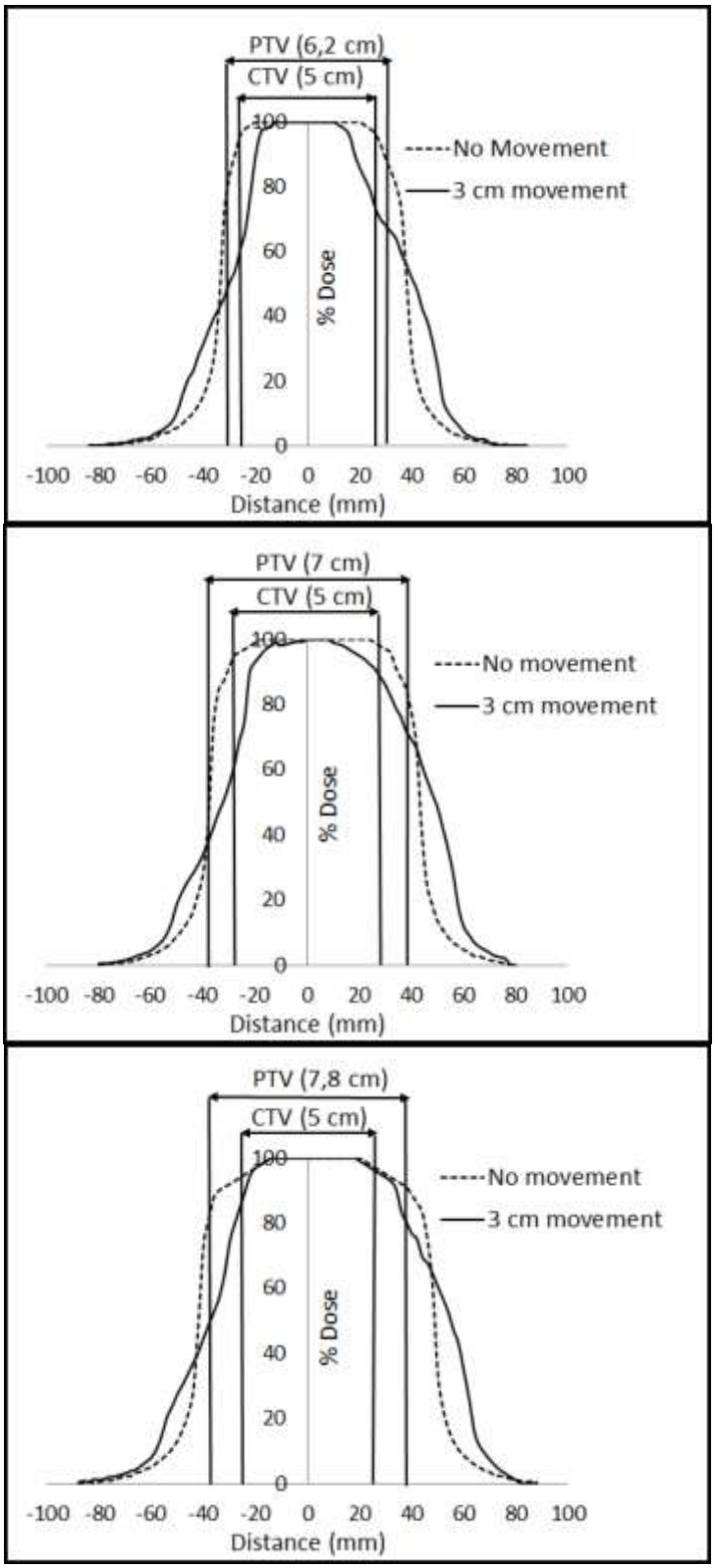

Fig. 5. Dose profiles along craniocaudal direction for IMRT plans

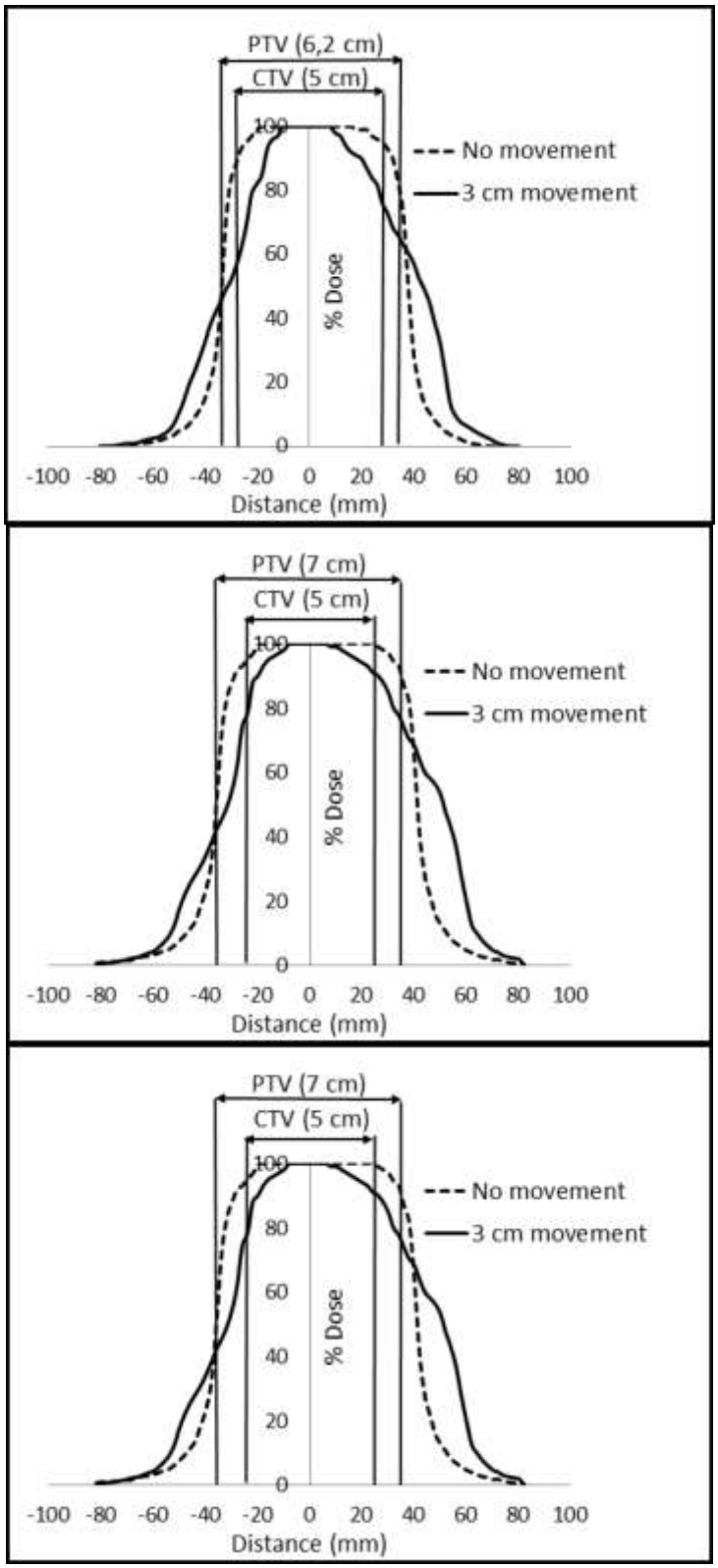

Fig. 6. Dose profiles along craniocaudal direction for VMAT plans

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