Rep Pract Oncol Radiother, 2007; 12(6): 345-352

Technical Note

Received: 2007.02.15
Accepted: 2007.07.24
Published: 2007.12.27

Evaluation of the technical status of radiotherapy simulators involved in clinical trials

Authors' Contribution:
A Study Design
B Data Collection
C Statistical Analysis
D Data Interpretation
E Manuscript Preparation
F Literature Search
G Funds Collection

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Source of support: Polish research project KBN No. 6 P05C 032 20.

Summary

Background Radiotherapy simulators play an important role in the preparation of radiation treatment. Their mechanical and geometrical parameters have to be identical with those of the treatment machines. Therefore, quality control protocols for the simulators should be comprehensive and the tolerance limits as high as those for treatment machines.

Aim Evaluation of the technical status of radiotherapy simulators involved in clinical trials.

Materials/Methods In this paper, results of quality control tests conducted in 12 Polish radiotherapy centres are presented. The tests were carried out within the framework of Polish research project KBN No. 6 P05C 032 20. 12 radiotherapy simulators installed in Polish radiotherapy centres were thoroughly tested. In order to control technical conditions of the simulators, a set of 24 tests was elaborated. The tests were divided into six thematic groups. The detailed range of the parameters controlled and the accepted ranges of tolerance limits are given. The values of tolerance limits are based on data found in the available literature.

Results The control of 12 simulators revealed the violation of accepted tolerance limits for 13 out of 24 controlled parameters. The most frequent violations of accepted tolerance limits occurred in the case of geometrical parameters of light simulation and mechanical parameters of the couch, both very important for the accuracy of the simulation process.

For 2 simulators almost 30% of controlled parameters were outside the tolerance limits.

Conclusions The control of radiotherapy simulators undertaken within the framework of the clinical trial revealed that in the majority of cases the simulators were in good technical condition. In 2 cases almost 30% of controlled parameters were outside the tolerance limits. In such cases the manufacturers' service should be called urgently for necessary repairs and regulations. After repeated quality control tests a decision should be taken regarding the accepted range of operations which could be used in clinical practice. A QA and QC system for radiotherapy simulators should be introduced in each radiotherapy centre.

Key words radiotherapy simulators • quality control tests

Full-text PDF: http:/www.rpor.eu/pdf.php?MAN=11488

Word count: 2233
Tables: 2
Figures: 9
References: 15

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Background

Radiotherapy simulators play an important role in the preparation of radiation treatment. They are used for initial simulation, preparing the patient for CT examination, for defining radiation fields for plans not requiring computation of spatial dose distributions, and for verifying field sizes and directions for plans prepared by 3D treatment planning systems. Radiotherapy simulators play an important role in preparing treatment plans, and therefore their mechanical and geometrical parameters have to be identical with those of the treatment machines. Therefore, quality control protocols for the simulators should be comprehensive and the tolerance limits as high as those for treatment machines. What is more, radiotherapy simulators fulfil the role of diagnostic X-ray units, providing additional medical imaging information.

Technical parameters of therapeutic units were checked according to well established, comprehensive quality control tests. Similar tests have been prepared for therapeutic simulators. In this paper, results of quality control tests conducted in 12 Polish radiotherapy centres are presented. The tests were carried out within the framework of Polish research project KBN No. 6 P05C 032 20. The experience gained during the project served as the guidelines to set up the Polish recommendations for the quality control protocol for therapeutic simulators.

Aim

Evaluation of the technical status of radiotherapy simulators installed in Polish radiotherapy centres involved in clinical trials.

Materials and Methods

Between October 2001 and June 2002, 12 radiotherapy simulators installed in Polish radiotherapy centres were thoroughly tested.

In order to control technical conditions of the simulators, a set of 24 tests were elaborated. The tests were divided into six thematic groups:
1. Mechanical parameters of the simulator,
2. Mechanical parameters of the couch,
3. Geometrical parameters of the light simulation,
4. Geometrical parameters of the X-ray beam,
5. Parameters of the television image chain,
6. Parameters of the X-ray source.

Tests were made according to Polish recommendations for QA of simulators. Detailed information on measuring methods may be found in [1]. The detailed range of the controlled parameters and accepted ranges of them are presented in. The values of tolerance limits are based on data found in the available literature [2–12].

When the controlled parameters are kept within the above tolerance limits, the simulation should assure proper simulation and adequate preparation of the patient for radiotherapy.

The following equipment was used for the control of the mechanical parameters of the simulator and the couch, and of the light simulation system and the radiation beam:
– electronic spirit level (Table 1 points 1.1–4.7),
– reference distance indicator (Table 1 point 3.5),
– Iso-Align device from Med-Tec [13] (Table 1 points 2.3; 3.1–4.5),
– phantom Beam Alignment Test Tool 162A from Gammex (Table 1, point 4.6),
– Kodak X –Omat V films in light protective envelopes (Table 1, points 2.4 and 4.4–4.7).

For the evaluation of the television image chain of the simulator a phantom Normi 4 from PTW
– Freiburg was used [14]. The phantom was equipped with:
– step wedge (from 1.1 to 1.6 mm Cu) for the evaluation of the image contrast (Table 1, point 5.1),
– a template of the spatial frequency (0.8–5.0 lp/mm) for evaluation of the image resolution (Table 1, point 5.2),

Table 1. Controlled parameters and the tolerance limits.

1	**Mechanical parameters of the simulators**	**Tolerance:**
1.1	vertical movement of the simulator gantry	2mm/0.2°
1.2	horizontal level of the image intensifier	1.5°
1.3	the indicator of the gantry angle	0.5°
1.4	the indicator of the collimator angle	0.5°
2	**Mechanical parameters of the couch**	**Tolerance:**
2.1	the horizontal level of the couch	0.5°
2.2	vertical movement of the couch	2mm
2.3	electronic and mechanical indicators of transversal, longitudinal and vertical movement of the couch	1mm
2.4	agreement of couch rotation axis with the collimator rotation axis	diameter 2mm
3	**Geometrical parametrs of the light simulation**	**Tolerance:**
3.1	position of the simulation cross image at the isocentre during vertical movement of the X ray head	2mm
3.2	agreement of the collimator rotation axis with the axis of light simulation	r=1mm
3.3	isocentre of the light field	1mm
3.4	laser centrators	1mm
3.5	telemeter	2mm
3.6	light field	1mm
4	**Geometrical parametrs of the radiation beam**	**Tolerance:**
4.1	agreement of the radiation beam axis with the axis of vertical movement of: a) X ray tube; b) image intensifier	2mm
4.2	agreement of the collimator rotation axis with the axis of radiation beam	r=1mm
4.3	agreement between light field and radiation field in fluoroscopy	1mm
4.4	isocentre of the radiation beam	1mm
4.5	agreement between light field and radiation field in fluorography	1mm
4.6	verticality of the radiation beam axis in fluorography	2mm
4.7	agreement of the position of the cross image at isocentre for small and large focal point of the X ray tube	0.5mm
5	**Parameters of the television image chain**	**Tolerance:**
5.1	contrast	6step wedge
5.2	resolution	0.8lp/mm
5.3	image geometry preservation	no distortion
6	**Parameters of the radiation source**	**Tolerance:**
6.1	agreement and reproducibility of the high voltage	10% and 5%
6.2	linearity and reproducibility of the exposure	linear function; 20%
6.3	half value layer	min 2.1mmAl for 80kV

– a template with a 10×10mm grid for the evaluation of the geometrical distortions (Table 1, point 5.3).

For the control of the radiation source parameters the following equipment was used:

– Nero™ mAx 8000 meter from Victoreen [15] (Table 1, points 6.1-6.3).
– a set of aluminium filters of high chemical purity (99%) Aluminium Half Value Layer Attenuator Set RMI 115A from Gammex, for half-value layer measurements (Table 1, point 6.3).

Table 2. Manufacturers, types and the years of installation of 12 controlled simulators.

Types of simulators	Manufactures	Number of simulators	The years of installation
Simview 3000	Siemens	4	1996, 1997, 1998, 1999
Simulix HP	Nucletron	3	1996, 1996, 1999
Simax	ZDAJ	1	1998
Ximatron C	Varian	2	1997, 1997
Ximatron CX	Varian	1	1999
Ximatron CDX	Varian	1	2001

Results and Discussion

Before the start of the project, data concerning the simulators in question were collected. These data were necessary for the appropriate choice and preparation of required equipment. Twelve simulators, 6 different models manufactured by 4 different companies, were controlled (Table 2). The oldest simulator was six years old, the newest one year old (Table 2). Throughout their periods of use, all simulators were periodically controlled by the manufacturers' maintenance service, and some of them were controlled within the quality assurance programmes adopted in particular centres.

Since the simulators are used to verify the geometry of the treatment plans, the groups of tests concerning the mechanical and geometrical parameters were considered the most important. Among the geometrical parameters, the following are regarded as the most important: the size of the isocentre of the light and radiation beams, the position of lasers, telemeter, light and radiation field size, the accuracy of collimator and gantry movements and couch positioning.

The control tests proved that both light and radiation isocentre size were within the tolerance limits for all simulators tested (Figure 1, Table 1, points 3.3 and 4.4).

The control of laser beams (side and sagittal) revealed inaccuracies of side laser positioning in two simulators (one side laser in the case of one simulator, two side lasers in the other one). The displacements of laser lights from the isocentre were 1.5mm, 2.0mm, and 2.0mm and 3.5mm respectively. The results of the laser control are presented in Figure 2. Inappropriate laser positioning may cause a systematic error in patient alignment. It has to be pointed out that in most radiotherapy centres proper laser alignment is the responsibility of the radiotherapy equipment maintenance team of the user. Proper procedure of laser control in each radiotherapy centre should be established.

Present radiotherapy machines have source-isocentre distance, SID, of 80 or 100cm. For this reason, the telemeter scale was controlled for this distance in terms of accuracy and linearity. In two simulators, a difference of 3 mm between the telemeter indications and measured nominal value of 100cm was detected (Figure 3). In two other simulators the telemeter scales were not linear (Table 1, point 3.5). For the adjustment of the telemeter scale, intervention of the manufacturer's maintenance service is necessary.

The evaluation of the agreement between the light field and a reference field size was conducted for a square field of the size 5cm, 10cm and 20cm. Inaccuracies of the setting of light field delineators were detected in three simulators. In two cases, the delineators were set 2mm beyond the right field size of 5cm and 20cm, and in one case they were beyond 2mm below the field size of 5cm. The results are presented in Figure 4. The inaccuracies in field sizes larger and smaller than 10cm rectangular field may result from the fact that in most simulators the field size calibration is performed only for the 10×10cm field. This clearly indicates that the quality control of simulators should include tests for other field sizes. The accuracy of field sizes is particularly important for small fields because in these cases the margins between the CTV (Clinical Target Volume) and PTV (Planning Target Volume) are small. It should be noted that 2mm inaccuracy in the position of one field delineator could be detected visually and should be noticed by radiographers, who should be properly trained (Table 1, point 3.6).

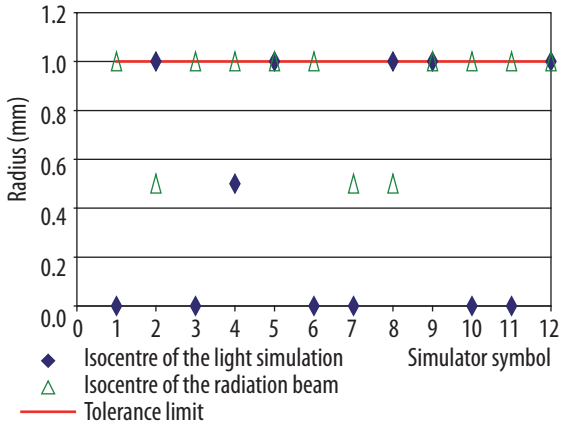

Figure 1. The size of the isocentre of the radiation and light beams.

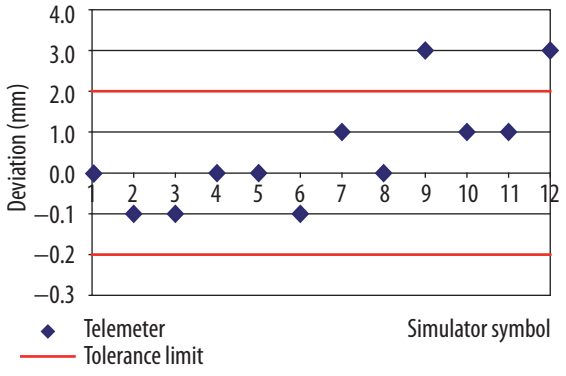

Figure 3. Deviation of the telemeter indications from the nominal value of SSD=100cm.

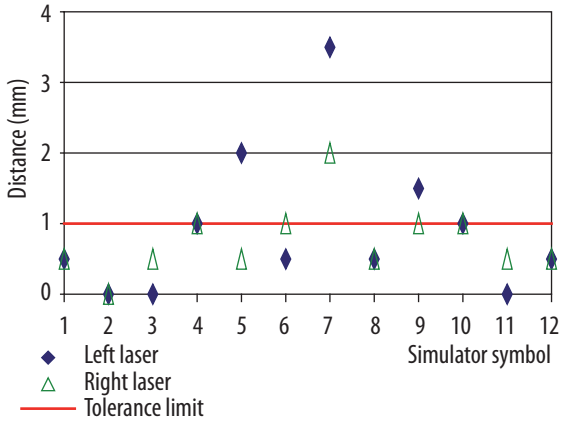

Figure 2. Distance between vertical line of the side laser and the isocentre of the light beam.

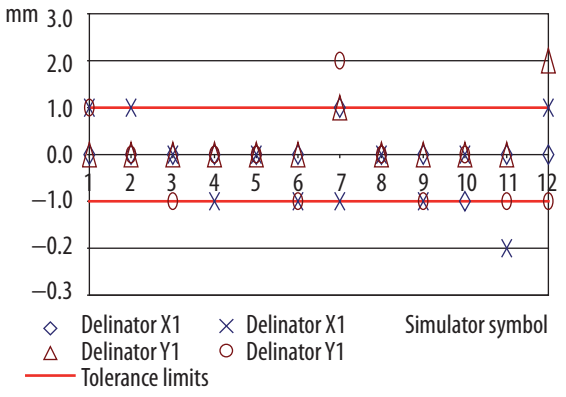

Figure 4. Accuracy of the delineator positions in relation to the reference field (5×5cm).

During preparation and verification of the treatment plan on the simulator, the field sizes are established on the basis of the fluoroscopic X-ray image. The agreement between the light and X-ray fields was controlled with X-ray films. Fluorography is used for evaluation and delineation of the treatment volume for treatment plans prepared without computerized treatment planning systems. The accuracy of the field size and the agreement between light and radiation fields was evaluated:

– with fluoroscopy – for rectangular 15cm field, for simulator gantry positions 0°, 90°, 270°;
– with films – for rectangular 10cm field for simulator gantry position 0°.

For one simulator a difference of 2mm between one light field edge and the radiation field edge was detected.

The simulator collimators' positions were controlled for rotation scale indications of 0°, 90° and 270° and for the agreement between the light simulation field and radiation field axes. The results were within accepted tolerance limits (Table 1, points 1.4, 3.2, 4.2).

The accuracy of the gantry rotation scale was evaluated for the indications 0°, 90°, 180° and 270°. The results were within the tolerance limits. For 4 simulators (Siemens) such evaluation could not be performed because it required the removal of the gantry housing by the manufacturer's maintenance service (Table 1, point 1.3).

The following parameters of simulator couches were controlled: horizontal position of the couch top (without additional weight), accuracy of vertical movement, accuracy of the mechanical and

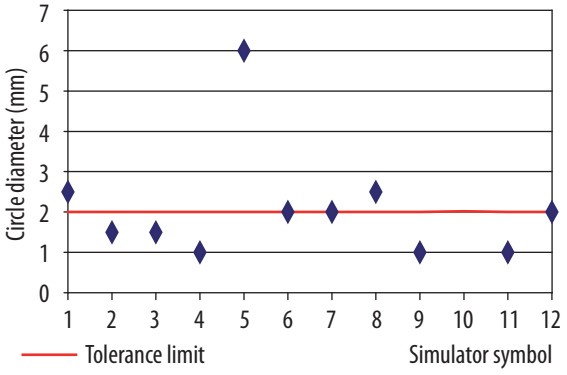

Figure 5. Agreement of the couch column rotation axis with collimator rotation axis.

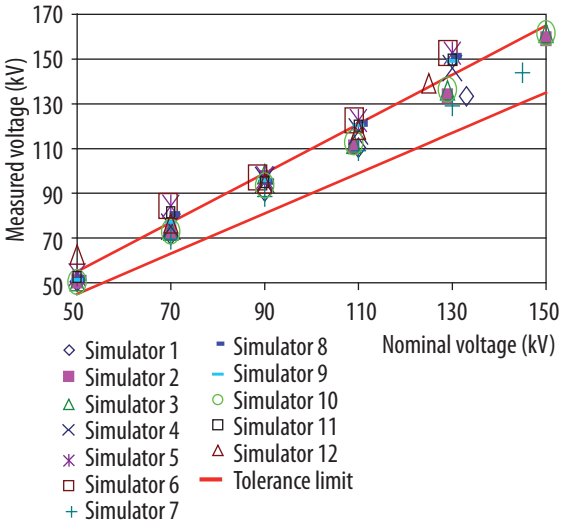

Figure 6. Agreement between measured high voltage values with console settings.

electronic scales of the couch top horizontal and vertical movements, and the agreement between the couch column and collimator rotation axes. The control revealed the following inaccuracies: in one case the couch top was 0.6° off the horizontal position, slightly beyond the accepted tolerance limit; in another case the vertical movement led to tilt of 3.5mm at the distance of 40cm; in five cases inaccurate indications of couch movement scale – in four cases it was an electronic scale, in one case it was a mechanical scale on the couch. In one case the inaccuracy was 3mm, in the others 2mm. Such inaccuracies may lead to serious consequences in situations when the isocentre position is set by couch movements in relation to the reference point. In three cases the top of the couch was loose and could lead to uncontrolled patient shift in relation to the lasers and a systematic error. The control of the couch column rotation revealed that in two simulators the column axis effectuated a circle 2.5mm in diameter, slightly beyond the tolerance limits; in one case the circle diameter was 6mm, which eliminated the unit from simulation of treatments using column rotation. It should be noted that simulations with column rotation are not frequent. The results are presented in Figure 5 (Table 1, point 2.1-2.4).

The next controlled parameter was the verticality of the central axis of the X-ray beam and its agreement with the position of the image of the cross for small and large focal spot of the X-ray tube. For all simulators tested these parameters were within the accepted tolerance limits (Table 1, point 4.6 and 4.7).

The tested parameters may be divided into two groups: parameters directly influencing the quality of treatment simulation and parameters linked with the specific construction of the simulator unit. The movement of the X-ray tube along the gantry axis (non-existent in radiotherapy machines) belongs to the first group. The parameters linked with image creation, such as parameters of the image intensifier, television image chain and radiation source, belong to the second group.

The control of the X-ray tube movement along the gantry in vertical position revealed two cases where the lamp tilted by 2.5mm at the distance of 60cm. The influence of tube movement on the position of the cross image position and the axis of the radiation beam were also evaluated. This control did not reveal any cases beyond accepted tolerance limits (Table 1, points 1.1; 3.1; 4.1).

Control of simulator parameters linked with image quality included horizontality of the image intensifier top and verticality of its movement in relation to the X-ray beam axis at the 0° gantry position. The results were within the accepted tolerance limits (Table 1, point 1.2 and 4.1).

Control of the parameters of the television image chain included evaluation of the image contrast, resolution, and image geometry preservation. In one case only was geometry distortion detected (Table 1, point 5.1-5.3).

Control of the parameters of the radiation source included: agreement of the actual high voltage values with nominal settings and its reproducibility,

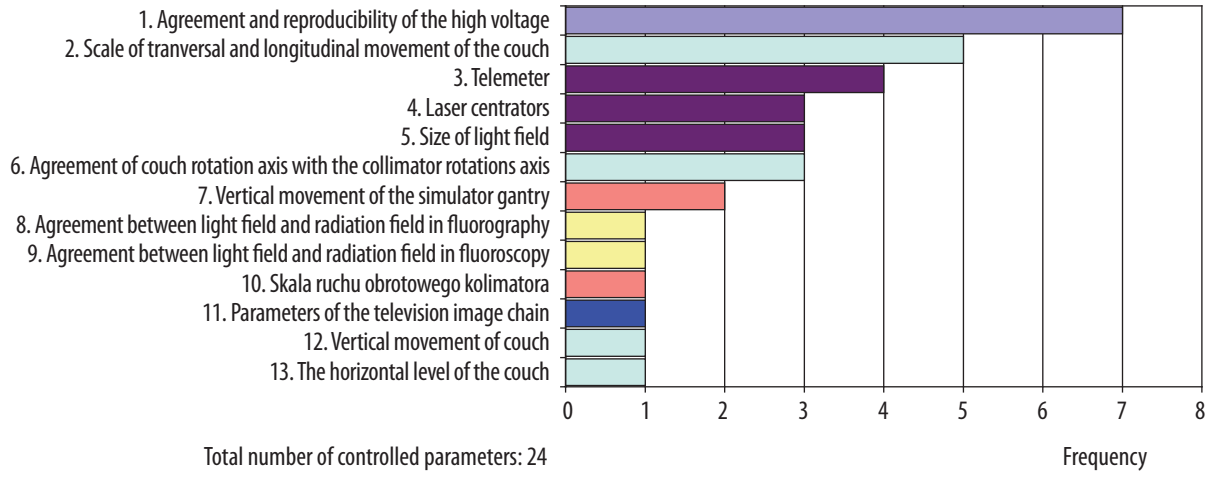

Figure 7. Parameter values beyond accepted tolerance limits.

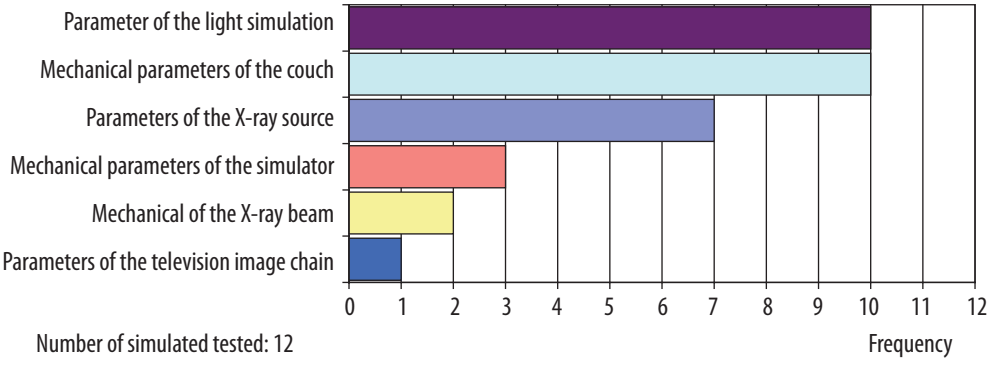

Figure 8. Frequency of tolerance limit violations for particular groups of parameters.

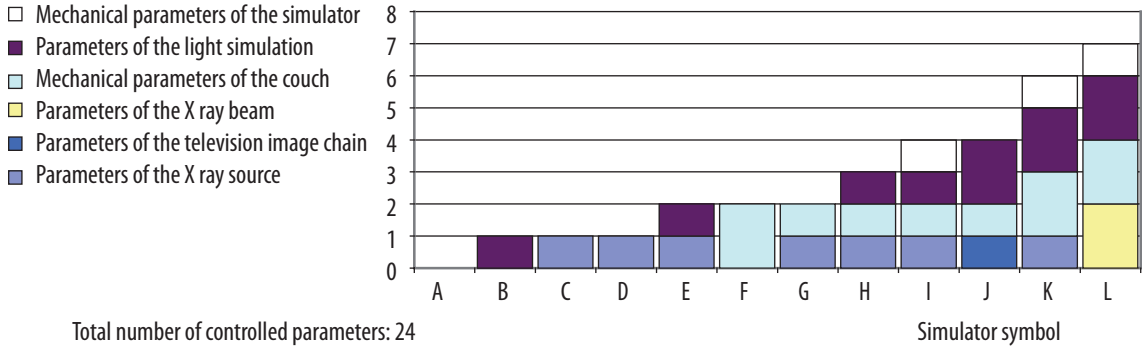

Figure 9. Number of parameters beyond accepted tolerance limits for particular simulators tested.

reproducibility of the exposure and linearity of the exposure as a function of tube loading (mAs), radiation beam quality (half value layers). These are standard tests for radiodiagnostic equipment.

The results were as follows: for 7 simulators the high voltage values did not agree with the console settings (Figure 6), but they were reproducible for all tested simulators. Other parameters were

within the accepted tolerance limits (Table 1, points 6.1–6.3).

In summary, the control of 12 simulators revealed the violation of accepted tolerance limits for 13 out of 24 controlled parameters. In Figure 7, these 13 parameters are listed. As shown in Figure 8, the most frequent violations of accepted tolerance limits occurred in the case of geometrical parameters of light simulation and mechanical parameters of the couch, both very important for the accuracy of the simulation process.

In Figure 9, the numbers of parameters beyond the accepted tolerance limits for particular simulators in different radiotherapy centres are presented.

The symbols assigned to particular simulators in different radiotherapy centres are not the same as those in.

Conclusions

The control of radiotherapy simulators undertaken within the framework of the clinical trial revealed that in the majority of cases the simulators were in good technical condition. In two cases (K and L in Figure 9) almost 1/3 of controlled parameters were outside the tolerance limits. In such cases the manufacturers' service should be called urgently for necessary repairs and regulations. After repeated quality control tests a decision should be taken regarding the accepted range of operations which could be used in clinical practice.

A quality control system based on a basic set of tests (performed weekly, and more frequently when required) assures early detection of any inaccuracies in simulator functioning. A good knowledge of simulator performance allows the user to limit use of the simulator in the range of parameters where the risk of errors is increased.

A quality control system for radiotherapy simulators should be introduced in each radiotherapy centre. This is particularly important when the simulator is to be used in controlled clinical trials in radiotherapy.

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