Maastro
in the best of hands

Manufacturing of realistic phantoms to aid in development and implementation of new technologies in radiotherapy

Didier Lustermans & Teun van Wagenberg

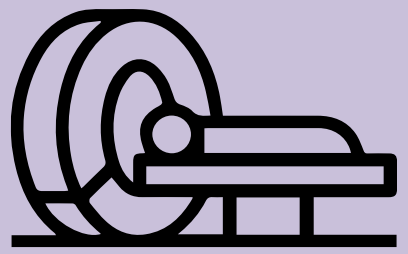
In this talk, you will get to know more about the need and reasons to use phantoms, the process of developing them and how we use it to create and implement new innovations.

Introduction

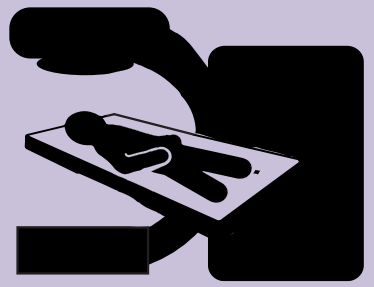
Phantoms in radiotherapy

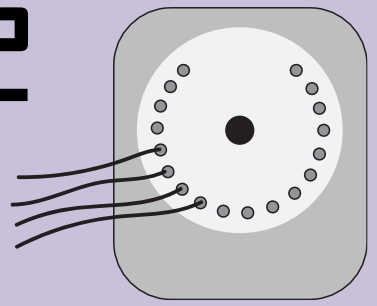
They are a tool for testing and validating radiotherapy equipment,
as these cannot be assessed on patients.

CT

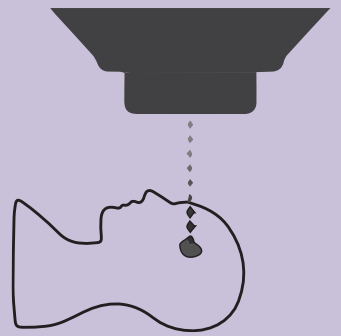


External beam





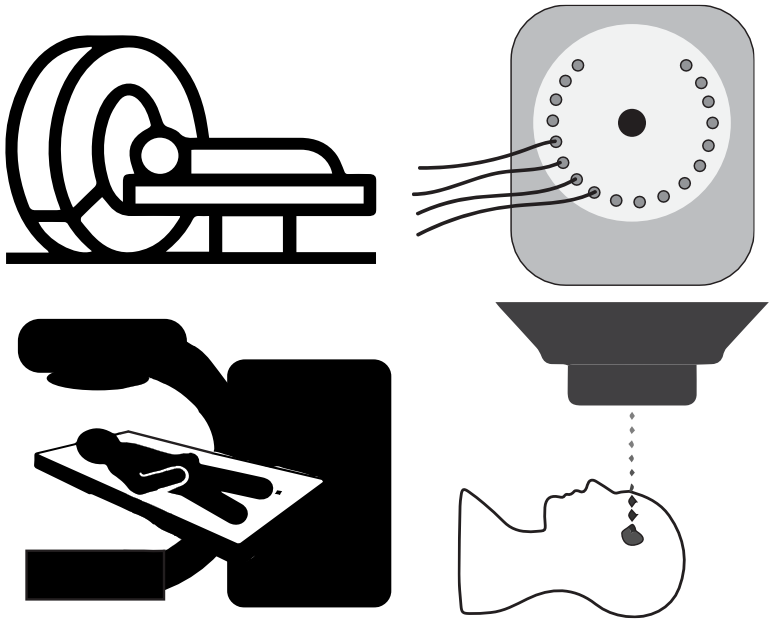
Brachytherapy



Proton Therapy

Introduction

Phantoms in radiotherapy



- Tool for quality assurance
- Tool for commissioning new equipment
- Tool for calibrating your equipment
- Tool for dosimetry verification
- Tool for research and development

Introduction

Tool for research and development

Phantoms for imaging and dosimetry

Limitations commercial phantoms

- Not flexible for every application.
- Mostly lack anatomical complexity.
- Expensive.

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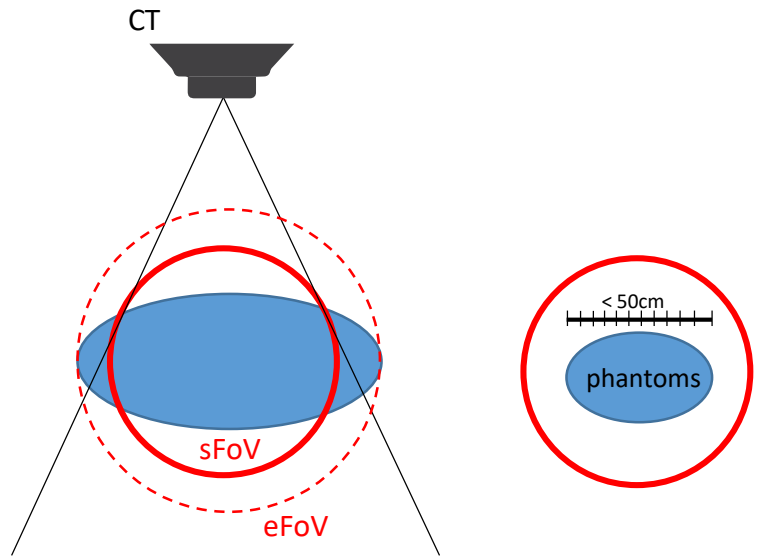
Question 1
For what application do we need the phantom?

Question 2
What is missing in commercial phantoms and needs to be added?

Example



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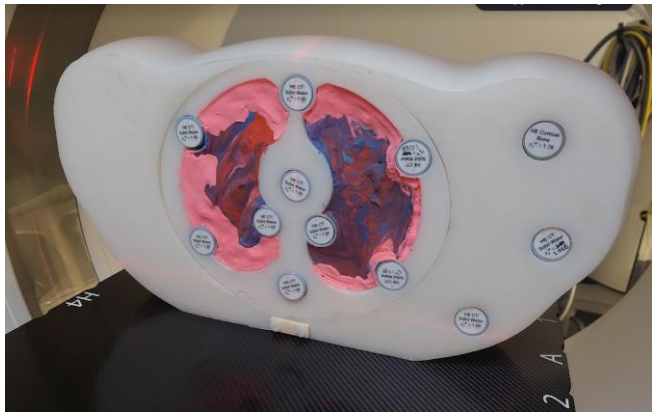
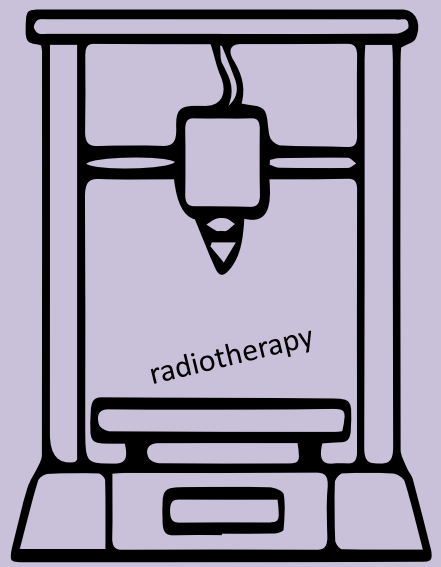


Evaluating eFoV for deep learning and the HyperSight (2 studies)

Introduction

Tool for research and development

Phantoms for imaging and dosimetry



1st publication
"3D printing" + "radiotherapy"

2014

2023 → 83 publications

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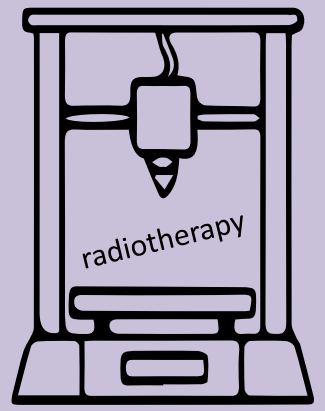
Phantoms for imaging and dosimetry



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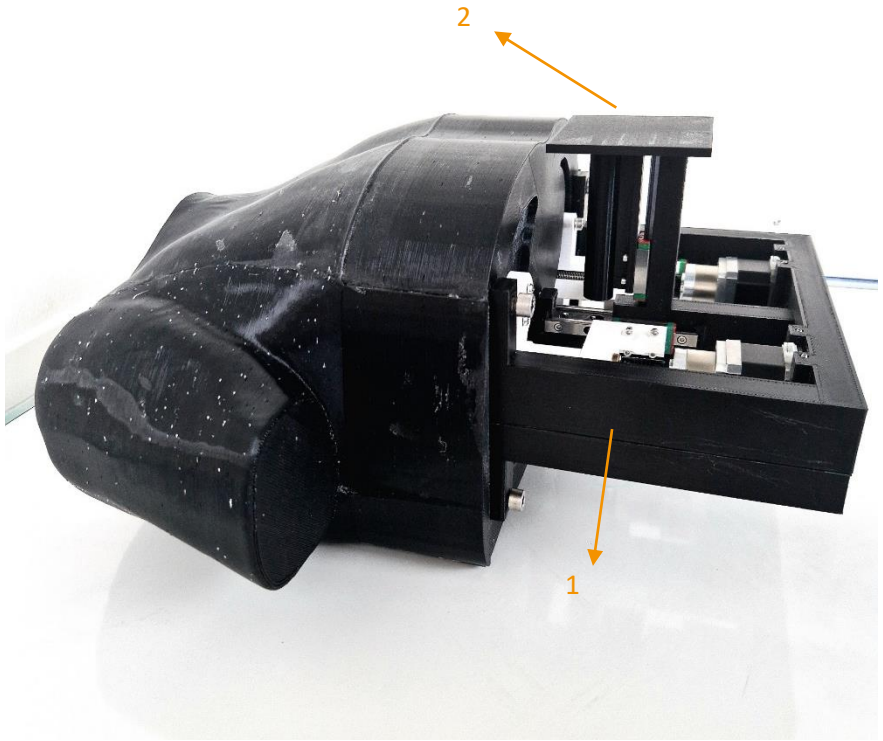
It offers an increased **customization** for multiple applications

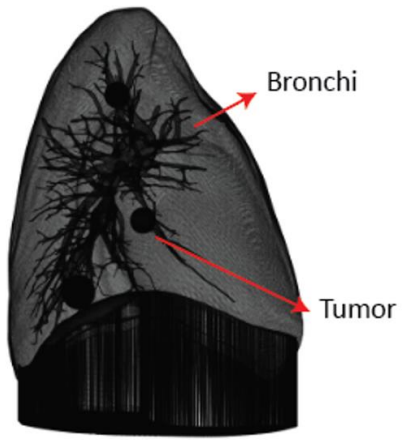
- Improving the realistic structures
- Tissue-equivalence of materials
- Adding dynamic movements

Thorax phantom



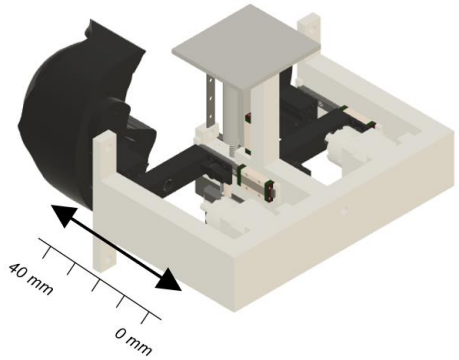
Internal structure

- Tissue-equivalent soft tissue
- Tissue-equivalent bone
- Compressible lungs

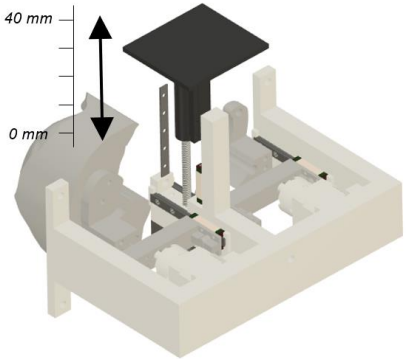


Mechanical device

1. Lung compression system



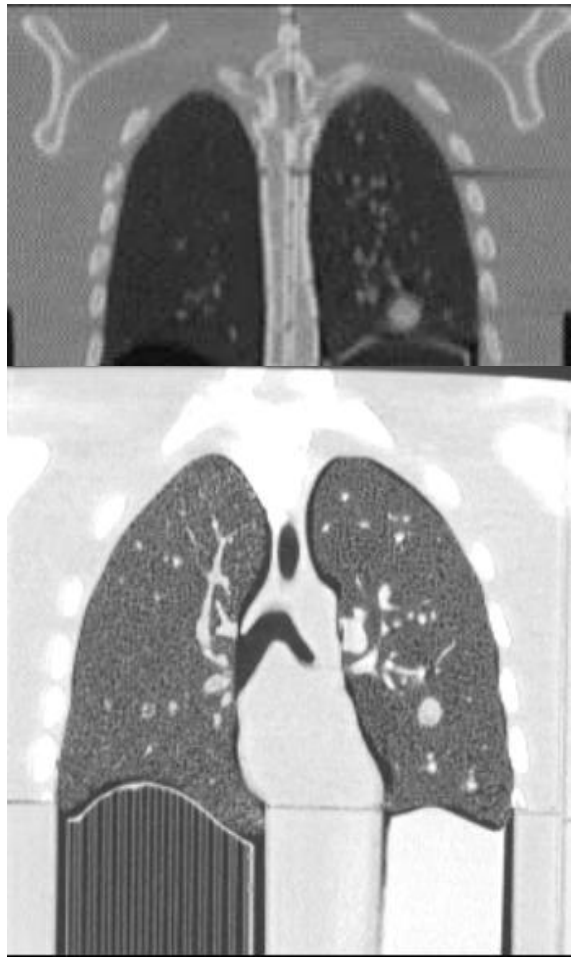
2. Chest Motion System



Application in 4DCT

4DCT

- Simulating tumor and breathing motion.
- Breathing phases are detected by the 4DCT with a tracking system.
- System is capable of simulating irregular breathing.



REALIZE LAB

Research and Engineering for Advanced Learning,
Innovation, and Zero-tolerance Execution

MAASTRO/UM

3D printing

7 commercial printers, 1 in-house made

Creality

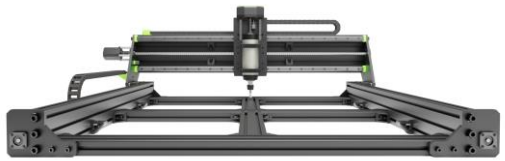
Raise 3D Pro

Bambu

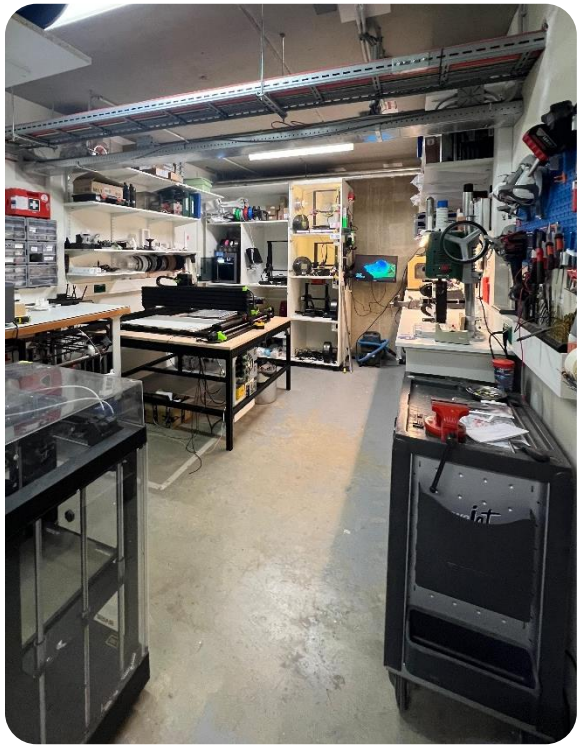
Mosaic

Laser cutting machine

CNC machines



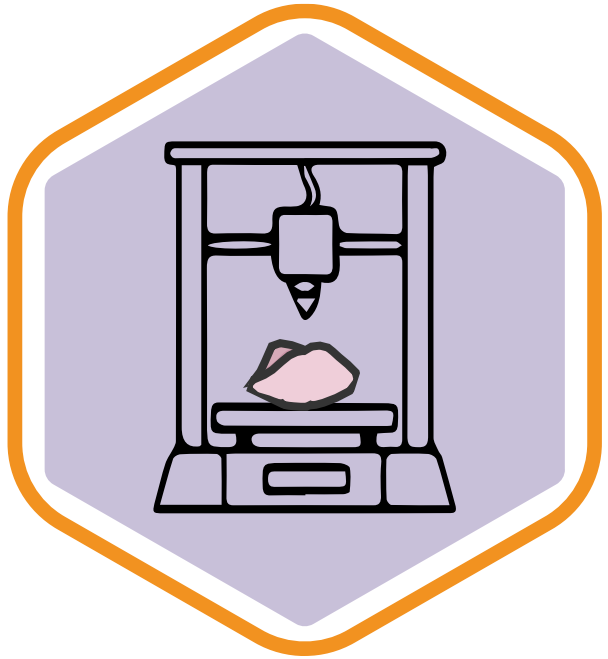
REALIZE LAB



Recently improved with safety and air vents.

Phantom manufacturing

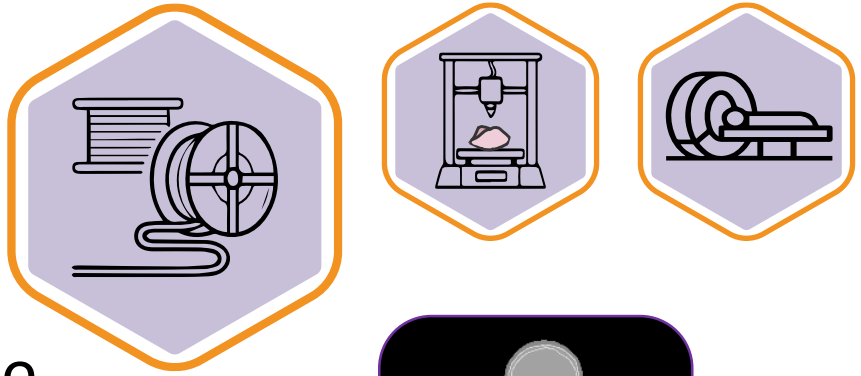
Material selection



3D printing

Imaging

Phantom manufacturing



Quantitative Imaging purpose

↓

Model selection -> human anatomy/XCAT

↓

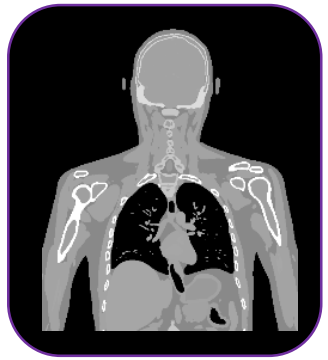
Scan them on a Dual-Energy CT scanner

↓

Assess materials for tissue-equivalence

↓

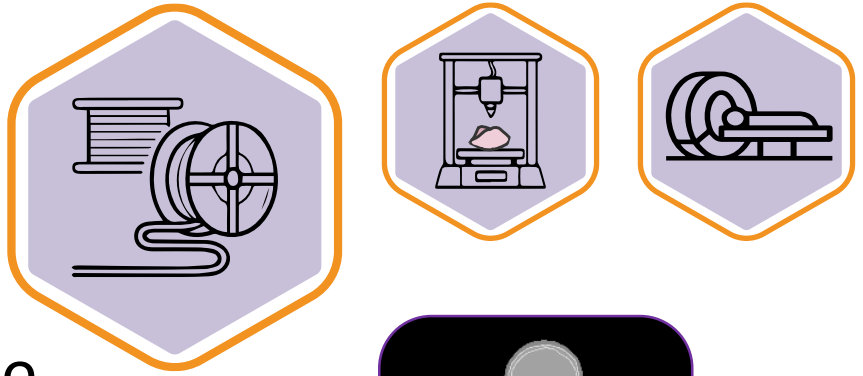
Assess the influence of the 3D printer settings



Physics quantities

CT number, Zeff, RED, SPR

Phantom manufacturing



Quantitative Imaging purpose

Example

- High Z-materials can provide close resemblance in CT number with bone
- However, the Zeff and RED do not match and induce problems with quantitative measurements

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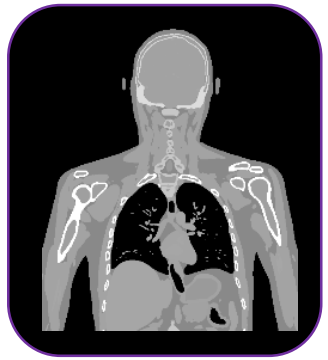
l-Energy CT scanner

r tissue-equivalence



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Assess the influence of the 3D printer settings

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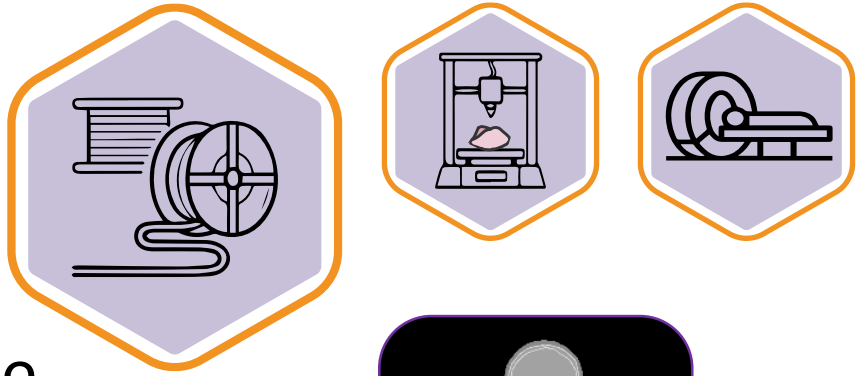

Quantitative Imaging purpose

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→

Custom bone material

A material is made consisting out of PLA and Ca

ysics quantities

umber, Zeff, RED, SPR

Assess the influence of the 3D printer settings

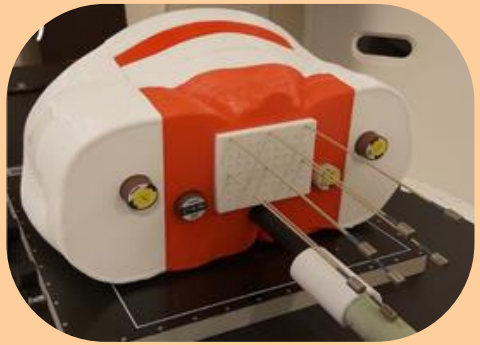
Phantom manufacturing

- Select the appropriate printer.
- Printing deformable materials that are orientation dependent.
- Water-cooling needed for certain pieces.
- Dual-extruder / multi-color print.

Phantoms

Static Phantoms

Single material head phantom

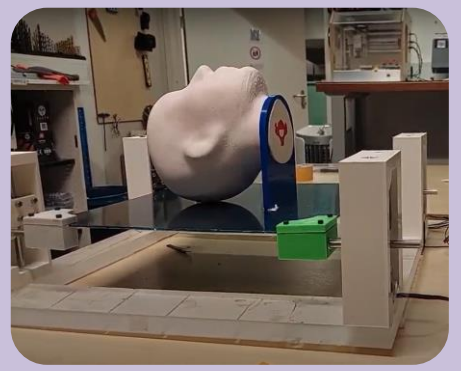


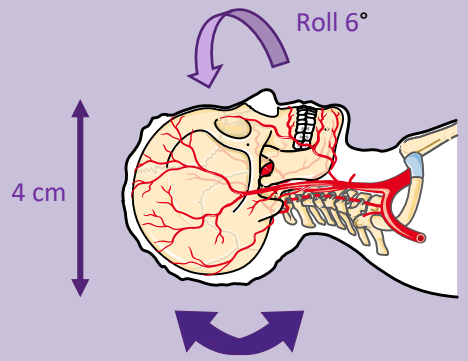
Pelvic phantom

Soft tissue + bone head phantom

Breast phantom

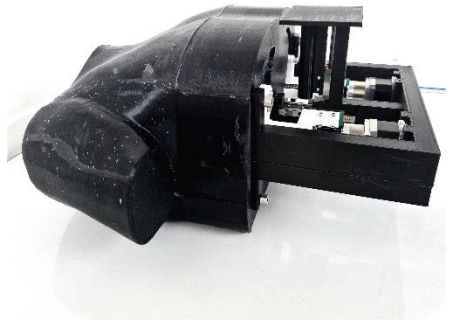
Dynamic Phantoms

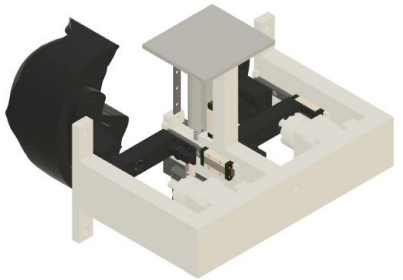




Motion Platform

Designed motion system





Dynamic Thorax phantom

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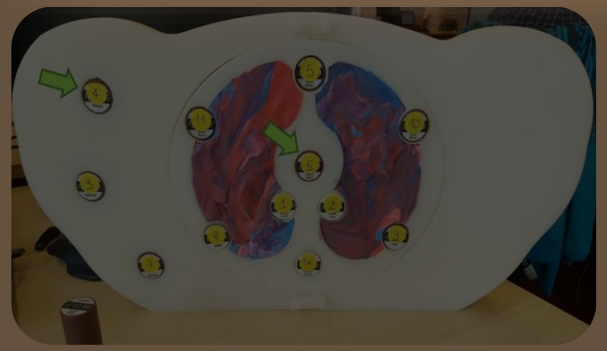
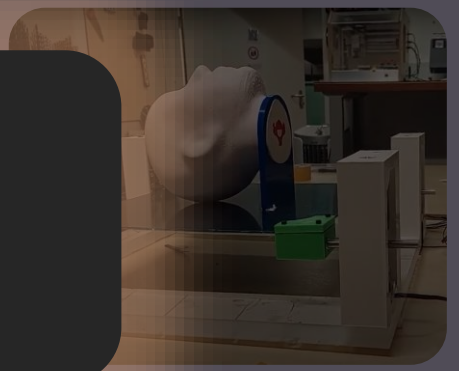


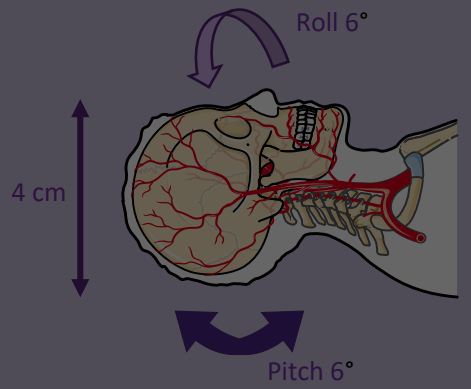
Breast phantom

Head dosimetry in brachytherapy

These phantoms are used for developing treatment verification methods

Dynamic Phantoms





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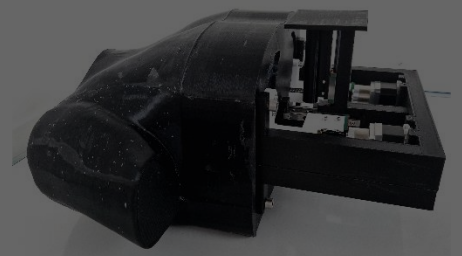

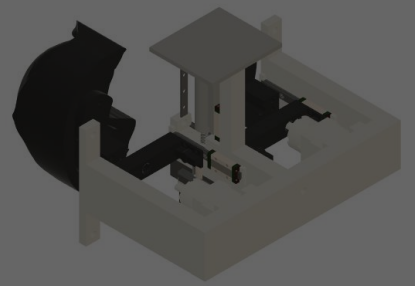

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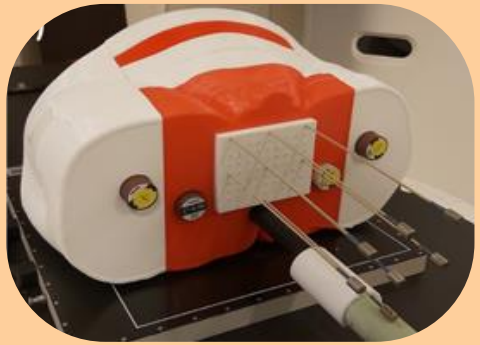
Phantoms

Static Phantoms

Single material head phantom



Pelvic phantom

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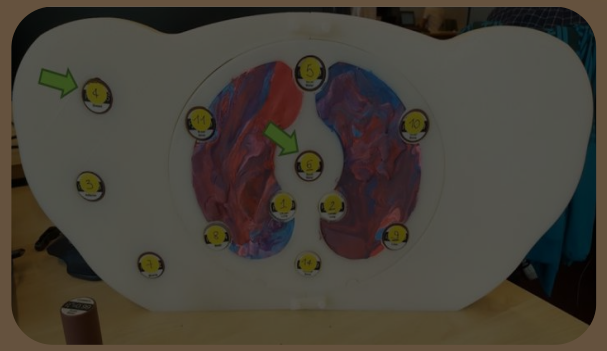
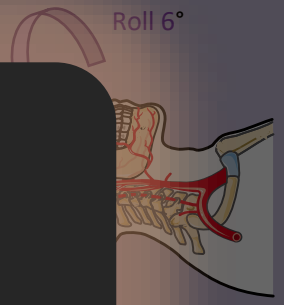


Breast phantom

Dynamic Phantoms

Pelvic dosimetry in brachytherapy

This phantom is used for developing treatment verifications



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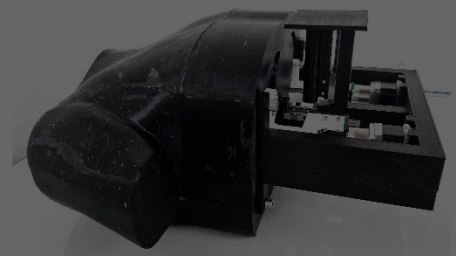

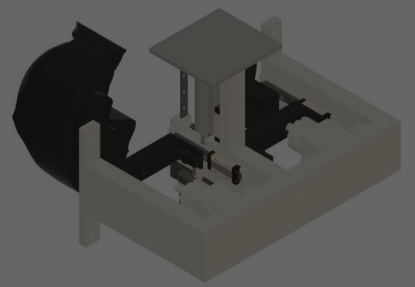

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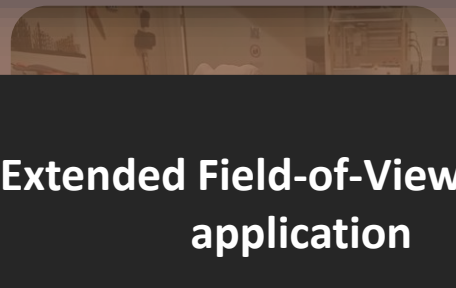
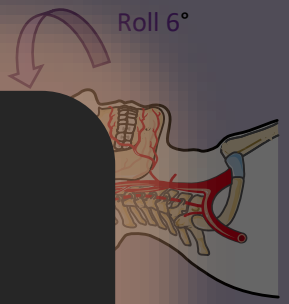
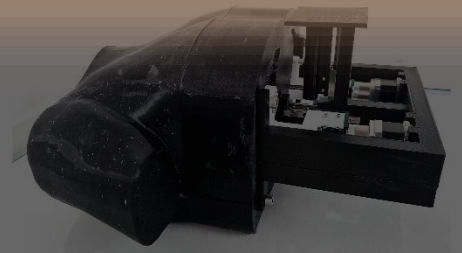


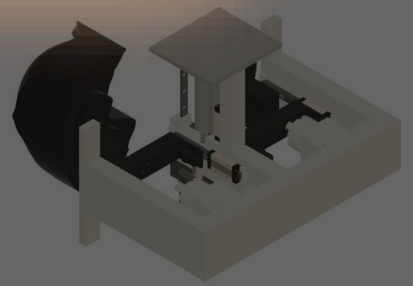


Extended Field-of-View (eFoV) application

Large phantom that is bigger than the standard FoV (sFoV) and used for verifying new algorithms

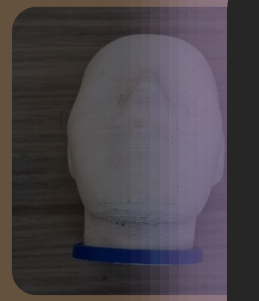
Designed motion system





Dynamic Thorax phantom

Phantoms



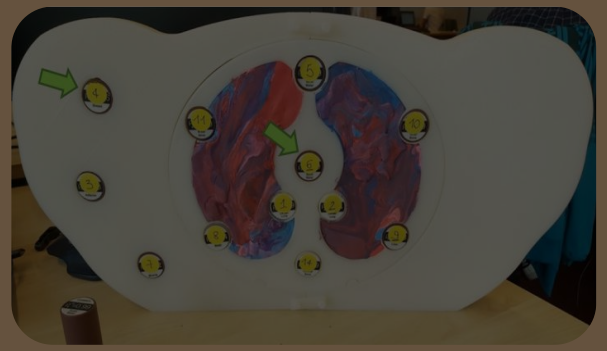
Single material head p

Introducing motion to the verification methods

The motion platform has been used in combination of static phantom to add motion to the development of verification methods

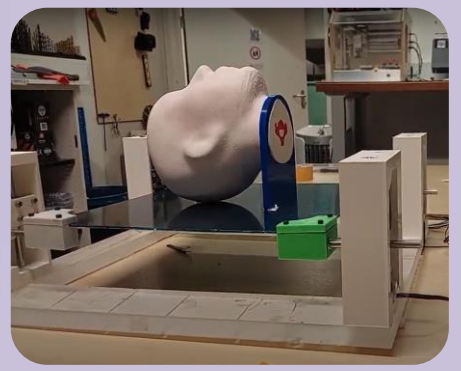
Pelvic phantom

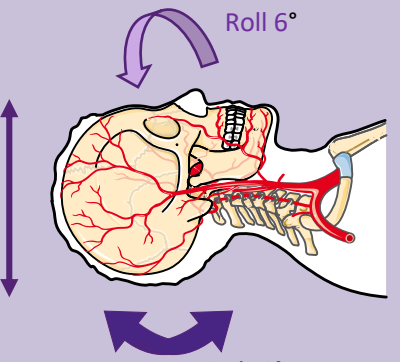
Soft tissue + bone head phantom



Breast phantom

Dynamic Phantoms





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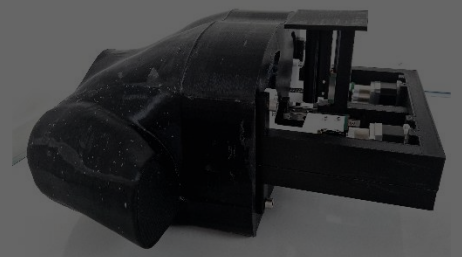

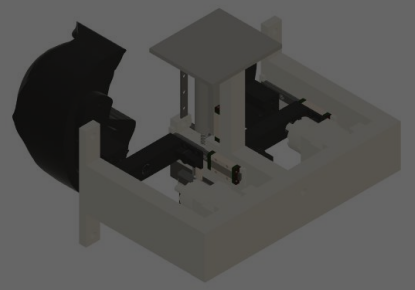

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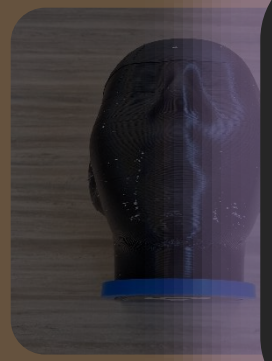


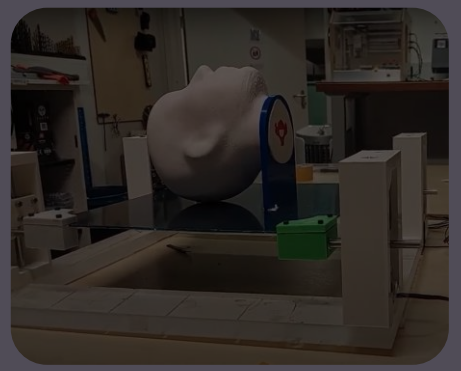
Soft tissue + bone head ph

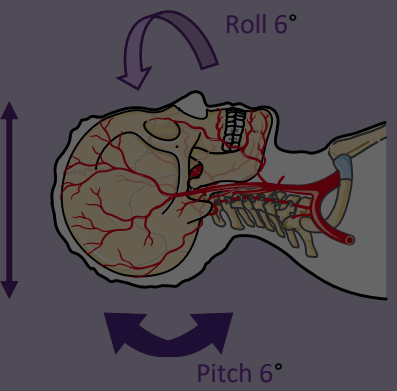
Breast phantom

Dynamic anthropomorphic phantom

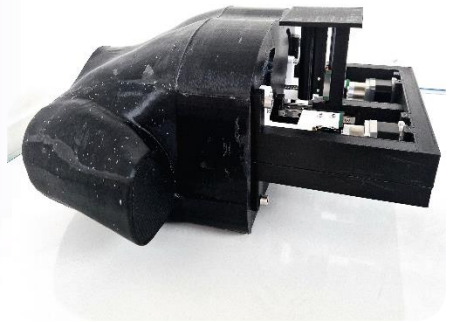
A phantom with a deformable lung with tumors and bronchi that can be used for multiple applications

Dynamic Phantoms

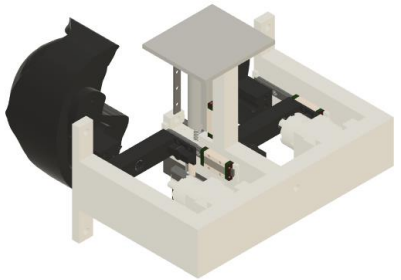




Motion Platform



Designed motion system



Dynamic Thorax phantom

Future perspective

- PIANOFORTE grant start.
- New PhD student focusing on 3D-printing.
- Adaptive phantoms.
- Breathing thorax phantom.
- Inflatable bladder.

REALIZE lab application

- In-house phantoms for certain applications.
- Aim for more realistic phantoms and customized to application.
- Testing and implementing new technologies for the clinic by using the lab.

Research to Clinic

Future perspective

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REALIZE lab application

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Projects in collaboration with the clinic

Realistic phantoms for Halcyon testing

Female thorax phantom for CT-QA

Motion platform for prostate marker tracking

Pregnant phantom for proton dosimetry

3D printed brachy applicators for GYN

Lung phantom for brachytherapy

Spine track (markerless spine position monitoring)

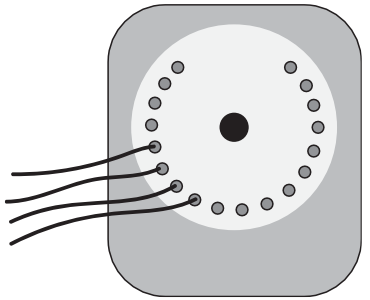
Iridium Imaging System

Example case: IrIS

How are these phantoms used to aid in development and implementation of new technologies?

Timeline of the development of IrIS (Iridium Imaging System) from idea to clinically used prototype

Background: brachytherapy



Brachytherapy

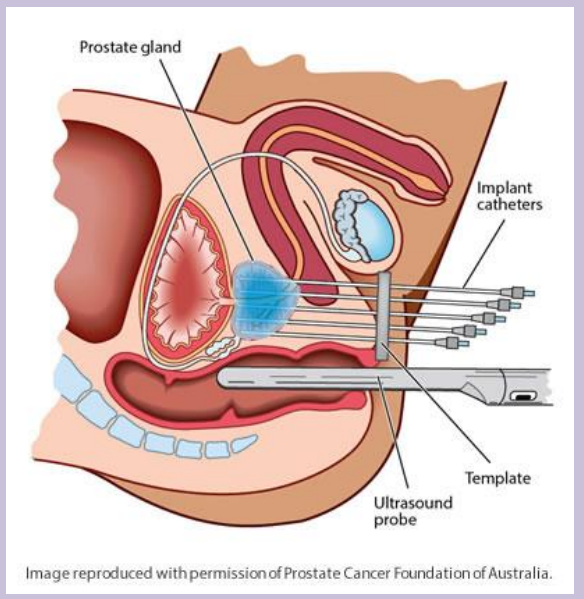
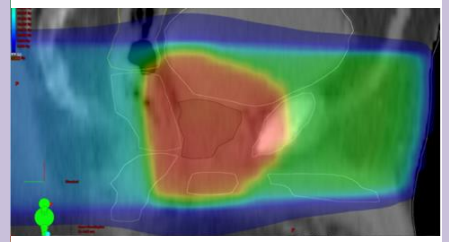


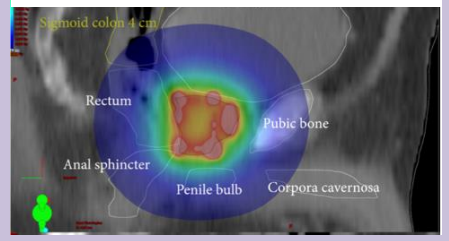
Image reproduced with permission of Prostate Cancer Foundation of Australia.

Bring radioactive source to the tumour, instead of external beam

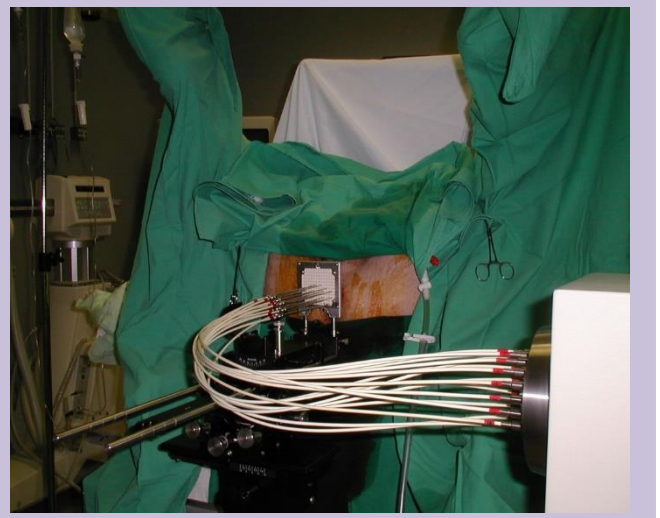
External beam



Brachytherapy



High dose to tumour, with low dose to surrounding tissue



More invasive, more manual work, prone to errors

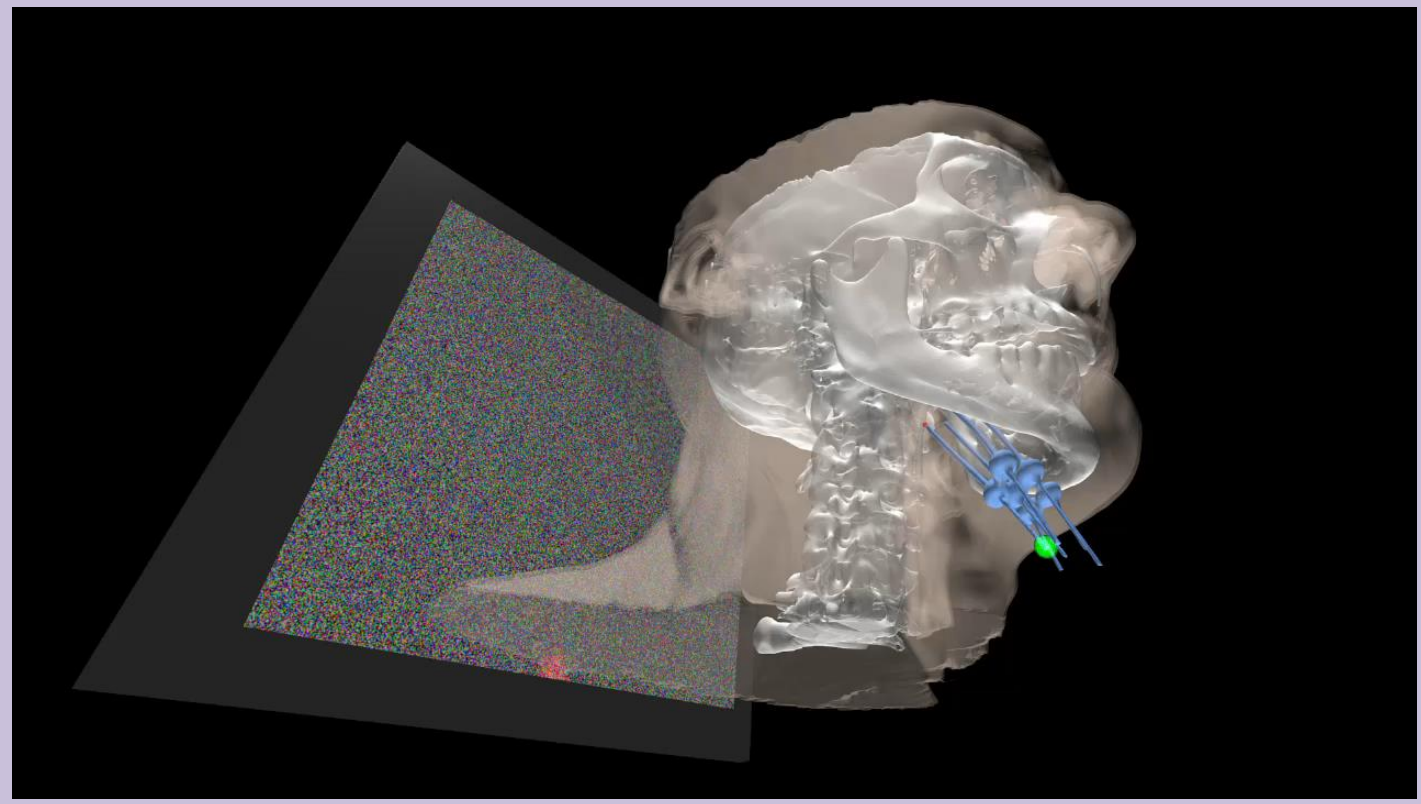
Iridium Imaging System (IrIS)

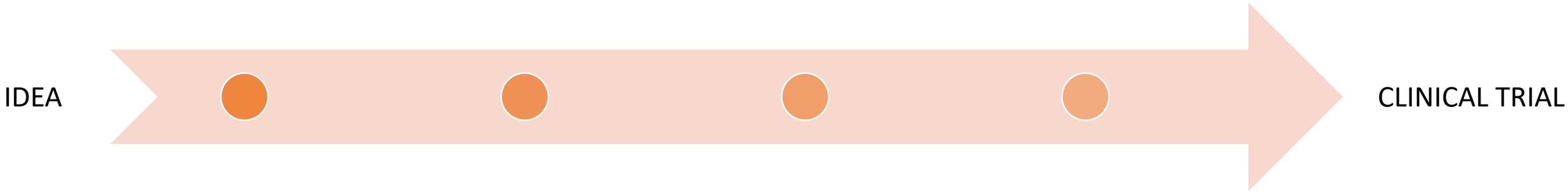
Goal:

- Determine what dose was actually delivered to the patient
- Detect when something goes wrong during the treatment

How?

Track the source while it is inside the patient



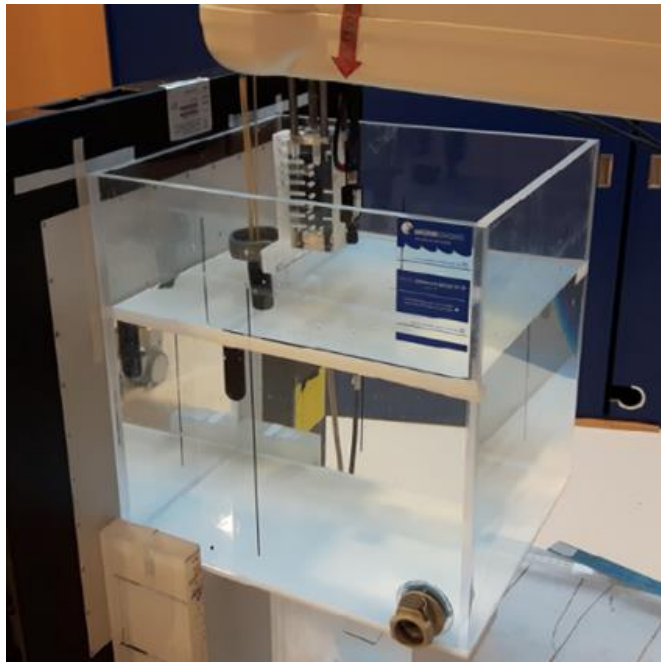


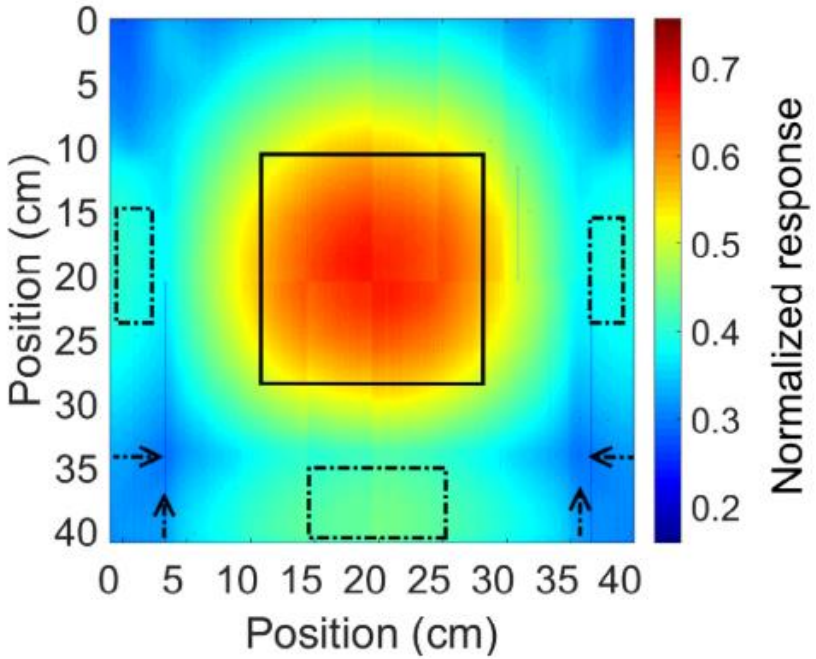
Why don’t we just put an imaging panel next to a patient?

1. Not allowed without proper testing
2. Easier to validate and test in a controlled and simplified environment

First published paper: 2007 (!)

IDEA → CLINICAL TRIAL





- Proof of principle in water tank
- Dwell positions are easily detectable with Gaussian fitting

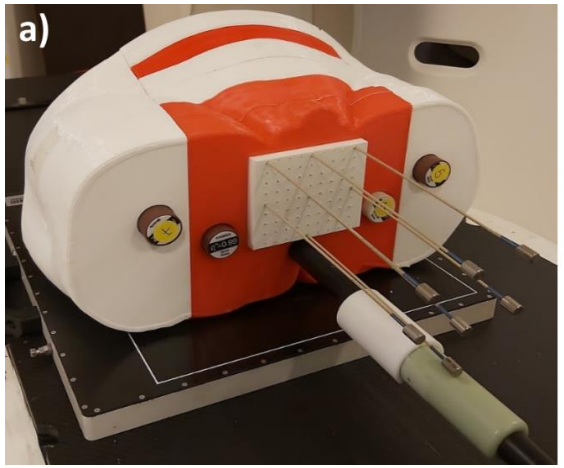
Image adapted from:
Fonseca et al., "Online pretreatment verification of high-dose rate brachytherapy using an imaging panel", Phys. Med. Biol. 2017

Water tank

Pelvic phantom

IDEA

CLINICAL TRIAL



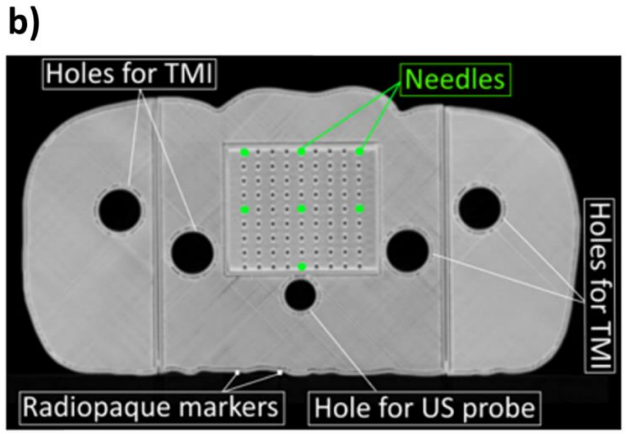


Image adapted from:
Fonseca et al., "Brachytherapy treatment verification using gamma radiation from the internal treatment source combined with an imaging panel — a phantom study", Phys. Med. Biol. 2021

- Pelvic phantom for brachytherapy
  - Needle implant
  - Inserts for tissue equivalent inserts
  - Ultrasound probe
- Gaussian fit replaced by marker triangulation method to track source

Water tank

Pelvic phantom

Head phantom

IDEA

CLINICAL TRIAL

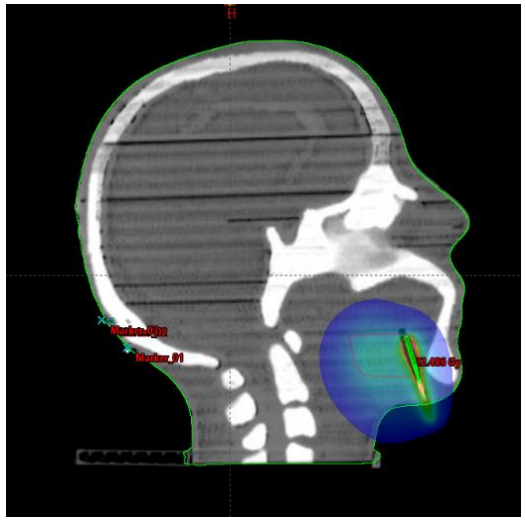


Image adapted from:
Van Wagenberg et al., "Treatment verification in high dose rate brachytherapy using a realistic 3D printed head phantom and an imaging panel", Phys. Med. Biol. 2023

- Head phantom to test other body site
- Realistic bone filament

- Showed that we can detect specific treatment errors, updated marker holder

Water tank

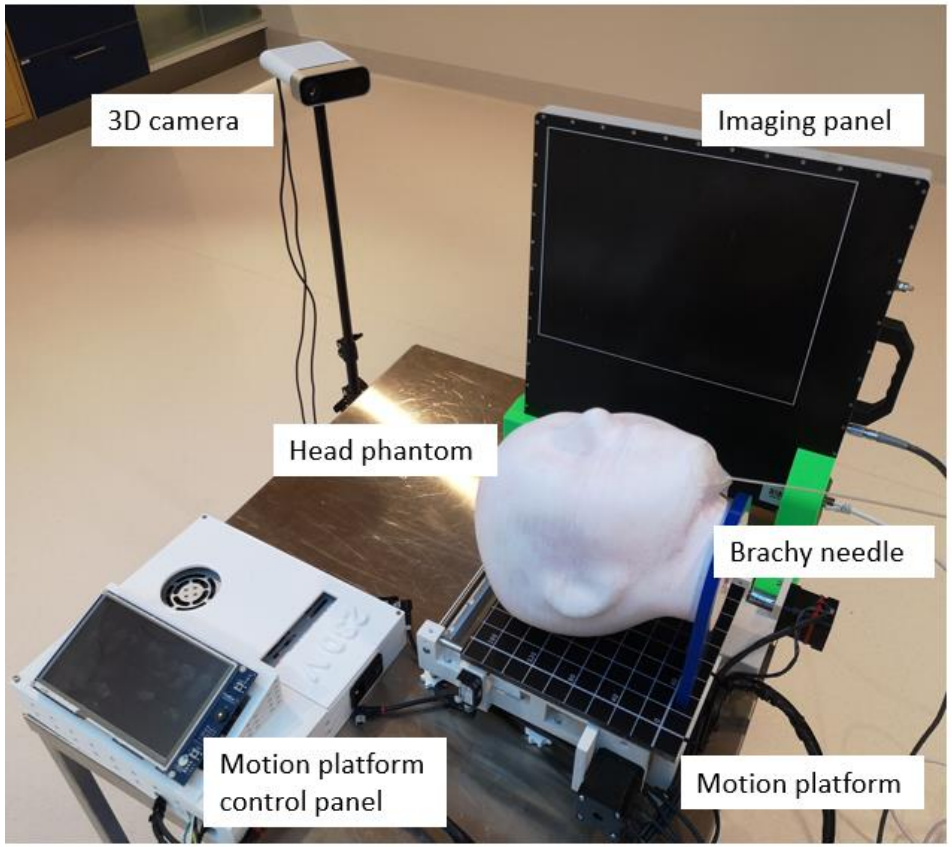
Pelvic phantom

Head phantom

Motion platform

IDEA

CLINICAL TRIAL



- Motion platform to simulate dynamic patient
  - Controlled movement to verify approach
- 3D camera used to distinguish internal/external motion

Final prototype (with 3D printed custom parts)

Clinical setup, used for real patients since March 2024

Take-home message

- In our lab, we can create realistic custom phantoms and other tools that are not available commercially for very specific applications

- These creations are used to develop, improve and validate new technologies that are used in the clinic