Breast cancer radiosurgery with a synchrotron radiation beam

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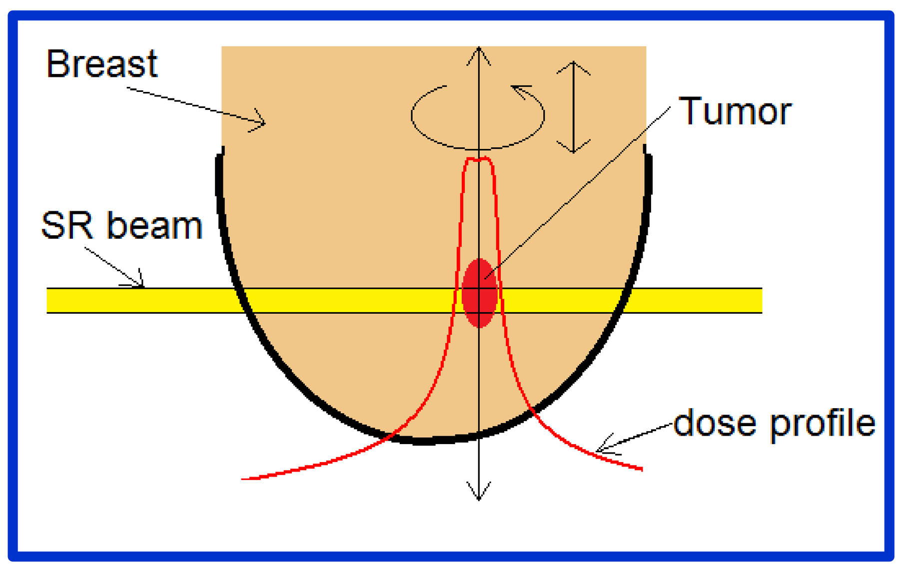
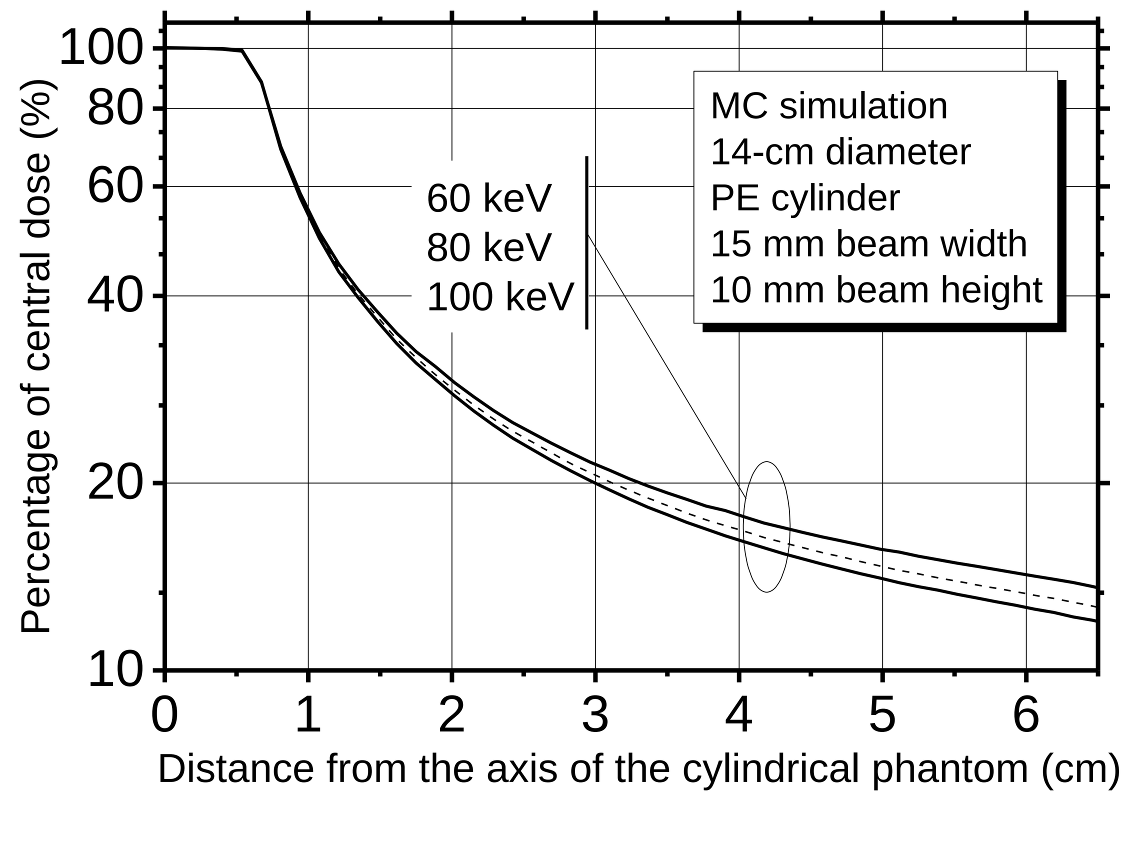
Background – In 2012, the team of Prof. Boone at Univ. California Davis proposed and demonstrated the feasibility of a X-ray tube operating at 320 kVp to deliver a kilovoltage external-beam rotational radiotherapy (kV-EBRT) for the breast cancer [1]. The orthovoltage X-ray tube is integrated in a dedicated breast computed tomography (bCT) platform and so CT imaging for tumor localization can also be performed with the same setup. Moreover the X-ray tube can rotate around the breast, so thanks to rotational summation of dose delivery of a collimated kV beam, dose sparing to the skin comes out to be comparable to conventional radiotherapy. The kV-EBRT was proposed as an alternative to the conventional radiotherapy on 6 MV tangential X-ray beams and shows the highest interest for small tumor of the size of few cm^3, and therefore in partial breast irradiation (PBI). We proposed to use a monochromatic synchrotron radiation (SR) X-ray beam and a dedicated setup for a new rotational radiotherapy technique for hanging breast (SR³T project, INFN, Italy) [2]. The irradiation geometry is the same of kV-EBRT, but now the source is a SR beam of equivalent or lower effective photon energy than for 320 kVp and the source position in fixed, while The patient is placed in prone position on a rotating and translating bed with a hole for the hanging breast.



Purpose - The aim of this work was to show, via Monte Carlo (MC) simulations and experimental data, the potential of **Synchrotron Radiation Rotational Radiotherapy** for application in breast radiosurgery with the patient in prone position, and compare its performance with respect to a 6 MV photon beam in the same irradiation geometry.

Materials and methods – We simulated the irradiation condition of the breast rotational radiosurgery using a MC code based on GEANT4 toolkit (version 10.00) [3, 4]. The hanging breast was modeled as a polyethylene cylinder (14-cm diameter and a 9-cm height). A monoenergetic laminar SR beam of size 1.5 cm × 1.0 cm (W × H) with energy of 60, 80 and 100 keV irradiated the phantom during a complete rotation with the center of rotation along the tumor mass. The simulations show dose distributions peaked in the center of rotation as expected from the principle of summation of the dose.
We also acquired a 2D dose map with an homogeneous PMMA (14-cm diameter) cylindrical phantom. Measurements were performed at Imaging and Medical Beamline (IMBL) of Australian Synchrotron (AS), Melbourne, Australia [5]. At 100 keV the SR beam of size 1.5 cm × 2.0 cm (W × H) irradiated a target volume in the center of the phantom during a complete rotation with a target air kerma of about 7 Gy. The 2D dose distribution in the midplane of the phantom was recorded with radiochromic film and isodose curves were evaluated.
To compare dose distribution between kilovoltage and megavoltage photon beams, this measurement was repeated at San Raffaele Hospital in Milan, Italy, using a Varian Clinac iX System Linac in RapidArc modality and delivering a photon beam of 6 MV [6]. The phantom and the irradiation geometry was the same of AS, with the difference than the irradiated target volume was of size 1.5 cm × 2.0 cm (W × H) and the target dose was of 6 Gy. Radiochromic film EBT3 recorded the 2D dose map and isodose curves were evaluated as before.

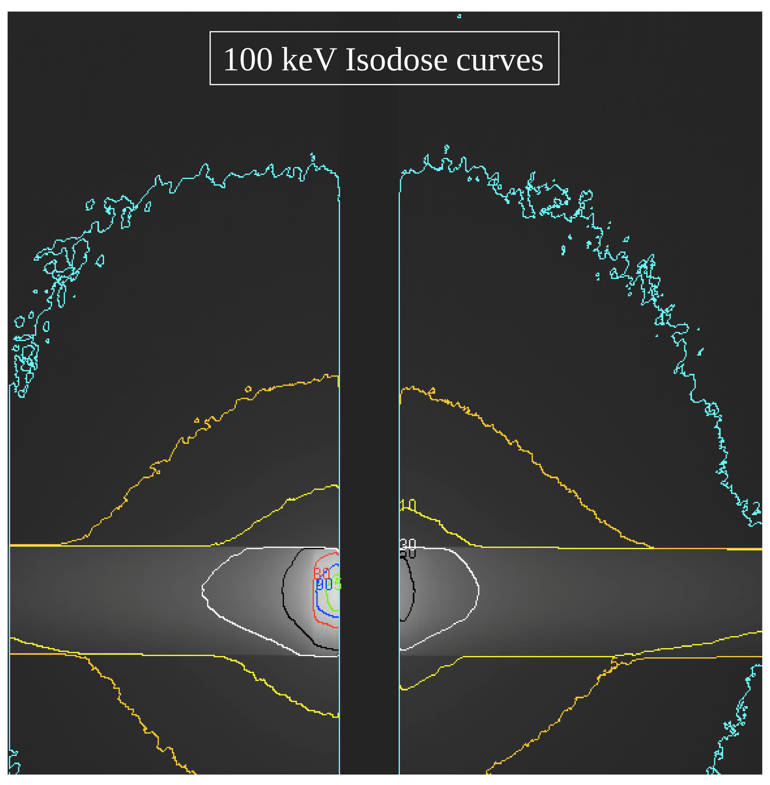
Simulated Radial Dose Profile



MC simulation of a polyethylene cylindrical phantom irradiated with a 1.5 cm collimated beam at 60, 80, and 100 keV

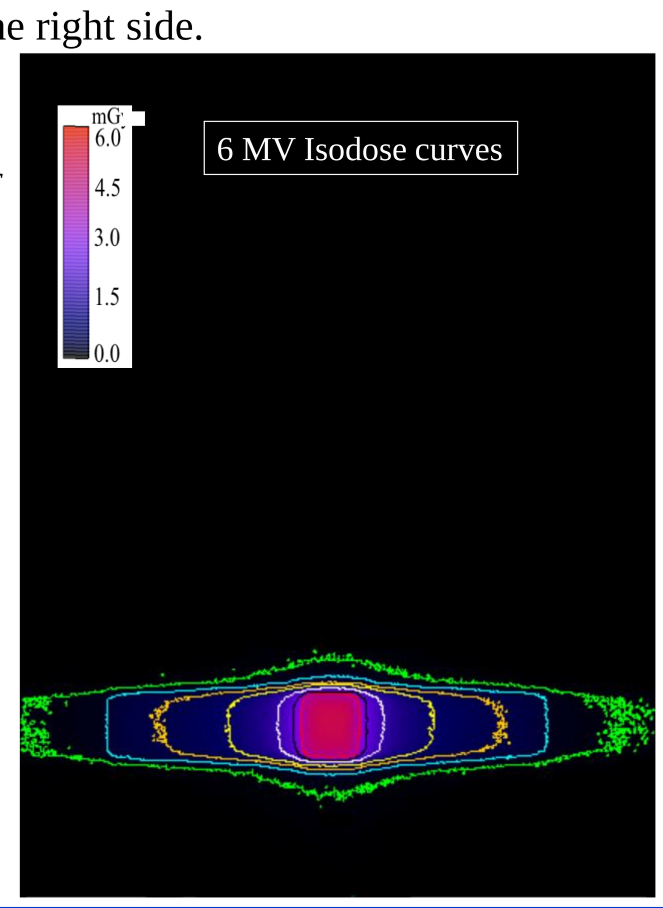
Measurements, 100-keV vs. 6 MV X-ray beam, PMMA phantom

Isodose curves at the mid-plane of the 14-cm diameter PMMA phantom recorded with calibrated EBT3 radiochrohttp://www.infn.it/thesis/thesis_dettaglio.php?tid=12210mic films. The pixel value were normalized to the maximum. The isodose legends in percent of the maximum dose are indicated on the subpanel on the right side.



Level value for each contour in the range of 2% to 95% of the target dose

Level 1	95	green
Level 2	90	blue
Level 3	80	red
Level 4	50	black
Level 5	30	white
Level 6	10	yellow
Level 7	5	orange
Level 8	2	cyan



Level value for each contour in the range of 0.1 Gy to 6.5 Gy

Level 1	6	green
Level 2	5	blue
Level 3	4	red
Level 4	3	black
Level 5	2	white
Level 6	1	yellow
Level 7	0.6	orange
Level 8	0.3	cyan
Level 9	0.1	green

Results – A collimated SR beam irradiating a simulated hanging breast (patient in prone position) in a circular orbit around a vertical axis through the tumour produces a dose distribution peaked at the axis of rotation. MC simulations on phantoms show the feasibility to perform partial-breast irradiation obtaining a surface dose from 11.9% of the target dose at 100 keV to 13.4% at 60 keV for tumour sited on the phantom axis. Measurements at 100 keV show a dose profile with a flat part in the center of about 1.5 cm width, equal to the horizontal size of the irradiating beam and the skin-sparing ratio (dose to the skin divided by the dose to the target) is about 10%. Measurements at 6 MV also show a peak width of 1.5 cm and the dose to the skin is 4% respect to the target dose thanks to the build-up effect. So at 6 MV with VMAT in the SR³T geometry (hanging breast) the dose is more conformed to the target compared to 100 keV with SR in the same geometry. We foresee the use of dose-enhancement agents (e.g. gold nanoparticles) in order to improve the dose to the target volume with proper sparing of healthy tissues.

References

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