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The effect of the on-line IGRT repositioning on the delivered dose in a pelvic phantom

PhD thesis

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1. Introduction

Radiation therapy of cancer patients has a history of a few decades in Hungary as well. Orthovoltage X-ray units were used for teletherapy in the beginning. Cobalt units which use ^{60}Co radioactive material as radiation source meant a significant progress in the seventies-eighties in the country, because they provided the possibility of megavoltage therapy. Several therapy centres purchased linear accelerators in the nineties. These can generate megavoltage photon- and electron beams without any radioactive source. Treatment planning systems has also been installed at the same time in numerous departments, thus the 3 Dimensional Conformal Radiation Therapy (3D-CRT) planning and delivering – which is still widely applied – became possible. So-called Intensity Modulated Radiaion Therapy (IMRT) was also available. The need of comparable treatment results and the more complicated technology necessitated the development of international guidelines and protocols. The Image Guided Radiation Therapy (IGRT) – which quickly evolved in the last few years – has allowed the further increase of precision. The result of an imaging modality is used during IGRT to correct the patient's position, or to control the therapy runoff. The tumour moves day-by-day in the patient. IGRT can be used to correct for this displacement. The patient is moved so to ensure that the relative position of the tumour to the isocentre is the same as it was planed. This means in practice that the position of the isocentre varies in the patient.

2. Objectives

Source-to-skin distance (SSD) and the treatment depth (TD) of the treatment fields change as a result of the isocentre displacement in the patient. Modified SSD and TD result in modified delivered dose. I tried to find out how big is the different between the delivered and the planned dose in case of using IGRT. Nevertheless I examined if this effect depends on the choosen irradiation technique or beam directions. I also attempted to answer the question if this dose deviation is clinically relevant, and if it depends on any other parameters? I tried to prove that the change in the size and fullness of hollow organs-at-risks (rectum, bladder) also has effect on the delivered dose.

I would like to create a phantom model which is capable to simulate the internal organ motions to answer the mentioned questions. Examination conditions were determined mostly with the help of the data that could be found in the literature, and with the geometrical parameters of the patients who were treated in the Insituse of Oncotherapy. Specific volume of the internal organs, the specific changes in the volumes, the direction and quantity of the usual internal organ motions and the relations between the different organs had to be determined.

3. Material and methods

3.1. The examined target region and radiotherapeutic possibilities

Nowadays an estimated 25 from 100 men diagnosed with cancer are having prostate tumor in Europe. Radiation therapy is a curative treatment option in such cases.

Four-field irradiation technique was commonly used with 60-70 Gy prescribed dose in the majority of oncology centers in the nineties. In many cases this dose was not enough for disease control, on the other hand prescribing higher dose was limited because of toxicities. This problem was thought to be solved by 3D Conformal Radiation Therapy (3D-CRT) technique in the second part of the decade, however the early and also the late side effects were realized in decreased number, but still remained. Intensity-Modulated Radiation Therapy (IMRT) and Intensity Modulated Arc Therapy (IMAT) techniques –

which are wide-spread in our time – give the opportunity of a better local control, because less side-effect occurs in addition to similar or better target coverage.

If the margin that is used due to organ motion – while defining the planning target volume (PTV) – is decreased, then less risk organ volume would be irradiated, less side-effects would appear, so escalated dose can be delivered to the target. To be able to do so, CTV motion has to be taken into account very precisely during the treatment. This problem was usually solved in various centers by using Image Guided Radiation Therapy (IGRT) based on different imaging-techniques.

According to the on-line IGRT protocol, the patient position should be aligned day-by-day to correct the interfractional internal organ motion that is measured on the day of interest. Nevertheless, changes in patient position and the altered anatomical layout (rectum and bladder filling) can modify the dose that is delivered by each treatment beam.

An inhomogeneous pelvic phantom with variable construction was used to model the internal organ motions and the changed in the organ geometries. The pelvic region was selected because equipments for creating a phantom to model the internal motions in this anatomical region were available.

3.2. Phantom set-up and CT acquisition

A pelvic phantom that was made of water-equivalent material (compound of C_8H_8 and 2.1% ± 0.2% TiO_2, mass density: 1.045 g/cm^3, electron density: 3.386×10^{23} e^-/g, CT-number as an average of 10 measurements: 3.8 HU) for verifying IMRT irradiation plans was used as a model of a patient in supine position, having prostate cancer. Our phantom is consisted of two parts. One half of it contained 1 cm wide planes, which were having symmetric outline that was similar to a human body contour. The other half contained an ovoid pair and a cube that was constructed from different, smaller parts. We created the model of the prostate and the organs at risk (OAR) in this half site. A measuring hole for a Farmer-type ionisation chamber (IC) was placed in the geometrical center of the phantom. This way, dose measurements in the center of the prostate were possible. For the simulation of the posterior prostate tissue and the anterior rectum wall a 1 cm thick phantom-part was placed below the hole. Rectal content was simulated with 2 cm air-

equivalent material (AEM) behind the rectum wall. The irradiation plans were based on this initial set-up (Figure 1.).

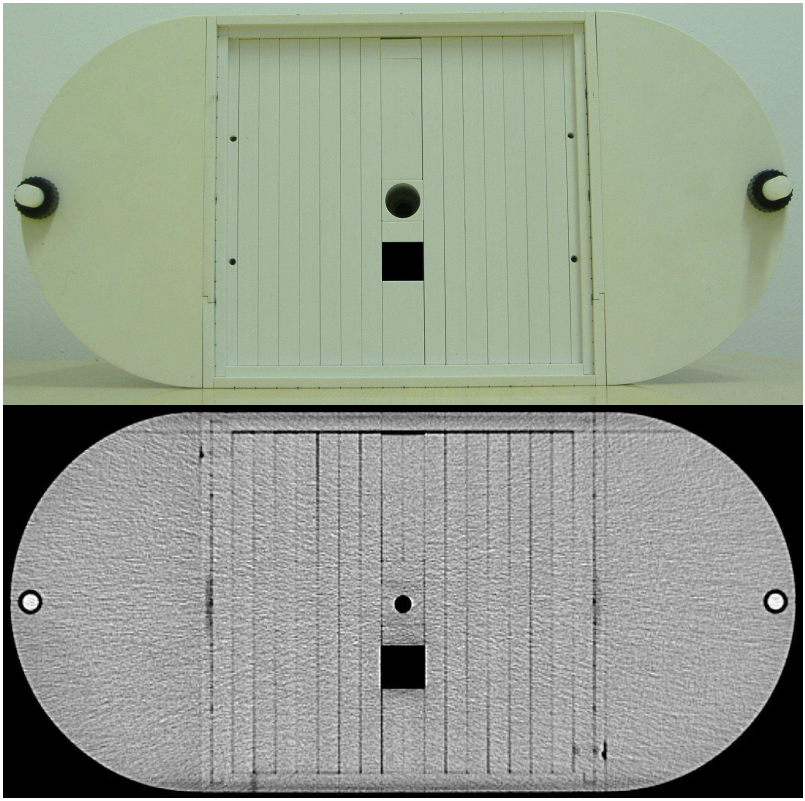


Figure 1. Initial phantom set-up

Modifying the thickness of the AEM the vertical position of the IC and was possible. The changes in rectum and bladder dimensions and anterior or posterior prostate displacements could be imitated with the IC displacing. The changes in the volume of rectal gas filling could be modeled with modifying the AEM thickness. Cranial and caudal motions could not be simulated with this phantom, due to symmetry reasons. The examination was restricted to up-down motions only.

Computed tomography (CT) scans were taken in the initial set-up with 3 mm slice increment on Siemens SOMATOM Definition machine (Siemens, Erlangen, Germany).

The primary coordinate-system was indicated with metal markers. It was placed into the geometrical center of the first cranial plane of the phantom.

3.3. Contouring

CT dataset was transferred to our TomoCON contouring and image fusion software. A structure set of a patient was used to help in the manual determination of the size and position of the anatomic structures in the phantom. The prostate was contoured around the active volume of the IC that could be precisely seen on each CT slice. Rectum was outlined as a whole organ starting 4.5 cm above the prostate and spread 2.4 cm below the inferior part of the prostate, containing the AEM plus 0.5 cm wall around. Bladder, seminal vesicles and femoral heads were also contoured. The CT series and the structure set were imported to our treatment planning system (PrecisePlan 2.03). Gross tumour volume (GTV), clinical target volume (CTV) and PTV was defined using the guidelines of ICRU report 50 and 62 according to RTOG 0126 study. Prostate was defined as the GTV. The CTV included the GTV and the seminal vesicles. PTV was obtained by a 1 cm 3D expansion of the CTV in all directions except posteriorly, where the margin was 0.5 cm.

3.4. Treatment planning

Irradiation plans were created for 70.2 Gy prescribed dose to the PTV in 1.8 Gy fractions. Because of the quite small size of the active volume of the IC (0.65 cc), for making the dose measurement possible, it should have been enough to plan the dose only to the GTV. A real treatment is always performed with irradiation plan to the PTV, so it was necessary to use such beams and plans that were used in clinical practice to get valid results from the measurements.

Dose restrictions were based on RTOG 0126 study. Thus no more than 2% of the PTV and none of the CTV received less than 70.2 Gy. The bladder and rectum dose limits are demonstrated in (Table 1.). Global dose maximum was not allowed to be into any organ-at-risk.

Table 1. Dose burden limits on OARs

	no more than 15% volume receives dose that exceeds	no more than 25% volume receives dose that exceeds	no more than 35% volume receives dose that exceeds	no more than 50% volume receives dose that exceeds
bladder	80 Gy	75 Gy	70 Gy	65 Gy
Rectum	75 Gy	70 Gy	65 Gy	60 Gy

The irradiation plans were created with our planning system using the built-in OmiWedge®, IMRT workflow® and IMRT optimizer® modules (Elekta, Crawley, UK). The isocenter was placed in the geometrical center of the active volume of the IC.

The 3D-CRT plan had 18 MV photon beams, using a three-field “box” technique, an anteroposterior (0°) and two opposed, wedged lateral (90°, 270°) fields (Figure 2.). All fields were shaped at the beam’s eye view to encompass the PTV using multi-leaf collimator (MLC). A 0.8 cm margin was added between the edge of the PTV and the MLC shape, to allow for beam penumbra.

The step-and-shoot “manual IMRT” (mIMRT) plan had 6 MV photon fields using five coplanar beam directions with gantry angles of 45°, 105°, 180°, 255° and 315°, respectively (Figure 3.). The following six different MLC shapes (segments) were created in all fields: 0.8 cm, 0 cm, and -0.8 cm margin was left between the PTV edge and the MLC shape, and all of these three segments were created with and without rectum shielding (Figure 4.). These geometric parameters were generated with the Elekta IMRT workflow®. The segment weighting optimization was done in an inverse planning procedure for our prescribed dose to the PTV and restrictions for the OAR burden with the IMRT optimizer® module of PrecisePlan.

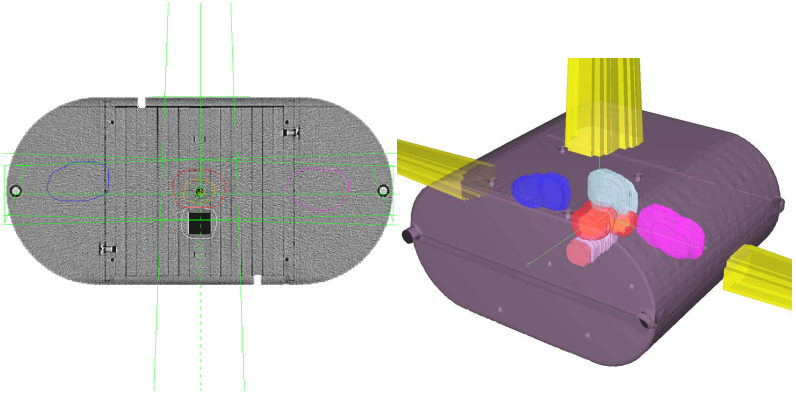


Figure 2. field arrangement – 3D-CRT plan

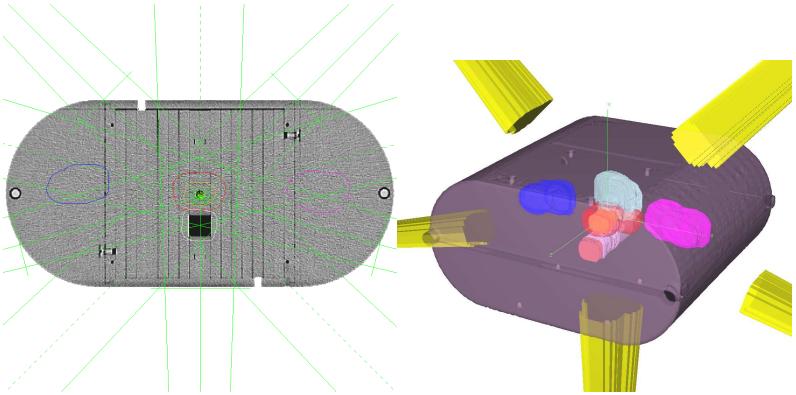


Figure 3. field arrangement – mIMRT plan

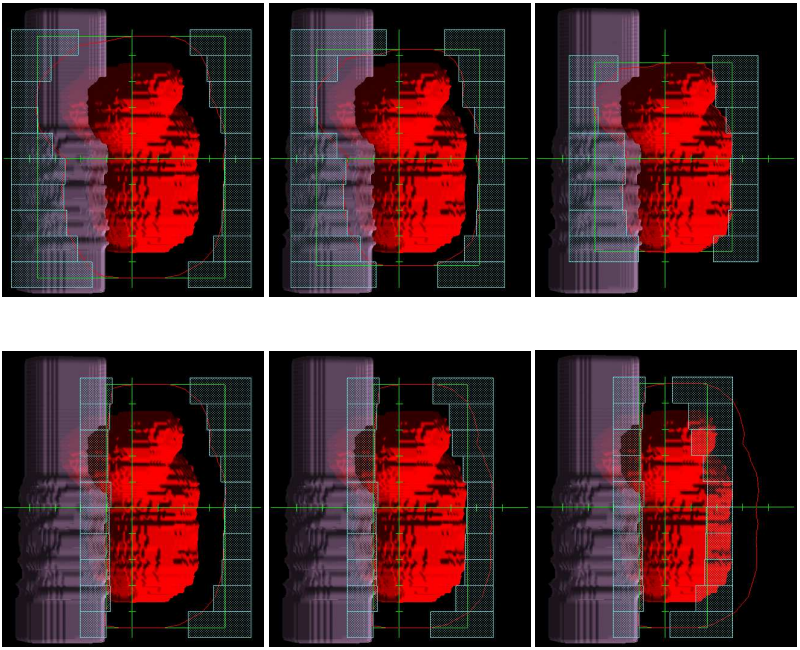


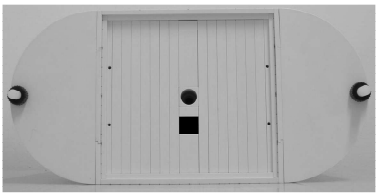
Figure 4. field segments – mIMRT plan

3.5. Dose measurements

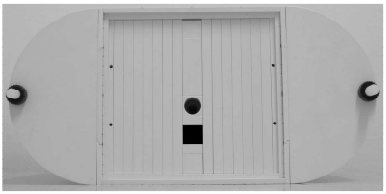
Phantom irradiations were performed with our Elekta Precise Treatment System linear accelerator in accordance with the created irradiation plans. Induced charge was measured first at the initial phantom set-up in cases of 3D-CRT and mIMRT irradiation with a Scanditronix-Welhöffer FC65-P type ionization chamber in nC units. Delivered dose was calculated according to the IAEA TRS-398 recommendation by using the water-equivalency of the phantom material. The obtained results were taken as initial values.

Organ motions were simulated thereafter by changing the construction of the phantom. Measurements were done with “normal”, decreased and increased AEM volume (rectum), so 1 cm anterior or posterior displacement of the prostate, (Figure 5.), which were corrected with shifting the phantom into the opposite direction. As a consequence, seven measurement arrangements were used for 3D-CRT as well as for mIMRT.

Measurements were repeated three times in each arrangement. Study of 6 MV single square beams (SSqB) was also done. An anteroposterior (AP, 0°), a lateral (LAT, 90°) and a posteroanterior (PA, 180°) beam was used with an amount of 50 MUs by a size of 5×5 cm^2 diaphragm in isocentric arrangement. The isocenter was placed at the same point as earlier. Initial dose values were measured with initial phantom set-up, afterwards organ motions were simulated as earlier, the phantom was similarly shifted, and the measurements were fulfilled in the same manner in cases of all three SSqBs.

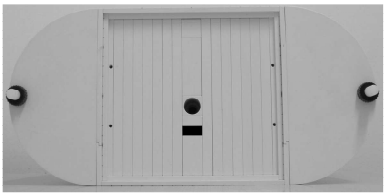


a)
initial set-up



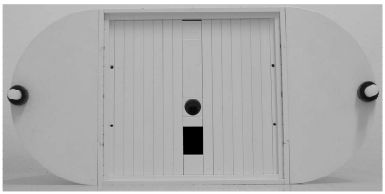
b)
R_0, P_1

c)
R_0, A_1



d)
R_{-1}, P_1

e)
R_{-1}, A_1



f)
R_{+1}, P_1

g)
R_{+1}, A_1

Figure 5. Different phantom set-ups.
Abbrevations: R_0, R_{-1}, R_{+1}: normal, decreased and increased rectum volume (AEM)
A_1, P_1: IC 1 cm anterior and posterior displacement

4. Results

Dose values measured at each irradiation and phantom construction are shown in (Table 2-6). The following abbrevations are used in the tables:

SD standard deviation

R_0 initial AEM volume

R_- decreased AEM volume

R_+ increased AEM volume

A_1 1 cm anterior displacement of the IC

P_1 1 cm posterior displacement of the IC

Dose variation was slightly below 1% at mIMRT. With not too much difference, it was around 1% in the case of 3D-CRT. We found, that the dose variation was affected only by the bladder volume, and it was up to 4.5% at AP SSqB. The most dose variation was discovered at PA SSqB case. It was affected by rectum volume as well as by the bladder volume up to 9%. The less dose variation that we measured was around 0,5%, in the case of LAT SSqB.

Table 2. Dose deviations as functions of organ motion – 3D-CRT

		mért dózis (Gy)	±SD (Gy)	**eltérés a tervezett dózistól (%)**	SD (%)
initial set-up (planned)		1.834	±0.002	-	-
R_0	A_1	1.855	±0.003	**+1.13**	0.14
	P_1	1.814	±0.004	**-1.13**	0.21
R_-	A_1	1.851	±0.002	**+0.93**	0.08
	P_1	1.813	±0.002	**-1.14**	0.13
R_+	A_1	1.851	±0.004	**+0.91**	0.20
	P_1	1.805	±0.004	**-1.58**	0.21

Table 3. Dose deviations as functions of organ motion – mIMRT

		measured dose (Gy)	±SD (Gy)	**deviation from planned dose (%)**	SD (%)
initial set-up (planned)		1.895	±0.050	-	-
R_0	A_1	1.904	±0.003	**+0.44**	0.16
	P_1	1.894	±0.003	**-0.05**	0.13
R_-	A_1	1.884	±0.002	**-0.60**	0.11
	P_1	1.883	±0.002	**-0.67**	0.12
R_+	A_1	1.912	±0.003	**+0.88**	0.14
	P_1	1.910	±0.002	**+0.79**	0.08

Table 4. Dose deviations as functions of organ motion – AP SSqB

		measured dose (mGy)	±SD (mGy)	**deviation from planned dose (%)**	SD (%)
initial set-up (planned)		355.0	±1.5	-	-
R_0	A_1	370.3	±0.2	**+4.32**	0.05
	P_1	340.3	±1.8	**-4.12**	0.51
R_-	A_1	370.4	±0.1	**+4.35**	0.03
	P_1	340.3	±1.4	**-4.13**	0.39
R_+	A_1	370.6	±0.1	**+4.39**	0.02
	P_1	339.8	±1.6	**-4.27**	0.44

Table 5. Dose deviations as functions of organ motion – PA SSqB

		measured dose (mGy)	±SD (mGy)	**deviation from planned dose (%)**	SD (%)
initial set-up (planned)		389.9	±1.0	-	-
R_0	A_1	374.2	±1.7	**-4.03**	0.43
	P_1	405.4	±0.2	**+3.98**	0.05
R_-	A_1	390.1	±0.2	**+0.04**	0.04
	P_1	423.4	±1.0	**+8.59**	0.24
R_+	A_1	361.2	±1.0	**-7.35**	0.26
	P_1	391.2	±1.1	**+0.34**	0.28

Table 6. Dose deviations as functions of organ motion – LAT SSqB

		measured dose (mGy)	±SD (mGy)	**deviation from planned dose (%)**	SD (%)
initial set-up (planned)		240.9	±0.4	-	-
R_0	A_1	241.3	±0.8	**+0.18**	0.35
	P_1	241.5	±1.0	**+0.24**	0.42
R_-	A_1	241.6	±1.0	**+0.28**	0.41
	P_1	239.7	±0.1	**-0.50**	0.04
R_+	A_1	242.5	±0.8	**+0.65**	0.31
	P_1	241.7	±0.1	**+0.35**	0.05

Summarized, deviation in the delivered dose could be observed due to the simulated organ motions, volume changes and position correction. The value of the dose variation was dependent on the examined beam direction in the SSqB cases. However, it was independent from the selected treatment technique (3D-CRT or mIMRT) in the composed plan measurements.

5. Conslusions

8.1. A pelvic phantom that is suitable for modelling the changes in rectum and bladder volume, and vertical internal motions of the prostate was constructed. Moreover it allows to measure delivered dose in the centre of the prostate-model. The treatment and the internal organ motions of a prostate cancer patient was simulated.

8.2. Dose modifying effect of the on-line IGRT technique was shown in the examined irradiation cases.

8.2.1. The clinically irrelevant scale of the dose deviation in the examined, practically used treatment techniques was proved.

8.2.2. It was observed during the SSqB measurements, that the dose deviation depends on the beam direction. Moreover, the value of the dose deviation can be high in some directions. The change in the bladder volume and the displacement of the prostate

have the most effect on the delivered dose at the AP-like fields. The delivered dose of the PA-like field is even effected by the changes in the rectum volume.

8.2.3. According to this, it is advisable to be deliberate at the selection of beam directions during the treatment planning. PA-like fields should be avoided as much as possible.

Patient position verification and the necessary corrections are done with two dimensional MV portal image acquisition in the Institute of Oncotherapy in Pécs. According to the research of Zsolt Sebestyén, the whole treatment of low-risk prostate cancer patients, and the boost treatment of the intermediate-risk and high-risk prostate cancer patients are treated with such a five-field technique, which mainly utilizes lateral directions. My results – mostly my conclusion on the deliberate selection of beam directions – proved the validity of using mainly lateral field from a different point of view. The introduction of this new irradiation technique in the mentioned cancer cases was confirmed.

6. Own publications related to the thesis

6.1. Publications

1. **Péter Kovács**, Zs. Sebestyén, R. Farkas, Sz. Bellyei, A. Szigeti, G. Liposits, K. Hideghéty, K. Dérczy, L. Mangel. A Pelvic Phantom for Modeling Internal Organ Motions. Med Dosim **2010**; doi:10.1016/j.meddos. 2010.04.002 in press (IF: 1.256)
2. **Kovács Péter**, Sebestyén Zs, Farkas R, Bellyei Sz, Mangel L. A képvezérelt sugárterápia formái és alkalmazása. Health Academy **1**(4):313-322; 2010. (hungarian)

6.2. Conference abstracts

1. **Kovács Péter**, Sebestyén Zs, Farkas R, Bellyei Sz, Dérczy K, Szigeti A, Liposits G, Mangel L. A belsőszerv-mozgás dózishatásainak vizsgálata verifikációs fantomban. Conference of the Hungarian Society for Radiation Therapy, Pécs, 2009. (hungarian)
2. **Kovács Péter**, Sebestyén Zs, Hideghéty K, Gulybán Á, Farkas R, Bellyei Sz, Szigeti A, Mangel L. Betegpozíció reprodukálhatóságának vizsgálata lézeres és infravörös rendszereknél. Conference of the Hungarian Society for Radiation Therapy, Pécs, 2009. (hungarian)
3. **Kovács Péter**, Sebestyén Zs, Farkas R, Bellyei Sz, Dérczy K, Szigeti A, Liposits G, Gulybán Á, Mangel L. A prosztata mozgás napi on-line korrekciójának hatása a leadott dózisra. Congress of the Hungarian Association of Medical Physicists, Szombathely, 2009. (hungarian)
4. **Péter Kovács**, Zs. Sebestyén, R. Farkas, Sz. Bellyei, K. Dérczy, A. Szigeti G. Liposits, Á. Gulybán, O. Ésik, L. Mangel. Organ motion correction with patient shifting during prostate cancer radiotherapy: effect on delivered dose. European Organization for Therapeutic Radiology and Oncology (ESTRO) Congress, Göteborg, Sweden, 2008.