Image guided small-animal scanned proton and x-ray reference irradiation

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Objective

Establishment of a small animal irradiation workflow for x-ray and scanned proton beams. Workflow includes pre-irradiation imaging (µCT) for individualized treatment planning, as well as post irradiation imaging (µMRI) for data evaluation.
Functional changes due to beam quality variations and LET dependencies will be visualized by multi-parametric MRI.

Aim:
- Reproducible positioning of animals in all steps of workflow
- Dose rate at isocenter > 1Gy/min for fast dose delivery
- Reduced scatter for highly precise irradiation
- Avoid transmission

Infrastructure & Workflow

Irradiation:
- 200kV x-ray unit (Reference)
- Synchrotron based scanned proton and carbon beam (MedAustron Ion Beam Therapy Center, Wiener Neustadt)
  - Nozzle mounted range shifter (RaShi)
  - Bolus in front of the target

Imaging:
- µCT X-Cube (Molecubes)
- 15.2T UHF MRI (BRUKER)

Treatment planning (RaySearch, Sweden) & dosimetry:
- µRayStation for x-rays (high resolution of 0.1mm)
- Clinical RayStation (8B and 11B) for protons (research version with 0.2mm resolution)
- Micro diamond detector (PTW), Adv. Markus Chamber (PTW), EBT3 films

Positioning

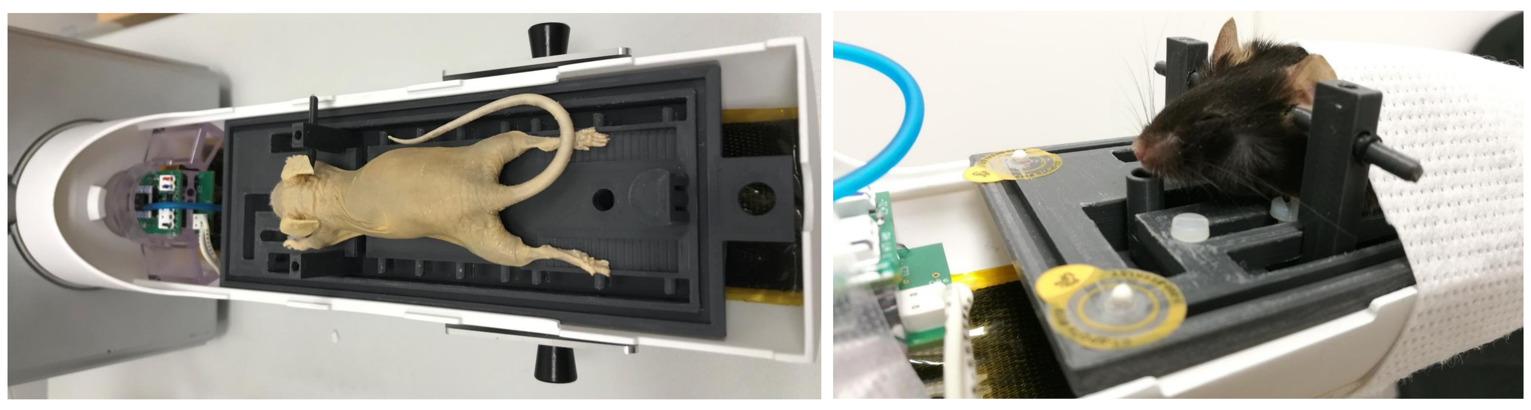


Figure 1: Mouse bed in µCT scanner (left: plastinated phantom, right: dead mouse)

Requirements:
One bed for all workflow steps with possibility to monitor vital signs of the animals (Figure 1 and 2).

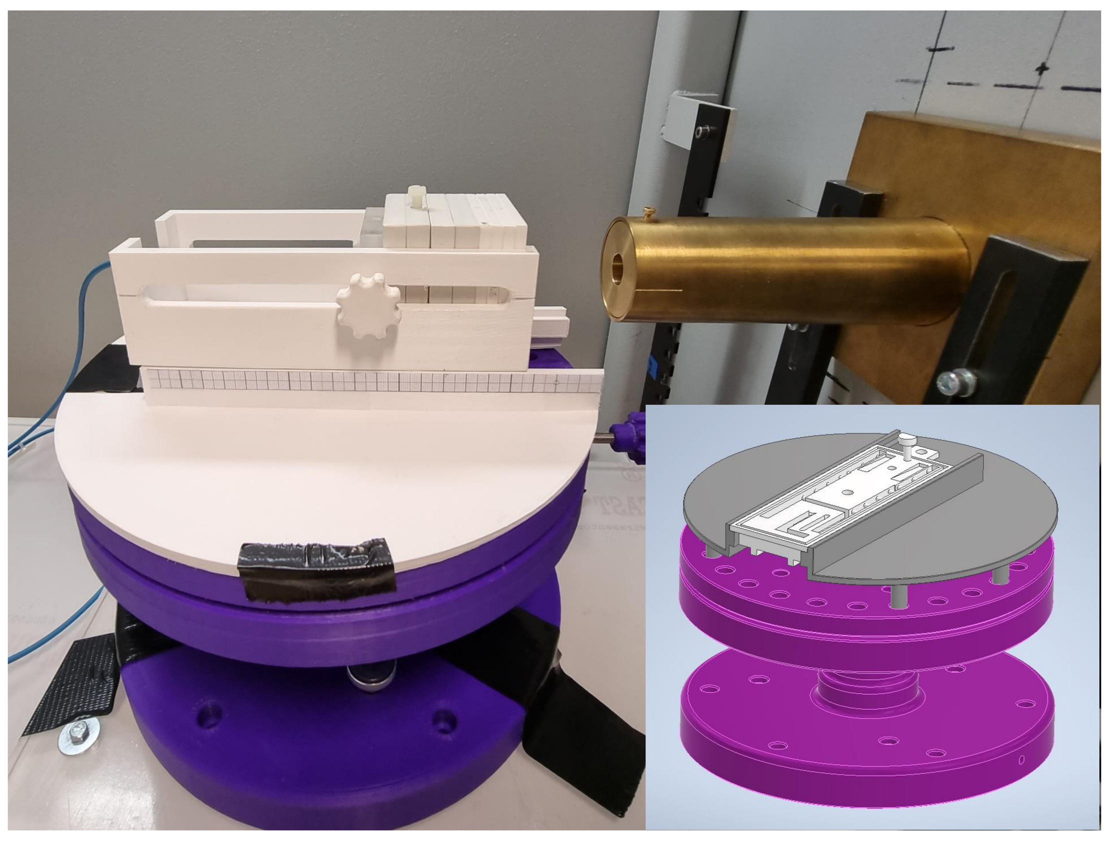
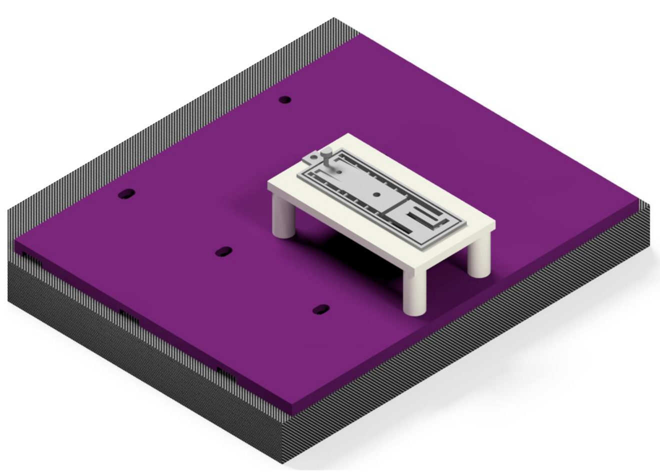


Figure 2: Left: Custom made 3D printed table with translational adjustment (1 mm) and rotation in 15° steps for the x-ray irradiation.
Below: Mouse bed placed on the robotic couch system of the treatment room including a customized holder. Robotic couch systems allows 6 DOF movement for positioning.

Dosimetry

X-ray: (Figure 3)
- Collimation from 12 cm to 1-35 mm diameter
- Using primary and secondary collimator

Protons: (Figure 4)
- Nozzle mounted collimation system
- Primary and secondary collimator



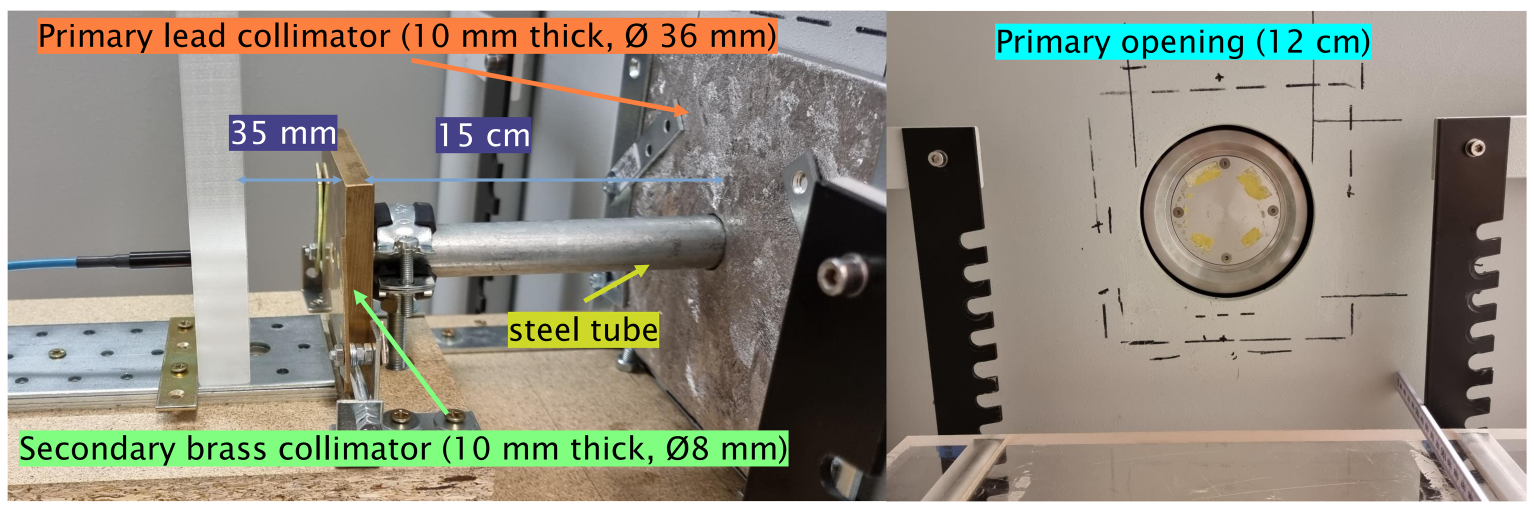


Figure 3: Dosimetry of reference irradiation – a collimated x-ray beam

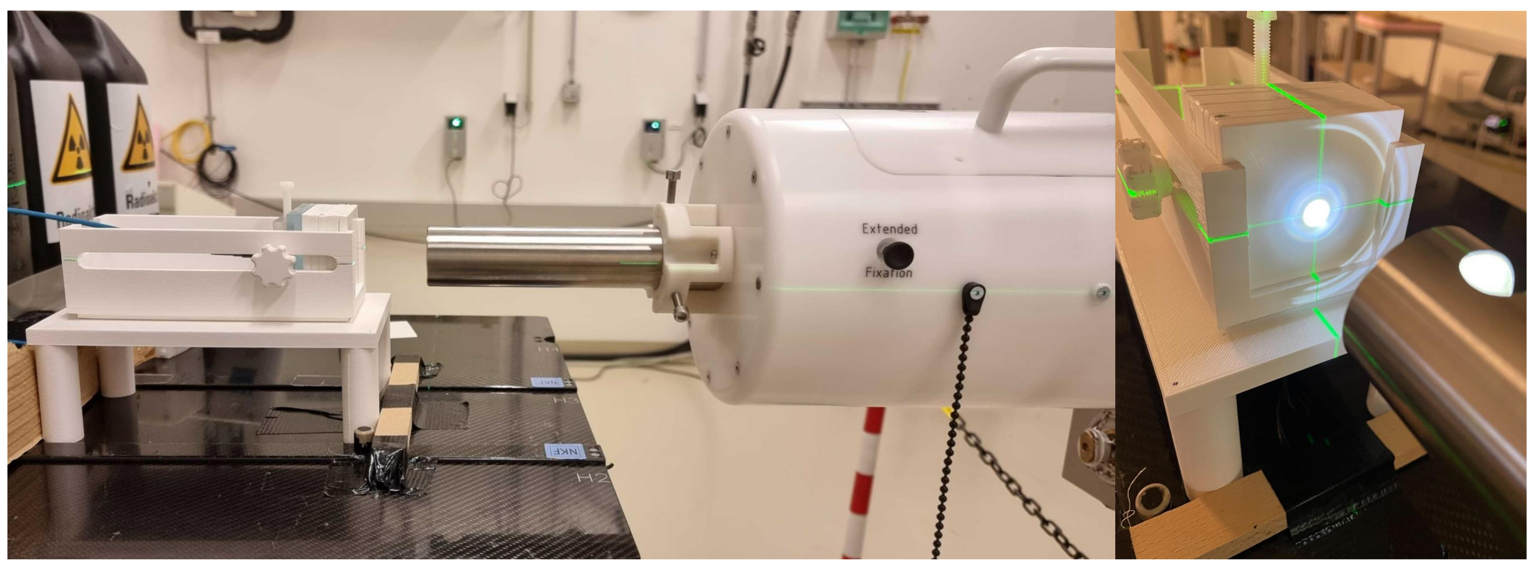


Figure 4: Proton beam dosimetry setup in two different views

Measurements

X-ray:
- Sufficient dose rate to guarantee fast irradiation in a convenient distance from the beam outlet (Figure 5)
- Reliable and highly accurate dose delivery for relevant field sizes

Proton:
- Uniform target dose down to 5 mm beam collimation for nozzle mounted range shifter
- Non-homogenous dose distribution for 12 mm collimator size for bolus range shifter (Figure 6)
- Beam model verified within 3%
- Spread out Bragg peak ranges 3 to 35 mm
- Achievable field sizes: ø 5-34 mm

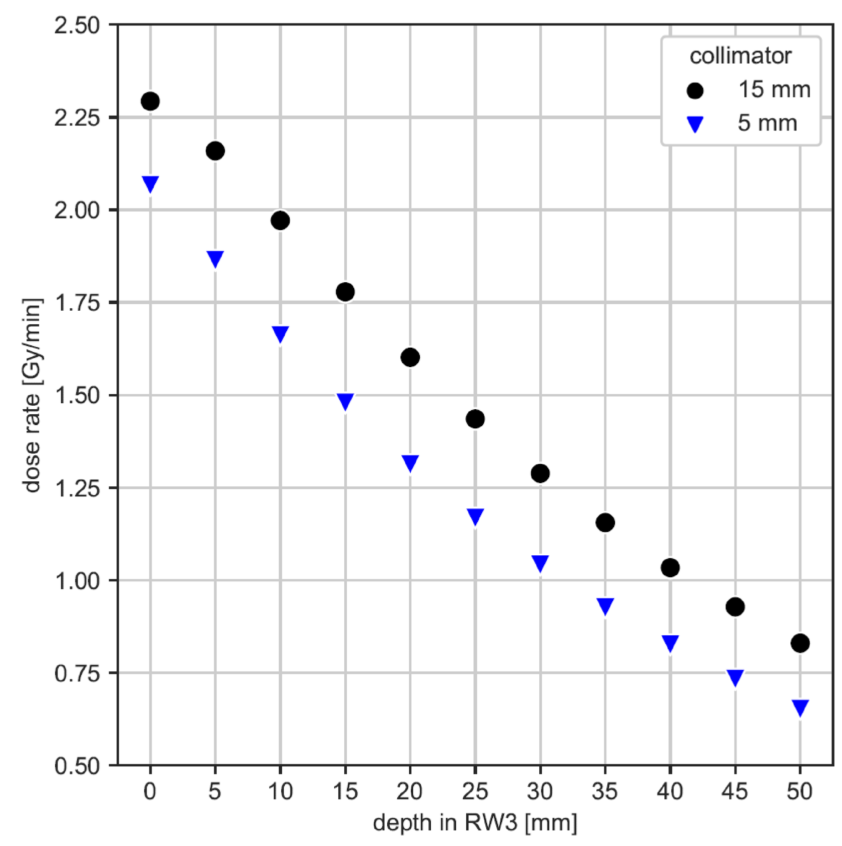


Figure 5: X-ray dose rate measured in RW3 using 5mm and 15mm secondary apertures

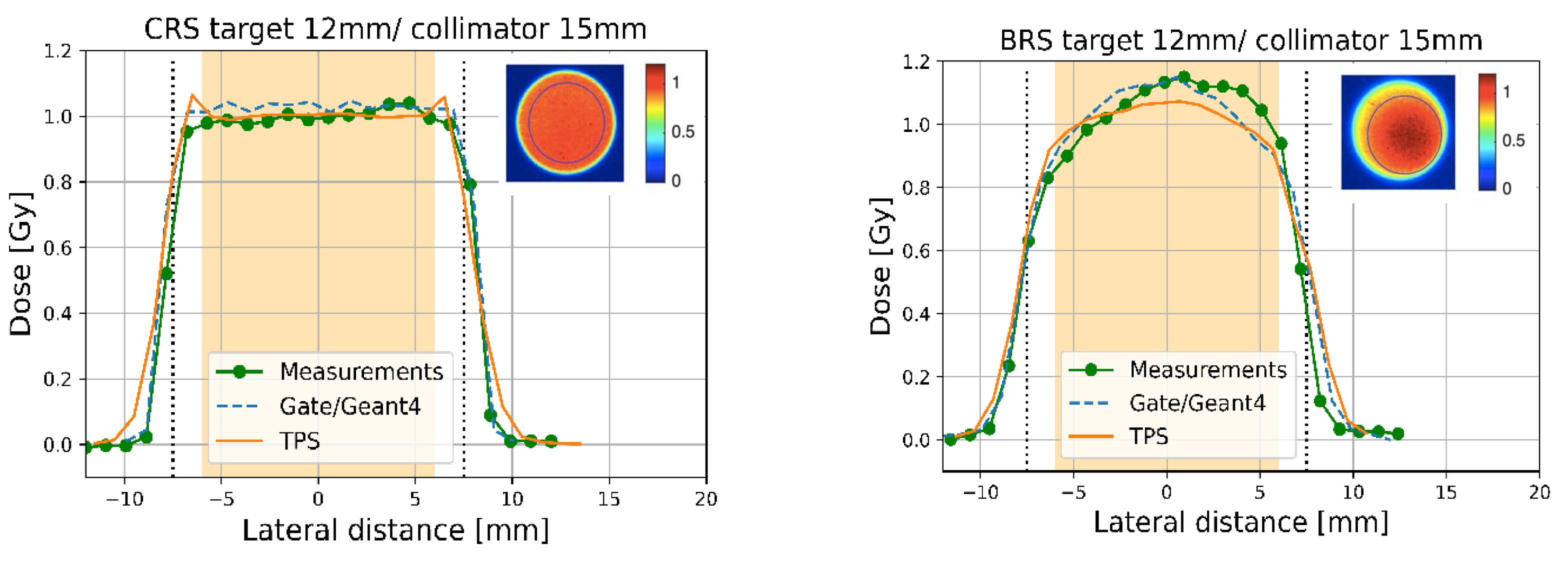


Figure 6: Lateral dose distribution for clinical nozzle mounted range shifter (left) and bolus range shifter (right). Both measurements were performed with a 15 mm beam collimation.

Conclusion & Outlook

Final Setup x-rays:
- Primary brass collimator (20 mm thick, ø 46 mm)
- Secondary collimator (20 mm thick, ø 5-35mm)
- Brass tube of 140 mm between primary and secondary collimator
- Isocenter/Surface at 30-50mm downstream of secondary collimator

Next Steps:
- µCT-based DRR creation and in-room registration workflow
- Isocenter calibration
- Alignment of all components
- Positioning of small animals in MRI scanner