NOWOTWORY 2001 / tom 51
Zeszyt 2 / 123–128

Quantitative evaluation of setup deviations during the course of pelvic irradiation with 4 fields box technique

Andrzej Dąbrowski, Paweł Kukołowicz, Elżbieta Sadowska[1]

Purpose. The results of quantitative assesment of the reproducibility of patients treated with box technique in the pelvic region are presented.
Material and methods. The reproducibility assesment was performed with portal film technique. For 10 patients 267 verification portal films were taken during the treatment and compared with simulator localization films. On the average the portal films were taken twice a week. During the treatment portal films were checked qualitatively to find large errors. Quantitative evaluation was performed after completion of the treatment. Results were analyzed in terms of systematic (simulator-to-treatment) and random (treatment-to-tretament) errors for individual patient and in the whole group of patients.
Results. The discrepancies between simulator and treatment films were less than 5 mm with the exception of one patient. The systematic and random errors in the group were less than 3 mm along each direction.
Conclusion. In general the reproducibility is good. The method used in the Holycross Cancer Centre in Kielce can be used for quantitative assessment of treatment reproducibility.

Ilościowa ocena odtwarzalności i powtarzalności napromieniania wiązkami zewnętrznymi pacjentek leczonych w rejonie miednicy techniką box

Cel. W pracy przedstawiono ilościową ocenę odtwarzalności napromieniania wiązkami zewnętrznymi pacjentek leczonych w rejonie miednicy techniką box.
Materiał i metody. Ocenę odtwarzalności zrealizowano techniką zdjęć portalowych. Dla 10 pacjentek wykonano 267 zdjęć portalowych, które porównano ze zdjęciami referencyjnymi, wykonanymi na symulatorze. Zdjęcia portalowe wykonywano średnio dwa razy w tygodniu przez cały czas trwania leczenia. W trakcie terapii zdjęcia analizowano jakościowo w celu wykrycia dużych błędów w odtwarzalności napromieniania. Po zakończeniu leczenia zdjęcia zostały poddane obróbce cyfrowej celem ilościowego określenia odtwarzalności napromieniania.
Wyniki. Wyniki analizowano w kategoriach błędu systematycznego (symulator-leczenie) oraz przypadkowego (leczenie-leczenie), oddzielnie dla poszczególnych pól. Analizę przeprowadzono dla każdego pacjenta oraz w całej grupie. Średnie przesunięcie środka pola promieniowania na zdjęciu portalowym względem środka pola promieniowania na zdjęciu referencyjnym tylko u jednej pacjentki przekroczyły wartość 5 mm. Wzdłuż każdej osi układu współrzędnych wartość błędu systematycznego i przypadkowego w całej grupie są mniejsze niż 3 mm. U dwóch pacjentek unieruchomionych za pomocą PELVICASTU nie stwierdzono poprawy powtarzalności napromieniania.
Podsumowanie. Stwierdzono, że odtwarzalność napromieniania jest dobra oraz, że wdrożona technika pozwala na ilościową ocenę powtarzalności napromieniania.

Key words: radiotherapy, quality control, portal technique, 4 fields technique
Słowa kluczowe: radioterapia, kontrola jakości, technika portalowa, technika 4 polowa box

Introduction

The high quality radiotherapy requires very precise, daily patient setup reproducibility during each treatment session [1]. If the treatment is performed properly the internal structures of patient body should remain constant in relation to beam edges and their position should be in agreement with prescribed setup. The errors of the data transfer from CT to simulator and from simulator to treatment unit or uncertainties of patient setup may increase the probability of normal tissue complication or decrease the probability of tumour control. Patient setup in deviations can be traced by comparing portal images with a re-

Medical Physics Department
[1] Radiotherapy Department
The Holycross Cancer Centre
Kielce, Poland

ference simulator image. Portal images are acquired either by means of conventional radiographic films or electronic portal image devices [2, 3].

The precise comparison between the reference and a portal image is difficult due to poor quality of images acquired at megavoltage machines. The difference of megavoltage X-rays attenuation of different human tissues is very small, much smaller than it is observed for orthovoltage radiation. The megavoltage radiation interacts with the matter mainly through Compton effect which does not depend on the atomic number. In consequence the bony structures cannot be sufficiently distinguished from the soft tissues. The contrast of portal images is also deteriorated due to scattered radiation and for Co60 beams due to very large source size.

The use of portal films for treatment verification has several drawbacks. After the completion of film exposure the irradiation has to be interrupted which prolongs the treatment time and increases the risk of patient motion. The result of control is not available before completion of patient treatment so on-line correction of patient position is not possible.

In modern radiotherapy the geometrical accuracy of patient setup must be checked at least during the first fraction and when any changes are introduced to the treatment technique. Recently radiotherapists tend to control patient setup before each treatment session [4-8]. The statistical analysis of results helps to estimate a safety margin around the clinical target volume [9, 10]. Excessive margin leads to an unwanted irradiation of surrounding healthy tissue, while a too tight margin may cause an underdosage of the clinical target volume.

In Holycroos Cancer Centre the procedure of quantitative verification of treatment geometry was implemented. The purpose of the present study was to quantify the setup deviations during the course of pelvic irradiation with four-field box technique.

Materials and methods

The study was performed for 10 patients treated isocentrically with 15 MV photons using Siemens KD2 linear accelerator. Patients were treated in the prone position with a four-field box technique. Fields sizes and positions were prescribed by radiation oncologist using simulator. Patient positioning entrance points for each beam and fields border were marked on the patient skin. Simulator film was taken for each beam. Two of ten patients were immobilised with PELVICAST system (ORFIT). In these cases entrance points and fields borders were marked on the thermoplastic shells. The shielding blocks were delineated on the localisation films and individually prepared for every patient. The iliac alas and femoral heads and sacrum canal were shielded. Each patient setup was performed by two radiographers. When all localisation lasers, two lateral and sagital one, fit the entrance points marked on the skin or plastic shell the setup procedure was regarded as being finished. After completion of irradiation of each single field the patient position was checked again and if there was any discrepancy between laser system and skin markers the setup procedure was repeated. One treatment session lasted for about 15 minutes. Portal films for each patient were taken at least once a week during all treatment time. Kodak X-Omatic films pelicula for Therapy Verification and Kodak Cassette for portal Verification were used. In total, the analysis covered 267 portal films. After each treatment session portal films were visually compared with the reference field. If discrepancy of more than about 5 mm had been noticed portal films were taken during next fraction and checks repeated. If the discrepancy persisted, new simulation was performed and the procedure of geometry control started from the beginning. After treatment completion the portal images were compared with the corresponding reference image to determine the deviations of patient setup. All reference and portal images were digitised with Agfa Snapscan scanner. Bony structures were outlined on each film: femoral heads and sacrum on lateral films, pelvic bones and symphysis pubis on AP/PA films. In the next step beam edges both on reference and portal films were found. This information anbled us to determine the central axis point on each film; then the images were scaled to the isocentric distance. Next the portal image was made transparent and was overlaid onto the simulator image so the outlined contours of bony structures delineated on the reference and the portal images corresponded to each other. The error of patient setup was described in terms of the displacement of the central axis point of portal film with respect to central axis point of corresponding reference image. The procedure of displacement determination is shown graphically in figure 1. The coordinates system used in this publication follows the ICRU 42 requirements [11]. The accuracy of the method was estimated to be about 1 mm.

The reproducibility and repeatability were described in terms of several statistical formulas for displacement values between portals films and corresponding reference film. More details may be found below. The analysis was done separately for every field i.e. AP and PA films and right and left lateral films and concerned either individual patient or the whole group of patients.

Statistical analysis

Let us denote by $(X_i)_k$ the displacement of central axis point of i-th portal film with respect to the central axis point of appropriate reference image in the X direction for k-th patient. Let us assume that for this patient the total number of portal images acquired is N_k. The repeatability is mathematically described by the mean value of displacements:

$$\bar{S}_k = \frac{\sum_{i=1}^{N_k} (S_i)_k}{N_k} \qquad (1)$$

The repeatability corresponds to the well know term, called in the literature the systematic deviation for an individual patient.

The reproducibility can be mathematically derived by standard deviation of displacements:

$$OS_k = \sqrt{\frac{\sum_{i=1}^{N_k} \left((S_i)_k - \bar{S}_k\right)^2}{N_k - 1}} \qquad (2)$$

The reproducibility corresponds to he variable formulated in the literature as the random deviation for individual patient.

For a whole group of patients the systematic deviation is determined by the average value of S_k:

$$\bar{S} = \frac{1}{K} \sum_{k=1}^{K} \bar{S}_k \qquad (3)$$

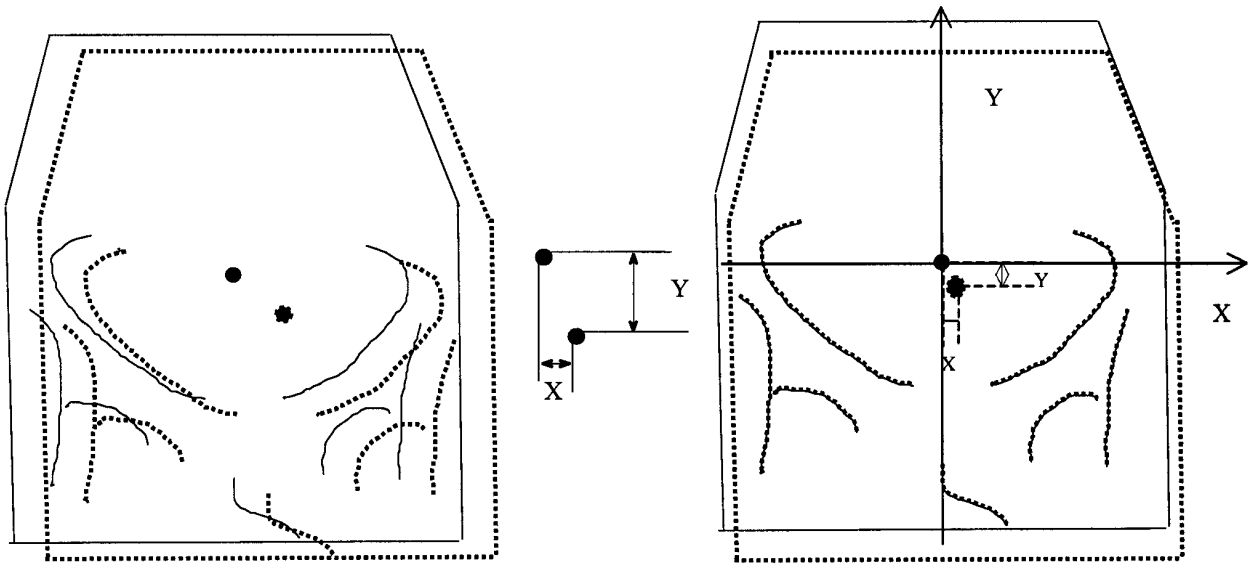

Fig. 1 The comparison of reference and portal images method overwiew. The bony structures outlined on reference and portal images are drawn with solid and dashed lines respectively. The Z-axis is directed up.

For a whole group of patients the reproducibility OS is described by equation:

$$OS = \sqrt{(OS_s)^2 + (OS_p)^2} \qquad (4)$$

where:

$$OS_s = \sqrt{\frac{\sum_{k=1}^{K} (\bar{S}_k - \bar{S})}{K-1}} \qquad (5)$$

$$OS_p = \sqrt{\frac{1}{K}\sum_{k=1}^{K}\sum_{i=1}^{N_k}\frac{((S_i)_k - \bar{S}_k)^2}{N_k - 1}} = \sqrt{\frac{1}{K}\sum_{k=1}^{K}(OS_k)^2} \qquad (6)$$

The same statistical formalism was used for other two directions Y and Z.

Results

Table I shows the results summary for each patient and each treatment field separately. Table II shows the results for the whole group.

Tab. II. The treatment repeatability S and reproducibility OS for the whole group of patients

	Treatment repeatability S			Treatment reproducibility OS		
Pole	S_x	S_y	S_z	OS_x	OS_y	OS_z
AP	-0.9	-0.7		1.9	1.6	
PA	-0.4	-0.7		1.3	1.6	
L		-0.6	0.1		1.7	1.4
P		-0.3	-0.3		1.7	1.8

Discussion

In general the accuracy of patient setup during radiotherapeutic treatment depends on many factors. The most important one are tumour localisation and methods of patient's immobilisation. Usually very good setup reproducibility is obtained for head and neck patients. In general special difficulties appear for patients treated both in the thorax and pelvic region. In the thorax region they are caused by breathing and related thoracic wall movements. In the pelvic region the skin markers are often considered as not reliable. The results obtained in the Holycross Cancer Centre have not confirmed such standing. The mean value of displacement was larger than 6 mm for only two patients (patients no 8 and 10). In all other cases the mean value of displacement was smaller than 4 mm. For the whole group the repeatability described as the average value of mean values of displacements obtained for individual patients is always smaller than 1 mm. The treatment reproducibility for the whole group described in terms of OS function is smaller than 3 mm for each direction and field. The results obtained for individual patients are different. Many factors may influence the setup quality, e.g. good reproducibility for obese patients is less likely.

The analysis of patient setup has been performed in terms of the repeatability and reproducibility. The repeatability is defined in terms of the deviations of central axis points obtained on reference and portal films respectively in relation to bony structures. In the literature the repeatability is referred to as systematic deviation or treatment to simulation deviation. The reproducibility is represented by the amount of dispersion of individual points (the position of central axis point in relation to bony structures) around the mean. In the literature it is referred to as random deviation or treatment to treatment deviation. The analysis of results obtained for PA field

Tab. I. The treatment repeatability S_k and reproducibility OS_k for ach patient

Patient Nr		Treatment repeatability S_k S_X [mm]	S_Y [mm]	S_Z [mm]	Treatment reproducibility OS_k OS_{kx}	OS_{ky}	OS_{kz}
	L		0.3	-2.3		0.7	0.7
1	P		0.5	-1.7		0.9	0.6
	AP	-0.1	0.1		0.8	0.6	
	PA	-0.4	-0.5		0.5	0.7	
	L		-2.0	1.1		2.5	1.3
2	P		-2.1	0.2		1.3	0.8
PELV	AP	-0.3	2.5		1.5	1.8	
	PA	-2.1	-2.1		0.9	1.3	
	L		1.9	0.2		4.9	2.1
3	P		1.1	-0.9		2.4	0.8
PELV	AP	-0.0	0.5		1.7	2.5	
	PA	0.1	1.0		1.2	2.4	
	L		-2.2	-0.1		1.2	1.1
4	P		-2.4	0.3		1.2	0.5
	AP	0.1	-2.1		1.2	1.3	
	PA	-1.0	-1.6		1.2	1.4	
	L		-1.0	0.2		1.6	0.7
5	P		-0.4	0.8		1.1	0.5
	AP	-1.1	-0.5		1.1	1.7	
	PA	1.5	1.1		0.6	1.5	
	L		-1.3	-0.5		1.7	1.1
6	P		-1.1	-2.7		1.9	2.9
	AP	-0.5	-1.3		1.1	1.7	
	PA	-0.4	-1.3		0.9	0.6	
	L		1.1	1.9		1.5	2.0
7	P		1.7	2.0		0.8	1.4
	AP	0.2	0.5		1.9	1.5	
	PA	0.6	1.2		1.6	1.0	
	L		1.2	-3.2		1.1	1.3
8	P		0.9	-6.0		1.1	1.7
	AP	-5.4	-1.0		2.4	0.5	
	PA	-6.2	0.2		0.4	0.2	
	L		0.9	-0.7		0.1	0.8
9	P		0.7	-0.7		0.9	1.2
	AP	-0.6	0.1		0.9	2.1	
	PA	0.4	-0.1		1.0	1.1	
	L		-4.8	3.7		2.1	1.9
10	P		-2.5	3.8		2.4	4.1
	AP	-3.2	-6.2		4.8	2.3	
	PA	1.5	-4.6		2.2	3.3	

for patient number 8 shows clearly the difference between repeatability and reproducibility. The mean difference between position of central axis point with respect to bony structures on portal images and reference image is -6.2 mm. At the same time the reproducibility expressed in terms of OS parameter is very small namely 0.4 mm along X axis. It means that the treatment geometry was almost the same for each treatment session however, unfortunately, the patient was not treated according to original plan. In clinical practice systematic errors may lead to much dangerous consequences than random errors. Such errors may cause the underdosage of the part of irradiated tumour and overdosage of some parts of normal tissues. The random deviations usually have less influence on the dose distribution but the dose distribution changes concern larger volume. It is very important to avoid or at least minimise the systematic errors. Whenever they happen, they should be traced and corrected as quickly as possible.

According to the quality control protocol in Holycross Cancer Centre if an error of patient setup is larger then 5 mm appropriate action should be undertaken. The action level for patient number 8 was only slightly exceeded so, unfortunately, the appropriate procedure has not been performed and the reasons of that error remain unknown. In case of another patient the systematic error exceeded the action level but for this patient the random error appeared to be very large, too. In such a case immobilisation with PELVICAST should be considered but according to technologists opinion the immobilisation system make patient daily setup very difficult. Our experience with this type of immobilisation system does not confirm that the quality of patients setup is better. The base plate of immobilisation system was usually too wide

for our patients making the immobilisation less reliable. The manufacturer of the system assured us that the new version of the system allows for changing the width of the base plate.

In author's opinion the quality of patients setup in the investigated group is good. Such good result could be obtained because the procedure of patient setup was performed very carefully by well trained technologists. The patient positioning was always done by two technologists standing on both sides of the treated patient. The technologists paid close attention on relaxation of gluteal muscles [13]. Tension of gluteal muscles may cause shift of entrance points marked on the skin. The patient position was checked after completion of irradiation of each individual field. The technologists noticed that the patient setup is more difficult during first few fractions.

It is very well known that one of the predominant factors influencing the repeatability is the so called transfer error[14]. It depends significantly on technical aspect of radiotherapy e.g. all discrepancies between lasers systems installed on CT, simulator and treatment units worsen the repeatability. Thus it is very important to control regularly parameters of all therapy machines. Every day before treatment or simulation of the first patient technologists checked the most important parameters of simulator and treatment units.

There are several papers concerning the problem of setup inaccuracies during the course of pelvic irradiation. The results obtained at Holycross Cancer Centre are similar to the results published by other authors [12, 15]. Green and co-workers evaluated the setup accuracy by the method of positioning [15]. Two techniques has been compared. The first one was the same as applied in our hospital, i.e. using tattoos. The other one was based on getting the position of isocentre by measuring the appropriate distance from the table top. Authors concluded that the second technique is more reliably. The results obtained in Holycross Cancer Centre show that the tattoo method may also be reliable.

The value of setup deviation is one of the basic quantitative information needed for delineation of the PTV. This value allows for the estimation of the safety margin that should be added to the clinical target volume to ensure that the adequate dose is delivered to malignant cells [9, 10]. Assuming that both systematic and random errors are of Gaussian shape and requiring that 95% of patients should receive the total prescribed dose, the clinical target volume should be enlarged by a margin of thickness equal to about twice of OS value. In modern 3D treatment planning systems the margin is added automatically and it can be done separately for each direction. In practice the most often one value of setup margin is applied. If such role is followed the setup margin is calculated as double value of a root of sum of squares of all individual OS values determined for three axis X, Y and Z. The data obtained in this work lead to the conclusion that the setup margin that should be added in order to account for patient setup inaccuracies is about 6 mm. It should be pointed out that the setup inaccuracies are not the only factors influencing the delineation of the PTV. Movement of the internal structures may also add their share. The authors would like to emphasise that the size of the margin is specific for the localisation, treatment technique and hospital.

Establishing the margin size helps to work out the decision rules whether to continue or interrupt irradiation of a patient. If the deviation between the reference and portal image exceeds the so called reaction level than appropriate procedure should be applied. It has been establishing as general rule in our facility that if the deviation between the reference and portal image taken during the first treatment session is larger than the value of setup margin (6 mm) the portal image should be taken again during the second treatment session. If the difference of at least 6 mm persists, the simulation has to be repeated and procedure of setup control starts from the very beginning.

Conclusions

1. The reproducibility of patient setup irradiated in the pelvic region is good.
2. The setup margin for patient treated in the pelvic region with box technique should be at least 6 mm.
3. The simulation should be repeated if during two consecutive treatment sessions the deviation between treatment and reference images is larger than 6 mm.
4. The described technique of comparison of portal images and reference image facilitates quantitative evaluation of patient setup reproducibility.

The authors acknowledge the fruitful help of prof. Barbara Gwiazdowska and Tomasz Burzykowski.

Andrzej Dąbrowski M.Sc.
Medical Physics Department
Holycross Cancer Centre
Artwińskiego 3
25-734 Kielce, Poland
e.mail:andrzejda@onkol.kielce.pl

References

1 Rabinowitz I, Broomberg J, Goitein M et al. Accuracy of radiation therapy using simulation and serial portal film measurements. *Int. J Radiat Oncol Biol Phys* 1985; 11: 1857-1867.
2 Bova FJ, Fitzgerald LT, Mauderli WM et al. Real time megavoltage imaging. *Med Phys* 1987; 14: 707-711.
3 Byhard RW, Cox JD, HornJD et al. Weekly localisation films and detection of field placement deviations. *Int J Radiat Oncol Biol Phys* 1978; 4: 881-887.
4 Gildersleve J, Dearnaley DP, Evans PM et al. Reproducibility of patient positioning during routine radiotherapy, as assessed by an integrated megavoltage imaging system. *Radiother Oncol* 1995; 35: 151-160.
5 Van De Steene J, Van Den Heuvel F, Bel A et al. Electronic portal imaging with on-line correction of setup error in thoratci irradiation: clinical evaluation. *Int J Radiat Oncol Biol Phys* 1998; 40: 967-976.
6 Griffiths SE, Khoury GG, Eddy A. Quality control of radiotherapy during pelvic irradiation. *Radiother Oncol* 1991; 20: 203-206.
7 Halverson KJ, Leung TC, Pellet JB et al. Study of treatment variation in the radiotherapy of head and neck tumors using fiber-optic on-line radiotherapy imaging system. *Int J Radiat Oncol Biol Phys* 1991; 21: 1327--1336.
8 Creutzberg CL, Althof VGM, Huizenga H et al. Quality assurance using portal imaging: the accuracy of patient positioning in radiation of breast cancer. *Int J Radiat Oncol Biol Phys* 1993; 25: 529-539.
9 International Commision on Radiation Units and Measurements. Prescribing, Recording, and Reporting Photon Beam Therapy, ICRU Report 50, ICRU, Bethesda, 1993.
10 International Commision on Radiation Units and Measurements. ICRU Report 62, Supplement to ICRU Report No. 50 (1993), ICRU, Bethesda, 1999.
11 International Commision on Radiation Units and Measurements. Use of Computers in External Radiotherapy Procedures with High Energy Photons and Electrons, ICRU Report 42, ICRU, Bethesda, 1993.
12 El-Gayed AH, Bartelink H, Bel A et al. Evaluation of the time trend of setup deviations during the course of pelvic irradiation using an electronic portal imaging device. *Radiother Oncol* 1992; 24: 45-54.
13 Czuchraniuk P, Bujko K, Kukołowicz P et al. Ocena wpływu napięcia mięśni na obszar napromienianych tkanek regionu miednicy. W: *IV ogólnopolska konferencja naukowo-szkoleniowa techników medycznych radioterapii*; 1999; Wrocław, s. A-14.
14 Bel A, Bartelink H, Vijbrief RE et al. Transfer errors of planning to simulator: a possible source of setup inaccuracies. *Radiother Oncol, 1994;* 31:176-180.
15 Greer PB, Mortensen TM, Jose CC. Comparison of two methodsfor anterior-posterior isocenter localization in pelvic radiotherapy using electronic portal imaging. *Int J Radiat Oncol Biol Phys* 1998; 41: 1193-1199.

Paper received: 20 January 2000
Accepted: 24 January 2001