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Dosimetry Contribution:

A fast and reliable method for daily quality assurance in spot scanning proton therapy with a compact and inexpensive phantom

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ABSTRACT

In a radiotherapy center, daily quality assurance (QA) measurements are performed to ensure that the equipment can be safely used for patient treatment on that day. In a pencil beam scanning (PBS) proton therapy center, spot positioning, spot size, range, and dose output are usually verified every day before treatments. We designed, built, and tested a new, reliable, sensitive, and inexpensive phantom, coupled with an array of ionization chambers, for daily QA that reduces the execution times while preserving the reliability of the test. The phantom is provided with 2 pairs of wedges to sample the Bragg peak at different depths to have a transposition on the transverse plane of the depth dose. Three “boxes” are used to check spot positioning and delivered dose. The box thickness helps spread the single spot and to fit a Gaussian profile on a low resolution detector. We tested whether our new QA solution could detect errors larger than our action levels: 1 mm in spot positioning, 2 mm in range, and 10% in spot size. Execution time was also investigated. Our method is able to correctly detect 98% of spots that are actually in tolerance for spot positioning and 99% of spots out of 1 mm tolerance. All range variations greater than the threshold (2 mm) were correctly detected. The analysis performed over 1 month showed a very good repeatability of spot characteristics. The time taken to perform the daily quality assurance is 20 minutes, a half of the execution time of the former multidevice procedure. This “in-house build” phantom substitutes 2 very expensive detectors (a multilayer ionization chamber [MLIC] and a strip chamber, reducing by 5 times the cost of the equipment. We designed, built, and validated a phantom that allows for accurate, sensitive, fast, and inexpensive daily QA procedures in proton therapy with PBS.

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Introduction

Daily quality assurance (QA) procedures are necessary to establish a safe and accurate dose delivery by the proton

therapy system before patient treatment.¹ Several methods are reported in the literature (e.g.,^{2,3} and⁴) to perform these QA measurements. The daily QA shown in the first work uses 2 independent beam monitoring and computer systems, and it is calibrated using Faraday cup and Hall probes for the beam positioning monitoring. This solution gives very good results but needs a lot of effort to implement the procedure; different detectors for calibration are not always present in a proton therapy center focused on clinical activities and, mostly, it is not based on any commercially

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available detectors. The solution proposed in the other 2 studies is based on a detector developed for photons and electrons. A proton therapy center has detectors dedicated to proton therapy. The MatriXX-PT is designed for proton therapy and is typically available also for other purposes (e.g., patient-specific QA) in a proton therapy department.

The challenge of daily QA procedure in a pencil beam scanning (PBS) proton therapy system with multiple gantry rooms is to develop sensible, specific, and cost-effective QA that allows the acquisition and analysis of several data in a short period of time.

In PBS, the current of the scanning magnets is set to deliver the beam at a given position, the beam is switched on, the dose delivered and monitored by a system of 2 integral monitor chambers and, once the dose per spot is delivered, the beam is switched off and the sequence is repeated for the next spot. This means that the spot does not move during the delivery. The characteristics of the beam to check on a daily basis are spot position, spot size, range, and dose.

The simultaneous measurement of those characteristics is complex to achieve. The first type of QA phantom developed in our center allows to measure all relevant dosimetric parameters, but it requires a somewhat long time (40 to 45 minutes) and it needs 3 commercial devices of relatively high cost.⁵ The start of clinical operation of the second gantry room for clinical use in our facility and the need of a backup system led us to develop a much cheaper, simpler, and faster system to perform all desired measurements related to dose and PBS characteristics. In this paper, we present the procedure and instrumentation developed in our center to perform the daily QA in a multiple room facility with a system using a homemade phantom and a single commercial device.

The tests performed on the phantom let us define the action levels and the procedure to follow every time the phantom provides out of tolerance results. These levels will be presented in the Discussion section.

Methods and Materials

Beam's characteristics

Our proton therapy center is a cyclotron-based facility (IBA, Louvain La Neuve, Belgium) and the available delivery technique is PBS. Energies vary continuously between 70 MeV and 226 MeV (4.1 cm and 32.0 cm in terms of range in water). The maximum field size is 40×30 cm. Spot size, measured as 1 sigma (1σ) of the spot profile's Gaussian fit, at the isocenter in air, varies between about 7.0 mm at 70 MeV and 2.5 mm at 226 MeV. A detailed description of our center is given in Schwarz *et al.* 2016.⁶

MatriXX-PT

The MatriXX-PT (IBA Dosimetry, Schwarzenbruck, Germany) is an array of 1020 vented ionization chambers, arranged in 32×32 grid, with a resolution of 7.619 mm from center to center.⁷ It can provide 2D absolute dose distribution in water-equivalent material when it is used with plastic phantom slabs (such as RW3, Gammex). This detector is cross-calibrated every month with a measurement performed with a farmer-type ionization chamber according to the IAEA TRS398 protocol.⁸

The measurements are controlled by the dedicated software produced by IBA Dosimetry, that is, OmniPro-IMRT. It is possible to acquire measurements both in single "snap mode" and in "movie mode" to perform dynamic measurements.

This type of device is commonly used in proton therapy facilities, mainly to perform patient-specific QA and daily QA.

Spot Positioning, Range Energy, and Absolute Dose (SPREAD) phantom

The SPREAD phantom is a dedicated device that we designed and built using polymethylmethacrylate (PMMA) slabs (Fig. 1A). The phantom weighs about 5 kg and has a volume

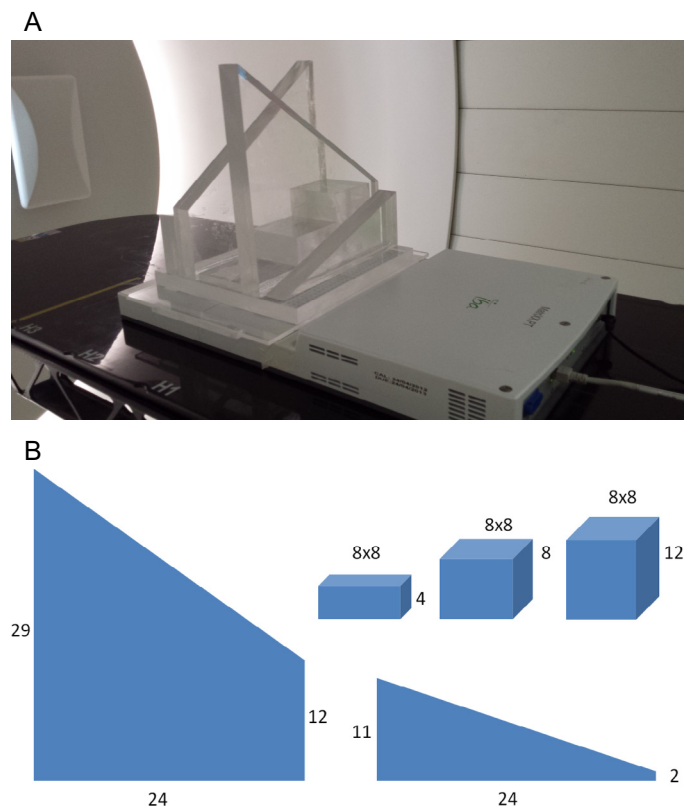


Fig. 1. (A) Photo of the SPREAD phantom on MatriXX-PT. (B) Dimensions of each part of the phantom expressed in centimeters. (Color version of figure is available online.)

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