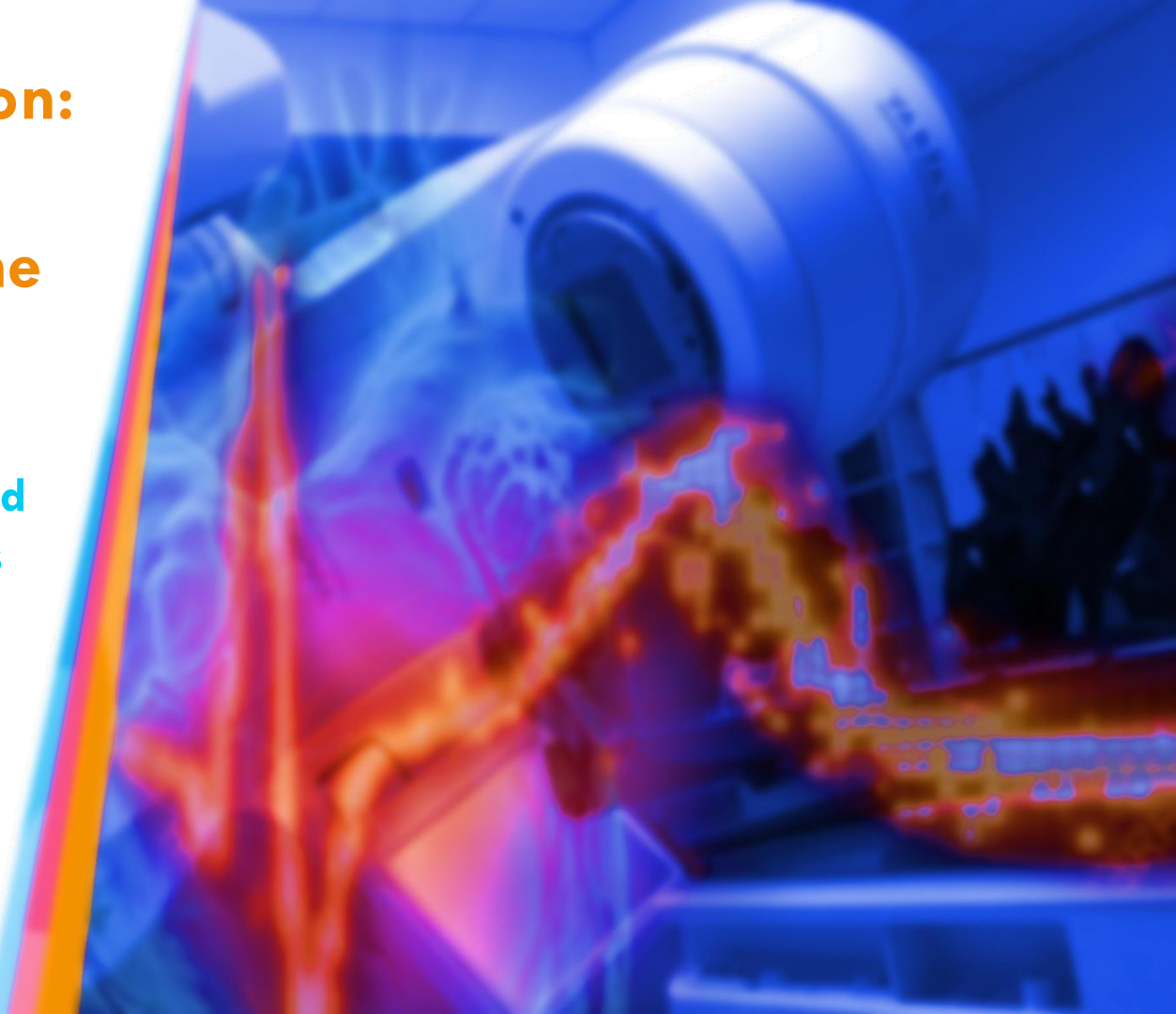


Cardiac radioablation: How can medical physicists shape the future?

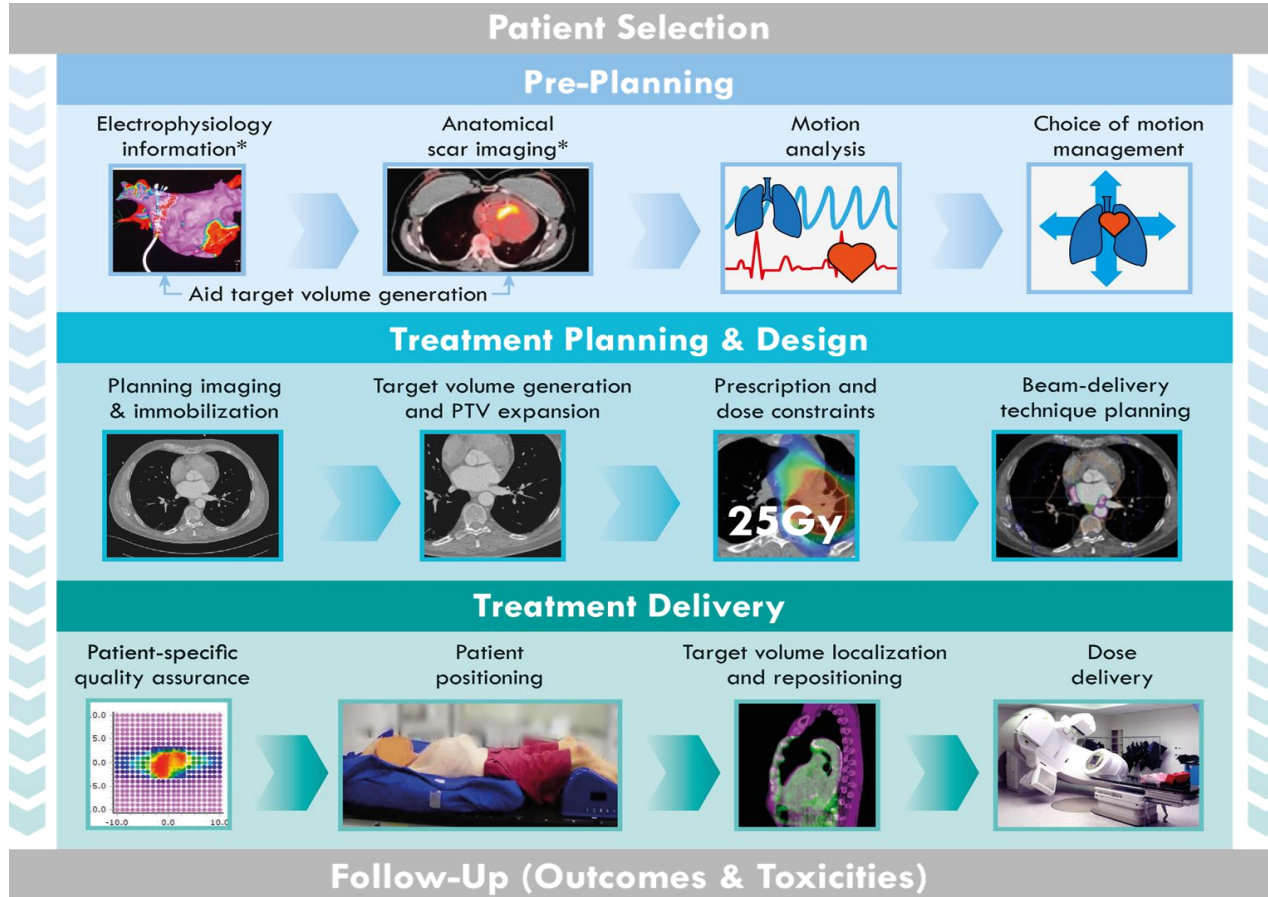
Challenges and research and
development opportunities

Suzy Lydiard

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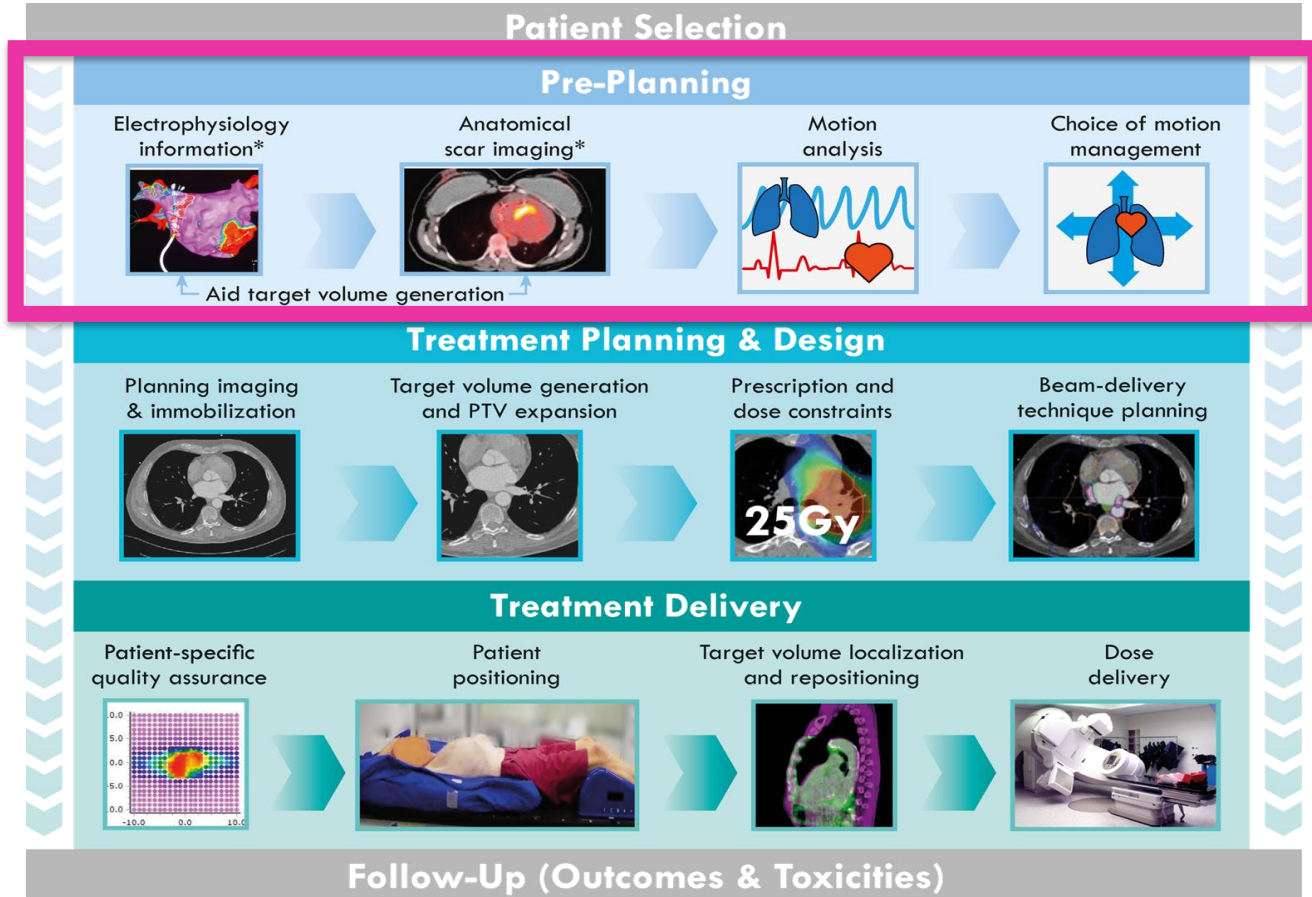
Cardiac Radioablation Overview



*Not always used in cardiac radioablation workflows

From Lydiard et al. A review of Cardiac Radioablation for Arrhythmias: Procedures, Technology, and Future Opportunities. IJROBP 2021

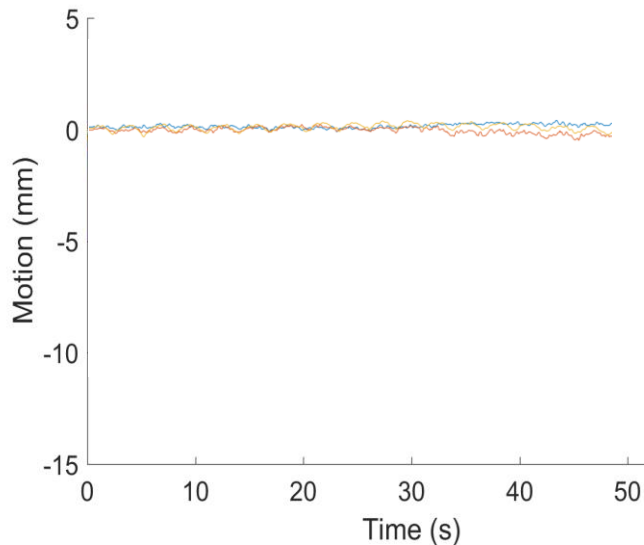
Cardiac Radioablation Overview



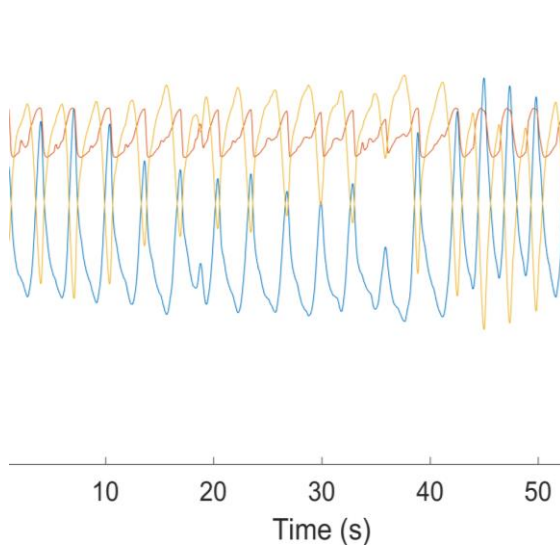
*Not always used in cardiac radioablation workflows

Pre-Planning: Motion Analysis

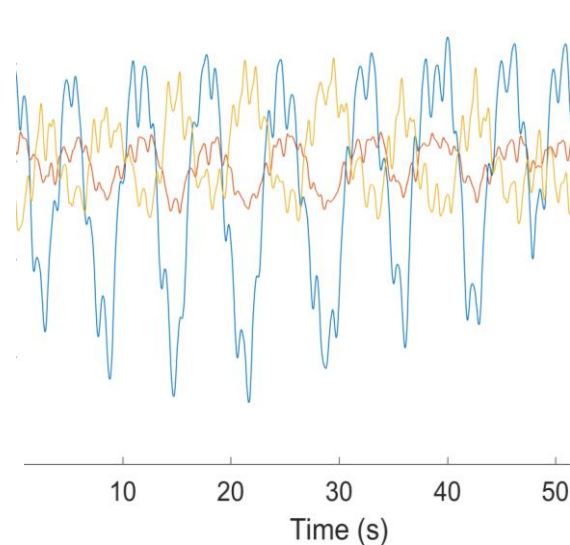
Prostate cancer



Lung cancer



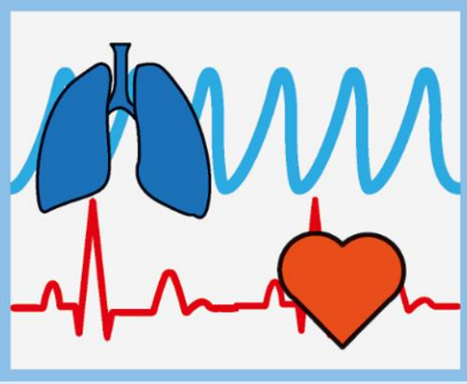
CR targets



Human target trajectories acquired as part of Calypso clinical trials (prostate & lung) or via Ultrasound for experiments published in Lydiard, S., et al Phys. Med. Biol (2018).

Pre-Planning: Motion Analysis

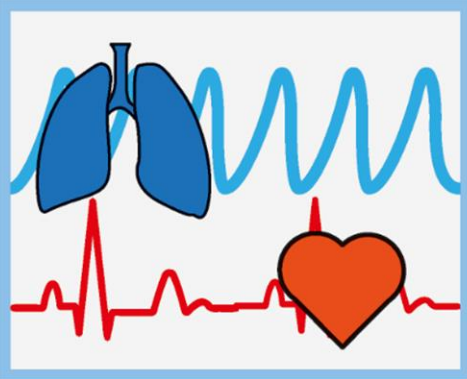
Motion analysis



- Free-breathing 4DCT
- ECG-triggered CT
- Transthoracic echocardiography
- Fluoroscopy of ICD leads or fiducials
- Population-based assumptions
- MRI

Pre-Planning: Motion Analysis

Motion analysis



- Abdominal compression: 4.4 mm (3-11 mm) axial, 4.7 mm (6-12 mm) coronal, 3.0 mm (1-7.2 mm) sagittal *Knutson et al (2020)*
- Respiratory-induced: 5.0 – 16.5 mm SI *Lydiard et al (2021)*
- Cardiac-induced: 3.3 – 4.5 mm on average, but maximum displacements up to 12.3 mm *Lydiard et al (2021)*
- Cardiac motion variable depending on specific sub-structure *Ouyang et al (2020)*


Pre-Planning: Motion Management

Motion type


Motion Management Techniques

Respiratory

- High magnitude
- Low frequency



Breath hold




Gated delivery



Combined ITV




Direct tracking



Cardiac

- Low magnitude
- High frequency



**Tracking* /
ITV /
Gated delivery***

**Tracking* /
ITV /
Gated delivery***

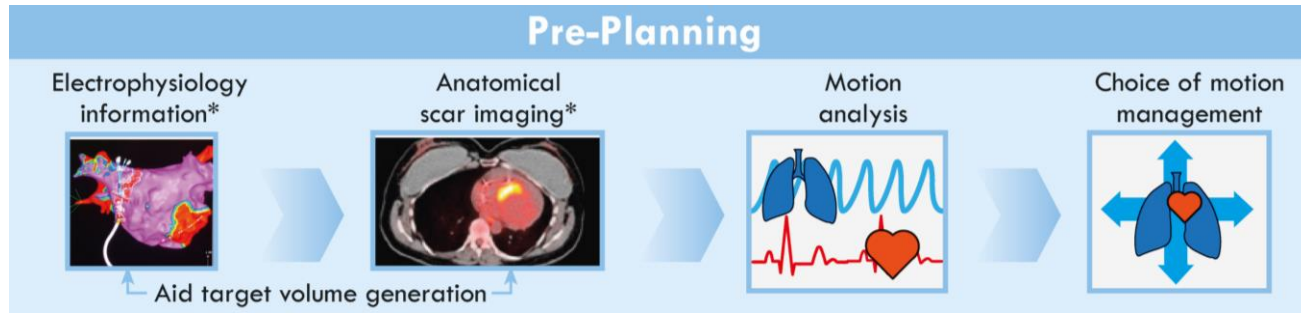
Direct tracking*



***Not yet used clinically**

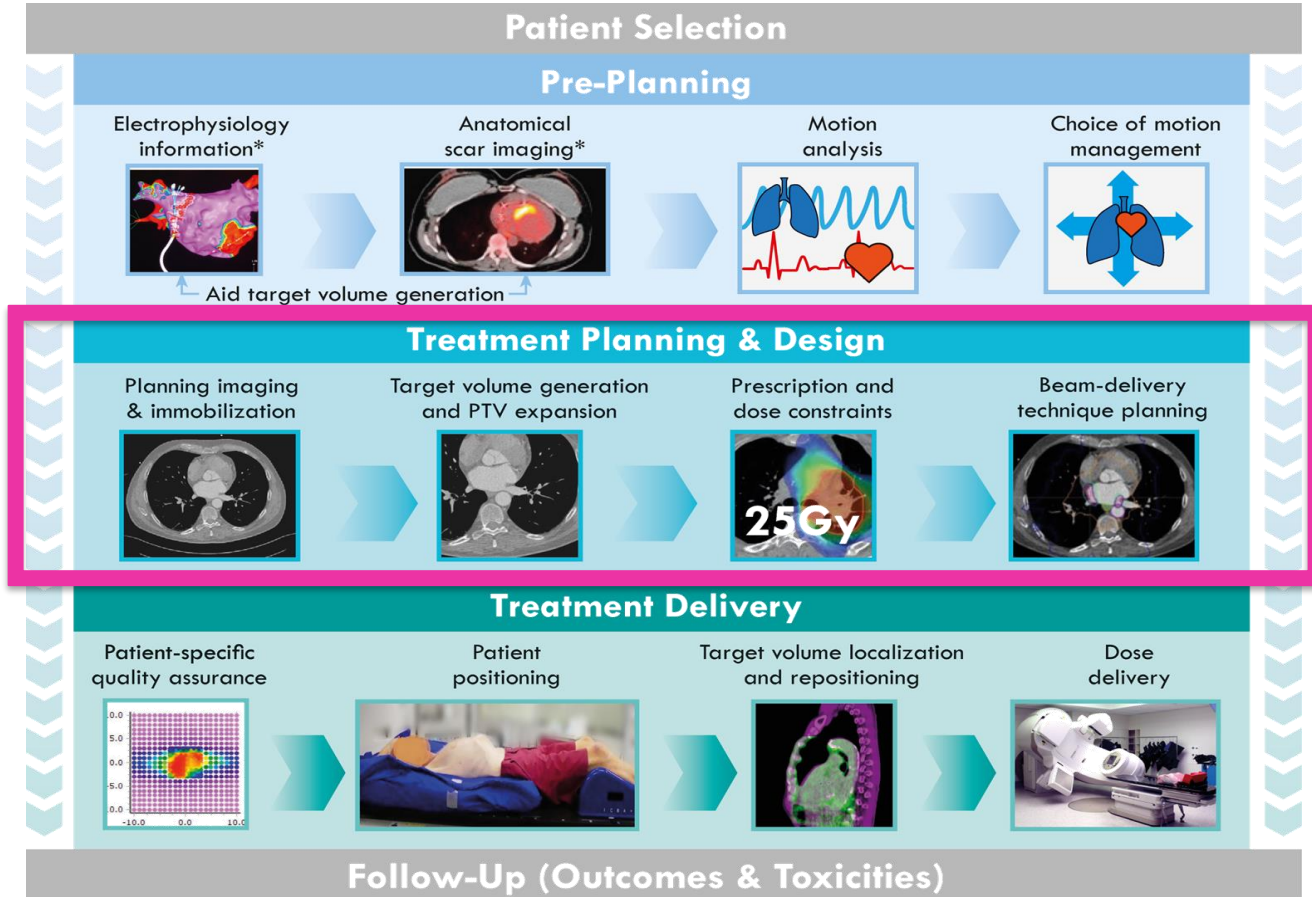
From Lydiard et al. A review of Cardiac Radioablation for Arrhythmias: Procedures, Technology, and Future Opportunities. IJROBP 2021

Pre-Planning: R&D



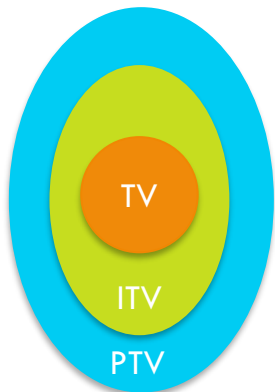
- Analysis of registration errors
- New multi-modality imaging tailored to CR to avoid multiple datasets
- Improvements or development of new imaging modalities specialized for cardio-respiratory motion
 - Further evaluation of cardio-respiratory target motion
- Guidance on optimal imaging modalities to assess target motion & motion compensation techniques
- Evaluation of current and/or development of new cardio-respiratory motion management techniques
 - Evaluation of surrogacy suitability

Cardiac Radioablation Overview



*Not always used in cardiac radioablation workflows

Treatment Planning & Design

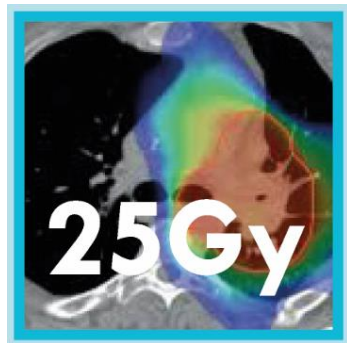


PTV volumes:

CyberKnife 21-193 cc

Linacs 42-299 cc

Resp-gating 3.5 cc



Esophagus

Stomach

Spinal cord/canal

Airways

Great vessels

Lungs

Liver

Bowel

Phrenic nerve

Chest wall

Ribs

Skin

Healthy myocardium

SVC

IVC

Coronary arteries

LADA

Pulmonary arteries

Valves

AV node

Coronary sinus

Pericardium

ICD



7.5-25mm collimators

45-94 directions

84-269 beams

22000-48000MU

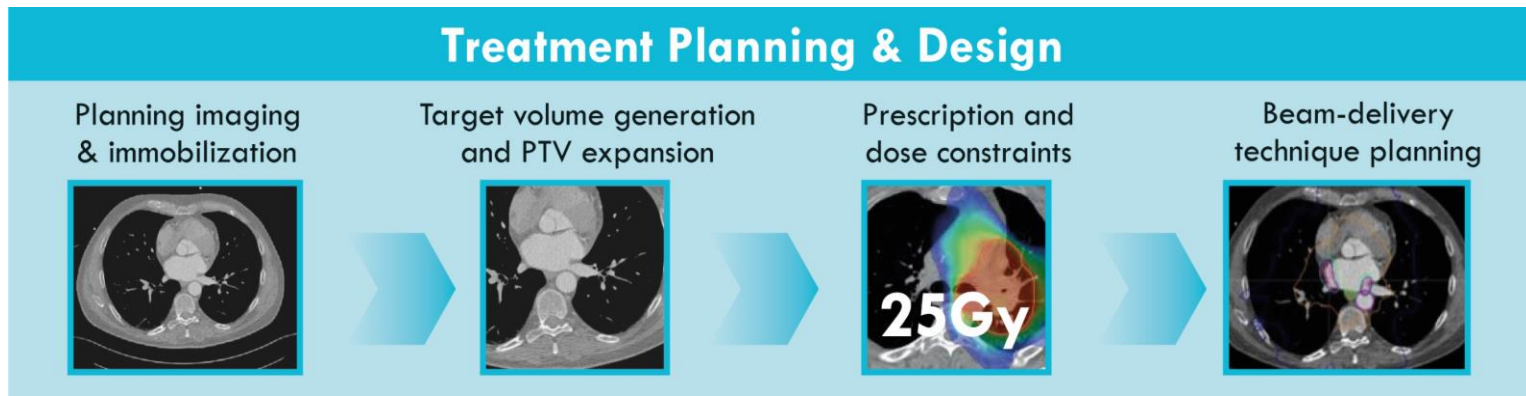


VMAT, IMRT, DCA

6FFF

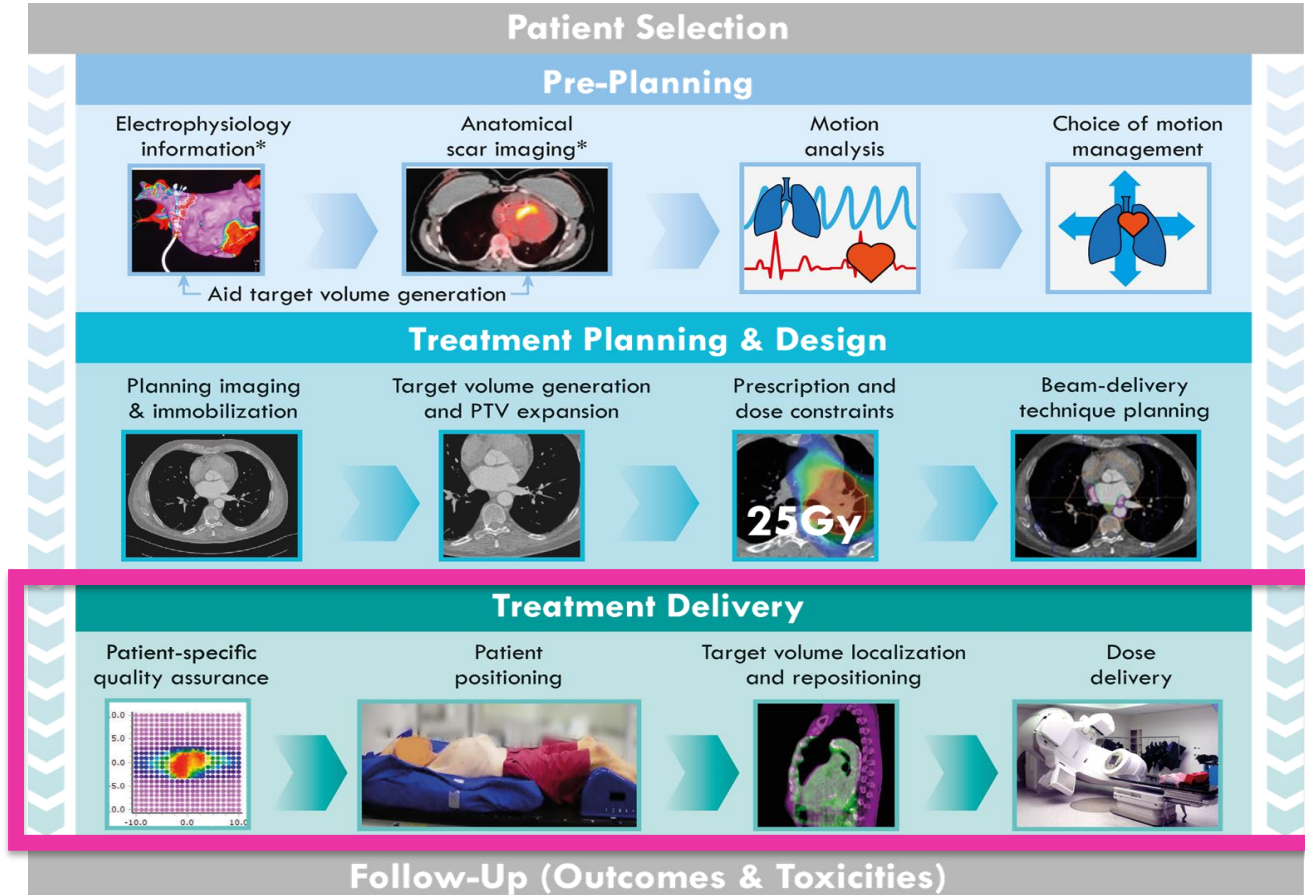
Monte Carlo, raytracing,
pencil beam convolution
superposition, collapsed cone
convolution

Treatment Planning: R&D



- **Radiobiology: target definition, prescription dose, planning dose coverage, OAR planning objectives, particularly intracardiac structures and long-term toxicities**
 - Compatibility between cardiology contouring and radiation oncology TPS
 - Guidance on appropriate plan quality analysis and improved reporting e.g. ICRU 91

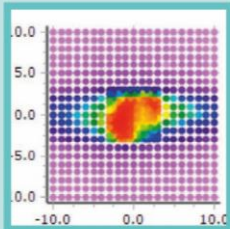
Cardiac Radioablation Overview



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Treatment Delivery & Follow-up

Patient-specific
quality assurance



Clinical Trial > [Int J Radiat Oncol Biol Phys.](#) 2019 Aug 1;104(5):1114-1123.

doi: [10.1016/j.ijrobp.2019.04.005](#). Epub 2019 Apr 16.

Radiation Therapy Workflow and Dosimetric Analysis from a Phase 1/2 Trial of Noninvasive Cardiac Radioablation for Ventricular Tachycardia

Nels C Knutson¹, Pamela P Samson¹, Geoffrey D Hugo¹, S Murty Goddu¹, Francisco J Reynoso¹, James A Kavanaugh¹, Sasa Mucic¹, Kaitlin Moore², Jessica Hilliard¹, Phillip S Cuculich³, Clifford G Robinson⁴

Dose
delivery



Treatment Delivery

CyberKnife



X-ray based translational & rotational spine alignment

Respiratory motion management with x-ray tracking of lead tips

56 – 114 minutes

Linear Accelerators

TrueBeam, Edge, VersaHD



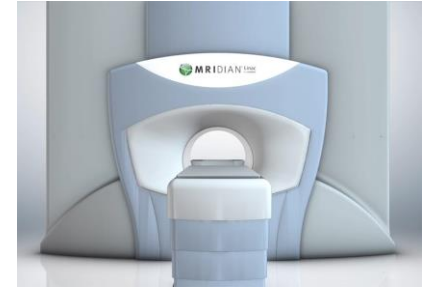
3D or 4D CBCT with bony and/or ICD registration
Fluoroscopy or portal imaging
6 dof couch

Repeat CBCT between arcs
Respiratory gating

4 – 32 minute treatment delivery in 30 – 60 minute appointment

MRI-Linacs

MRIdian

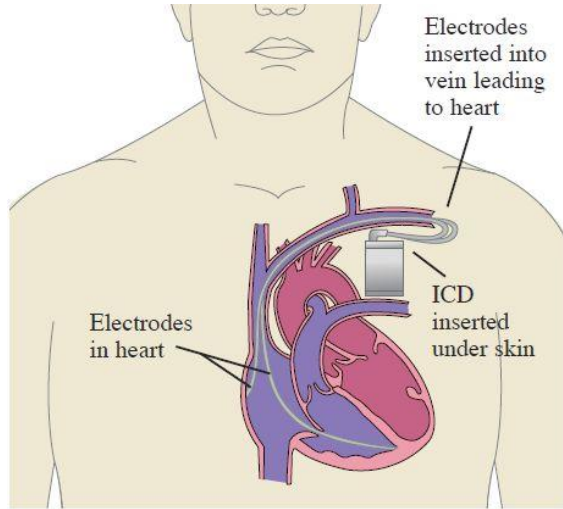


3D MRI & 2D sagittal cines
ICD safety

Liver dome tracking
Expiration breath-holds

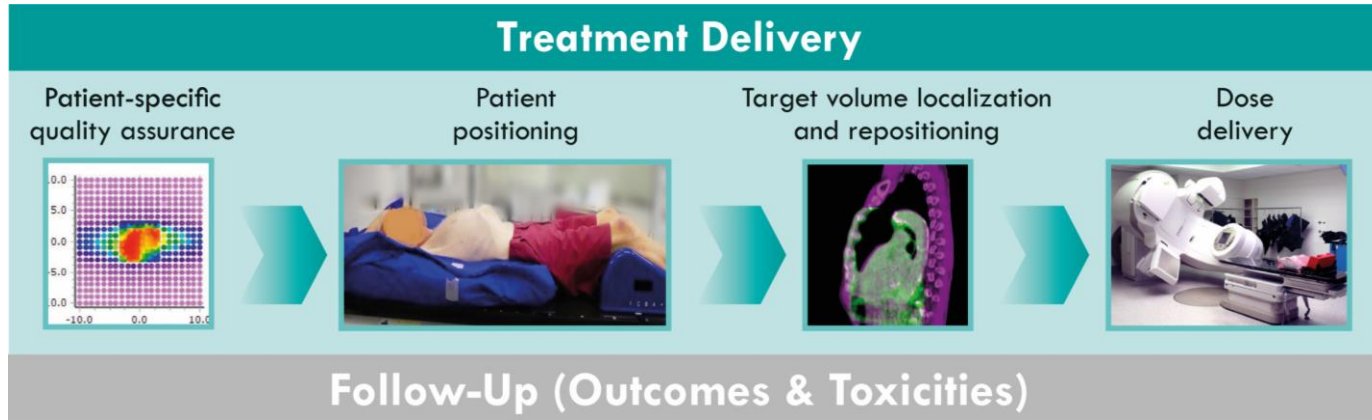
46 minute treatment delivery
148 minute treatment time

ICDs



- Cardiac rescue team on standby during treatment delivery
- During treatment delivery:
 - ICDs either disconnected
 - Temporarily programmed to monitor-only
 - Left in regular mode and performance evaluated via remote monitoring
- After treatment delivery: reconnected, re-programmed, modified ICD settings

Treatment Delivery & Follow-up: R&D



- Guidance on quality assurance and/or new CR-tailored phantoms
- Evaluation of the accuracy of current targeting and imaging methods
- Further development of targeting and intrafraction imaging methods, including non-invasive real-time adaptive targeting tools
- Further investigation into MRI-Linac & heavy-ion treatment deliveries
- Treatment delivery dose verification of clinical treatments, including new techniques
- Follow-up including registration of pre- and post- EP and anatomical information

Thank you!

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 @SuzyLydiard

image-x.sydney.edu.au

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