State of the ART

High Tesla MRgART

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COI

- License revenue from IBA
- Consulting for Elekta

Agenda

- Technology overview
- Implementation timeline
  - Construction
  - Installation
  - Commissioning
- Workflow overview at our site
- How are we using the Unity
  - Statistics on what kind of cases we have treated
  - Case highlight
- Treatment throughput and machine reliability

TECHNOLOGY OVERVIEW

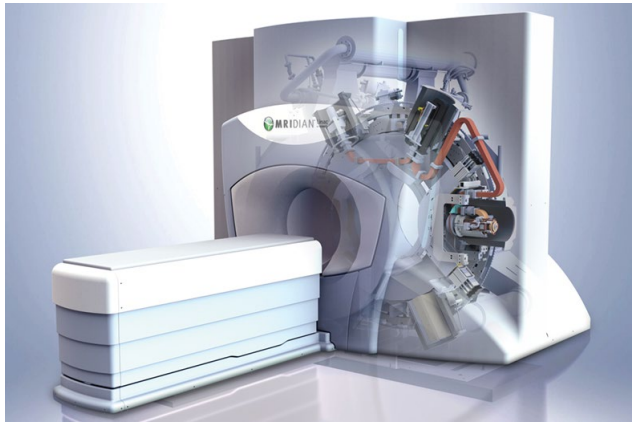
Commercial Implementations

FDA 510k cleared

Elekta Unity

B_{field} = 1.5 T
E = 7 MV

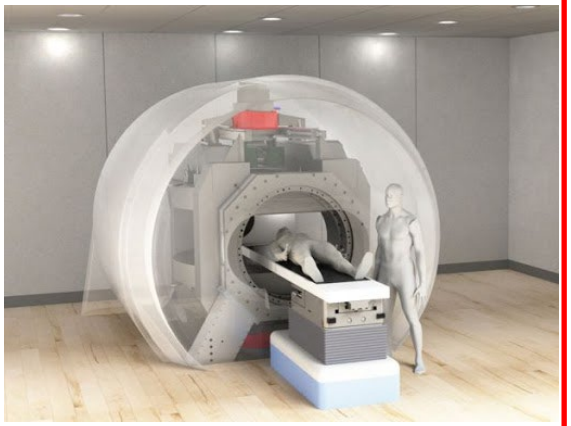
Viewray MRIdian



B_{field} = 0.35 T
E = 6 MV

FDA 510k pending

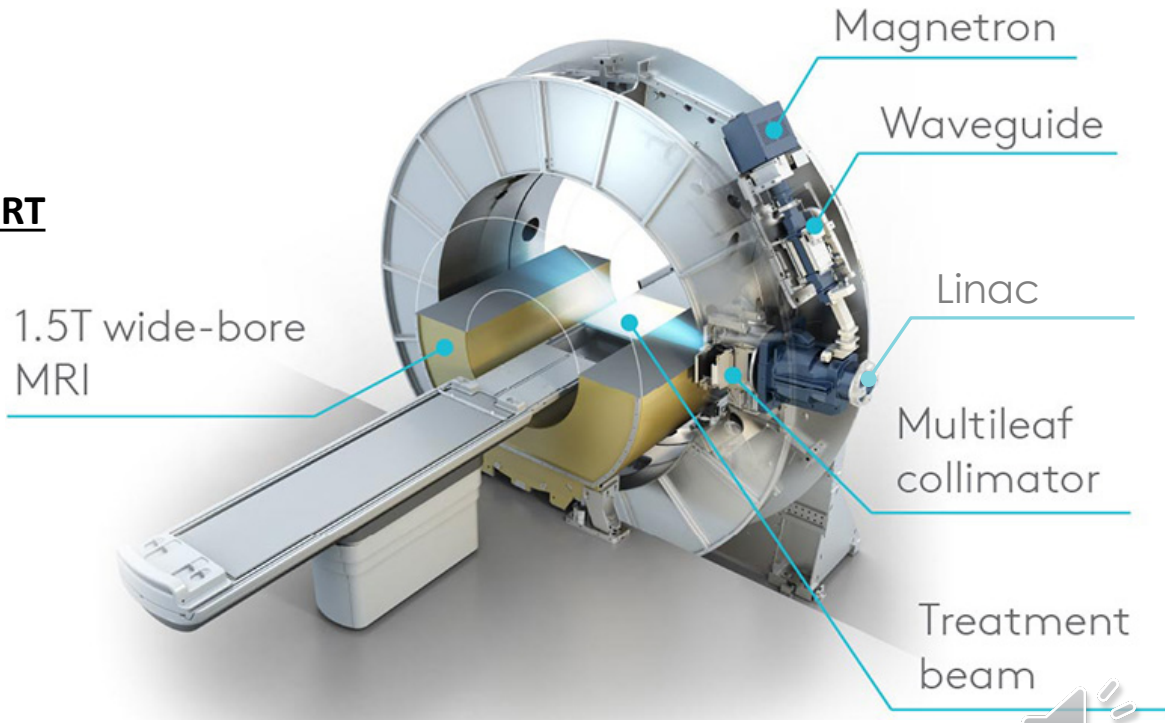
Magnet*Tx* Aurora RT



B_{field} = 0.5 T
E = 6 MV

Unity overview

- Beam Energy: **7 MV FFF**
- SAD: **143.5 cm**
- Maximum Field Size: **22x57.4 cm²**
- Treatment Delivery: **Step & Shoot IMRT**
- Dose Rate: **425 MU/min**
- Max Gantry Speed: **6 RPM**
- Leaf Speed: **6 cm/s**
- Collimator: **90°**

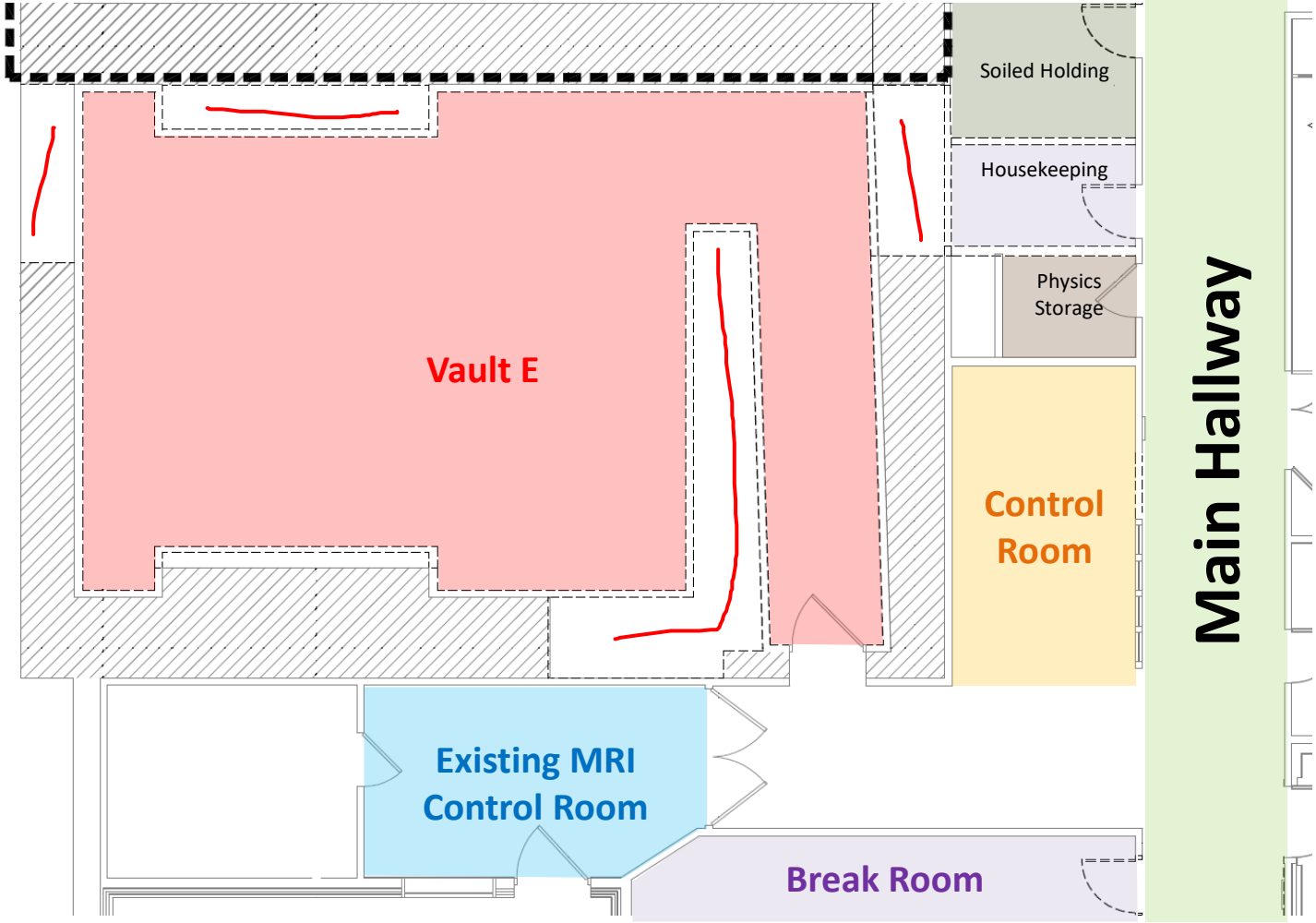


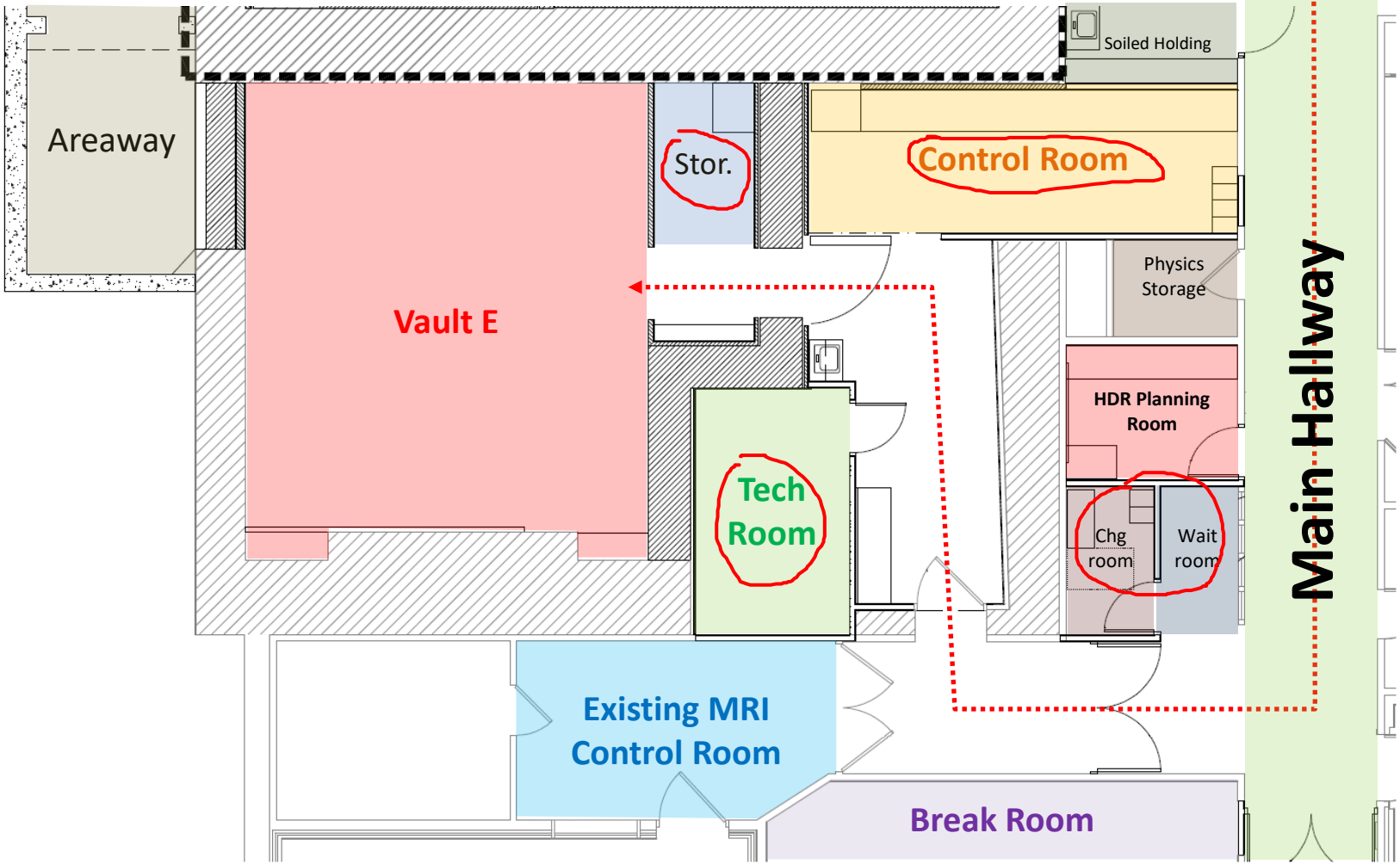
Construction: ~6 months (Highly Variable)

Installation: ~6 months (~3 months for new installations)

Commissioning/training: ~3 months

IMPLEMENTATION TIMELINE


Soiled Holding
Housekeeping
Physics Storage
Vault E
Control Room
Main Hallway
Existing MRI Control Room
Break Room


Areaway
Soiled Holding
Stor.
Control Room
Vault E
Physics Storage
HDR Planning Room
Tech Room
Chg room
Wait room
Main Hallway
Existing MRI Control Room
Break Room

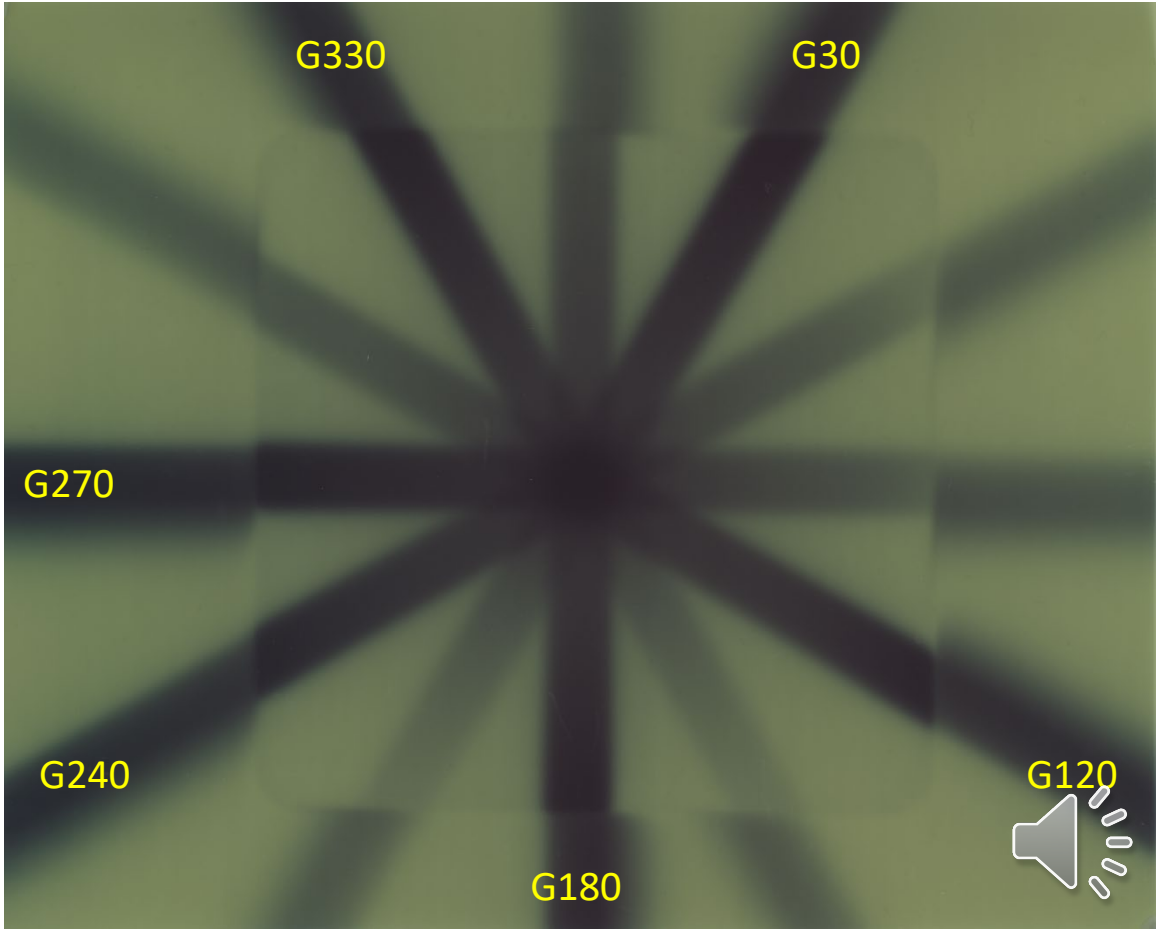
Implementation timeline

MV isocenter, MR-MV alignment

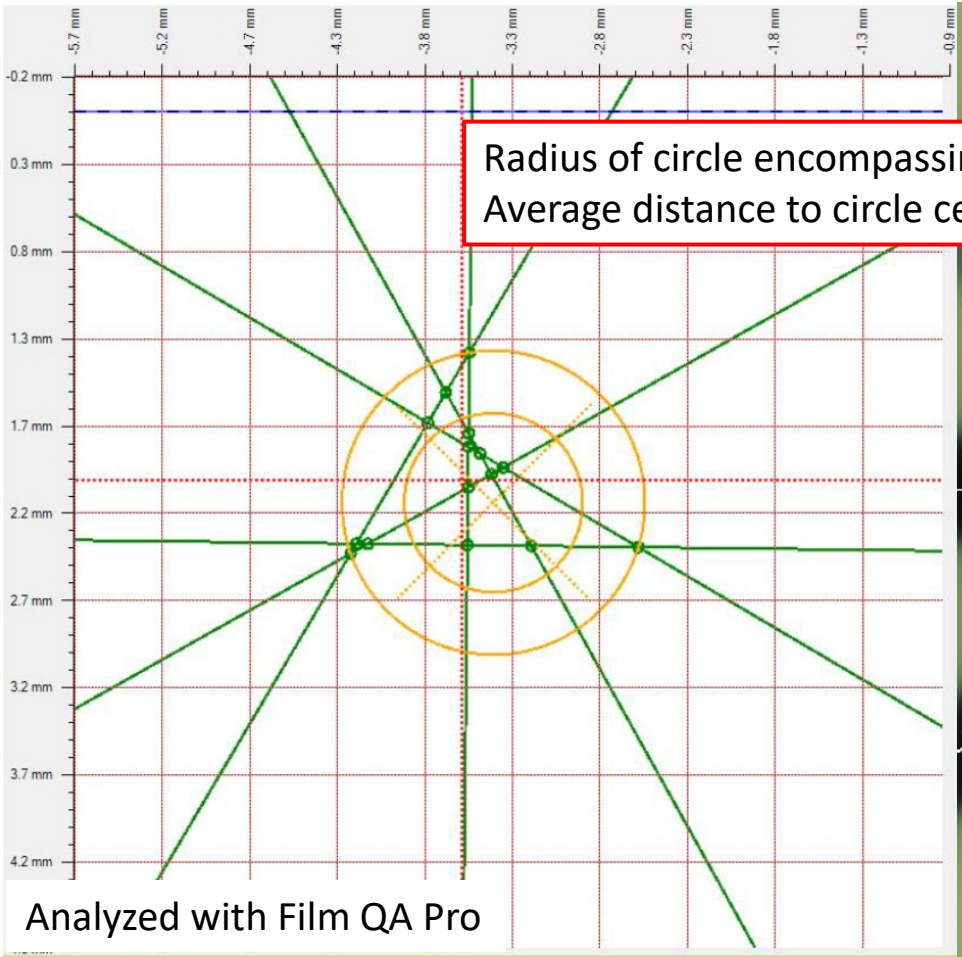
COMMISSIONING: MECHANICALS

MV isocenter - starshot

- Need to add copper plates to eliminate ERE
- Analyze spokes only within the central region

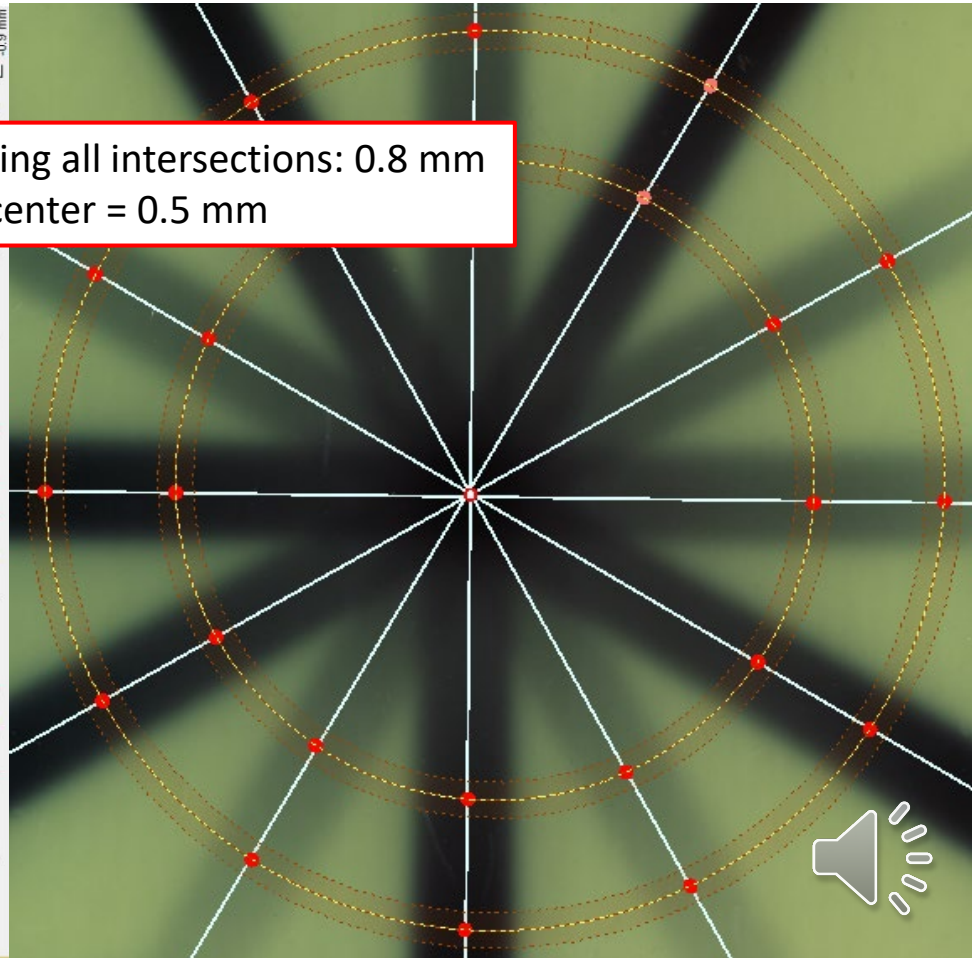


MV isocenter - starshot results



Radius of circle encompassing all intersections: 0.8 mm
Average distance to circle center = 0.5 mm

Analyzed with Film QA Pro

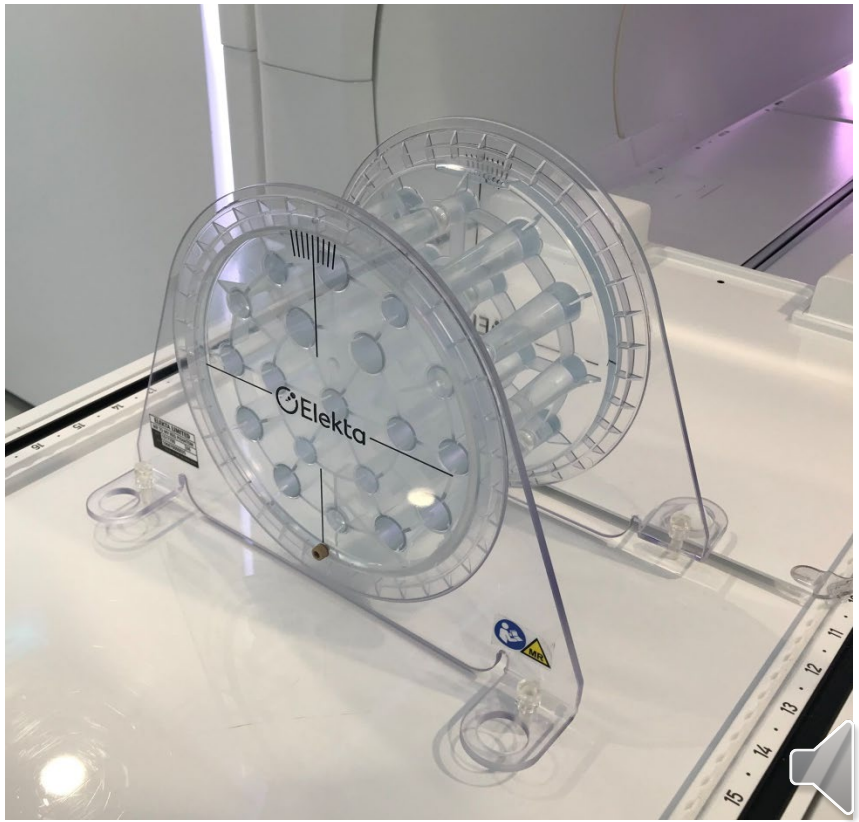


MR-MV alignment

- MRI and gantry are mechanically aligned during installation
- Any offset between the systems needs to be quantified and accounted for during treatment planning

MR-MV alignment phantom

- Alignment evaluated using the MR-MV isocenter phantom
  - 7 ZrO_2 spheres in a known geometry surrounded by copper sulfate solution
- EPID and MRI images are acquired without moving the phantom
- Analyzed using QA alignment software
  - 0.307 mm (lat), 0.998 mm (sup/inf), 0.015 mm (ant/post)



Absolute dose calibration

COMMISSIONING: DOSIMETRY

Dose calibration methodology

- Followed TG-51 formalism with modifications by Malkov *et al*[1]

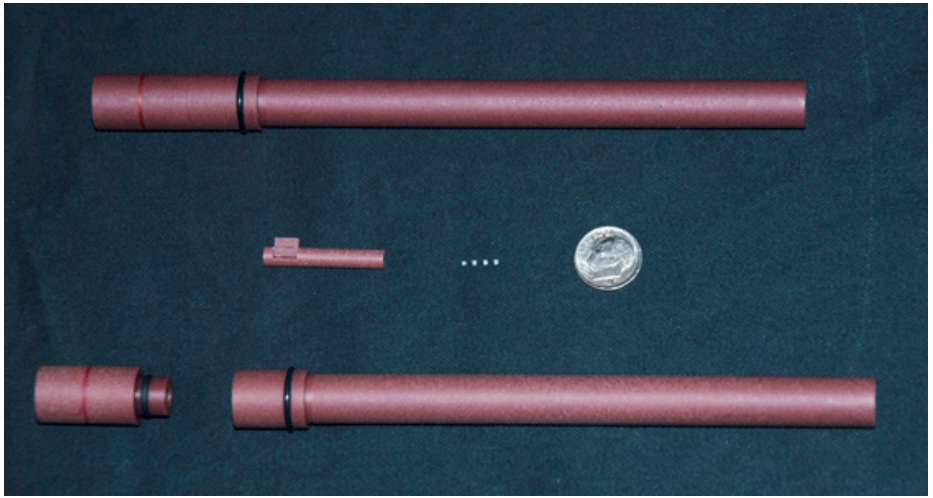
$$D_W^Q = M k_Q k_B N_{D,w}^{^{60}Co}$$

  - Due to extended SAD, beam quality specifier was $TPR_{20,10}$
    - TG-51 requires $\%dd(10)_x$ for k_Q determination
      - Conversion following the formalism of Kalach *et al*[2]
  - K_B factor accounts for changes in chamber response due to the magnetic field
    - TN30013 chamber aligned parallel with the magnetic field
      - 0.994 (O'Brien et al)[3]
      - 0.988 (Malkov et al)[1]
  - Output measured at 90° to remove dependence due to varying helium level

1. Malkov V N and Rogers D W O 2018 Monte Carlo study of ionization chamber magnetic field correction factors as a function of angle and beam quality *Medical Physics* **45** 908-25
2. Kalach N I and Rogers D W 2003 Which accelerator photon beams are "clinic-like" for reference dosimetry purposes? *Med Phys* **30** 1546-55
3. O'Brien D J, Roberts D A, Ibbott G S and Sawakuchi G O 2016 Reference dosimetry in magnetic fields: formalism and ionization chamber correction factors *Med Phys* **43** 4915

Dose calibration validation

- Independent validation performed with UW Calibration Lab TLDs
- Construction of probes
  - 4 TLDs embedded in a solid water phantom with minimal air-gaps
- Result: 0.991 ± 5%

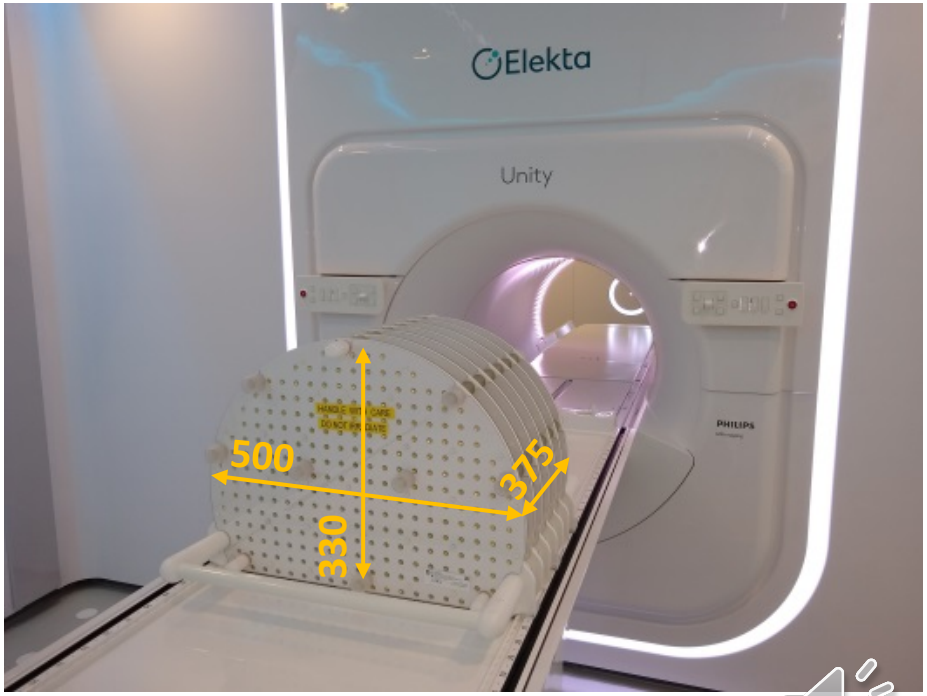


Geometric accuracy

MRI COMMISSIONING

Geometric accuracy

- Assessed using the vendor supplied 3D geometry phantom
  - Markers in 7 planes
    - 25 mm in-plane spacing
    - 55 mm plane spacing
  - Overall size
    - 500x375x330 mm^3

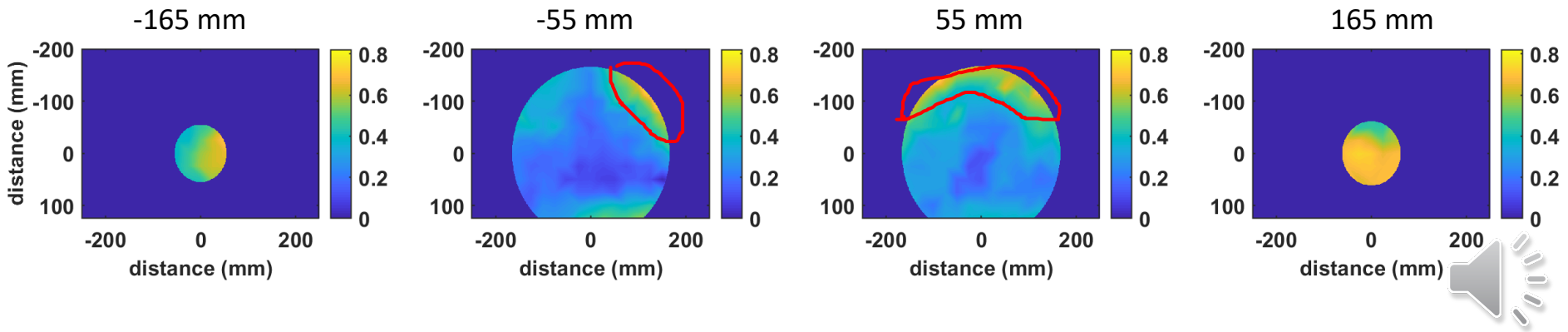


Geometric accuracy – results

- Geometric accuracy is assessed within variable diameter spherical volumes

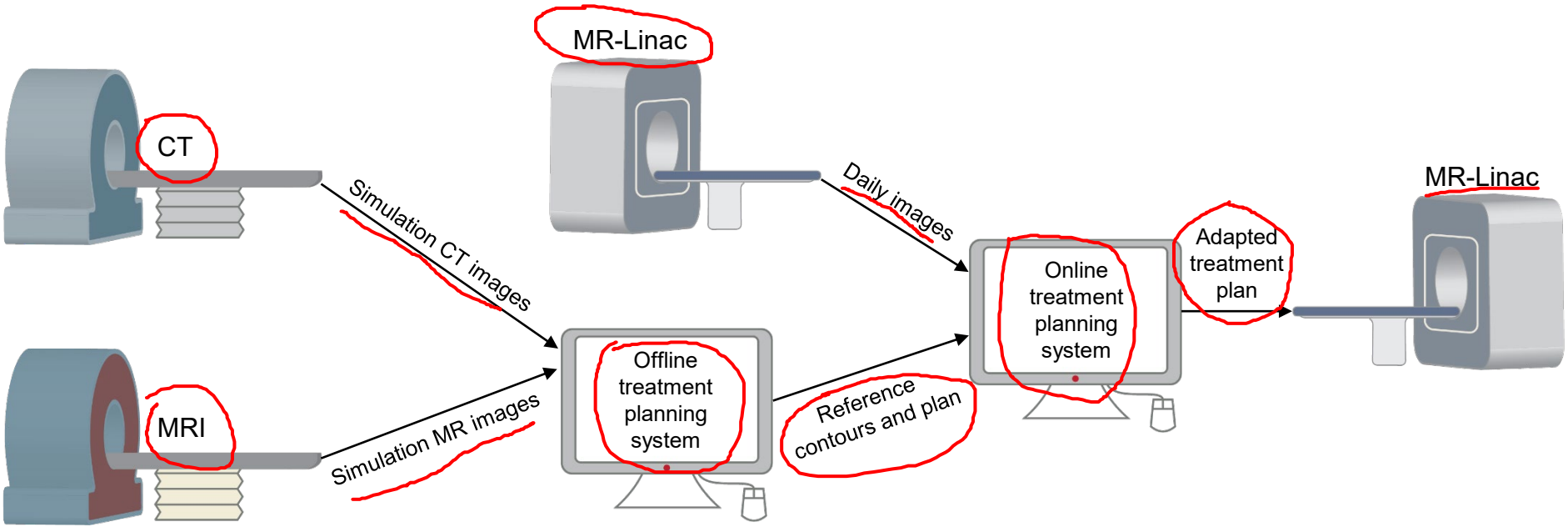
	Maximum distortion (mm) – Excluding 2% of markers with greatest values				
	400 mm DSV	350 mm DSV	300 mm DSV	200 mm DSV	100 mm DSV
Total	2.05	0.82	0.68	0.52	0.32
RL	0.64	0.43	0.35	0.27	0.16
AP	1.72	0.64	0.51	0.38	0.22
FH	0.45	0.39	0.36	0.28	0.19

Distortion map for 350 mm DSV

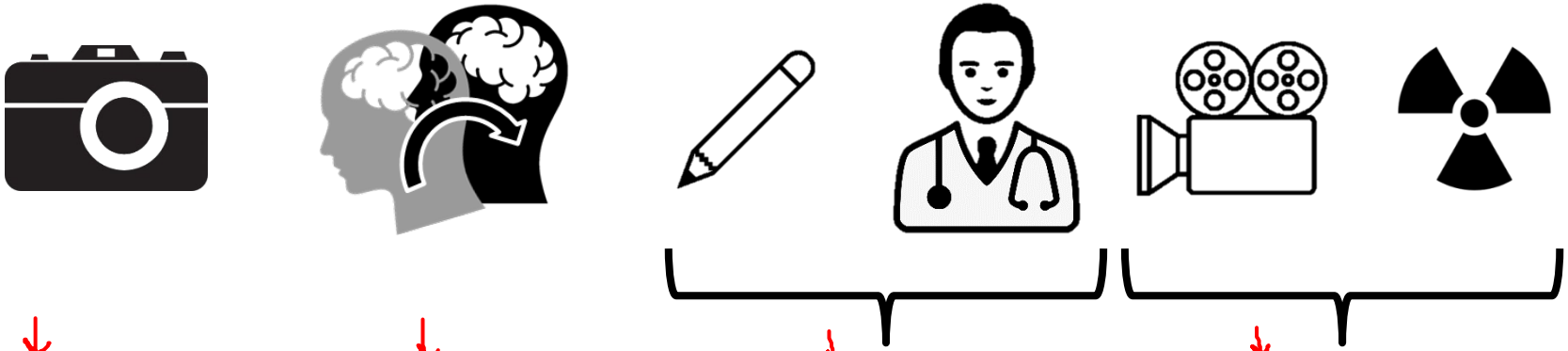


ADAPTIVE THERAPY WORKFLOW

Workflow overview



Online treatment process



- Setup and image patient
- Register daily and planning datasets
- Re-contour and re-plan as needed
- Motion monitoring (3-planes) and radiation delivery

1 Physician

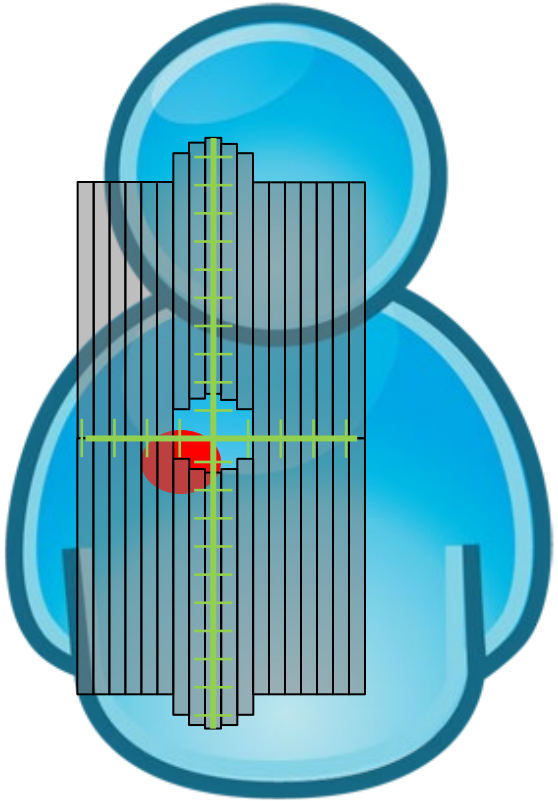
1 Physicist

2 RTT techs

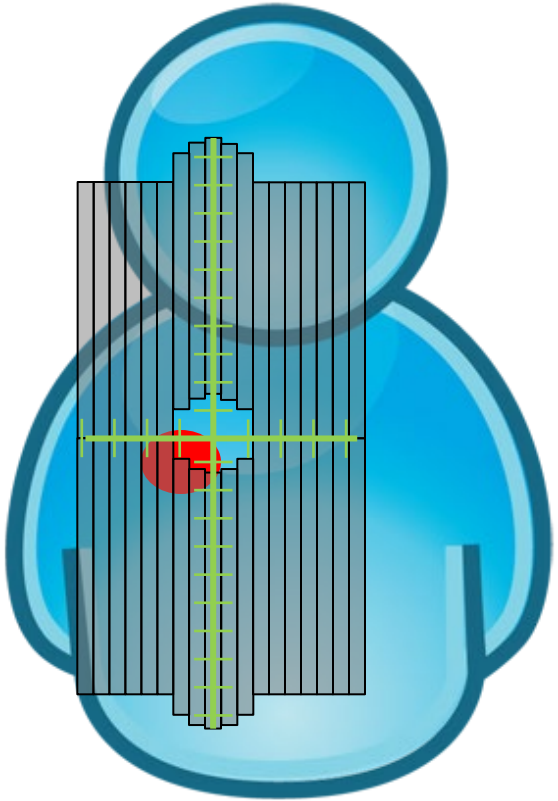
Understanding the adaptive planning process

- Adapt to position
  - MLC position is shifted to account for daily setup errors
  - Plan is re-calculated with new MLC positions
    - No new contours are drawn!
- Adapt to shape
  - New contours are drawn to account for anatomical changes
  - Plan is re-optimized and re-calculated

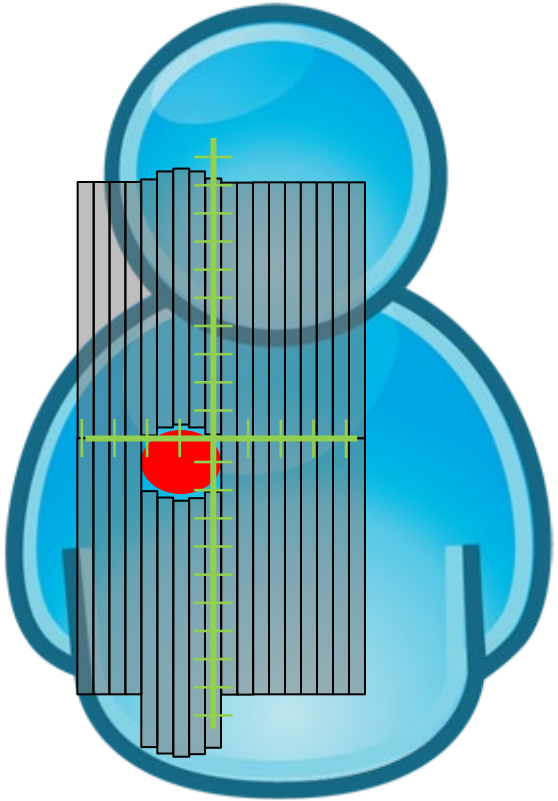
Standard linac: Table shift



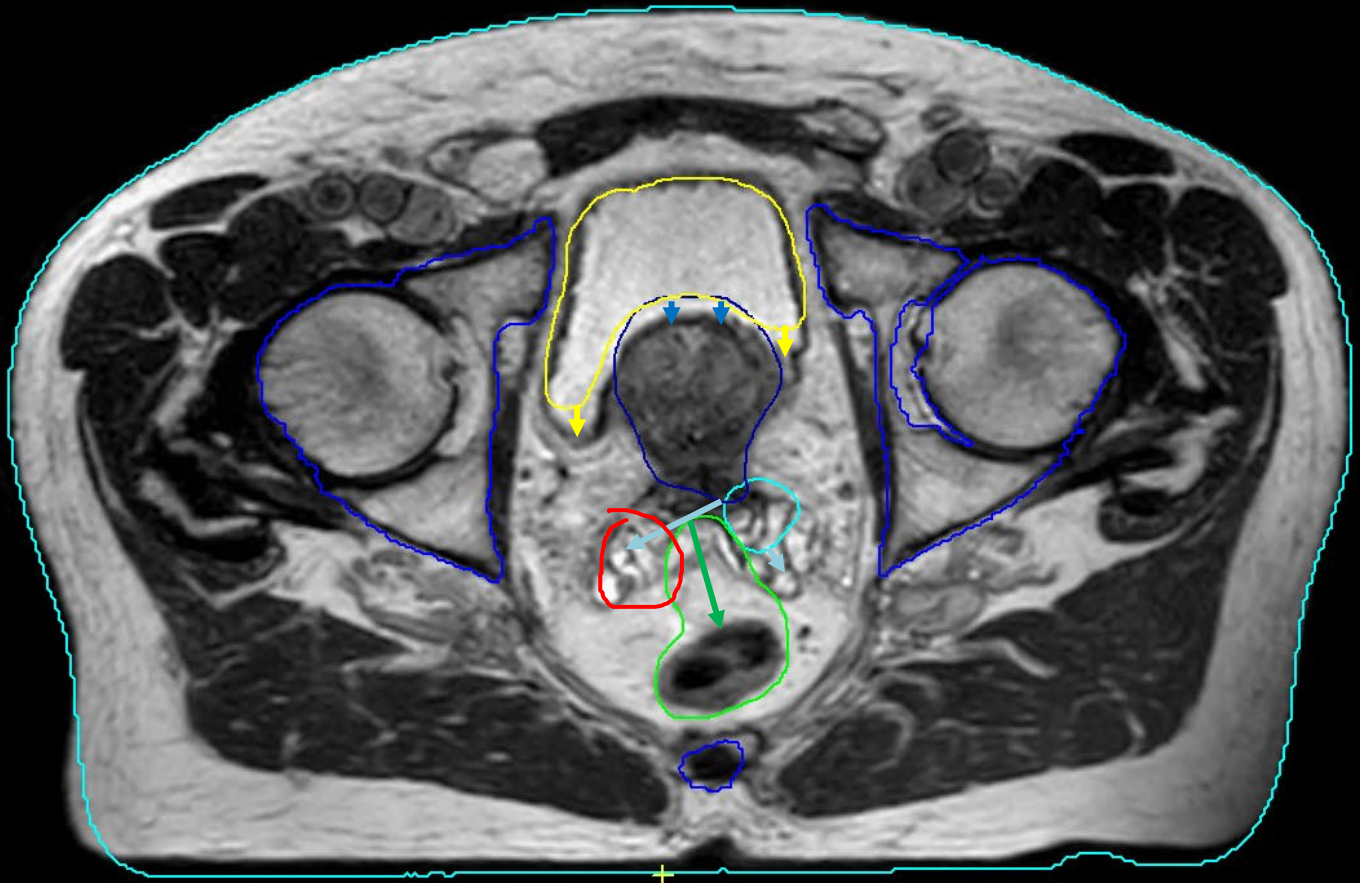
MRI linac: Adapt to Position



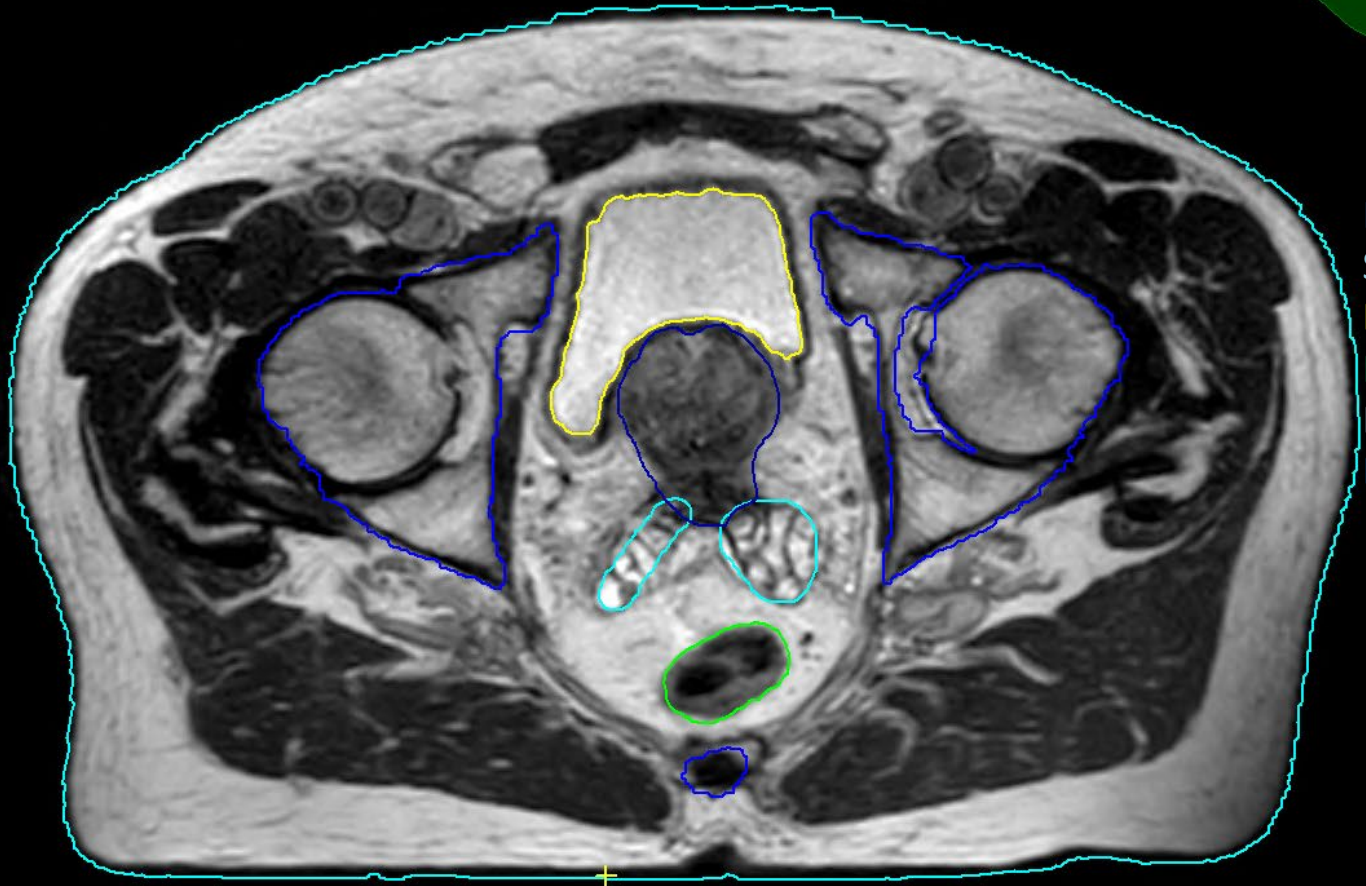
MRI linac: Adapt to Position



Adapt to Shape: Original contours



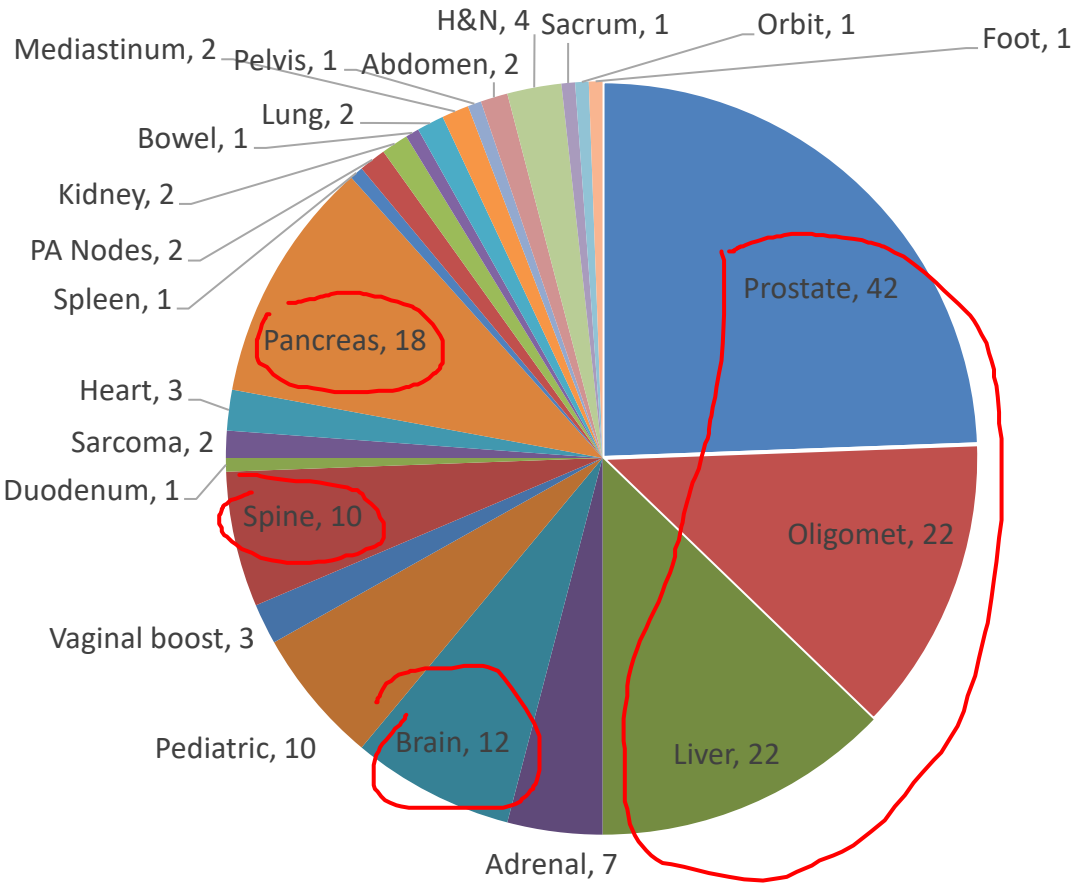
Adapt to shape: Adapted contours

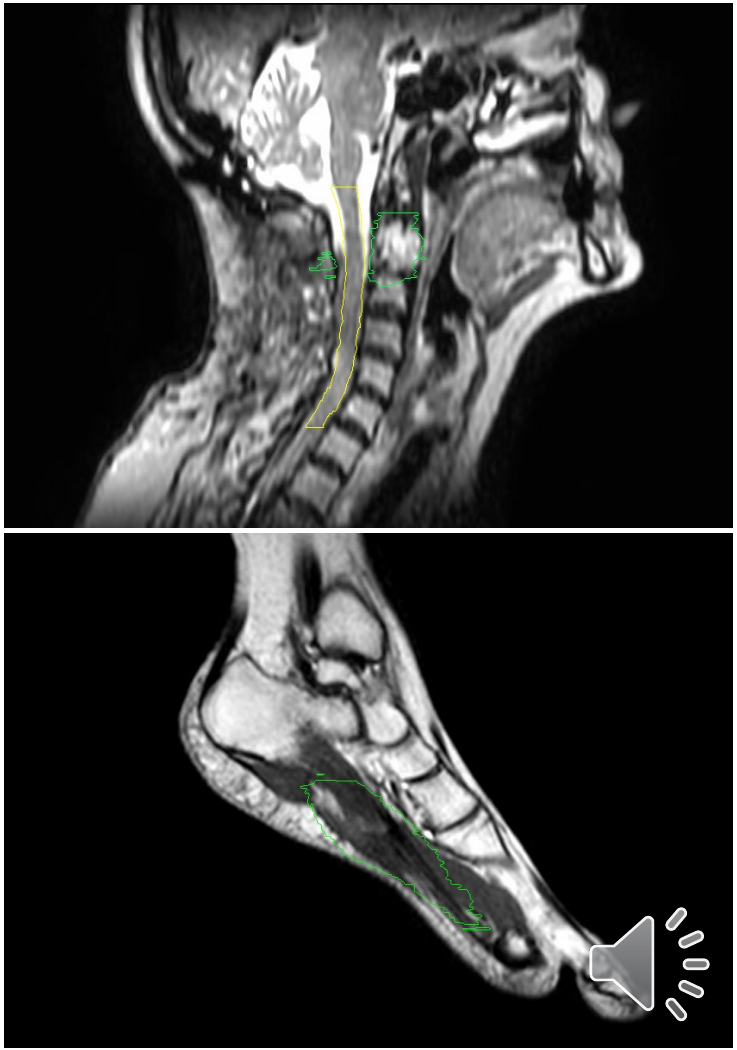


Statistics and case highlights

HOW ARE WE USING THE UNITY?

Sites treated





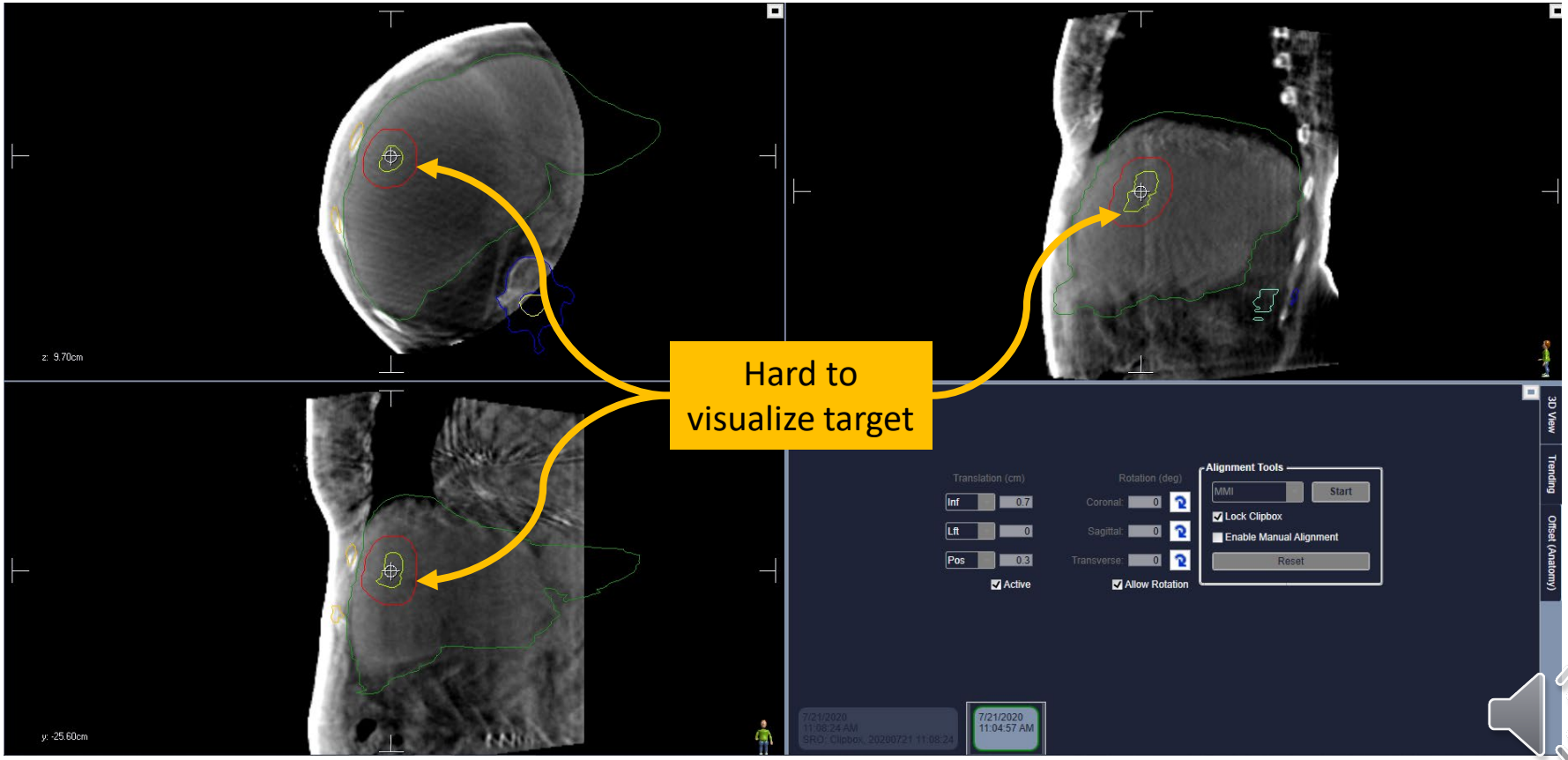
Case highlight: Liver

- Potential benefits
  - Visualizing tumor
    - Far superior to CBCT
  - Visualizing adjacent OAR's
    - Adapt plan if position of OAR's change throughout treatment to achieve ablative doses
    - 3 fx RX: 45-60 Gy, Limit to bowel is 35 Gy
- Challenges
  - Motion
    - Typically can use abdominal compression to reduce motion

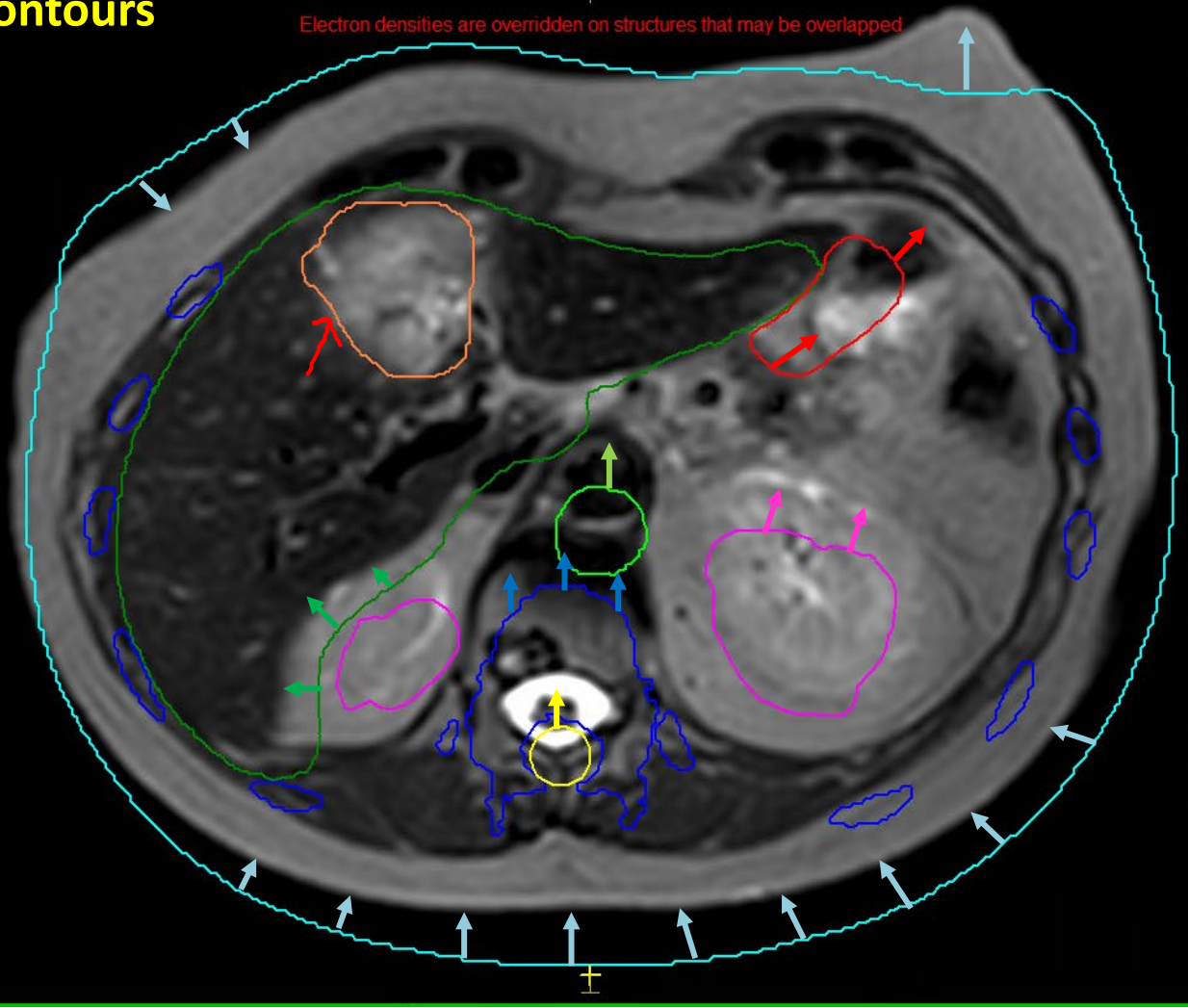
Standard planning strategy

- Unity
  - HCC: 45 Gy / 3fx
  - Mets: 54-60 Gy / 3 fx
  - 3-5 mm PTV around ITV
    - 8-10 mm with KV imaging
  - 11 coplanar beams
  - Step and shoot IMRT
- Unity imaging
  - T2 navigator triggered MRI

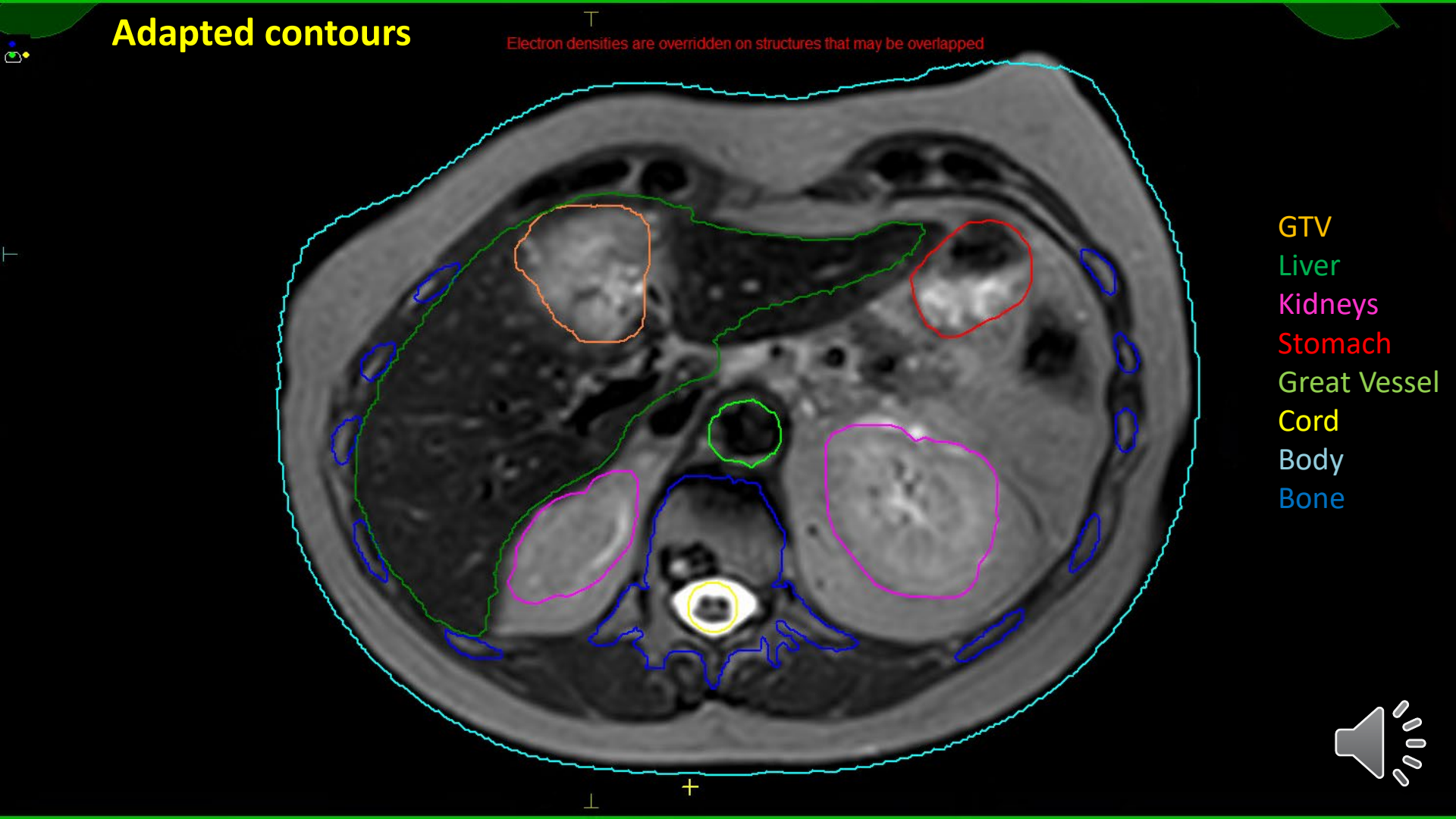
Standard of care – CBCT



Original contours



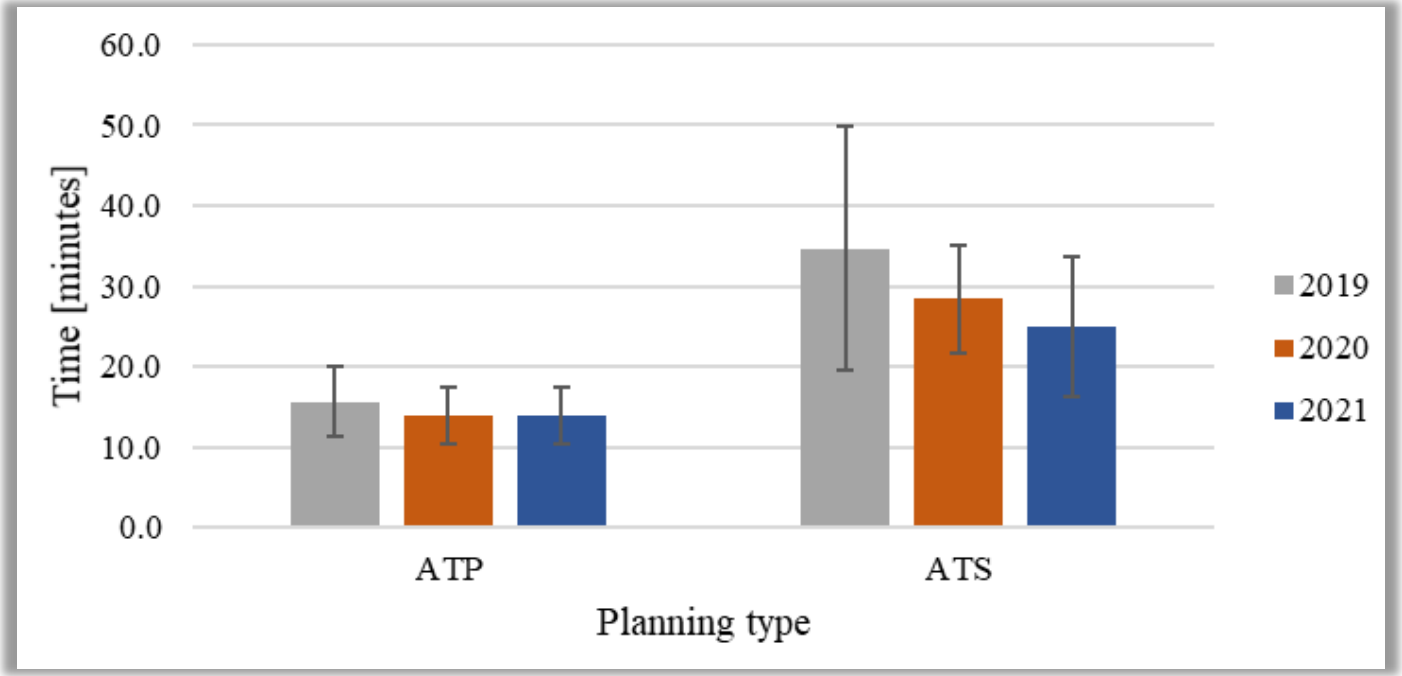
Adapted contours



Treatment throughput and uptime

MR-LINAC

Planning and review time



Included
- Registration
- Contouring (if needed)
- Plan optimization
- Plan approval
- Second check

Not Included
- Patient ingress/egress
- Image acquisition
- Treatment delivery

Slide from David Dunkerley, PhD

Machine uptime

	Versa A	Versa B	Unity	GammaKnife
Start Date:	12/1/2018	12/1/2018	5/20/2019	12/1/2018
End Date:	12/1/2019	12/1/2019	12/1/2019	12/1/2019
Down Time [Hr]	15.75	62.95	28.03	0.00
Workdays In Range (M-F)	261	261	139	261
Holidays in Range	10	10	4	10
Principal period of maintenance (PPM) [hr/d]:	14	14	14	14
Total PPM [hr]	3514	3514	1890	3514
Up-Time [%]:	99.55%	98.21%	98.52%	100.00%

Thanks!