PATIENT POSITIONING CONTROL VERYFICATION IN RADIOTHERAPY — THE BASIS OF MARGIN DEFINITION FOR CLINICAL TARGET VOLUME*

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One of crucial steps in radiotherapy planning is patient positioning. Cancer radiotherapy requires high precision and specificity throughout whole therapeutic sessions. Due to the various parameter changes, implementing an appropriate treatment plan faces obstacles. While implementing the radiotherapy plan, targeting precisely and intensively areas of cancerous activity at a desired degree of tumor penetration, therefore, sparing underlying tissues from radiation exposure is of very important. The study aims to quantitatively determine the magnitudes of error in anteroposterior, mediolateral and craniocaudal directions, and determine the margin between clinical target volume to planning target volume based on systematic and random errors. Performing patient positioning control routinely before each therapeutic session allows obtaining a comparison of planned geometry and their early correction. Acquiring optimal results requires cooperation between medical personnel and patient. In this paper, the experience in determining margins added to the clinical target volume in different anatomical tumor geometries is presented.

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1. Introduction

Radiotherapy is an essential component in cancer treatment. Out of two-thirds of cancer patients, 80% receive photon radiotherapy alone or in

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combination with chemotherapeutic agent [1]. At our facility the Department of Radiation Therapy in Saint Lukas Hospital in Tarnów, the conformal 3D teleradiotherapy is of a frequent use.

The first step of radiation treatment planning is based on computed tomography (CT) scans performed at the very beginning of the procedure. Defining the CTV (Clinical Target Volume), PTV (Planning Target Volume) and Organs at Risk (OAR) is necessary. The CTV is obtained by using CT scans containing patient's anatomy, tumor location, and its potential direct or through blood microinvasion, the status of lymphatic system, nerves and areas of decreased resistance, frequency and location of metastases to the regional lymph nodes plays a role when optimizing PTV by an adequate margin adding to the CTV. The margin extent depends on the type and location of cancer, organs' mobility, patient's position aberration and dosimetric aberration. Certain cancer locations (*i.e.* head and neck tumors) require using thermoplastic immobilizing masks which help in margins' minimization [2].

The main goal in radiotherapy planning is delivering planned isodose to the PTV, therefore, achieving optimal statistical parameters of the dose distribution in defined areas. The aim of radiotherapy is to deliver a planned dose to the PTV, obtaining local disease control and sparing the healthy tissue, thus minimizing side effects events [3, 4]. Defining too small PTV may reduce the chance for cure, while too large PTV may result in radiation injury. The radiation tolerance of normal tissue depends on its anatomical organization (serial, parallel, both), irradiated volume and dose fractionation (*i.e.* hyperfractionation, conventional fractionation, hypofractionation) [5]. The extent of radiation side effects is also related to the photon energy, dose rate, total treatment time, as well as patients individual radiosensitivity. After simulating and accepting the treatment, plans are ready to be implemented [2–6].

2. Material and methods

Verification of patient positioning is based on Cone Beam Computed Tomography — volumetric verification (CBCT) shown in Fig. 1 as well as portal images, obtained by using Electronic Portal Imaging Device (EPID) presented also in Fig. 1.

Volumetric verification relies on a comparison between the CT used for organ contouring the megavoltage (Fig. 1 A4, B4, C4) or kilovoltage (Fig. 1 A3, B3, C3) tomography performed just before irradiation which is regarded as tree-dimensional verification. Anatomic accordance evaluation based on the tomography enables noticing both bone and soft tissue discrepancies. Such a procedure allows a direct patient positioning correction when a soft tissue is our target volume *i.e.* prostate or minor pelvis localization presented in Fig. 1, left and right side of the figure, respectively [4]. In the case of portal images, two orthogonal projections, pointed at the isocenter (defined in the treatment plan), mostly from the gantry angles 0°, 90° or 270° are performed (Fig. 1 A1, A2 both 90° projections). Then two-dimensional images are compared with the Digitally Reconstructed Radiograph (DRR) obtained by using previous CT scans and tomographic projection of the irradiated area on which the shape of the verified area is marked are fused and compared [5] in our study for the 90° angle shown in Fig. 1 B1, B2 and fused C1, C2.

Patients treated radically were divided into subgroups according to the irradiated area: head and neck, pelvis, chest and extremities.

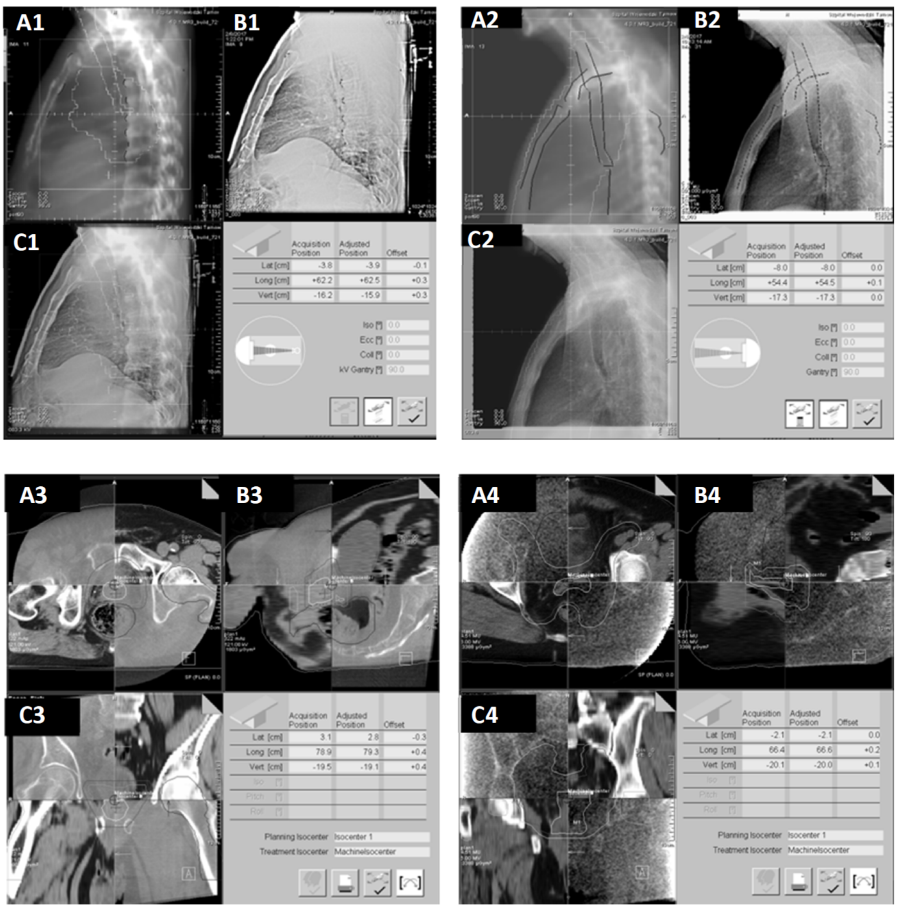

Fig. 1. Portal images of a chest area (upper line) and CBCT of the pelvis area (lower line). Left-hand side images are performed with the kilovoltage radiation, right-hand side images with the megavoltage [Author's property].

The applied correction method is performed in two steps: on- and off-line. Patient positioning is verified both before irradiation (on-line) and after (off-line). After careful consultation, off-line images are used for setting the shift vector. The off-line results were also adopted for CTV–PTV margins determination. In the verification process, both extended No Action Level (eNAL) and Shrinking Action Level (SAL) were included. This approach consists of performing images during the first three treatment fractions, its analysis and setting the shift vector which is later on compared with established levels of reaction (different for certain localization and treatment schedule). If the level of reaction is exceeded, the shift vector is applied. Finally, the verification is carried out during the 10^{th}, 20^{th} and 30^{th} treatment fraction. In case the level of reaction is exceeded in any imaging, further control and determining a new shift vector is obligatory.

For adequate position verification in different areas, reliable anatomic points of reference must be specified. Most frequently, we determine patient position on the basis of bones next to the irradiated area [7, 8].

3. Analysis and results

In all analyzed subgroups, for each patient and each possible shift direction, a systematic and stochastic error value was determined, taking into account the shift between the actual isocenter (during the relevant therapeutic session) and the planned one regarding the number of fractions with the portal control and isocenter localization.

Then, the systematic error was calculated for the homogeneous group of patients. Systematic error is given as a standard deviation calculated from the set of systematic errors of individual patients.

We also determined the stochastic error for the group of patients and presented as the mean value of the set of stochastic errors for individual patients. The total systematic error used for determining the CTV–PTV margin was calculated as the root of the total square of the mentioned above values of systematic error and the truncation error related to the apparatus inaccuracy.

In order to determine the CTV-PTC margin, we used Stroom's formula (1). Stroom's formula ensures 99% of the CTV receives more than or equal to 95% of the prescribed dose [10]

$$M = 2 \times \varSigma_{\text{tot}} + 0.7 \times \sigma_{\text{tot}} \,, \tag{1}$$

where $\varSigma_{\text{tot}}$ — total systematic error (the difference between the planned and accomplished isocenter), σ_{tot} — total stochastic error (the variance between the accomplished isocenter against its mean location) [1, 9, 10].

Table I presents the CTV–PTV margin obtained by using Stroom's formula and calculated for given anatomical localization. The data sets were collected at our facility during 2015 and 2016, for each type of radical treatment with same anatomical localization group. Presented values are calculated for every probable shift vector in 3D scheme.

TABLE I

Marginal values, M, calculated from Stroom's formula [Author's property].

Anatomical area	Direction of margin determination			Number of measurements
Year 2015				
	LAT [cm]	LONG [cm]	VERT [cm]	
Head and neck	0.53	0.44	0.50	78
Chest	0.72	0.78	0.80	180
Pelvis	1.07	1.04	1.08	172
Extremities	1.28	1.23	1.21	7
Year 2016				
Anatomical area	Direction of margin determination			Number of measurements
	LAT [cm]	LONG [cm]	VERT [cm]	
Head and neck	0.56	0.56	0.52	90
Chest	0.74	0.80	0.82	168
Pelvis	0.92	0.80	0.99	169
Extremities	1.47	1.54	0.87	8

4. Conclusions

There are many cases of positioning errors qualified for optimization and correction [2–5, 7–11]. Radical and unified elimination of all error cases is one of the main obstacles in radiotherapy positioning. There are many reasons of isocentrer shifting *i.e.* (1) patient preparation inconsistency caused by external systems due to differences between laser centrators and the therapeutic table mobility, (2) the table deflection (hard table available during the tomography, flexible table available on the accelerator), (3) stress problems of flexed buttocks — as the radiotherapy procedure is running, patient starts feeling more comfortable and relaxes the muscles, (4) the comparison issue: matching and comparing geometrically unidentical objects in radiotherapy planning, (5) the medical staff experience in positioning, (6) the limited accuracy of available tools such as telemeter scale step and electronic scale difference (5 mm and 1 mm, respectively) or the lack of exact size parameters of positioning equipment (*i.e.* pelvis holders) which are often not defined by manufacturer, (7) quality of compared images, (8) difficult patient–medical personnel cooperation and (9) pain sufferers [12, 13].

Achieving identical patient positioning, matching the one shown on the tomography scans in every therapeutic session is practically impossible. Due to experimental character of performed positioning control, the results are given with measurement uncertainties. In CTV–PTV margin definition, the uncertainties might be important and are classified into 3 main groups [7]:

(a) First group — systematic error type one σ^1 which represents the mean value obtained from the means calculated for each patient from the whole analyzed subgroup. The type one uncertainty informs about measurement uncertainty correlated with *i.e.* transfer error or table deflection.

(b) Second group — systematic error type second σ^2 which represents systematic error distribution in one coherent subgroup of patients (standard deviation from mean values obtained from each patient). This second type of errors has the main influence on the margin definition CTV–PTV and depends on the error normal distribution. The error reports isocenter shift regarding planned isocenter placement as a two folds greater vector in $\sim 5\%$ of patients.

(c) Third group — random error type three σ^p — the mean value of standard deviation values for given group of patients. Random error may cause systematic error maximization (as the character of the error is random, the error value is approximately zero). Third type errors do not have a major influence on the CTV–PTV margin definition and it may occur as a result of *i.e.* medical personnel cooperation, the time length of therapeutic session *etc.*

In the presented study, the CTV–PTV margin was calculated by using Stroom's formula. The chosen formula is internationally accepted and provides more accurate targeting PTV than van Herk's formula still used in radiotherapy planning [1, 9, 12]. The Polish Society of Medical Physics and Engineering recommends using Stroom's formula as a standard formula for treatment planning. However, caution is warranted against adopting generic margin recipes as different margin generating recipes lead to a different probability of target volume coverage [6–8]. Results of the positioning control are satisfying in both analyzed years: 2015 and 2016 (Table I). The CTV–PTV margins are placed on comparable and definitely low level. When it comes to lower limbs, results comparison and interpretation is difficult due to low statistical power, discrepancy in field size and its localization. The uncertainties which are the result of systematic error may rise due to reduced precision of outlined target, instantaneous organ position of human body (inhaled, exhaled lungs), patient positioning difficulties and radiotherapy system planning which limits the dose distribution calculation [13].

Pelvis localization causes obstacles regarding appropriate and repeatable positioning which often results in largest systematic error value. Such a maximization of the systematic error does not occur when it comes to patients with head and neck tumors where the organ position is stable and motionless. The random error occurrence basically shows the technicians–patient cooperation in positioning implementation.

A results analysis showed that pelvis displacement or rotation during the therapy in regard to the planned position was often observed.

Thanks to creating data base of protocols with patient positioning, targeting anatomical regions demanding positioning correction, training and achieving higher quality standards regarding young medical personnel co-operating directly with patients, we have improved positioning control for pelvis region (up to $\sim 10\%$ — Table I). The collaborative approach of medical personnel — physicians, medical physicists and technicians — resulted in higher quality standards in radiotherapy planning and implementing consensus of the Tarnów Hospital.

5. Summary

A patient positioning control verification is one of the key elements in quality control in radiotherapy which allows early geometrical error detection, occurring during the patient preparation before the treatment. Detecting geometrical errors as early as possible gives the opportunity to deliver a proper dose value to the target volume.

Radiotherapy, especially radical radiotherapy is a long-term process often consisting of 20 fractions. Thus, accurate positioning projection of anatomical regions is of great importance. One has to keep in mind that some organs are placed in the neighborhood of the planned isocenter and/or motionless with respect to the target volume — the tumor. Another issue is the difference between planned and delivered dose distribution occurring during different therapeutic sessions.

The consequences of too low or too high absorbed dose in the target volume may result in the lack of the successful treatment outcome. The total random error elimination is hardly achievable. Systematic errors might be corrected (by *i.e.* correcting the CTV–PTV margin and OAR shielding) which leads to increasing the success achieved by implemented radiotherapy treatment. We believe that a proper treatment planning, individual CTV–PTV margins preparation (for each anatomical region), improving personnel qualifications, patient positive approach during the therapy and medical equipment are the critical factors playing the main role in the achieving higher standards of the radiotherapy. We noted that proper immobilization and adding extra positioning verification points gives a chance to deliver the accurate dose to the anatomical structures such as the head and neck. Lastly, it is important to remember that in some cases, preparing a treatment plan which fulfills our expectations is impossible. In such cases, the decision about proceeding patients' treatment lies in the oncologist hands.

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