Investigating aperture-based approximations to model a dynamic collimation system for pencil beam scanning proton therapy

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Purpose

The Dynamic Collimation System (DCS) is a collimation system capable of providing energy layer-specific collimation for pencil beam scanning proton therapy through the use of trimmers that independently and rapidly move to intercept scanning proton beams [1]. The aim of this work is to investigate the accuracy and limitations of current proton therapy analytical dose calculations used in FDA-approved treatment planning systems to represent treatment plans collimated by the DCS, where collimators are treated as an infinitesimally thin beam-limiting aperture [2,3].

Background

Main components of the DCS include two pairs of nickel trimmers located on separate planes (upper and lower) that rapidly and independently move and rotate to intercept the scanning proton beam while also matching the beam divergence [4]. The trimmers are mounted below a polyethylene range shifter of 4 cm water equivalent thickness.

The Astroid® (.decimal, Sanford, FL) treatment planning system currently approximates the DCS as an infinitesimally thin beam-limiting aperture placed halfway between the two pairs of trimmers. While this approximation has been validated in the absence of a range shifter [5], this work investigates potential aperture-based approximations for modeling range shifted, DCS-collimated dose distributions.

Methods

A TOPAS Monte Carlo model of the IBA dedicated nozzle at the Miami Cancer Institute (MCI) was benchmarked through commissioning measurements taken at MCI. The DCS trimmers were incorporated as a TOPAS extension that rotate and linearly translate as a function of beam position. The aperture approximation was reproduced using large production range cuts on secondaries and by setting the material's density high enough to block all primaries.

This model was then used to simulate DCS- and aperture-collimated three-dimensional dose distributions for comparison, using the following collimation geometries:

1. A full simulation of the DCS (gold standard)
2. A single aperture placed halfway between the two trimmer planes,
3. Two apertures located at planes centered on the upper and lower trimmers, and
4. Four apertures, located at both the upstream and downstream faces of each pair of trimmers.

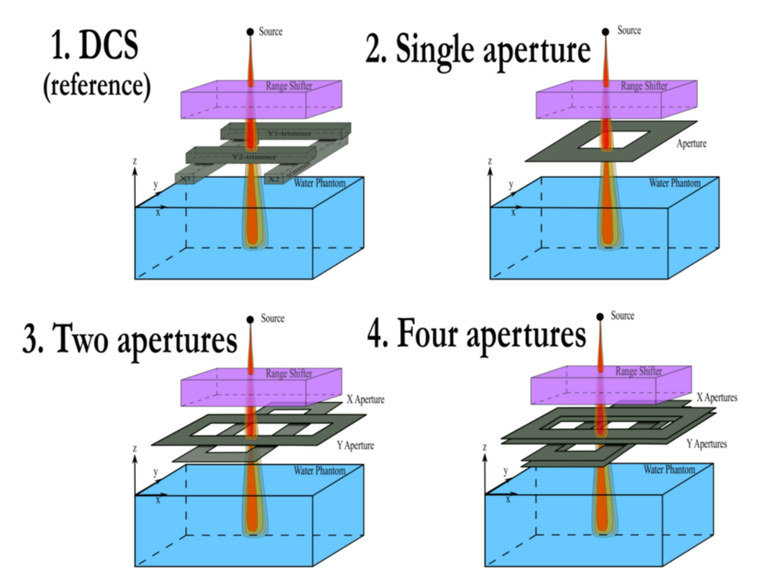

Fig. 1: Illustration of the DCS and aperture-based approximations investigated.

Results

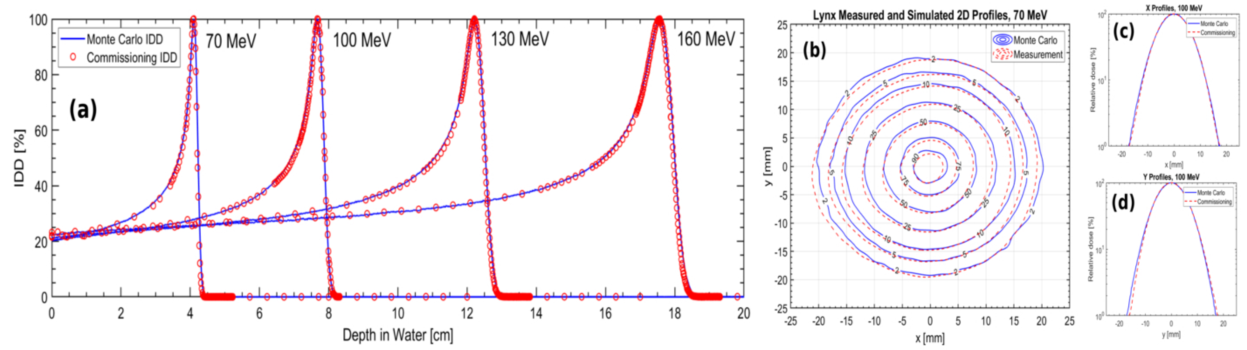

Fig. 2: Comparison of measured and Monte Carlo simulated (a) Integral depth dose curves (IDDs), (b) 70 MeV Lynx 2D profiles, (c) 100 MeV lateral intensity X profiles at isocenter, (d) 100 MeV lateral intensity Y profiles at isocenter.

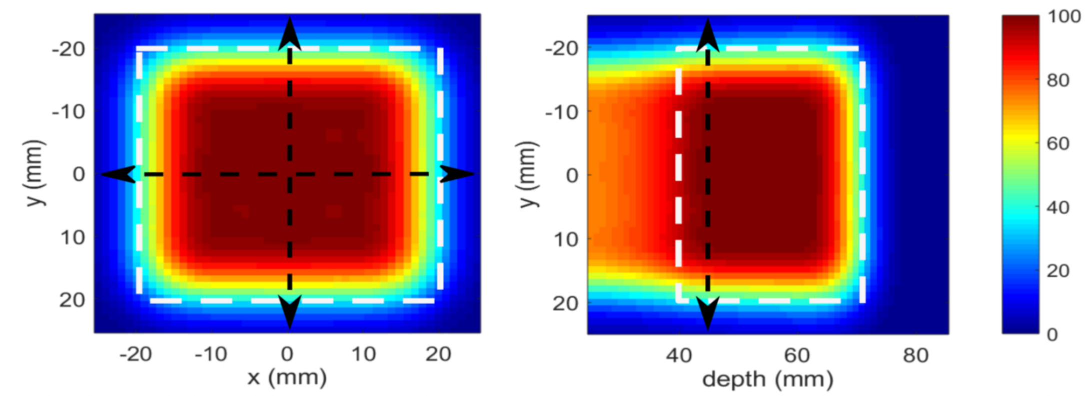

Fig. 3: Axial and coronal slices of DCS-collimated spot-weight optimized cube dose distribution. Black lines indicate line profiles in Figure 4. White lines indicate a 5 mm target expansion where the average dose difference was assessed in Table 2.

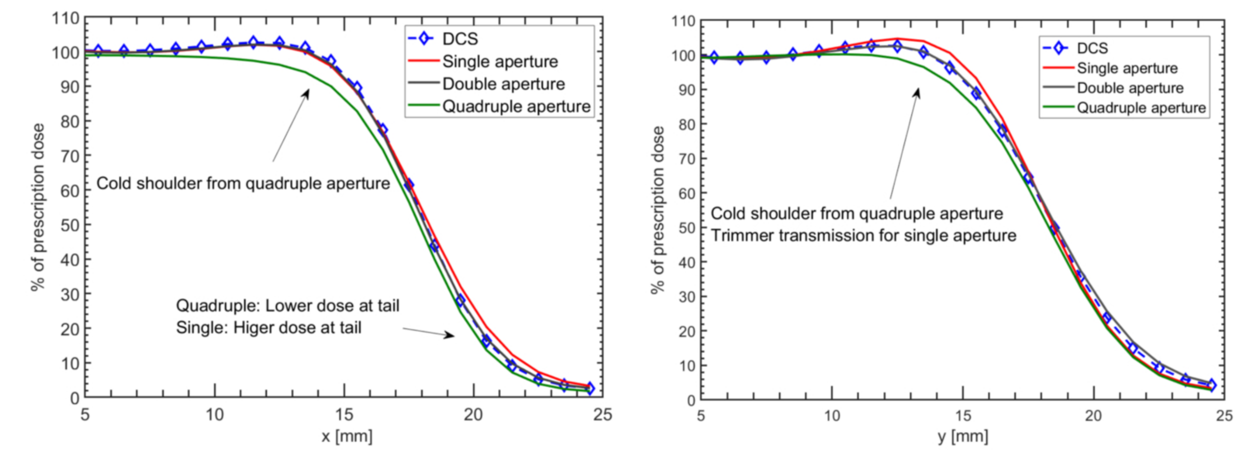

Fig. 4: X (left) and Y (right) one-dimensional lateral profiles through the center of the proximal surface of the cube distribution (45 mm depth).

Table 1: Averaged commissioning metrics for TOPAS model of MCI beamline for 70 - 160 MeV.

IDD gamma pass rates (1%/1mm, 0.5%/0.5mm)	Depth of Bragg peak (% error)	Depth of distal 80% (% error)
99.39%, 91.22%	0.187%	0.139%

Table 2: The root-mean-square error (DCS - Aperture(s)) within the three-dimensional region indicated by the white lines in Fig. 3 (Target + 5mm expansion).

DCS vs. Single Aperture	DCS vs. Two Apertures	DCS vs. Four Apertures
2.11%	1.32%	2.39%

Conclusions

- A TOPAS Monte Carlo model of the IBA dedicated nozzle at MCI was commissioned for 70 - 160 MeV.
- 3D treatment plans representing a cube target volume were simulated and spot weights were optimized for DCS-collimated dose distributions and applied to aperture-collimated dose distributions for comparison.
- The double aperture approximation most accurately represented the DCS-collimated dose distribution in the presence of a range shifter.

Ongoing and Future Work

- The beam model is being further refined to more accurately model the beam's divergence at the trimmer planes.
- We hypothesize that discrepancies will increase due to a larger spot size at the trimmer planes.

References

1. Hyer et al., Medical Physics, 41(9), 2014
2. Hong et al., Phys Med Biol, 41(8), 1996
3. Soukup et al., Phys Med Biol, 50(21), 2005
4. Geoghegan et al., Medical Physics (in press), 2020
5. Nelson et al., PTCOG 59 Meeting, 2020

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