Pol J Med Phys Eng 2010;16(1):23-34.
PL ISSN 1425-4689
doi: 10.2478/v10013-010-0003-y
website: http://www.pjmpe.waw.pl

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Treatment planning system and dose delivery accuracy in extracranial stereotactic radiotherapy using Elekta body frame

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The purpose of this study was to measure the photon beam transmission through the Elekta Stereotactic Body Frame (ESBF) and treatment couch, to determine the dose calculations accuracy of the MasterPlan Treatment Planning System (TPS) using Pencil Beam (PBA) and Collapsed Cone (CCA) algorithms during the use of Elekta Stereotactic Body Frame (ESBF), and to demonstrate a simple calculation method to put this transmission into account during the treatment planning dose calculations.

The dose was measured at the center of an in-house custom-built inhomogeneous PMMA thorax phantom with and without 'the frame + treatment couch'. The phantom was CT-imaged inside the ESBF and planned with multiple 3D-CRT fields using PBA and CCA for photon beams of energies 6 MV and 10 MV. There were two treatment plans for dose calculations. In the first plan, the 'frame + couch' were included in the body contour and, therefore, included in the TPS dose calculations. In the second plan, the 'frame + couch' were not included in the body contour and, therefore, not included in the calculations. Transmission of the 'frame + couch' was determined by the ratio of the dose measurements with the 'frame + couch' to the measurements without them. To validate the accuracy of the calculation model, plans with and without the 'frame + couch' surrounding the phantoms were compared with their corresponding measurements.

The transmission of the 'frame + couch' varies from 90.23-97.54% depending on the energy, field size, the angle of the beams and whether the beams also intercept them. The validation accuracy of the Pencil Beam (PBA) and Collapsed Cone (CCA) algorithms were within 5.33% and 4.04% respectively for the individual measurements for all gantry angles under this study.

The results showed that both PBA and CCA algorithms can calculate the dose to the target within 4.25% and 1.95% of the average measured value.

The attenuation caused by the ESBF and couch must be accounted into the planning process. For MasterPlan, the 'frame + couch' should be contoured and included in all calculations. This can be done easily and accurately.

Key words: SBRT, body frame, plan verification, beam attenuation.

Introduction

During the recent years, several different positioning and immobilization frames and devices have been introduced to the market and the Elekta Stereotactic Body Frame (ESBF) is considered as one of them [5, 8, 10, 14, 16-17]. These frames allow the patient to be immobilized during treatment settings [4]. In addition to that, there is a large growing use of carbon fiber materials in radiation therapy due to their high mechanical strength, low specific density, and radio translucence [9]. There has been recent literature on the use of these devices in treatment, but none focused on their use in planning and their related transmission effects when the treatment radiation beams are going through them. In most cases, some of the treatment radiation beams will have to pass through the frame and treatment couch before reaching the patient. The frames are generally made of wood, carbon fiber, and plastic of varying thicknesses. These frames are not necessarily uniform in construction, therefore, beams pass through the frame may face varying degrees of transmission based on the frame and what part of the frame is transversed. In addition to the frame, the transmission through the treatment couch should be put in our mind during the treatment steps of the patient. If these transmissions are not taken into account during TPS calculations, underdose may result. Also, the field size and beam energy are very important factors during the use of the immobilization devices in the radiation treatment.

This work presents the transmission measurements of the 'frame + couch' and using it to present an easy method to put the used frame and couch into consideration during the planning process and be included in the dose calculation. This paper also calculates the transmissions using both Pencil-Beam-Algorithm (PBA) and Collapsed-Cone-Algorithm (CCA). The calculated results are compared with the corresponding measured data. Differences have been noted in dose in homogeneous and heterogeneous situations [7-8]. Also, the effect of beam energy and field size in the presence of the ESBF during the treatment is included in this study.

Materials and methods

Irradiation arrangements

All measurements were performed on an Elekta Synergy linear accelerator at the Medizinische Hochschule Hannover (MHH), Radiation Oncology Dept., Germany. A custom PMMA thorax phantom was built in the MHH research workshop. The scheme in Figure 1 shows the phantom which consists of 10 slabs with 3 cm thickness for each slab and containing air cavities to simulate the lung shape. It also contains 3 positions for measurements at the center of the phantom and the other two points were put in the center of each lung.

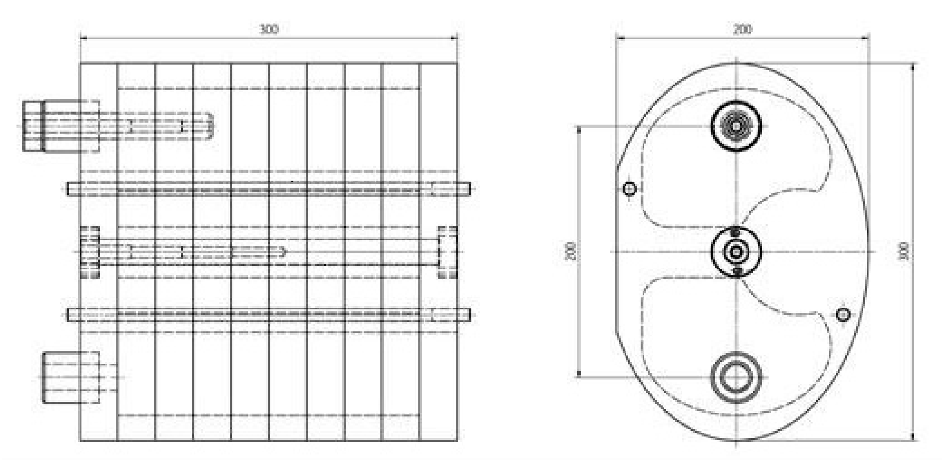

Figure 1. The scheme of the custom-built PMMA thorax phantom

This study was conducted using the thorax phantom with a PTW ionization chamber of 0.6 cm^3 (Model 30013) vented sensitive volume placed at the center of the phantom. Our measurements were carried out in two settings: In the first setting

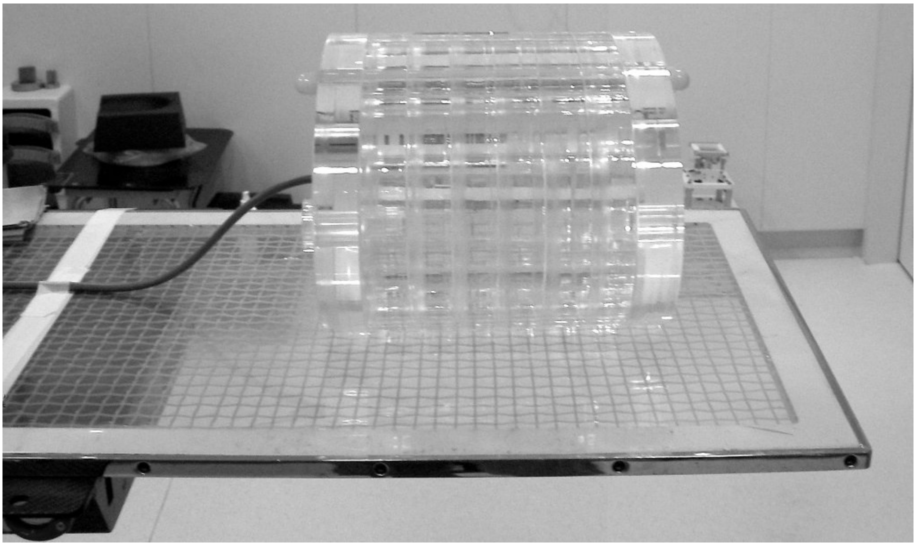

Figure 2. The custom-built PMMA phantom on the treatment couch without frame and using a racket that allows posterior beams to pass without any attenuation to the phantom.

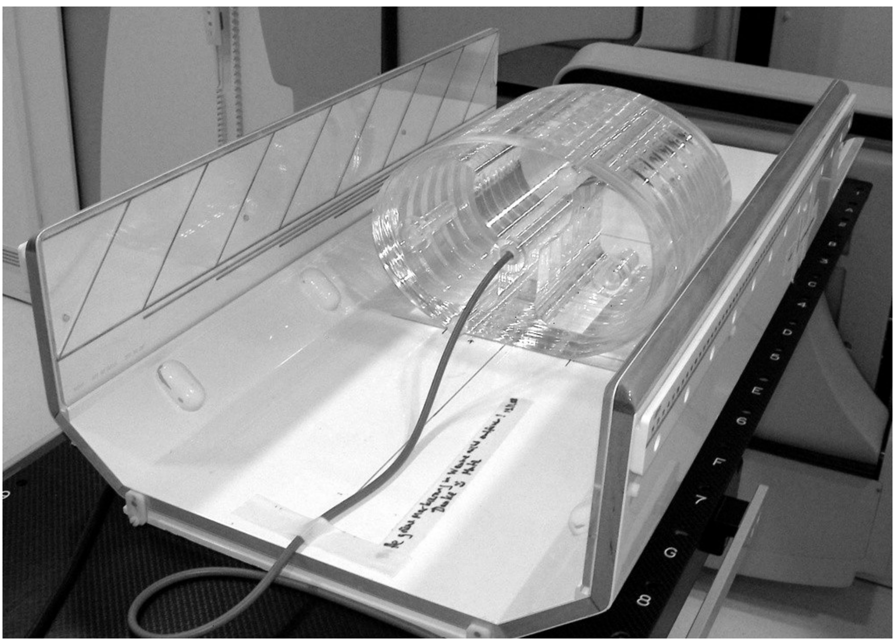

Figure 3. The custom-built PMMA thorax phantom was put into the ESBF and the complete set-up was placed on the treatment couch.

(set-up A), the phantom was directly placed on a racket frame that was fixed to the treatment cauch without the ESBF. This racket frame allowed the posterior and posterior oblique beam angles to pass through the phantom without intercepting the couch as shown in Figure 2. In the second setting (set-up B), the phantom was put into the ESBF and both were placed on the carbon fiber treatment couch as shown in Figure 3. Each arrangement was adjusted in a way that the ionization chamber was positioned in the isocenter of the linac. The center of the phantom was aligned to the scale value 480 mm of the body frame.

Multiple gantry angles were used to irradiate the phantom to measure the transmission of several different parts of the frame and couch. The angles and their corresponding frame locations were: 75° – side of frame including plastic edge; 90° – side of frame; 120° – corner of frame; 140° – bottom at an oblique angle; and 180° – bottom. Figure 4 shows a computed tomography (CT) image with the angles displayed. Each beam delivered 200 MU, with both a 6 and 10 MV energies and using 10×10 cm^2 and 4×4 cm^2 field sizes on Elekta Synergy linac.

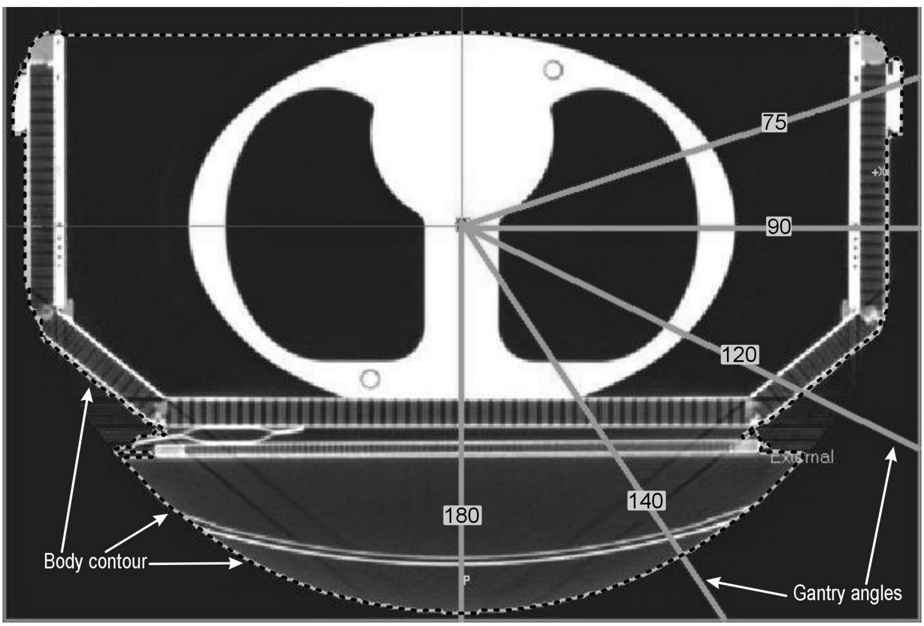

Figure 4. CT image of phantom in ESBF. Body contour is shown as grey and black dotted line and gantry angles are shown in grey color.

Transmission measurements

The transmissions of incident beams passing through the ‘frame + couch’ were determined for each gantry angle by the ratio of the readings measured from the setup with the ‘frame + couch’ to the reading from the setup without them.

A calibration measurement was made with the same PTW electrometer (Unidos) and ionization chamber as a method to convert all other measurements to dose. Repeated measurements were performed and the average value was used.

Validation of treatment planning calculation

The thorax phantom was CT imaged inside the ESBF with a slice thickness of 2 mm. The data set was imported to (TPS) for dose calculation. The treatment planning system only uses CT data for dose calculation which is included in the external contour. So the two different arrangements used can be both modeled with one CT data set: one time only the phantom itself was included in the external contour (set-up A: phantom only), the other time the phantom as well as the ESBF and the treatment couch were included in the external contour (set-up B: phantom in ESBF on treatment couch). The calculated doses by MasterPlan in the two different external contours were compared with the corresponding measurements. Calculations were carried out using Pencil Beam (PBA) and Collapsed Cone algorithms (CCA) for both energies and field sizes used in this study. The comparisons were carried out to validate the treatment planning calculation model.

Results

Transmission measurements

For 6 MV, the transmission of the ‘frame + couch’ averaged 93.51% (ranged from 90.53% to 96.41%) for 10×10 cm^2 field size and 92.83% (ranged from 90.23% to 96.13%) for 4×4 cm^2 depending on the gantry angle used. For 10 MV, the transmission of the ‘frame + couch’ averaged 94.91% (ranged from 93.40% to 97.54%) for 10×10 cm^2 field size and 94.25% (ranged from 92.18% to 96.72%) for 4×4 cm^2. The transmission was lowest through the Bottom at an oblique angle (140°) and through the bottom of the ‘frame + couch’ at angle (180°). The transmission was the highest when it traversed the side and the corner of the frame at angles (90° and 120°).

These values are shown in Tables 1 and 2. We can notice from these results that the attenuation effect decreases with increasing energy and increases with decreasing field size.

Table 1. Measured transmission values of ESBF and treatment couch for $10 \times 10\ cm^2$

Gantry Angle	6 MV Trans. [%]	10 MV Trans. [%]
75°	92.27	93.56
90°	96.41	97.54
120°	94.53	95.19
140°	90.53	93.40
180°	93.75	94.77
Avg.	93.51	94.91

Table 2. Measured transmission values of ESBF and treatment couch for $4 \times 4\ cm^2$

Gantry Angle	6 MV Trans. [%]	10 MV Trans. [%]
75°	91.11	93.41
90°	96.13	96.72
120°	93.55	94.68
140°	90.23	92.18
180°	93.06	94.19
Avg.	92.83	94.25

Validation of treatment planning calculation model — Set-up A: phantom only

The reported data in Tables 3 and 4 shows that the average calculated doses of all beam angles using in set-up A for 6 MV were (1.17% to 2.16%) and (0.77% to 1.88%) of the measured values for PBA and CCA respectively. For 10 MV the differences were (−1.95% to 0.08%) and (−0.13% to 1.57%) for PBA and CCA respectively.

Table 3. Measured dose versus calculated dose for the PB and CC Algorithms validations in set-up A for standard field size 10 × 10 cm^2

Gantry Angle	6 MV					10 MV				
	Measur. [cGy]	PBA [cGy]	Diff. [%]	CCA [cGy]	Diff. [%]	Measur. [cGy]	PBA [cGy]	Diff. [%]	CCA [cGy]	Diff. [%]
75°	194	186	4.12	190	2.06	202	198	1.98	198	1.98
90°	195	188	3.59	190	2.56	203	200	1.48	198	2.46
120°	201	194	3.48	196	2.49	208	206	0.96	202	2.88
140°	190	186	2.11	188	1.05	197	198	−0.51	196	0.51
180°	160	164	−2.50	158	1.25	172	178	−3.49	172	0.00
Avg.	188	183.6	2.16	184.4	1.88	196.4	196	0.08	193.2	1.57

Table 4. Measured dose versus calculated dose for the PB and CC Algorithms validations in set-up A for field size 4 × 4 cm^2.

Gantry Angle	6 MV					10 MV				
	Measur. [cGy]	PBA [cGy]	Diff. [%]	CCA [cGy]	Diff. [%]	Measur. [cGy]	PBA [cGy]	Diff. [%]	CCA [cGy]	Diff. [%]
75°	180	174	3.33	178	1.11	182	184	−1.10	182	0.00
90°	181	178	1.66	178	1.66	183	186	−1.64	182	0.55
120°	186	184	1.08	184	1.08	188	192	−2.13	188	0.00
140°	174	172	1.15	174	0.00	179	182	−1.68	180	−0.56
180°	144	146	−1.39	144	0.00	155	160	−3.23	156	−0.65
Avg.	173	170.8	1.17	171.6	0.77	177.4	180.8	−1.95	177.6	−0.13

Validation of treatment planning calculation model — Set-up B: phantom in ESBF on treatment couch

The average calculated doses over all beam angles in set-up B by using the 'frame+couch' for 6 MV were (2.72% to 4.25%) and (1.12% to 1.95%) of the measured values for PBA and CCA respectively. For 10 MV the differences were (−0.59% to 1.94%) and (0.00% to 1.46%) for PBA and CCA respectively. These comparisons are reported in Tables 5 and 6.

Table 5. Measured dose versus calculated dose for the PB and CC Algorithms validations in set-up B for standard field size 10 × 10 cm^2.

Gantry Angle	6 MV					10 MV				
	Measur. [cGy]	PBA [cGy]	Diff. [%]	CCA [cGy]	Diff. [%]	Measur. [cGy]	PBA [cGy]	Diff. [%]	CCA [cGy]	Diff. [%]
75°	179	170	5.03	172	3.91	189	184	2.65	184	2.65
90°	188	178	5.32	182	3.19	198	192	3.03	190	4.04
120°	190	186	2.11	190	0.00	198	198	0.00	198	0.00
140°	172	166	3.49	172	0.00	184	180	2.17	184	0.00
180°	150	142	5.33	146	2.67	163	160	1.84	162	0.61
Avg.	175.8	168.4	4.25	172.4	1.95	186.4	182.8	1.94	183.6	1.46

Table 6. Measured dose versus calculated dose for the PB and CC Algorithms validations in set-up B for field size 4 × 4 cm^2.

Gantry Angle	6 MV					10 MV				
	Measur. [cGy]	PBA [cGy]	Diff. [%]	CCA [cGy]	Diff. [%]	Measur. [cGy]	PBA [cGy]	Diff. [%]	CCA [cGy]	Diff. [%]
75°	164	158	3.66	160	2.44	170	170	0.00	168	1.18
90°	174	168	3.45	168	3.45	177	178	−0.56	174	1.69
120°	174	176	−1.15	176	−1.15	178	186	−4.49	182	−2.25
140°	157	152	3.18	158	−0.64	165	166	−0.61	166	−0.61
180°	134	128	4.48	132	1.49	146	142	2.74	146	0.00
Avg.	160.6	156.4	2.72	158.8	1.12	167.2	168.4	−0.59	167.2	0.00

Slightly higher point-wise differences between measured and calculated doses can be found for the PBA and 6 MeV beam energy, however in the average over all examined beams mostly deviations under 3.2% can be found. The only exception is the case for the $10 \times 10\ cm^2$ field in the set-up B. Here the averaged deviation is 4.25%, the highest average value found in the study. The Collapsed Cone algorithm gives good results (differences below 2%) for both phantom settings, all energies and beam sizes.

Discussion

The transmission through the ESBF ranged from 92.83% to 94.91%, depending on beam angle, field size and energy. Therefore, from the results presented here, the transmission of the ESBF and carbon fiber couch must be taken into account during the planning process to be included in the dose calculation process [12]. From analysis of the presented results, we notice that the values of the transmission loss and the deviations of the treatment planning validations for both phantom settings decrease as the energy of incident beams increases. We can also notice that the CCA calculation values are more accurate than the corresponding values of PBA over all gantry angles, field sizes and energies that have been used in this study [11]. This was expected due to the large air filled volumes in the phantom.

There are two methods to either overcome or correct the dose error coming from the use of the 'frame + couch' during the treatment. The first method requires manual modification of the monitor units derived from the planning process. Implicit to this approach is the possibility of errors in either calculation or transcription. The second method is adding the 'frame + couch' directly into the planning process and allows the planning system to calculate the dose and associated MUs, accounting for the transmission of beams by the frame. This method in the case of MasterPlan only requires that an additional contour be created. This is far easier and reducing the error possibility than the MU correction method. However easy it may be, the important question is whether this method is accurate.

The first step was to validate the MasterPlan calculation model in the thorax phantom without the 'frame + couch'. The results showed that these calculated doses were around 2% of the measurements for both algorithms and energies under this study.

Once PBA and CCA were validated, the dose to the phantom with the 'frame + couch' were calculated and compared with the measurements. The results show that the average calculated dose value using the selected gantry angles were in the accepted range for medical treatment [13]. There is good agreement between the results obtained in this study and several publications [1-3, 6].

Conclusion

The transmission of the ESBF and couch were shown to vary from 92.83% to 94.91% depending on the beam angle, field size and X-ray energy used. Therefore, it must be accounted for in the treatment planning process. It was shown that, simply by contouring the ‘frame + couch’ and including it within the body contour, MasterPlan can accurately calculate the resulting transmission and dose. We recommend using Collapsed Cone algorithm over Pencil Beam algorithm especially for heterogeneous medium.

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