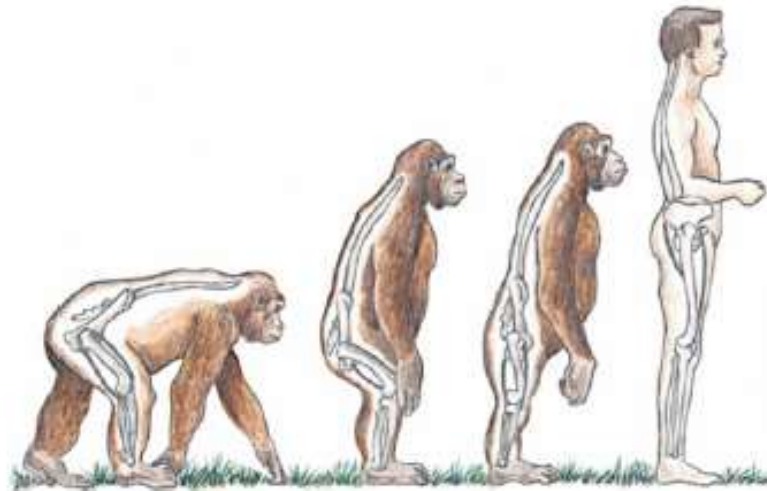


Protons Can Be Delivered as Easily as Photons



Thomas Rockwell Mackie
Emeritus Professor, University of Wisconsin
Madison WI



... and Allow Protons to Their Full Promise of Superiority

Received: 10 January 2021 | Accepted: 10 January 2021

DOI: 10.1002/acm2.13450

JOURNAL OF APPLIED CLINICAL
MEDICAL PHYSICS

PARALLEL OPPOSED EDITORIAL

Proton therapy needs further technological development to fulfill the promise of becoming a superior treatment modality (compared to photon therapy)

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³ Department of Radiation Oncology, Mayo Clinic Arizona, Phoenix, Arizona, USA

Correspondence

Yi Rong, Department of Radiation Oncology, Mayo Clinic Arizona, Phoenix, AZ.

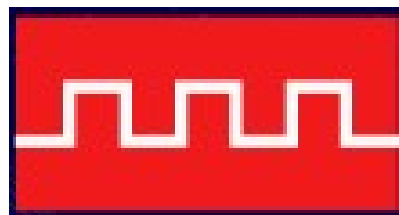
Email: rongyi@gmail.com

Daniel E. Hyer and Xuanfeng Ding contributed equally to the manuscript.

Disclosure and Potential Conflicts of Interest Statement



I am the Co-founder, Chief Innovation Officer and Chairman of the Board and have financial interest in Leo Cancer Care which is developing an upright radiotherapy system.



COSYLAB

I am a Board Member and have financial remuneration by Cosylab which provides and maintains control software to science laboratories and radiation therapy equipment worldwide.

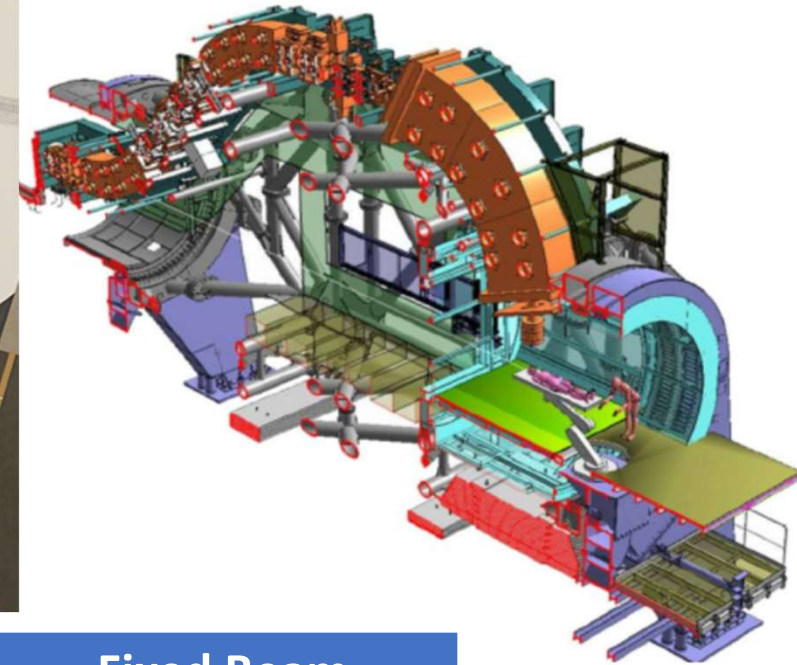
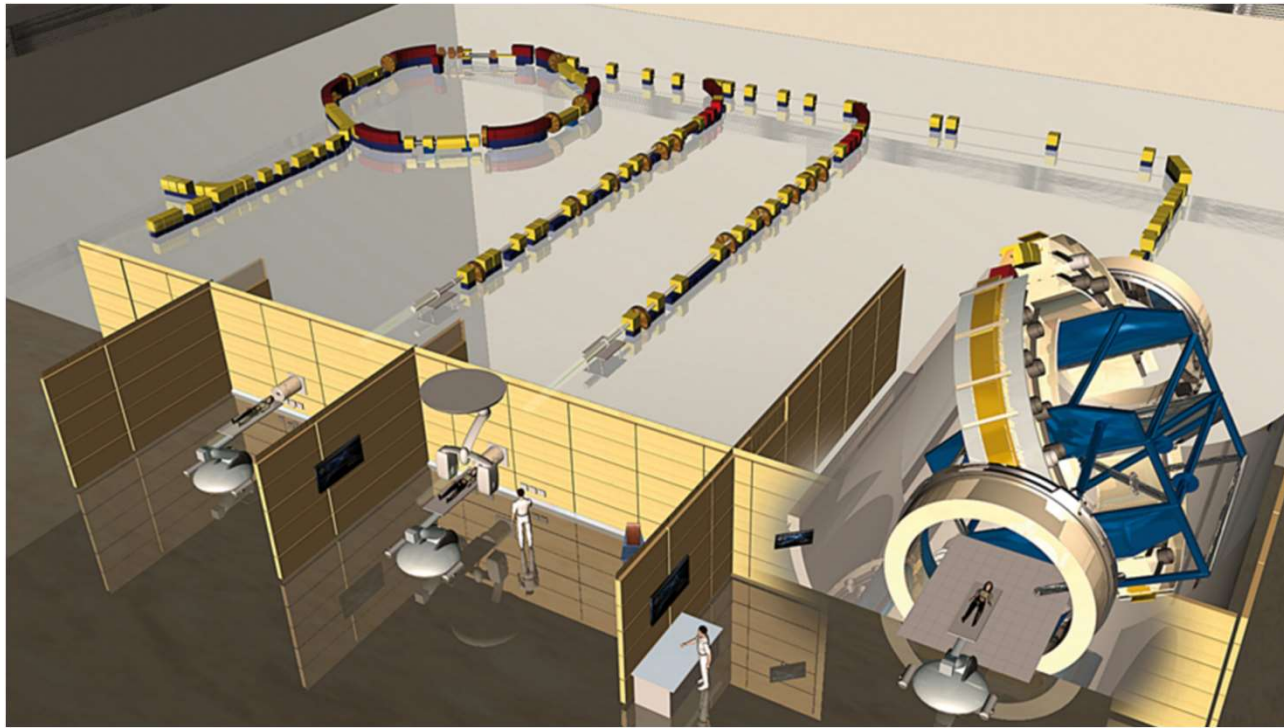
Overview

- **Eliminate complex building projects and high costs**
- **Reduce proton beam commissioning**
- **Use a fixed horizontal beam with an upright positioning system**
- **Upright positioning may be better much of the time**
- **Patients prefer to be upright**
- **High-quality CT scan needed in the upright treatment position**
- **Similar QA used in photon radiotherapy**
- **Planning more like photon radiotherapy**
- **Intensity-modulated arc therapy (IMAT)**
- **What about other imaging systems?**
- **Eliminate the need for specialty proton medical physicists**

Multi-room Construction Projects Are Massive

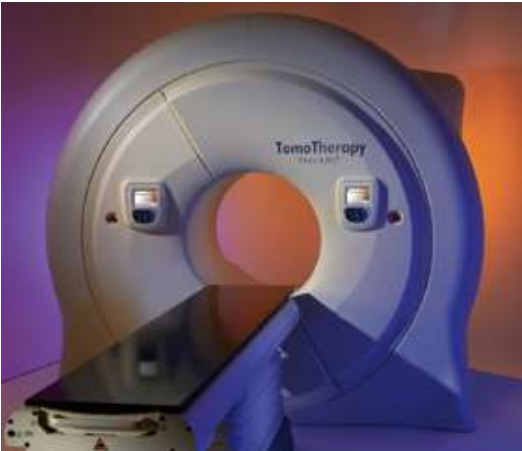


Heidelberg Particle Beam Facility Has Rotating and Fixed Beams



	Rotating Beam	Fixed Beam
Patient Recumbent	✓	Clumsy?
Patient Upright	Not Necessary	✓

Coplanar Photon Beam Radiotherapy Systems



TomoTherapy (MVCT)



MRIDIAN (MVCT)



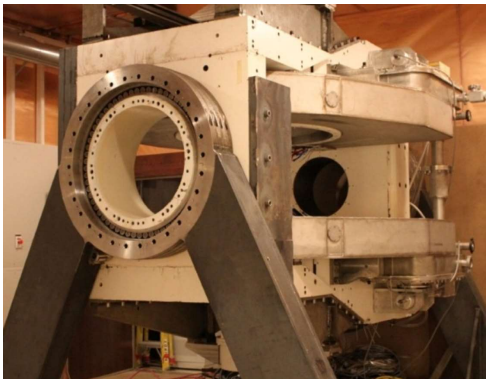
Varian Halcyon (CBCT)



Elekta Unity (MRI)



Reflexion (PET)



Aurora (MRI)

Note: All These Systems Have Built-in IGRT

Most Proton Radiotherapy is Coplanar

Int J Radiat Oncol Biol Phys. 2016 May 1;95(1):224-33. doi: 10.1016/j.ijrobp.2015.09.033. Epub 2015 Sep 30.

Reassessment of the Necessity of the Proton Gantry: Analysis of Beam Orientations From 4332 Treatments at the Massachusetts General Hospital Proton Center Over the Past 10 Years.

Yan S¹, Lu HM², Flanz J², Adams J², Trofimov A², Bortfeld T².

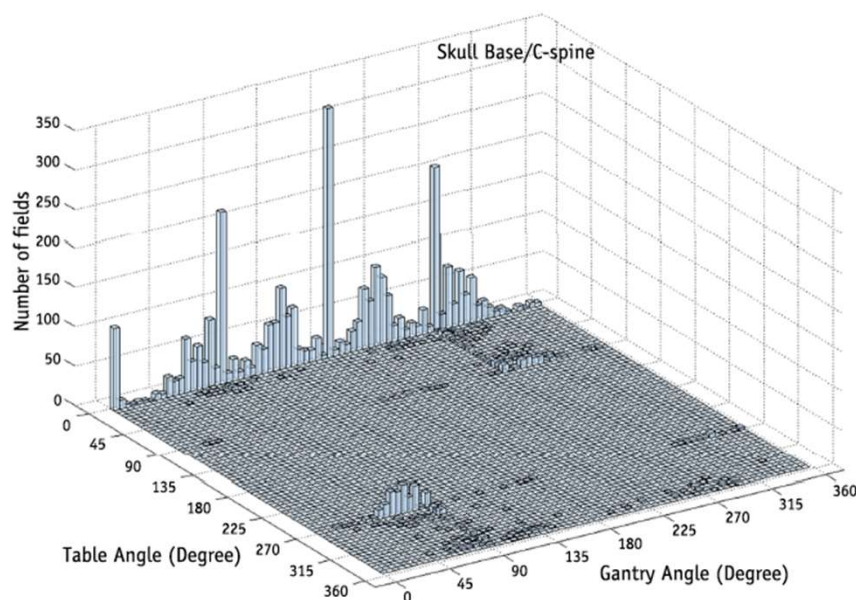
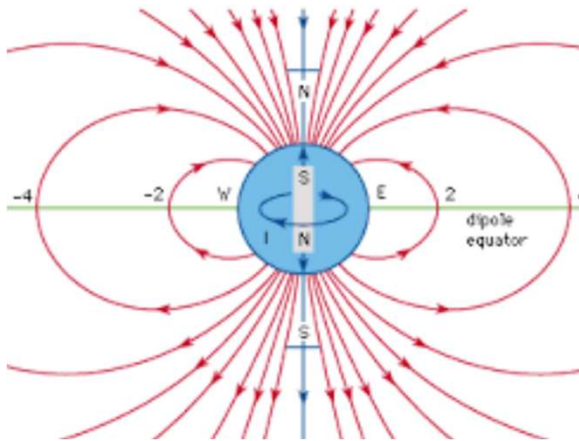


Fig. 1. Three-dimensional histogram of gantry and table angles used for skull base/cervical spine (C-spine) treatments.

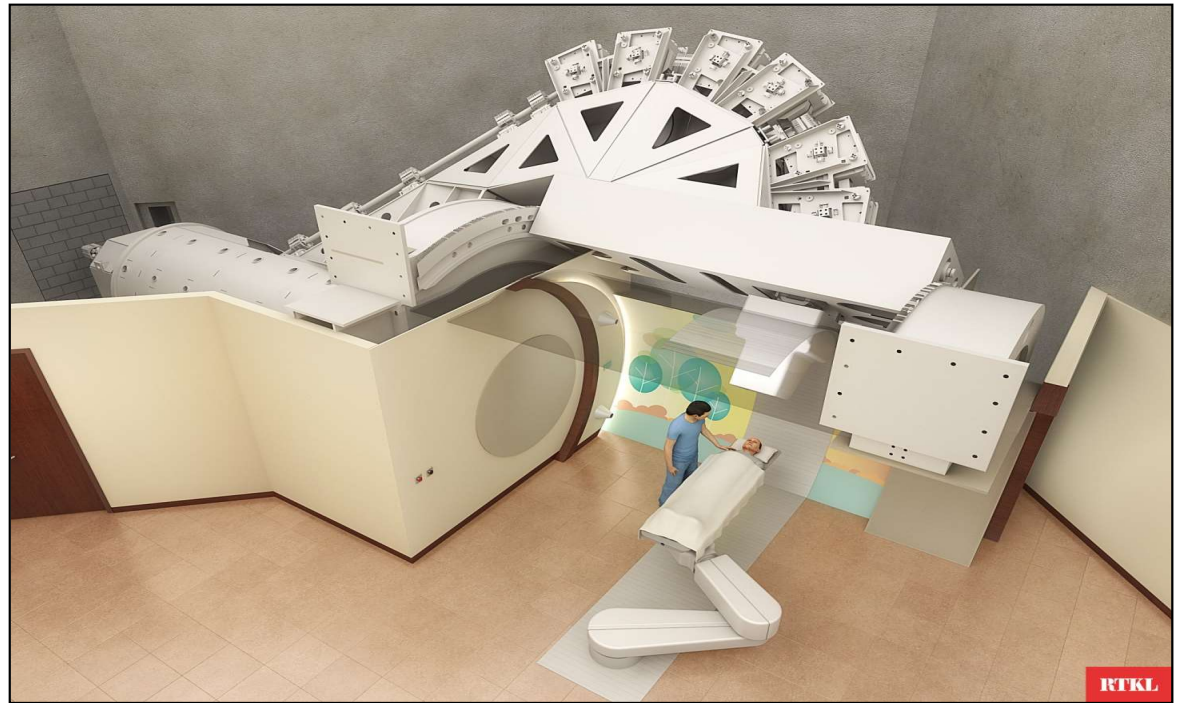
- **Vast majority coplanar only**
- **You can treat all cases with a carefully designed beam delivery and an upright patient positioning system**

The Beam Magnet System Has to be Tweaked for Every Gantry Angle

- For mechanical variation
- To adjust for changing direction from Earth's magnetic field

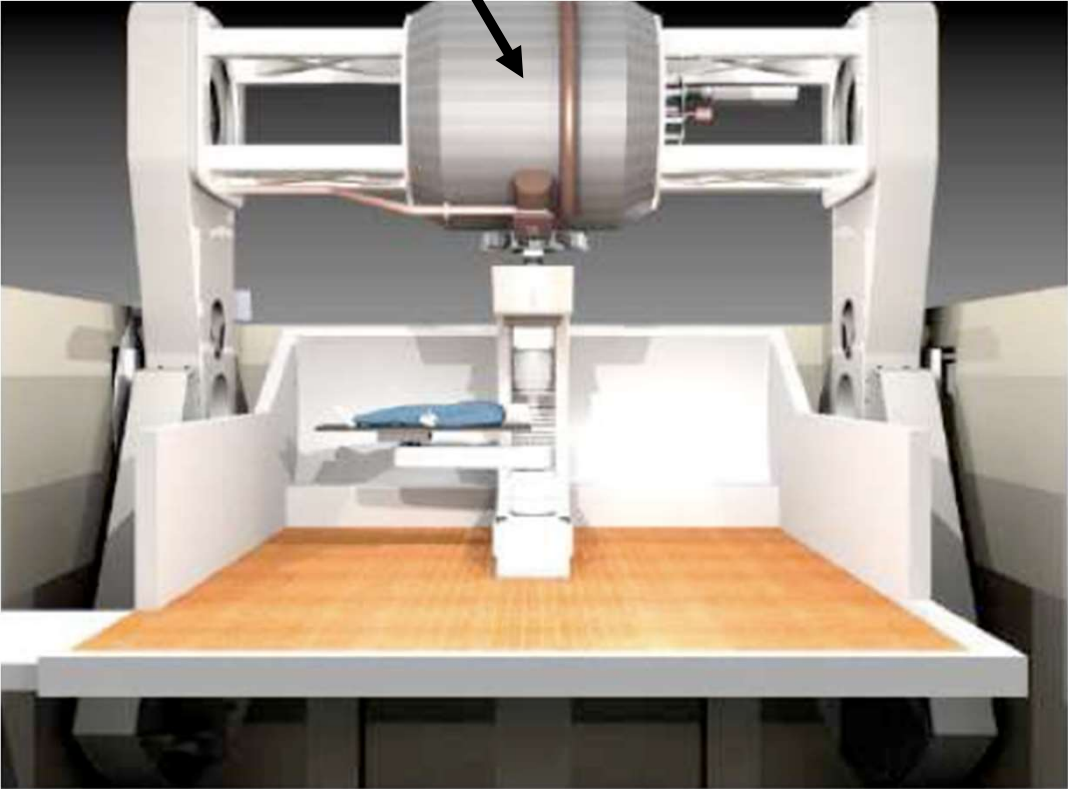


$$\vec{F} = q(\vec{v} \times \vec{B})$$



MeVion S250i-FIT Treatment Room

MeVion 250 MeV Synchrocyclotron



Compact MeVion 250 MeV Synchrocyclotron



Conventional Linac Vault

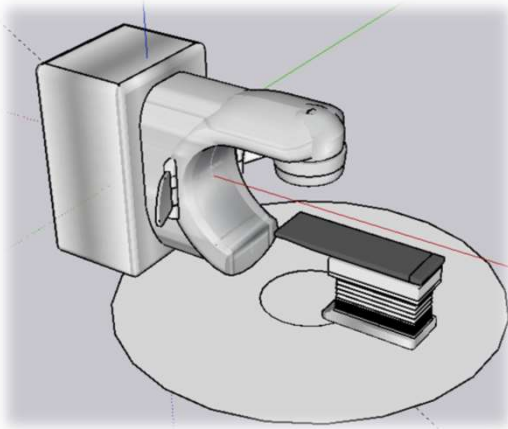
Patient Positioner and Upright CT

Rendering of MEVION FIT (Stanford University)

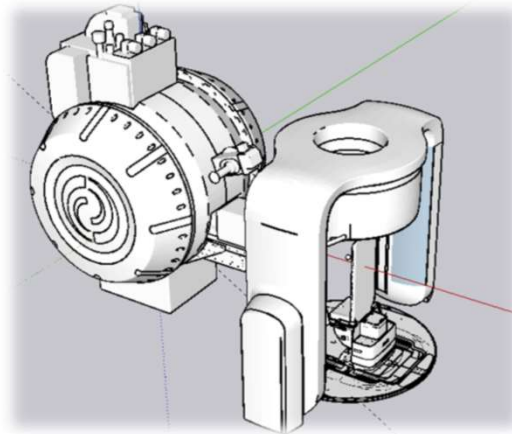


How Small is it Really?

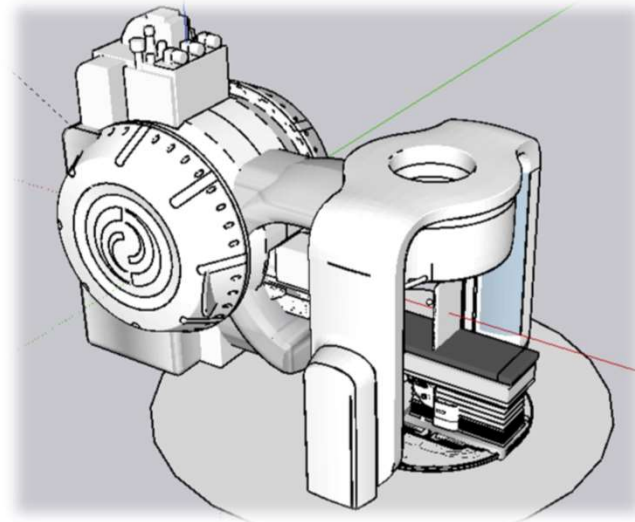
VARIAN TrueBeam



MeVion Accelerator +
LEO System
= MeVion S250i FIT

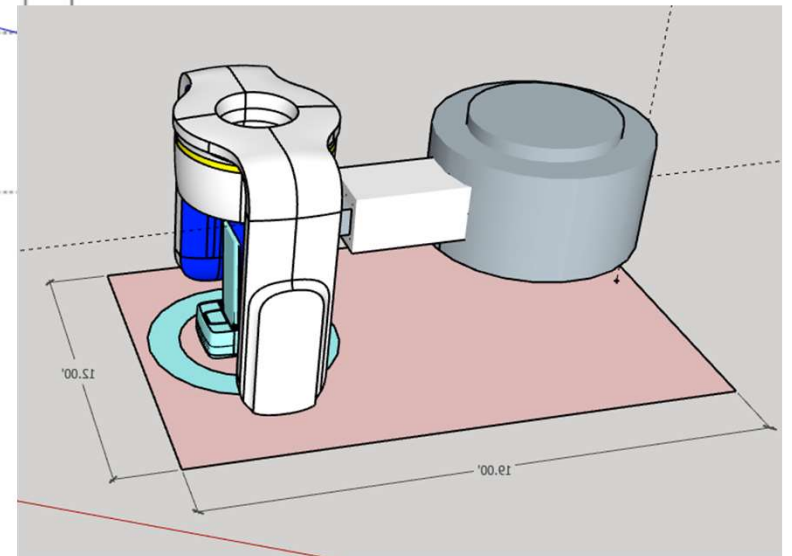
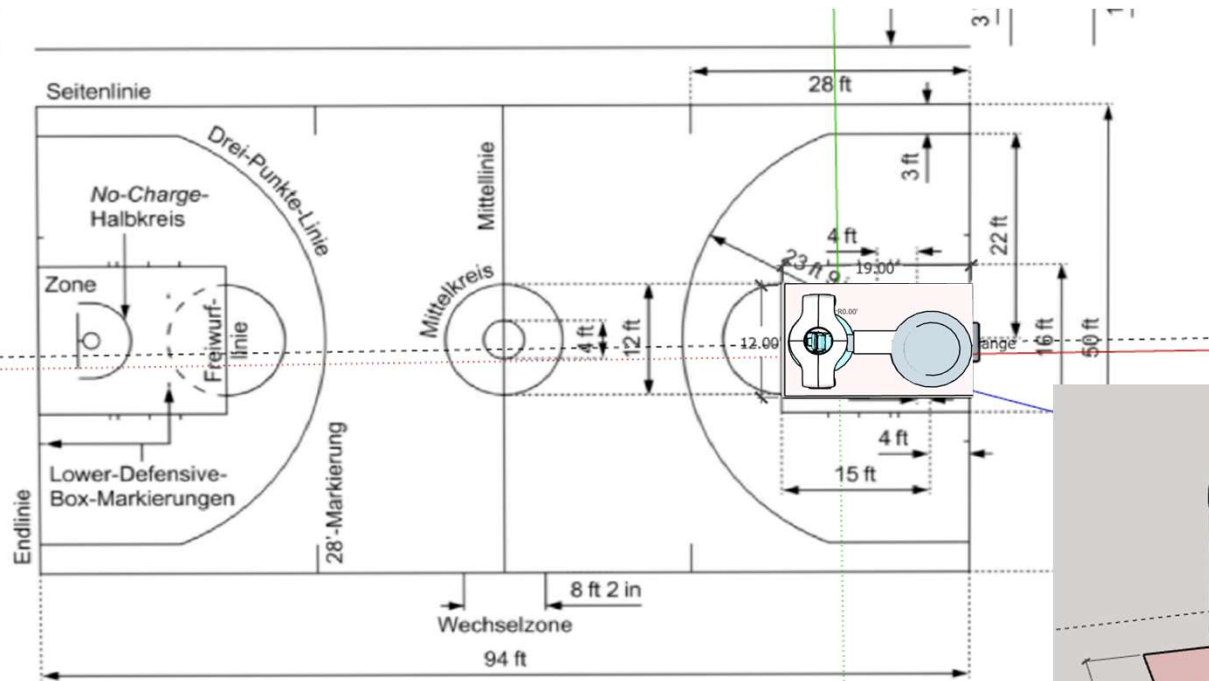


VARIAN TrueBeam
MeVion S250i FIT

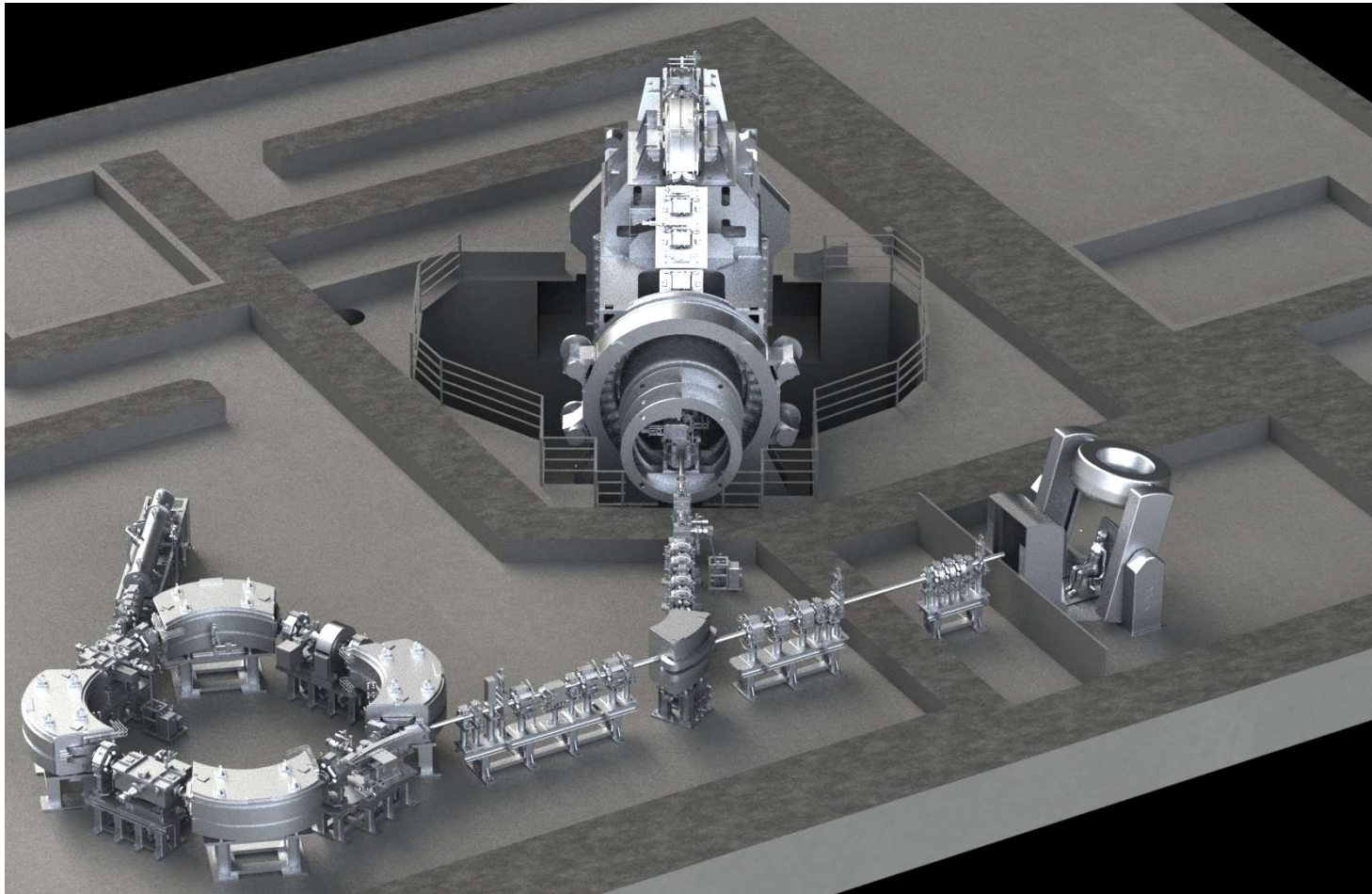


From Niek Schreuder, Leo Cancer Care

It Would Fit in the "Paint" of a Basketball Court



One Hitachi Gantry + One Upright Room with Hitachi Synchrotron (UW-Madison)



Enablers for Upright Proton Radiotherapy



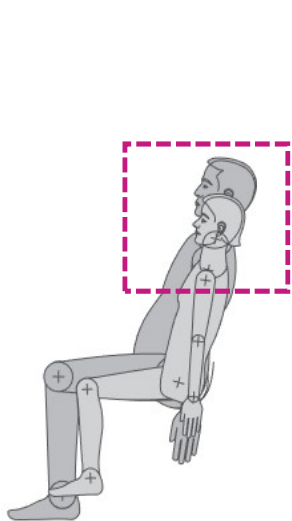
Upright CT at the Isocenter

A Dual-Energy CT Capable
Of Imaging Head & Neck,
Breast & Lung, Prostate

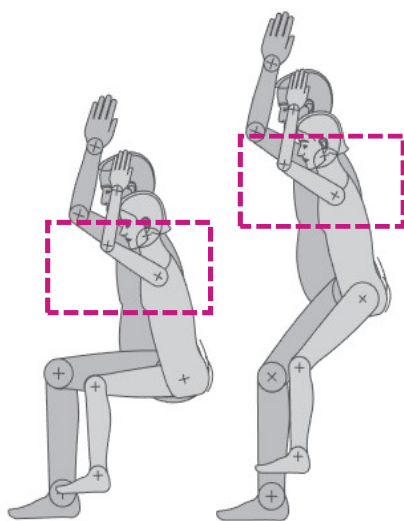
Upright Positioning

An Upright Positioning
System Capable of Treating
Head & Neck, Breast &
Lung, and Prostate

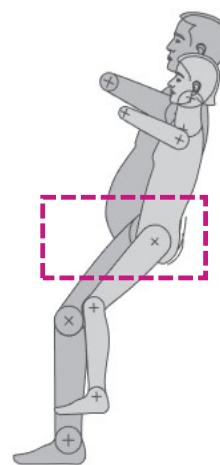
Designed for a Variety of Upright Postures



Head & Neck



Breast & Lung



Prostate / Pelvic

1. Postures we need to be able to position the patient to treat <95% of cancer cases



2. Develop a patient positioner that can do that

Multi-Axis Patient Positioner



Upright Positioner at Lyon France

1. Patient Posture

Not DICOM parameters Yet

Above Floor Motorized

- Seat Height
- Seat Pan Angle
- Shin Rest
- Heel Stops

Non-Motorized

- Indexed Backrest angle
- Arm rests

Necessary Immobilization

- Vac Lock Bag
- Abdominal Belt
- Face Mask

2. Patient Setup

Standard DICOM Parameters

Below Floor Motors

- Z - Elevation
- X - Left-Right
- Y – Front-Back
- Yaw
- Pitch
- Rotation

Medical Pediatric Upright Seats are Available

TransMotion Medical Child Seat with Belt

- Plastic coated foam construction
- Claims nontoxic with anti-microbial protection, washable, and odor, urine, and stain resistant
- 4 inches of vertical adjustment of the shoulder straps for large size
- 2 year warrantee



Small



Medium



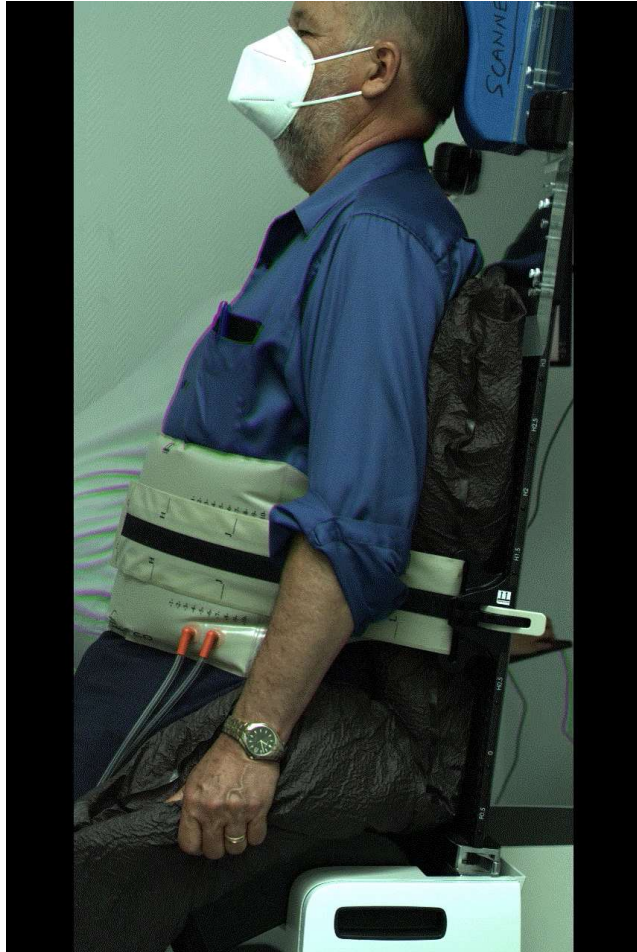
Large



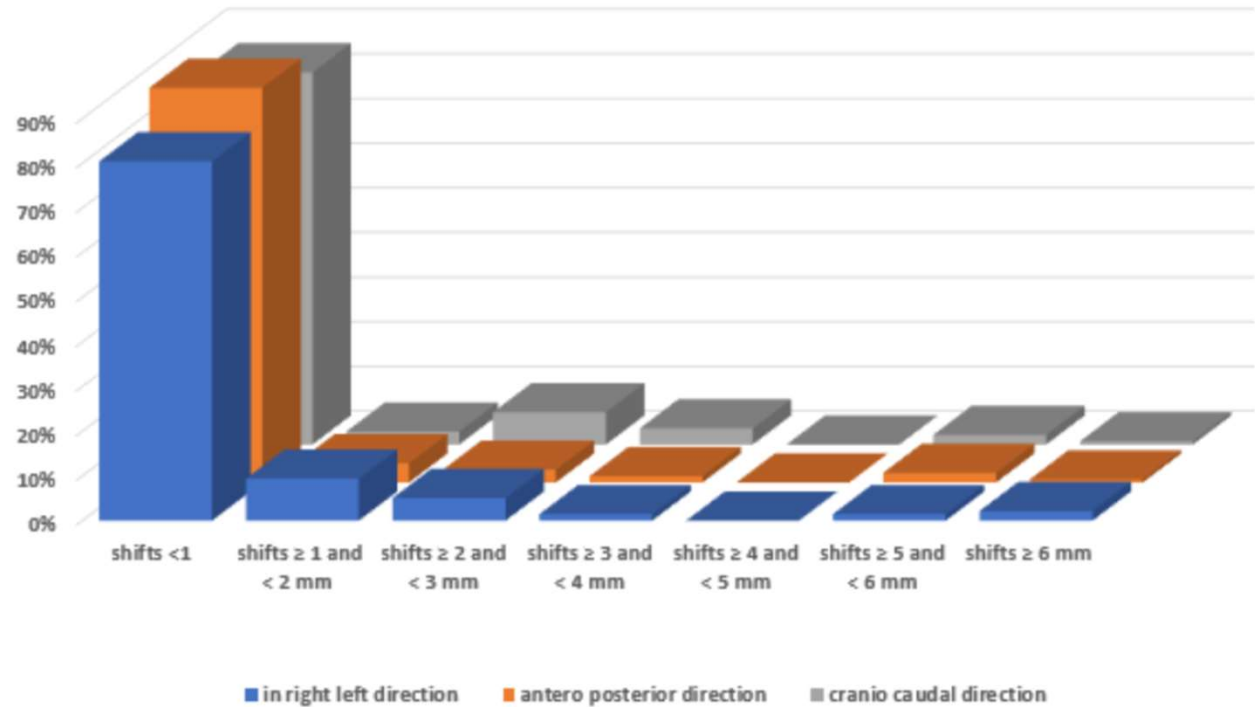
Large Size

<https://mfimedical.com/products/transmotion-medical-child-seat-with-belt?variant=33230211383373>

Multicamera System for Setup and Surface Registration

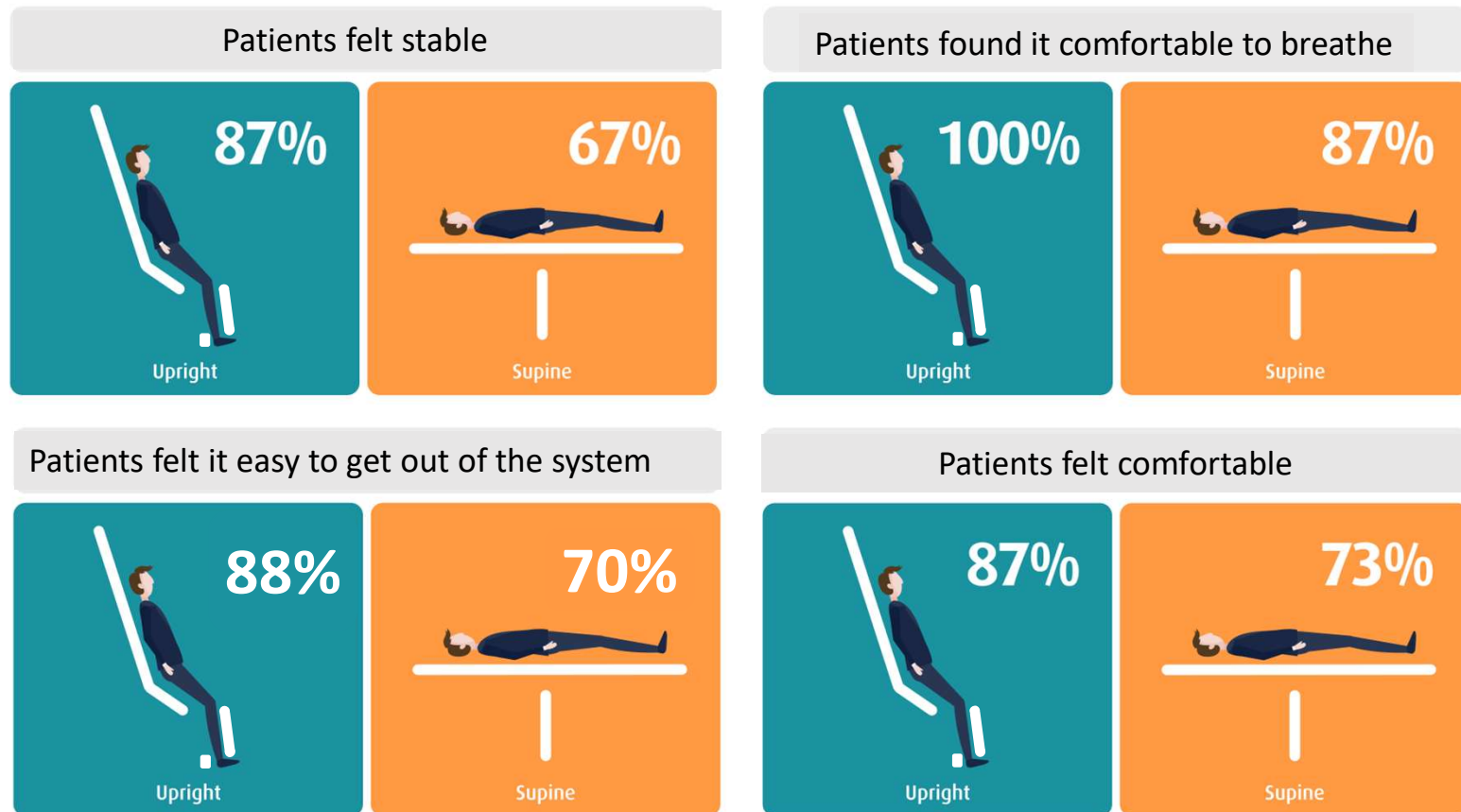


Intra-fraction Shifts Over 20 Minutes of Simulated Helical Treatments



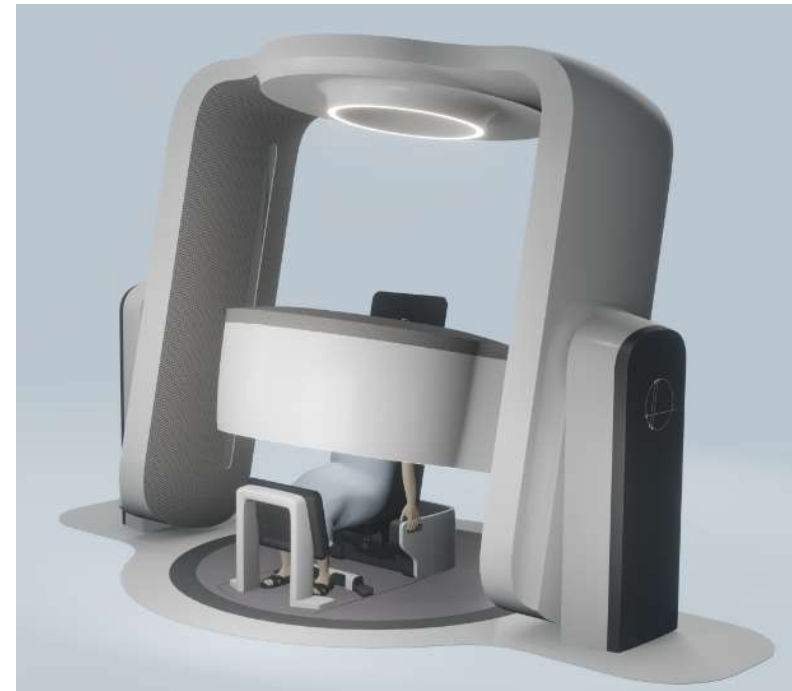
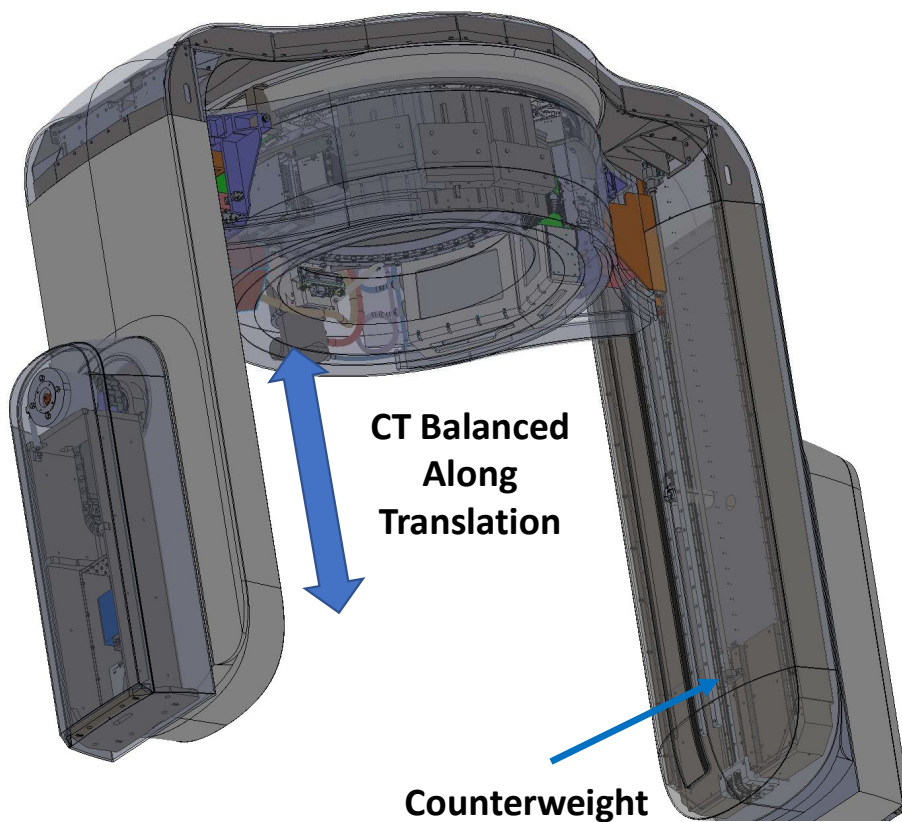
~80% of patients have shifts of < 1 mm

Patient Stability and Comfort Questionnaire Results from 15 Patients



Boisbouvier et al. TIPSRO 24: 124-130 (2022)

Diagnostic Quality CT Scanner for Planning and Adaptive Radiotherapy



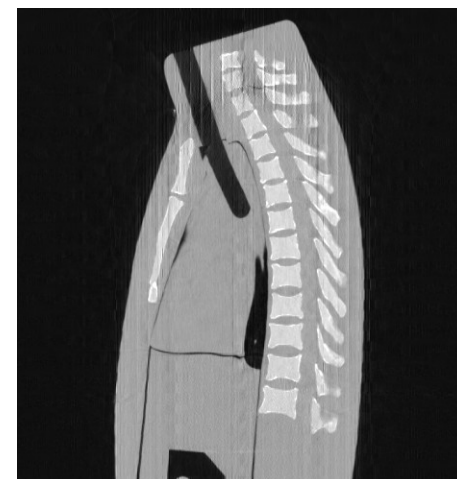
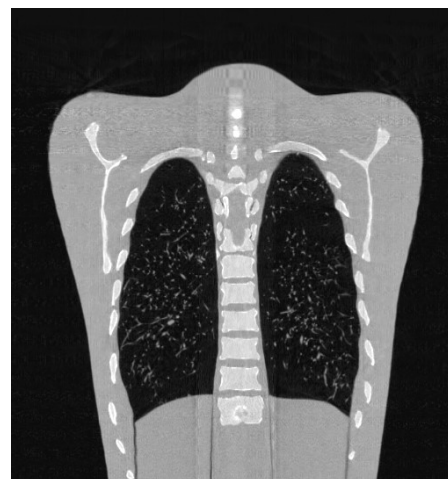
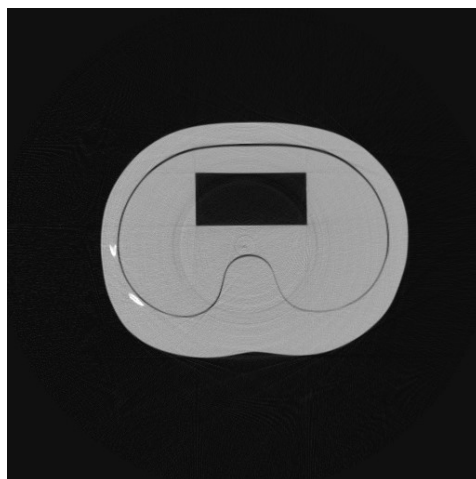
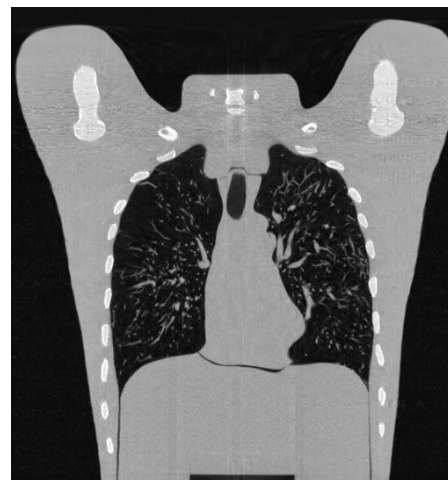
Phantom CT Scan

Lungman Phantom



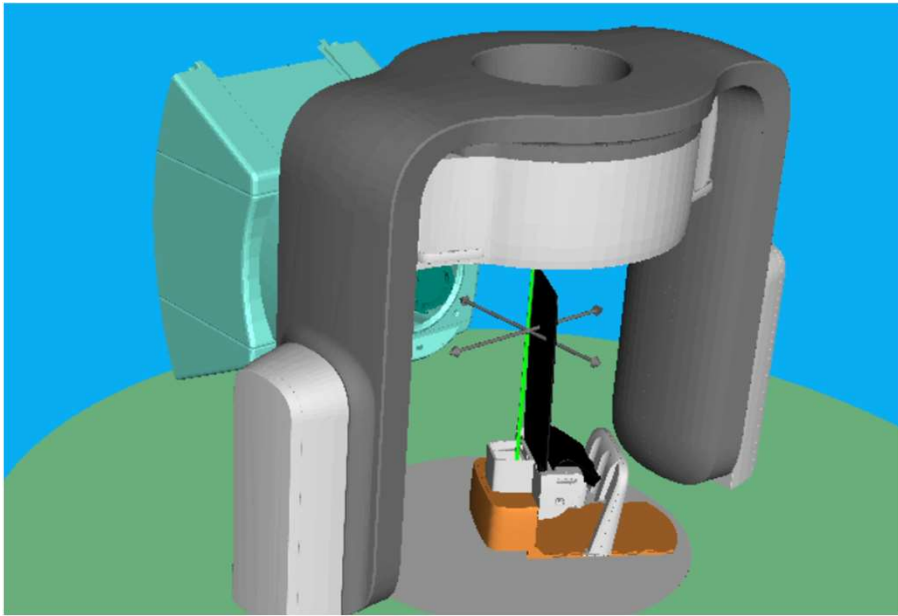
Scan Parameters

- 140 kV, 100 mAs
- 1 s rot speed
- 32 row detector
- pitch = 0.93
- 2 mm Al filter
- Large focal spot

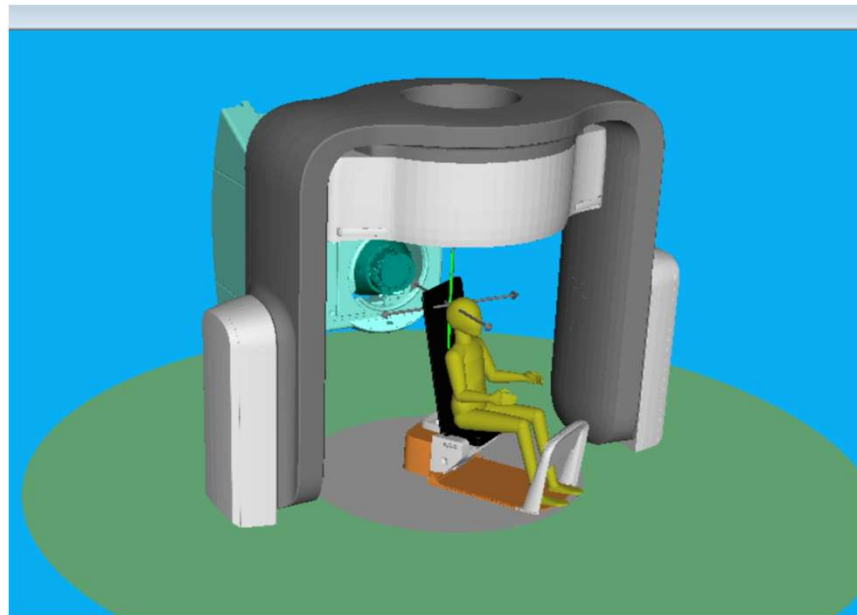


Scanning Workflow

Imaging Sequence – CT SIM



Imaging Sequence + Treatment Sequence

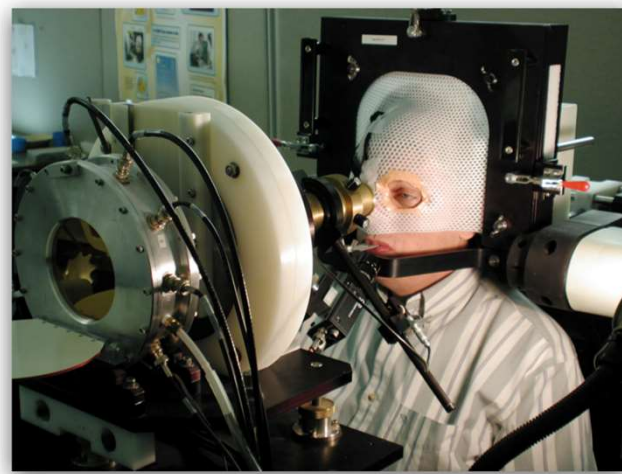
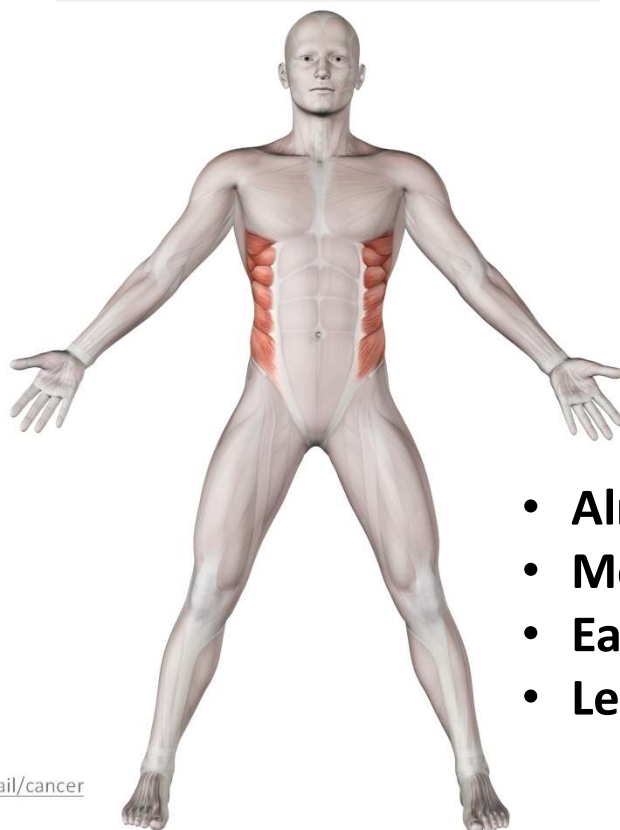


CT Data Sent to Treatment Planning

From Niek Schreuder, Leo Cancer Care

Indications for Upright – Head and Neck

Head & Neck
10 % of Cancer Cases

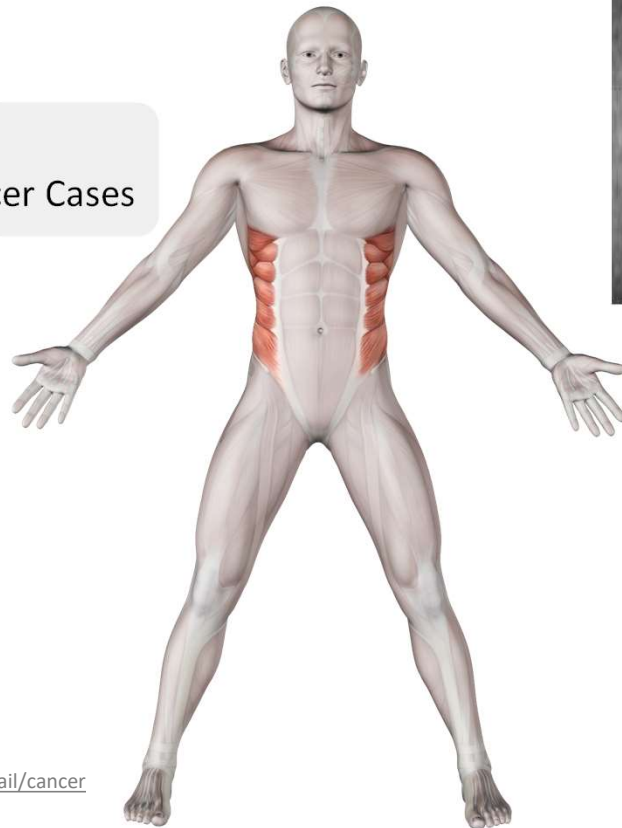


- **Already used for eye treatments**
- **More stability and accuracy**
- **Easier to swallow**
- **Less gastric reflux issues**

Indications for Upright - Lung

LUNG

22% of Cancer Cases

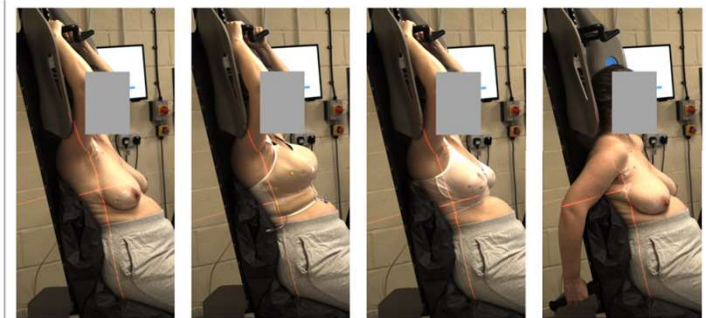


A. Upright

B. Supine

- Lung more inflated
- Less lung movement

Indications for Upright- Breast



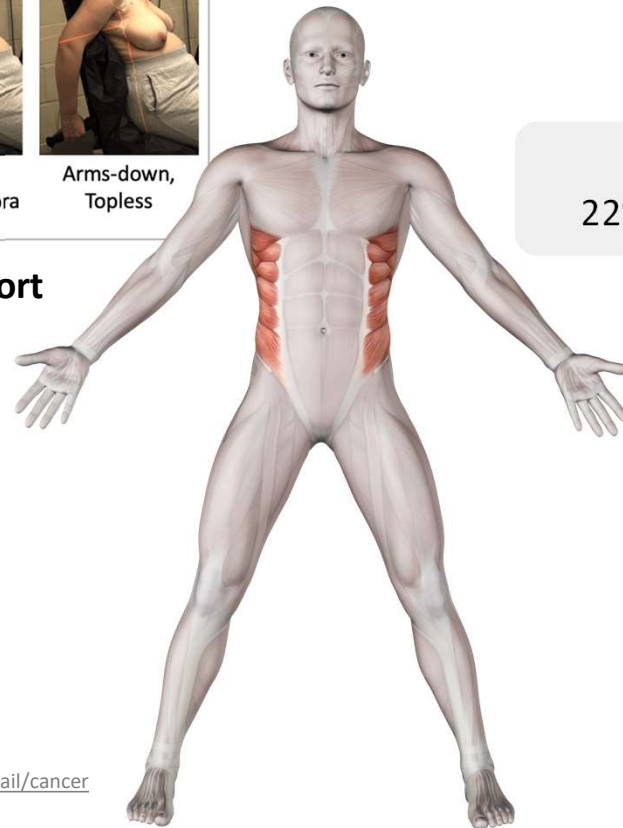
Arms-up,
Topless

Arms-up,
Support 4 All bra

Arms-up,
Chabner XRT bra

Arms-down,
Topless

Upright Breast Support



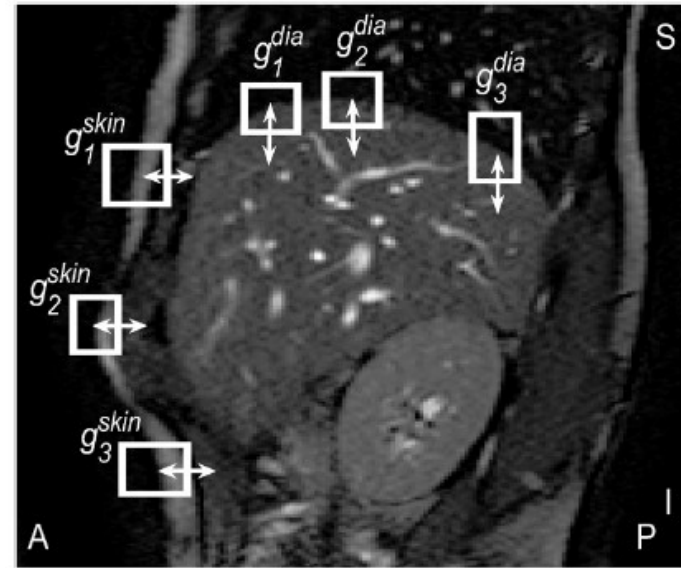
BREAST

22% of Cancer Cases

- Control of skin folds
- More reliable positioning

Indications for Upright - Liver

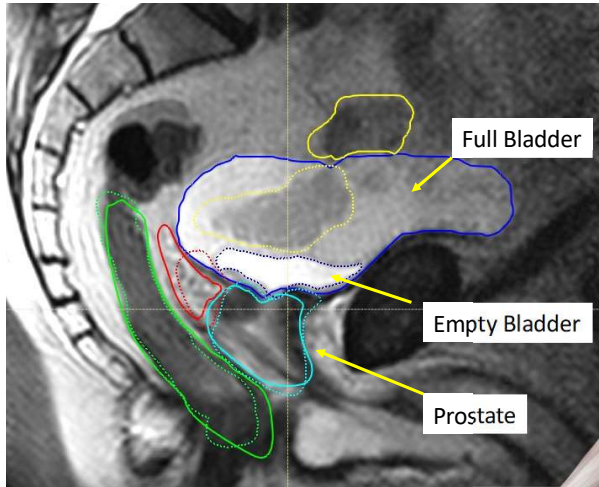
LIVER
9% of Cancer Cases



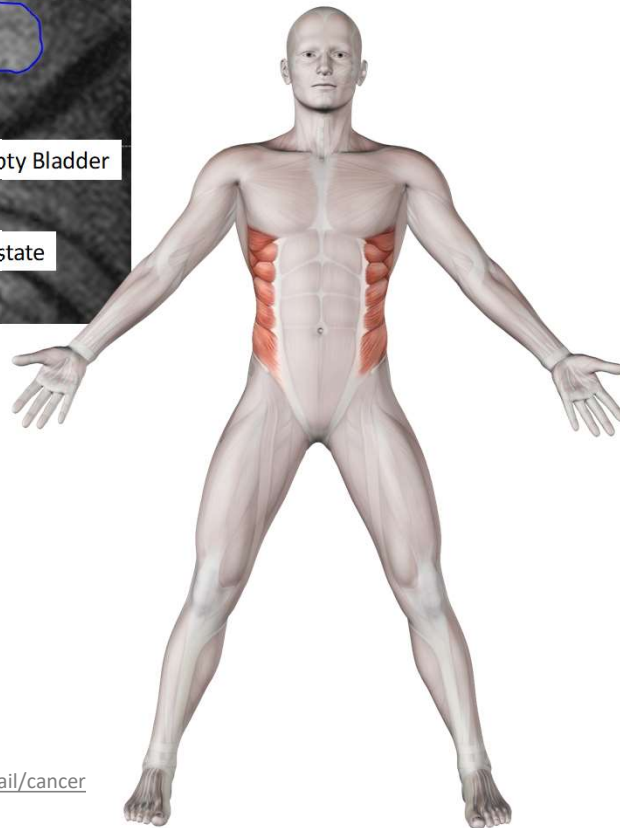
Upright MRI Scan

- No systematic organ drift

Indications for Upright - Prostate



Upright MRI Scan



PROSTATE
13% of Cancer Cases

- Prostate is more stable
- No bladder filling needed

Indications for Upright

Head & Neck
10 % of Cancer Cases

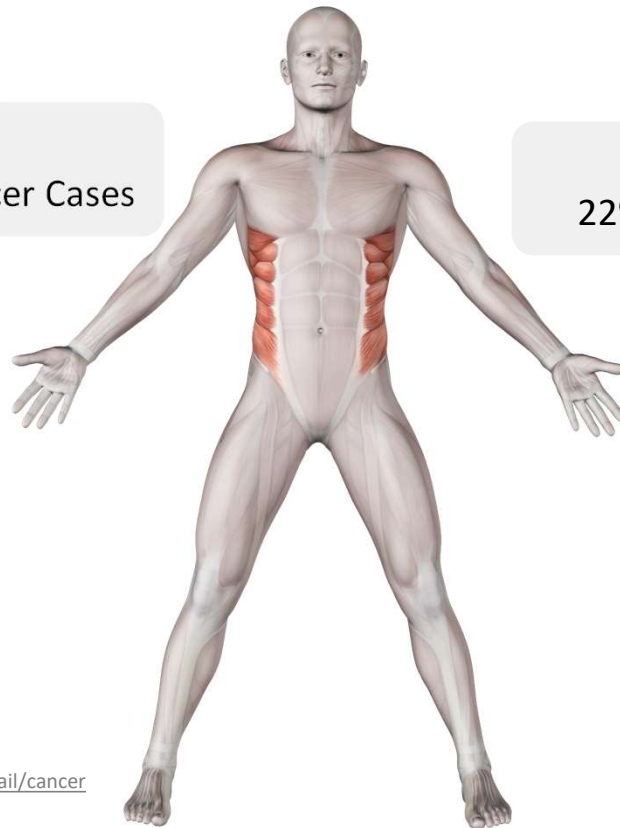
LUNG
22% of Cancer Cases

LIVER
9% of Cancer Cases

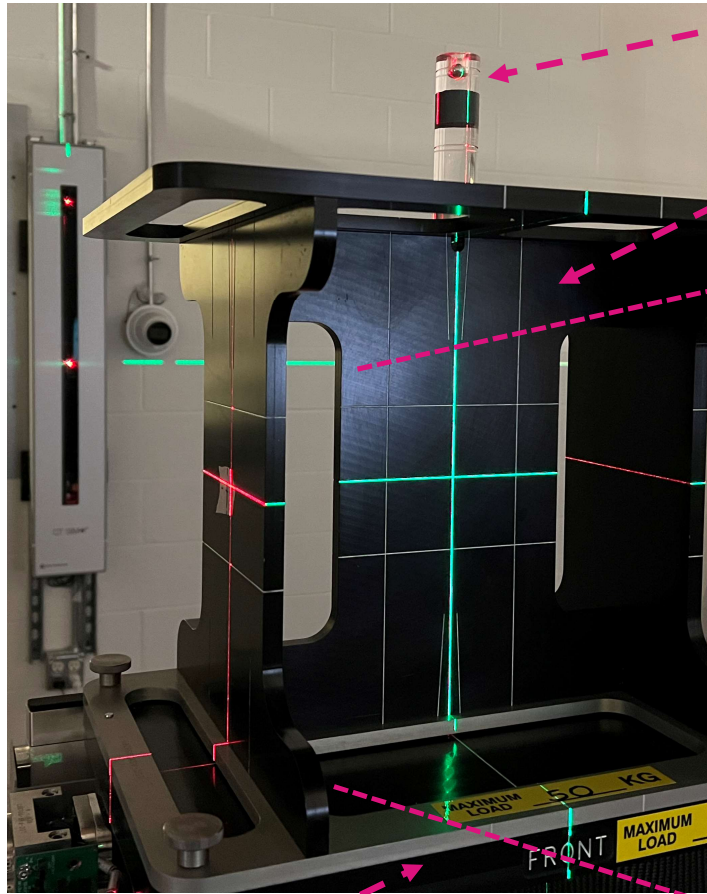
BREAST
22% of Cancer Cases

PROSTATE
13% of Cancer Cases

76% of
all Cancer
Incidences



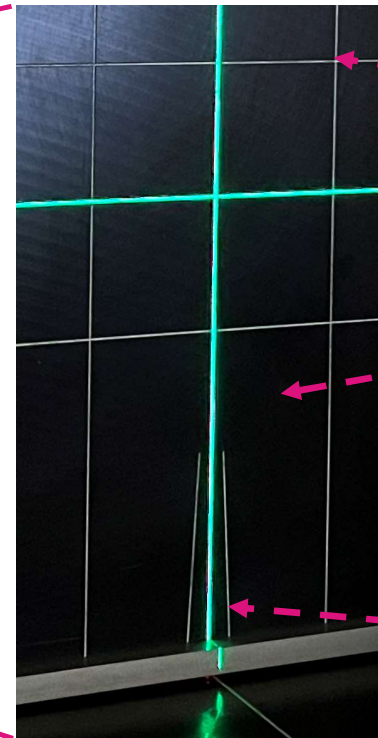
QA Test Fixtures Mounted on Upright Positioner



Winston-Lutz Test Fixture

General Upright Test Fixture

Table Fixture

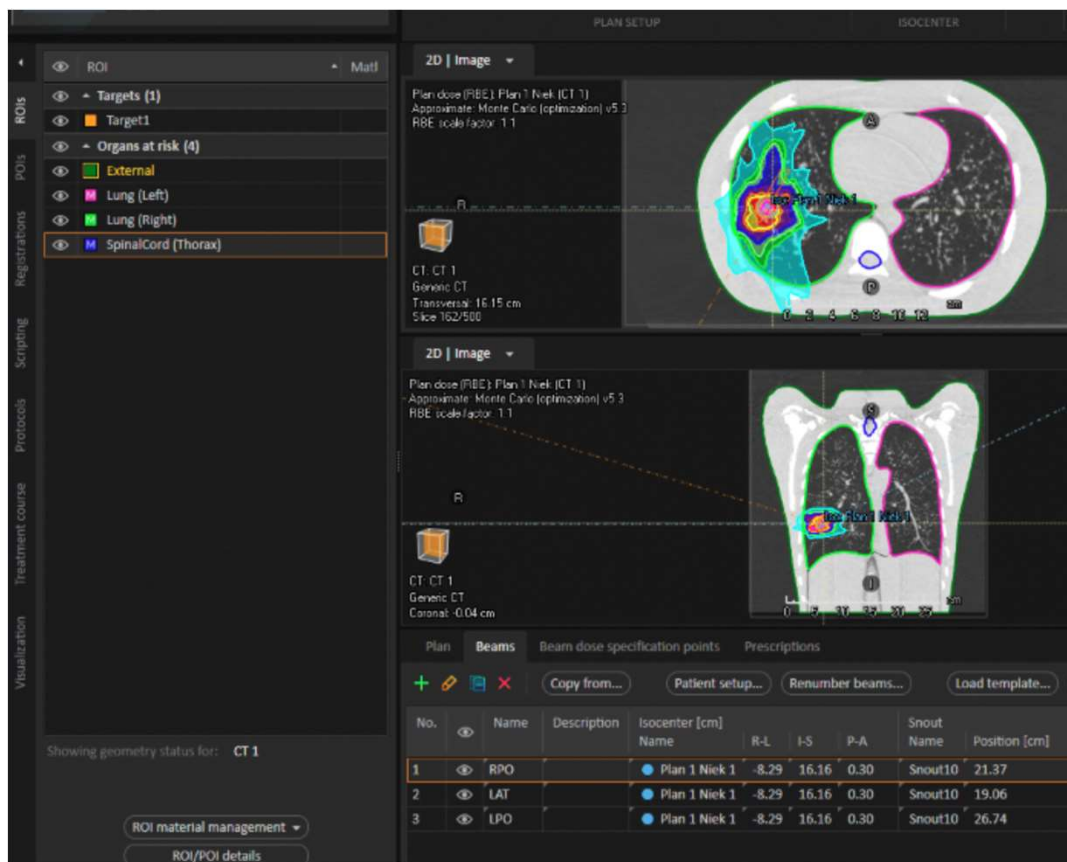


10 cm x 10 cm Scribe Lines

Film Attachment Surface

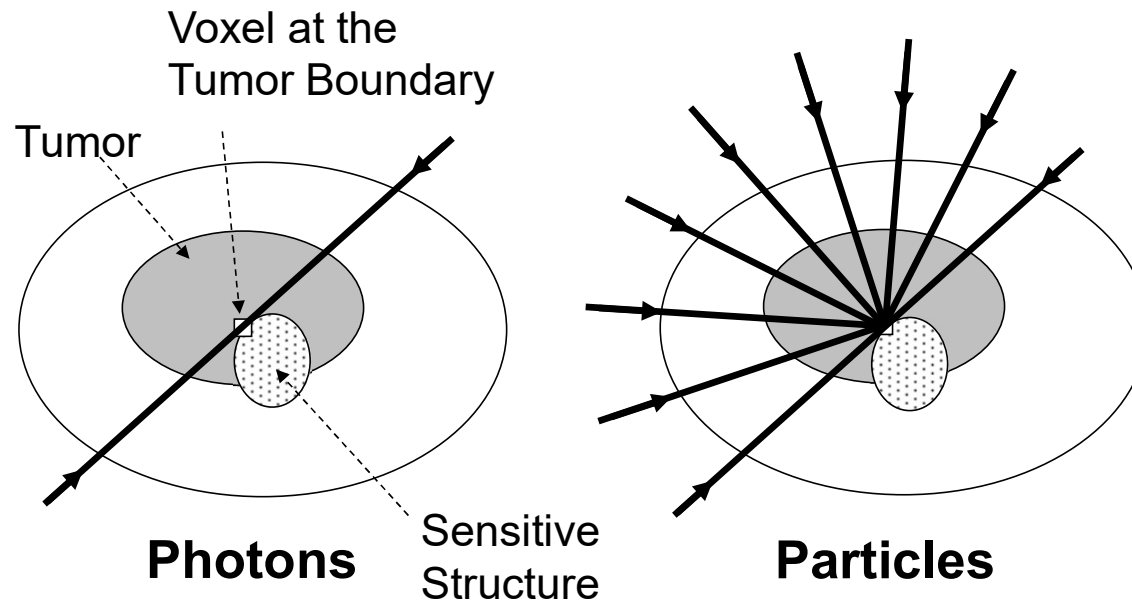
+/- 3 deg Scribe Lines

RayStation Supports Upright Radiotherapy



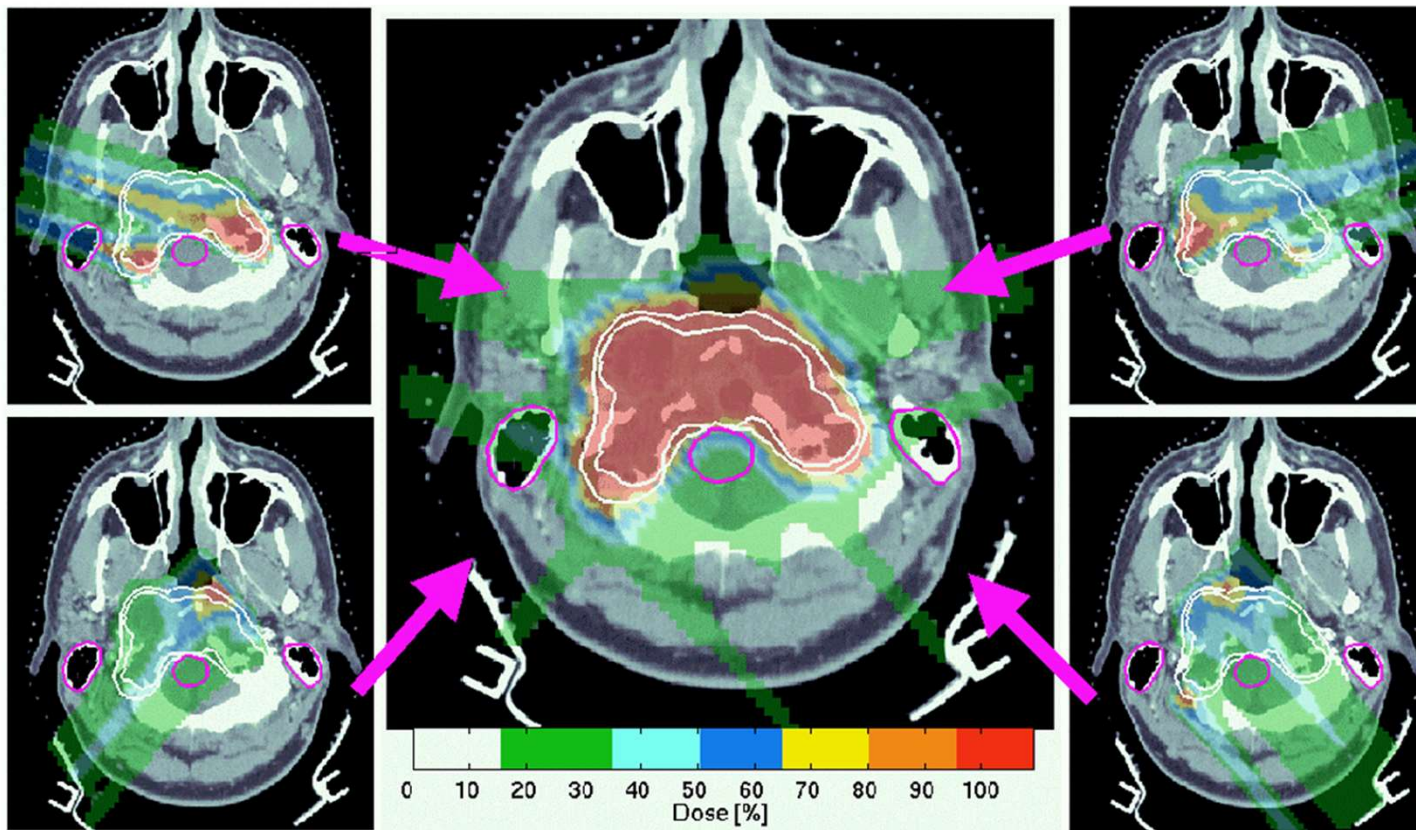
RayStation 10A and beyond is 100% ready for upright treatment planning

Particle Beams Stop Thereby Providing More Degrees of Freedom for Avoiding Normal Tissue



Multiple paths to the distal edge of a tumor reduces uncertainty.

IMPT is Nearly Mature Technology

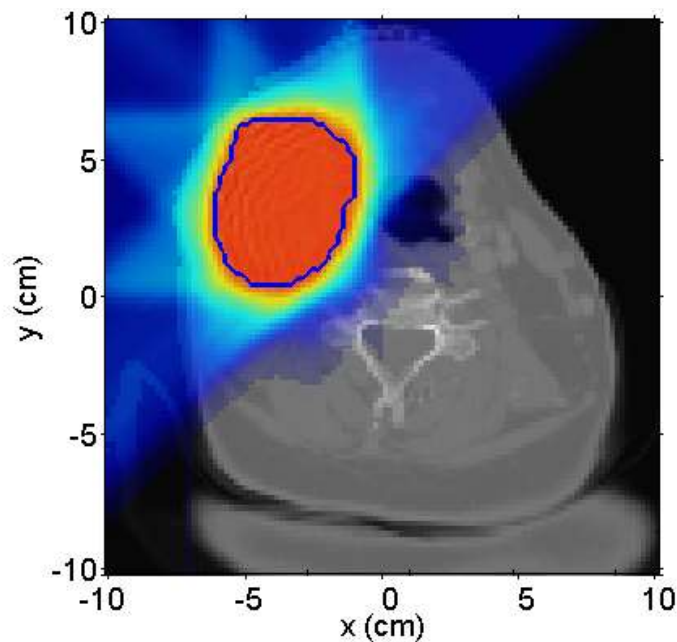


- Need to plan for robustness
- Affect of severe density heterogeneity is more important than for photon radiotherapy
- Effect of motion is more important than for photon radiotherapy

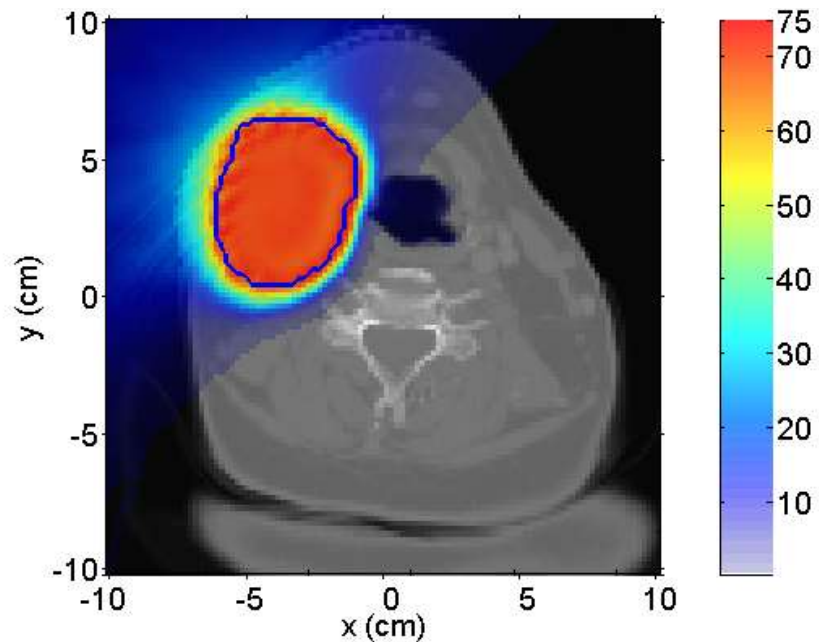
From Paganetti and Bortfeld, Proton Beam Radiotherapy – State of the Art

Spot Scanning and Arc Dose Distributions

Spot Scan Dose Distribution, 5 directions



Arc Distribution, 25 directions

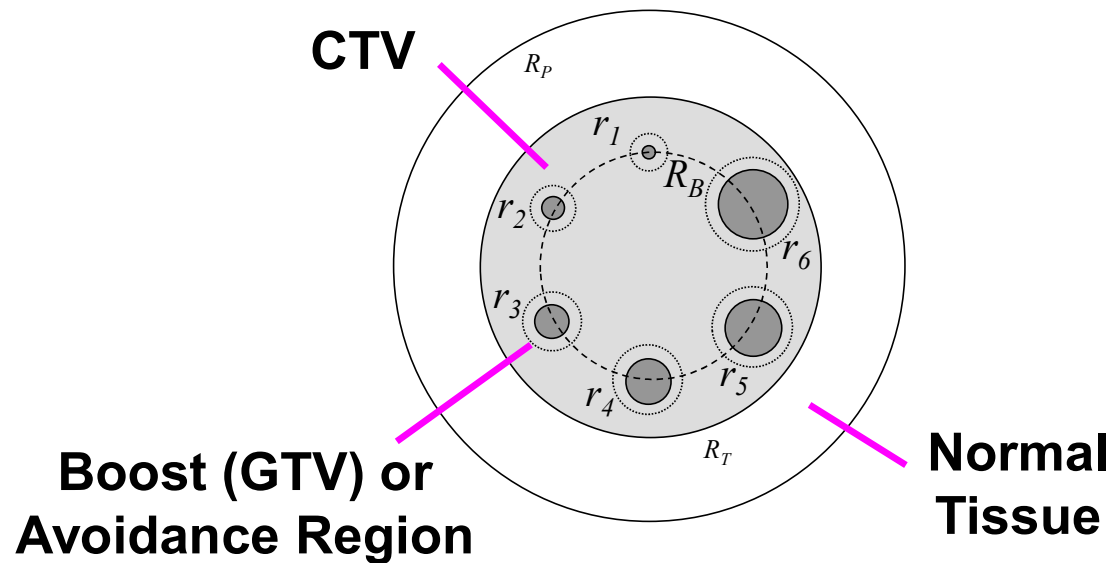


Arc Distributions Can Limit the Path Through Tumor and Reduce Spots on the Periphery Directed Towards Sensitive Normal Tissues

From Ryan Flynn, University of Iowa

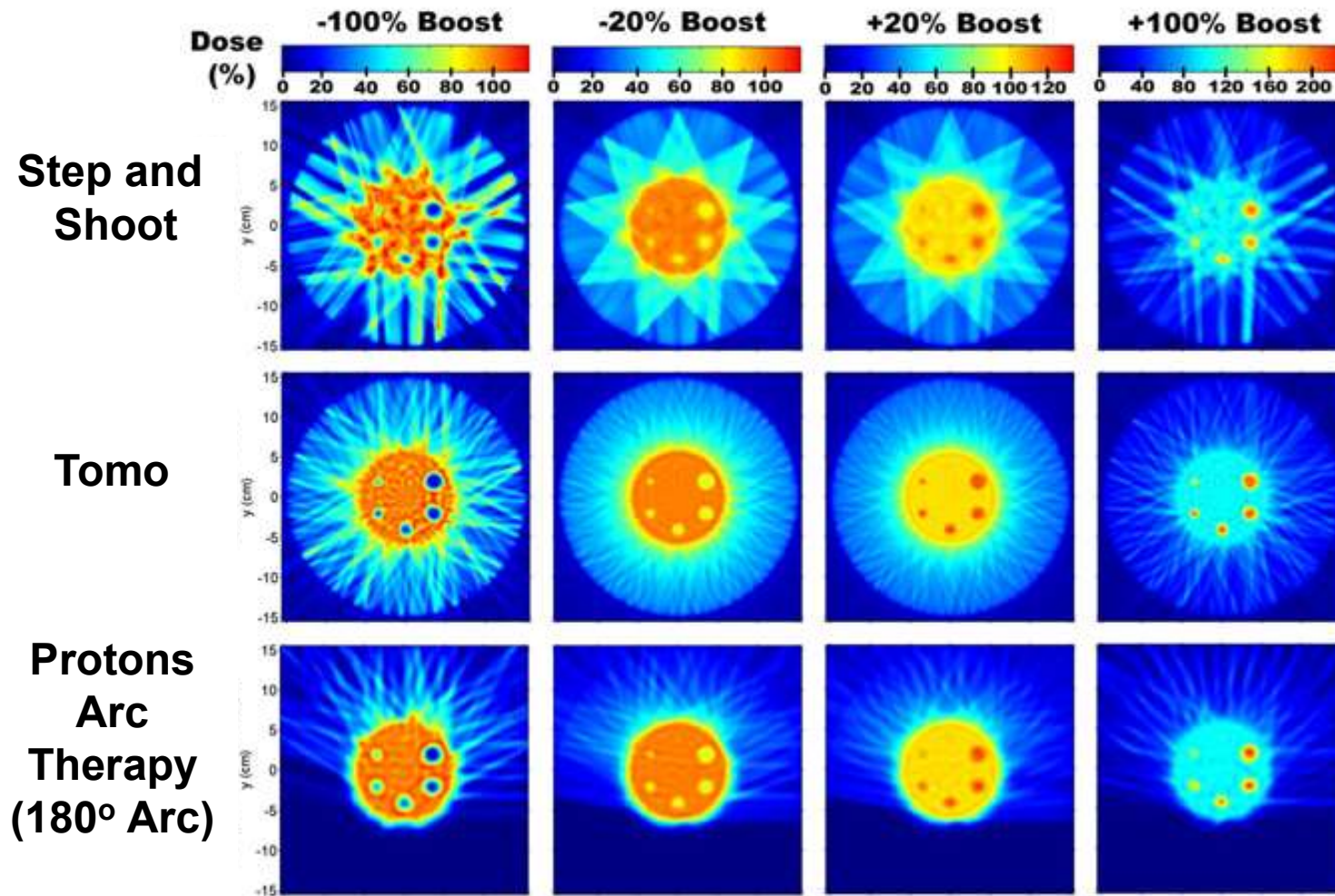
Dose Contrast Resolution

Apply Boost or Avoidance (Negative Boost) Dose to Regions of Varying Size



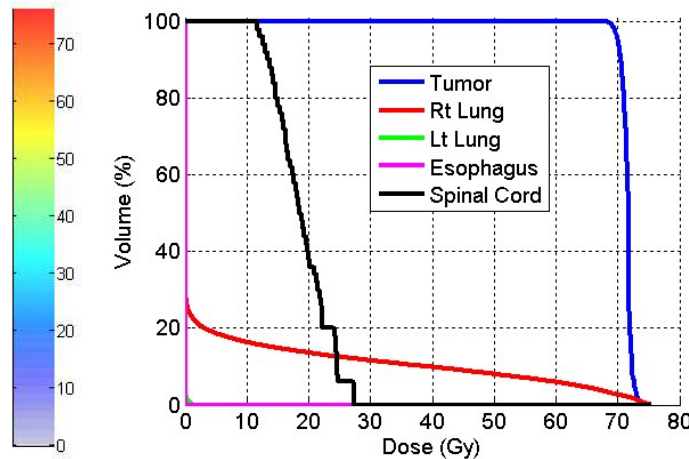
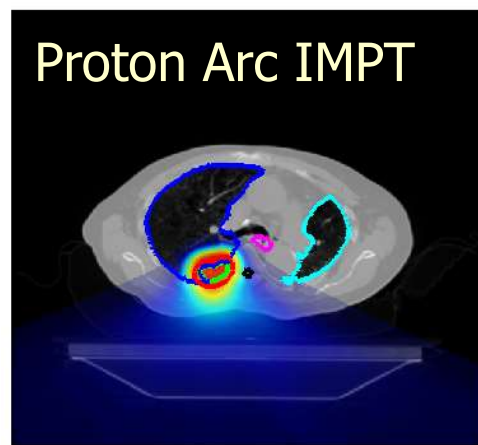
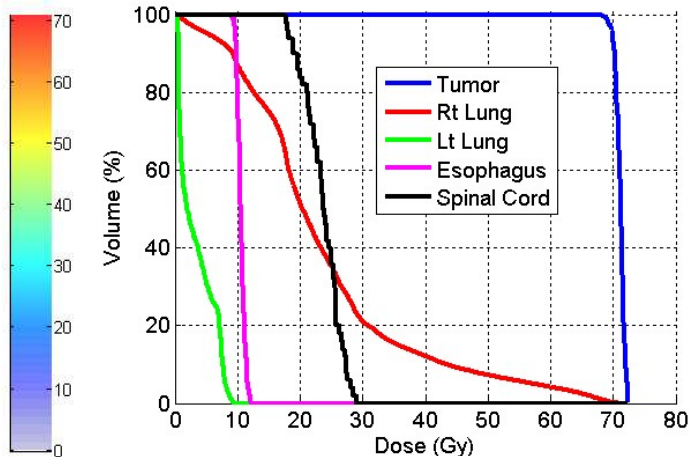
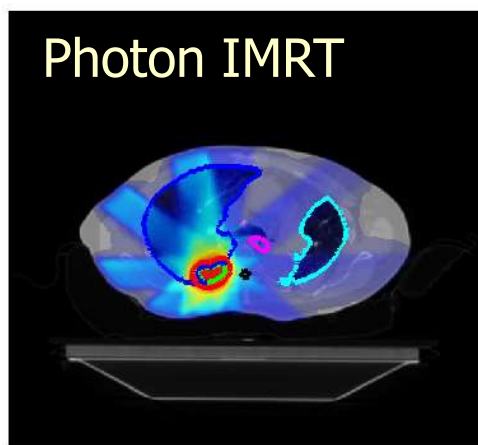
From Ryan Flynn, University of Iowa

Conformity and Normal Tissue Dose



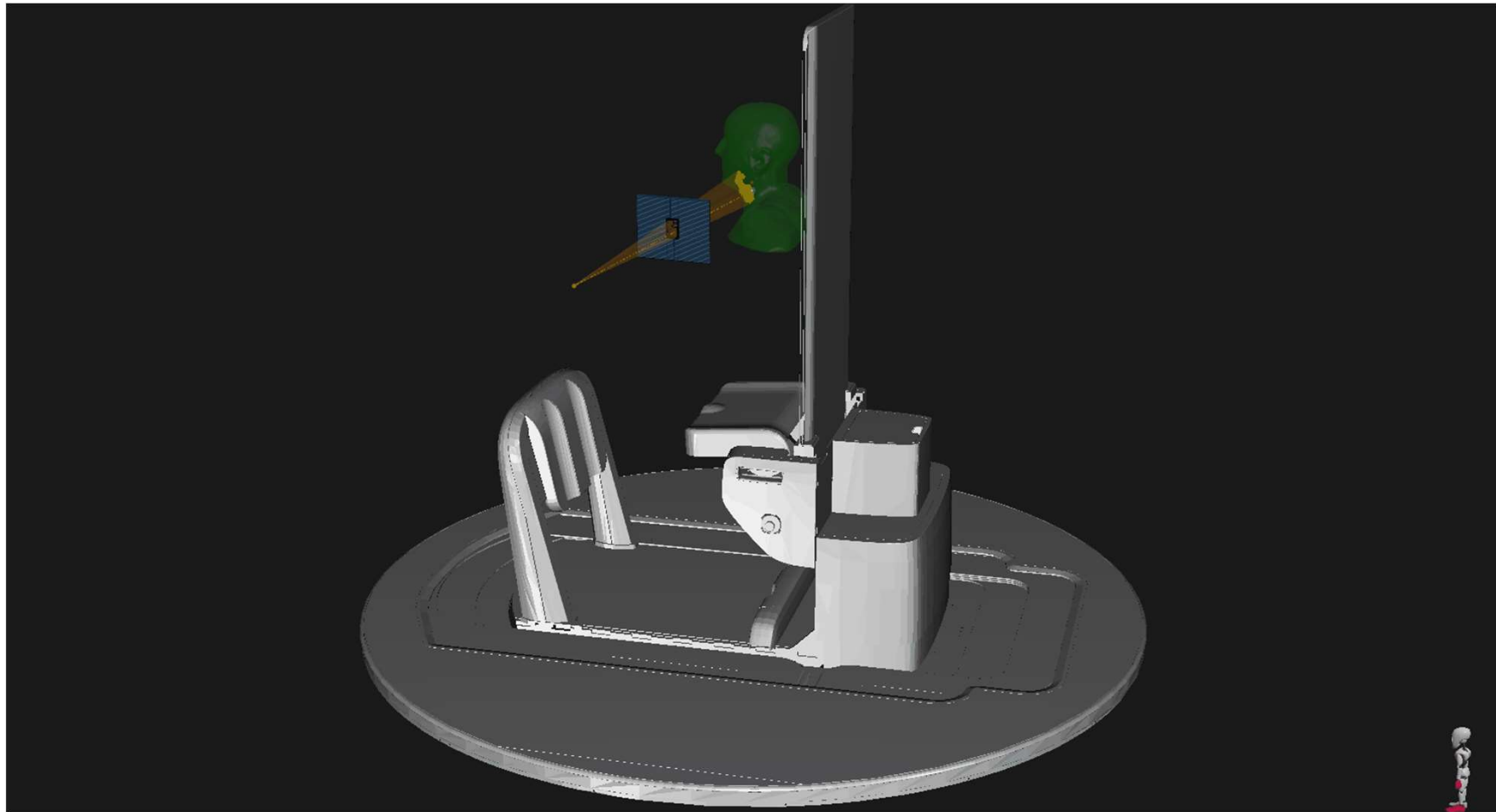
From Ryan Flynn,
University of Iowa

Comparison of Photon IMRT and Proton Arc IMPT



From Ryan Flynn,
University of Iowa

Upright Proton Arc Therapy Rendered by RaySearch



Proton Radiotherapy Should Not Be a Specialization

🕒 APRIL 21, 2015

Proton cancer therapy among areas threatened by skills shortage

by Cockcroft Institute



Proton Radiation Therapist, Emory Proton Therapy Center

🏢 Emory - 3.9 ★

📍 Atlanta, GA



Apply Now

Job Details

📅 Full-time

💰 Estimated: \$58,000 - \$82,000 a year

Qualifications

Writing skills

ARRT (T) Certification

ARRT Certification

CPR Certification

BLS Certification

Full Job Description

Overview

At Emory Healthcare, we integrate science and caring to change the face of health care. Our team members are courageous individuals who are willing to challenge the status quo and help find solutions to complex problems. We're empowered to influence change for, and with, our patients, their families, the community and each other.

As one of the leading academic medical systems, we're eager to share what we learn

Take Home Messages

- **Upright radiotherapy can:**
 - **Eliminate complex building projects and high costs**
 - **Eliminate proton gantry commissioning**
 - **Eliminate the need for specialty proton medical physicists**
- **High-quality upright CT scanner is required for upright radiotherapy**
- **QA and planning can be more similar**
- **IMPT and IMAT is nearly mature for upright radiotherapy**

Thank You

Or Perhaps Children Should Be Forward Leaning?



Fabricated by Niek Schreuder and Featuring His 3 yr Old Granddaughter