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ORIGINAL PAPER

# Development of cylindrical stepwedge phantom for routine quality controls of a helical tomotherapy machine

Krzysztof Mikołajczyk [a,*], Tomasz Piotrowski [b]

[a] Department of Medical Physics, Greater Poland Cancer Centre, 15th Garbary Street, 61-866 Poznań, Poland
[b] Department of Electroradiology, University of Medical Sciences, 10 Fredry Street, 61-701 Poznań, Poland

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**Abstract** The aim of this study was to design a cylindrical stepwedge phantom and an appropriate treatment procedure, based on which parameters of tomotherapy machine and generated beam of radiation will be defined. The accuracy of parameter determination, which can be defined with the aid of the measurement system, was also evaluated.

The cylindrical phantom that we developed and manufactured (stepwedge phantom) consists of four cylinders with different diameters made of polycaprolactam-PA-6, i.e. material with high mechanical strength, low water absorption (making measurements repeatable) and a density comparable to that of human soft tissues. The appropriate treatment procedure is carried out in a dynamic mode, which is focused on specific properties of the tomotherapy machine. It means that a phantom situated on the couch moves to the inside of the rotating linear accelerator.

A total of 18 procedures were implemented in order to calculate the following parameters: couch velocity, dose rate value at a depth, Dose Ratio coefficients, dose variation (so-called Dose Flatness) coefficients, and the time of gantry rotation. Reference intervals for these parameters were determined to be as follows: for the couch velocity: ±1.2%, the average dose rate measured at depth: ±1.8%, the calculated values of the coefficients Dose Ratio: ±0.5% and Dose Flatness: (0.53—0.65)%, the time of gantry rotation: ±3%.

The final results showed that during a single irradiation procedure, which lasts 5 min, the cylindrical stepwedge phantom allows to precisely determine the values of the above-mentioned parameters. Its use in the daily dosimetric measurements can ensure better control of the work of the tomotherapy machine.


* Corresponding author.
*E-mail address:* krzysztof.mikolajczyk@gmx.com (K. Mikołajczyk).

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## Introduction

In teletherapy, quality assurance involves performing a number of procedures that test radiotherapy equipment in terms of proper mechanical work as well as radiation dosimetry. A number of tests have been developed for tomotherapy machines [1—4] that partly overlap the tests for traditional linear accelerators [5—10]. Depending on the movements of the linac (mounted on the ring gantry) and the couch (while treating or while measuring) the appropriate tests can be: static, where the gantry and the couch are fixed, or irradiation is performed from a few selected angles; and dynamic, where the couch is in motion while the gantry is rotating. In general, all tests can be divided into five groups. Most of these tests require additional equipment and accessories. Beside megavoltage computed tomography (MVCT) detector, which is part of the tomotherapy equipment, the system includes thimble ionization chambers (Exradin A17 and A1SL ion chambers), X-ray films, phantoms: Water Tank, Slab Solid Water Phantom, Cheese Phantom (some of them supplied by the vendor).

The first group of tests allows for the verification of several mechanical alignments. This set of tests check: the alignment of the radiation source in the *x*-direction against multi-leaf collimator (MLC), in the *y*-direction against the y-jaw, jaw symmetry, beam planarity (to verify that the beam is parallel to the plane of gantry rotation), the lateral alignment of the MLC relative to the center of rotation and that the MLC is aligned parallel to the rotational plane, MVCT detector alignment (ensures that the MVCT detector array is centered and aligned with respect to the jaws) [2,11]. All tests are performed in static mode. On-board MVCT detector and film (Kodak EDR2 Film) placed between two solid water plates are used in these tests. The last time a new independent tool for tomotherapy QA was presented [12]. The dose magnifying glass (DMG) is a 128 channel array of Si strip detectors. It was used to measure three tomotherapy QA parameters: MLC alignment, leaf latency and leaf output factor (LOF).

The second group of tests checks the MVCT detector: monitoring image quality (spatial resolution and contrast, noise, uniformity), measuring the dose delivered during acquisition of MVCT and verifying the correctness of conversion density — HU. MVCT detector and Cheese Phantom are required in this case [11]. The third group of tests allows for the verification of laser alignment, the red laser movement, the Virtual Isocenter and movement, the longitudinal motion alignment and the sag of treatment couch [11].

Tomotherapy is unique in its action, due to the irradiation provided in a helicoidally way and the behavior of the MLC collimator [13]. The fourth group of tests allows for the verification of the uniformity of the couch motion, the leaf opening synchronized with gantry rotation and the couch translation synchronized with gantry rotation [14]. Slab Solid Water Phantom and films are required in these tests.

The last group of tests allows for the verification of the beam quality. These includes the measurements of longitudinal, transversal and percentage depth dose (PDD) profiles. Water Tank and ionization chamber are used in these tests [11]. The MVCT detector can be used for measuring the transversal profile [15]. The next test in this group monitors the output consistency (stationary and rotational output) using an ion chamber or on-board monitor chambers (the detectors of tomotherapy machines). The measurement of rotational output variation can be performed using the Cheese Phantom and films [14] or monitor chambers [11]. The last test is a dosimetric verification which allows us to compare the dose to be delivered by the treatment planning system (TPS) with the measured, for the plan using intensity modulated radiation therapy (IMRT) [11,16—18].

The last time the Tomotherapy Inc. has offered TQA (TomoTherapy Quality Assurance™). This easy-to-use application automates the collection — and simplifies the analysis — of key metrics for machine QA. It is intended to monitor the changes in the system performance that may provide early indications for maintenance or dosimetric validation. Output data is acquired only from the dose monitoring system and the detector array. It allows to measure the monitor chamber and detector output constancy, verify the rotational variation and by using the stepwedge to provide a measurement of the couch velocity, energy, and synchrony of the couch, the multi-leaf collimator and the gantry.

Large variety of tests ensures proper operation of equipment. However, they are time-consuming and the amount of time used for patient treatment is significantly reduced. The solution in this case seems to be the TQA. It allows us to provide measurements of several parameters of the device at the same time. However, the TQA and most of the verification tests use on-board equipment like MVCT detectors or ionization chambers. There are few advanced tests performed independently of the irradiation machine.

All of the above deficiencies in the verification tests have contributed to the design of the phantom — the cylindrical stepwedge phantom. The measurement system allows us to verify the compliance in several areas of machine work, in a single irradiation procedure: the couch velocity, the gantry time rotation and changes in the dose rate in the longitudinal plane. An additional requirement was that the measurements were made independently from the machine, so that the results could be more objective by using of additional equipment.

## Material and methods

### The preparation of cylindrical stepwedge phantom

The phantom used was made of cast polyamide PA-6 (polycaprolactam). This material is fully suitable for dosimetric applications of this study. Its stiffness and hardness make it possible, as a result of further processing, to obtain the desired shape with specific dimensions. Mechanical resistance guarantees the use of the material without fear of any damage caused by everyday use, and low water absorption, compared with other plastics, ensures constancy of internal environment of the measuring system and thus the repeatability of measurements. Density of 1.12 g/cm$^3$ is comparable to that of human soft tissues.

The phantom consists of four coaxially connected cylinders with diameters of 40 mm, 60 mm, 80 mm, 100 mm