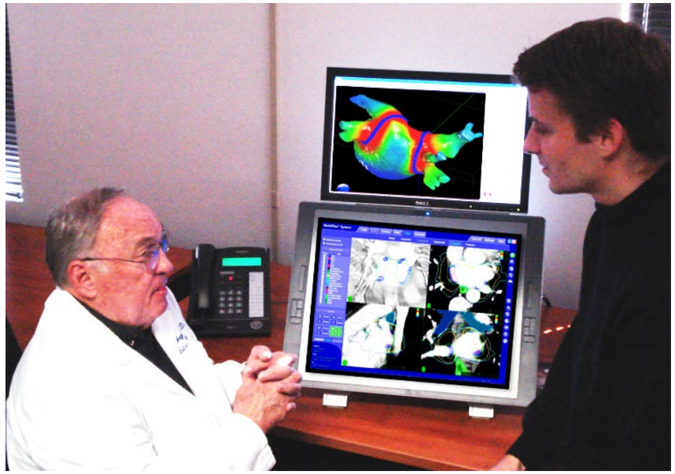
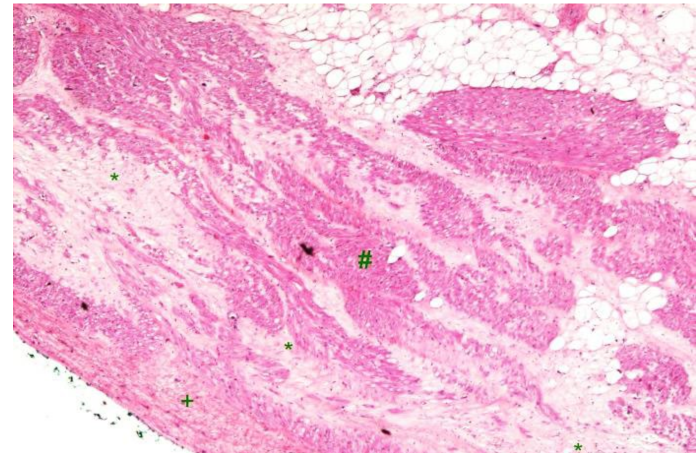
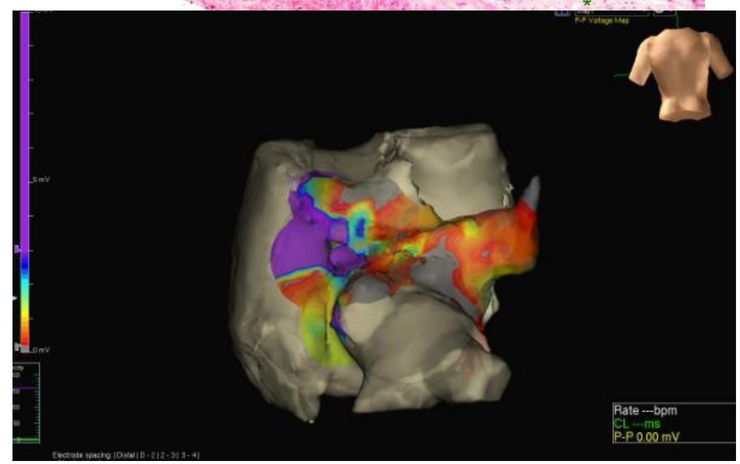
UKSH



C A U
Christian-Albrechts-Universität zu Kiel
Medizinische Fakultät





Was wird uns zukünftig beschäftigen?

Stereotactic Arrythmia Radioablation (STAR) oder Herz-Radiochirurgie für Ventrikuläre Tachykardie

Dr. Oliver Blanck

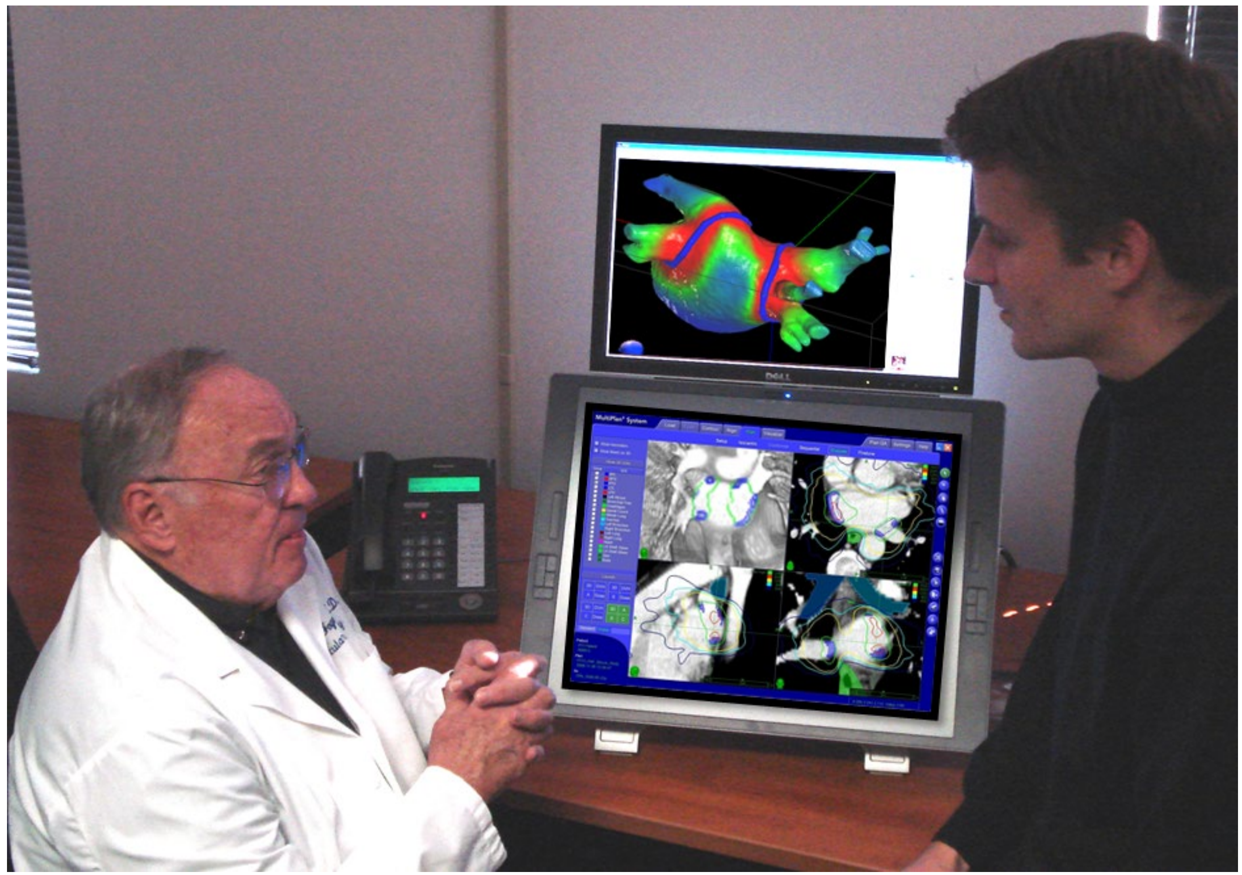
Wissenschaftlicher Mitarbeiter
UKSH, Campus Kiel, Klinik für Strahlentherapie

Leiter Operatives Geschäft, Medizinphysik, Forschung und Entwicklung
Saphir Radiochirurgie (Güstrow, Frankfurt am Main, Kiel)

Historical Review and Disclosures

The **inventor of STAR was Prof. Thomas Fogarty** in 2001. In 2006, he founded the company **CyberHeart**, which evaluated STAR in animal models. CyberHeart's focused on the treatment of **atrial fibrillation.**

In 2010 CyberHeart was discontinued because it ran out of initial funding. CyberHeart was bought by Varian in 2018.



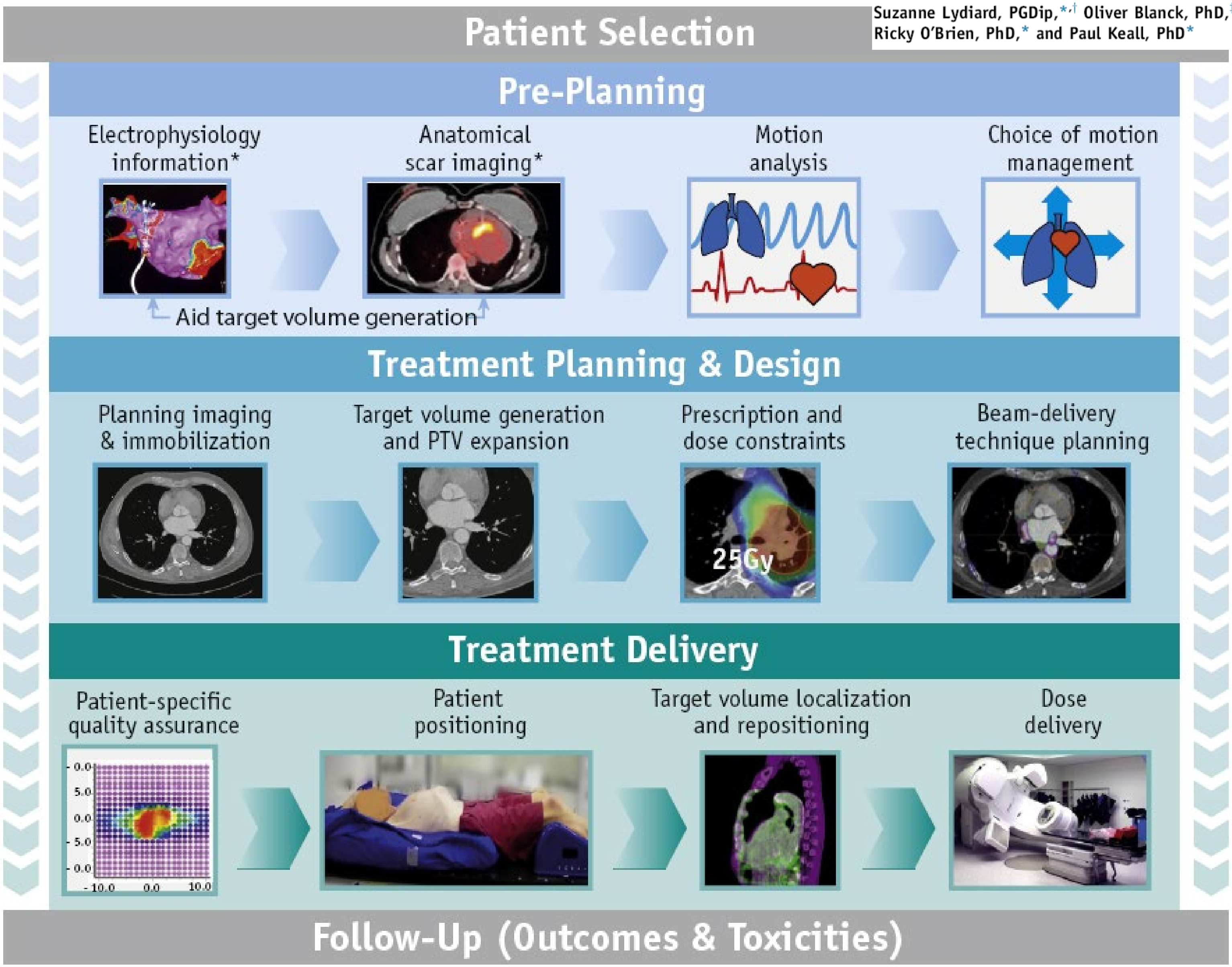
Disclosures: Aside from having been employed by CyberHeart from 2008-2010 I have ***none***.

Procedural Overview for STAR

Critical Review

A Review of Cardiac Radioablation (CR) for Arrhythmias: Procedures, Technology, and Future Opportunities

Suzanne Lydiard, PGDip,*,† Oliver Blanck, PhD,‡ Geoffrey Hugo, PhD,§ Ricky O'Brien, PhD,* and Paul Keall, PhD*



STereotactic Arrhythmia Radioablation (STAR)

1) Dose-Response Relationship

2) Target Definition and Conversion

3) Motion Management

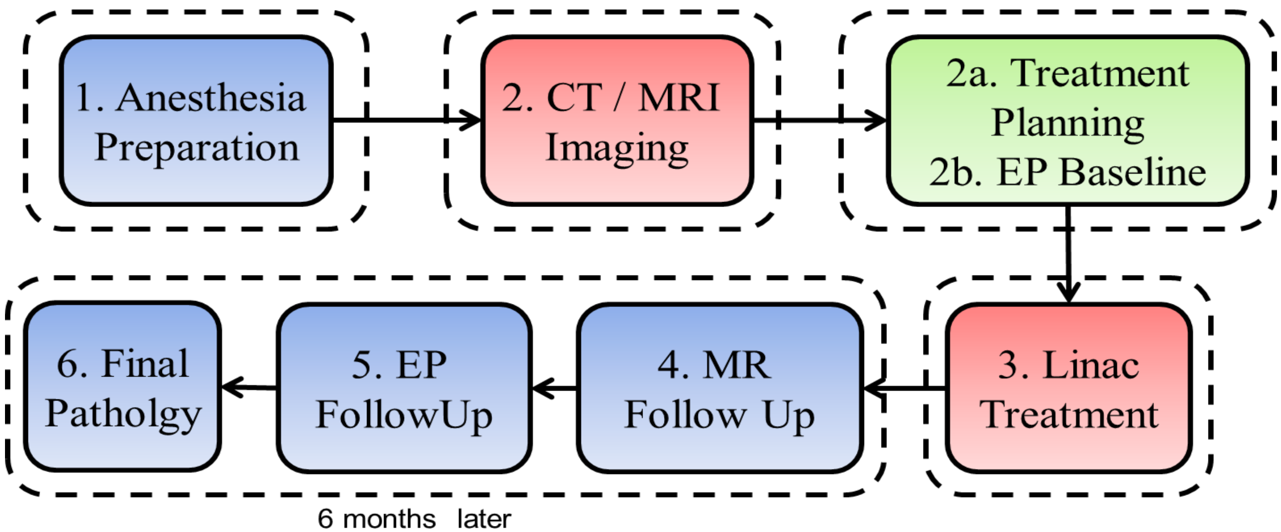
4) Treatment Planning

5) Treatment

Dose-response relationship

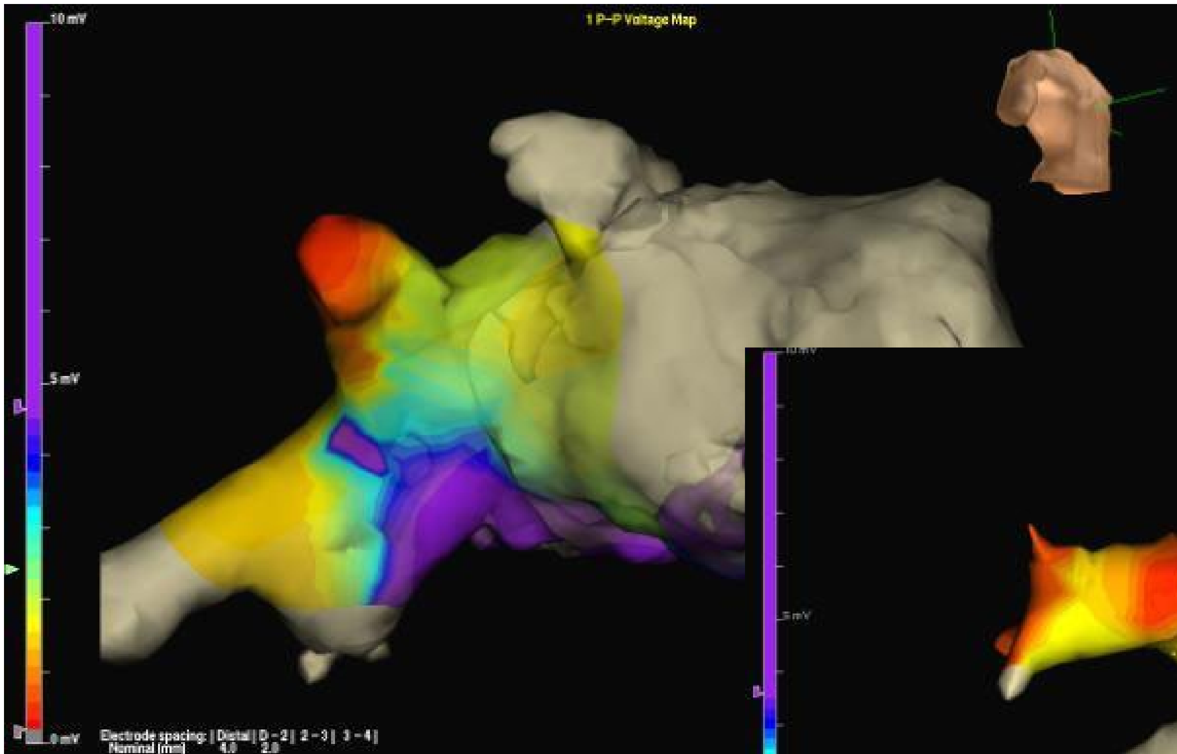
Homogeneous 15-40 Gy (2.5 Gy steps), randomized, double blinded

Animal Model	Porcine / Göttingen Mini Pig *(n = 13, 40-60kg)*		
Dose Finding	*Pathology only* 0 Gy / 15 Gy *(died)* 17.5 Gy 20 Gy 25 Gy	*Full Data* 22.5 Gy 27.5 Gy 30 Gy 32.5 Gy	 35 Gy 37.5 Gy *(died at 1 month)* 40 Gy
Follow-Up Period	6 months for all pigs		



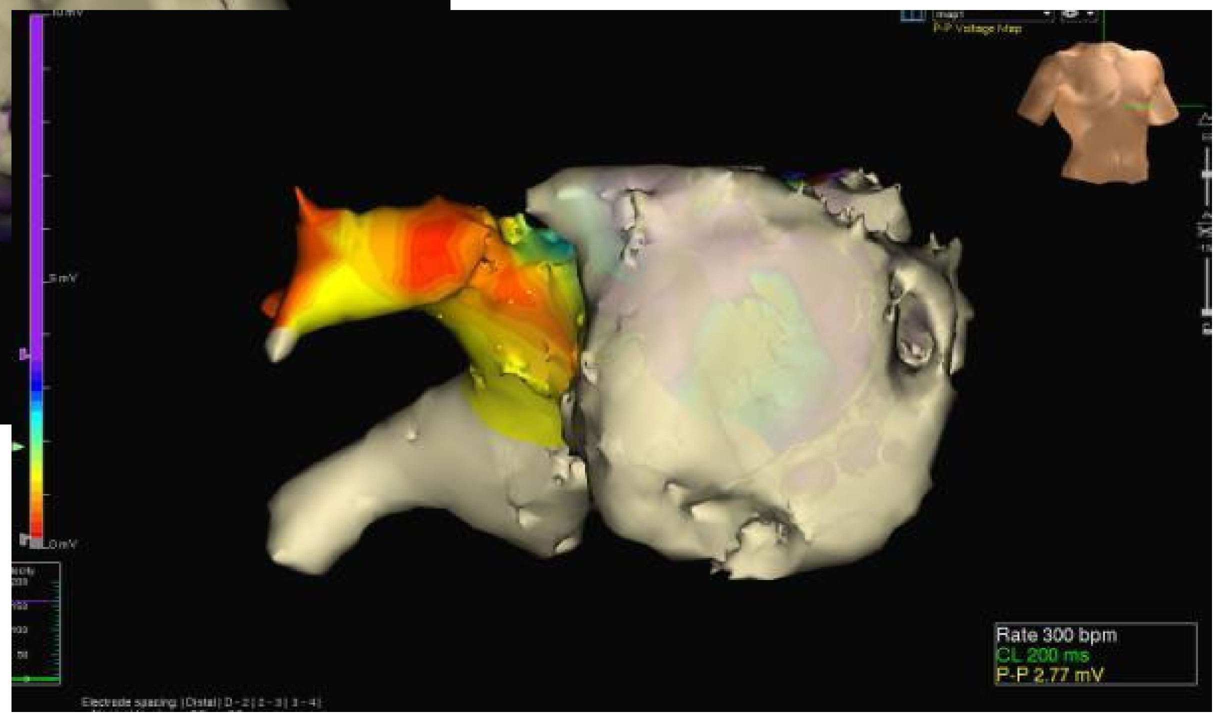
Dose-response relationship

Minimal electrophysiological changes with 22.5 Gy



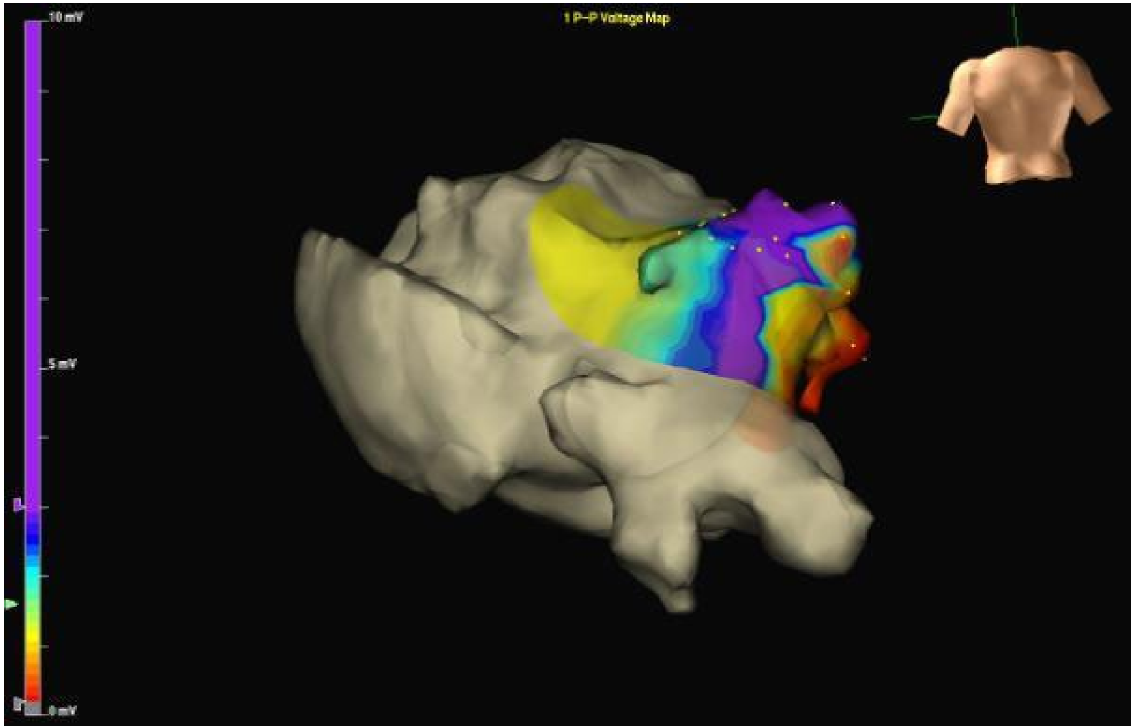
Day of Treatment

6 Months post treatment

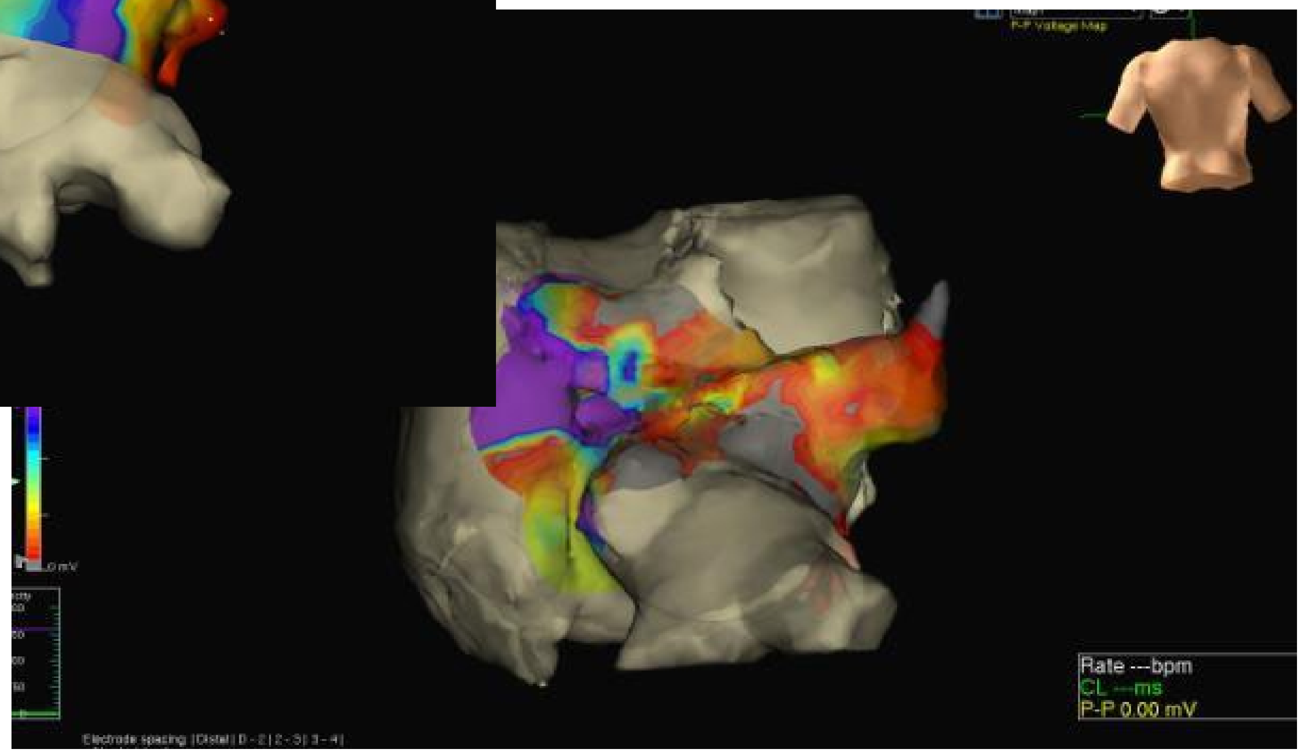


Dose-response relationship

Decreased electrophysiological signals with 32.5 Gy



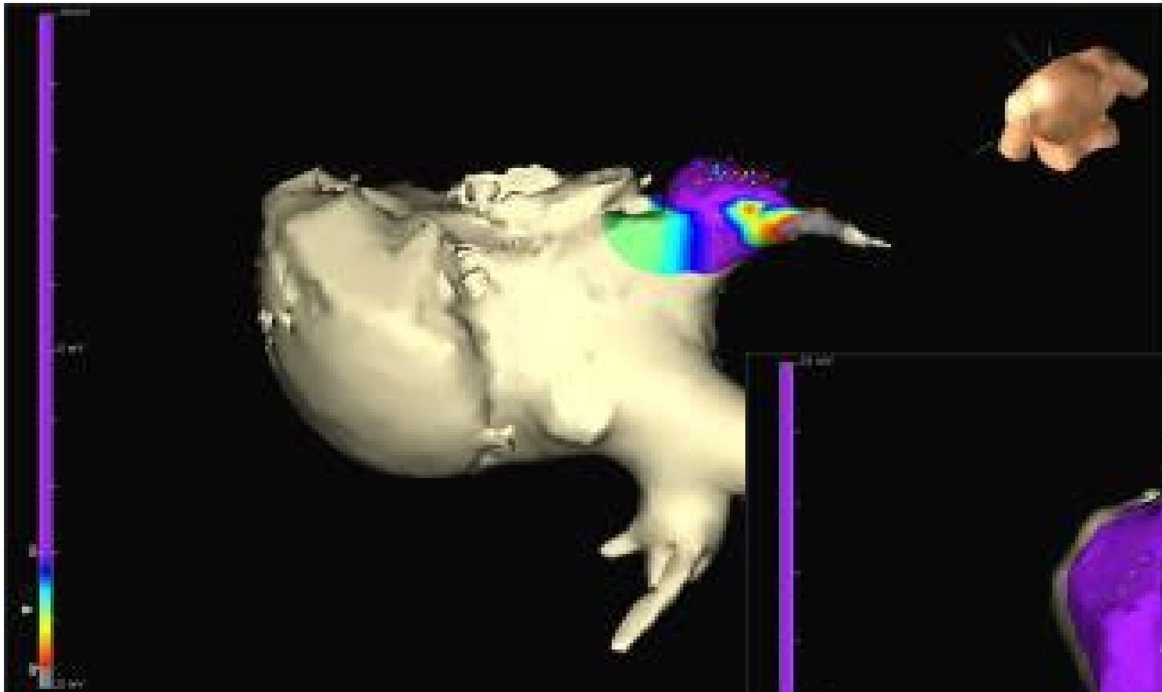
Day of Treatment



6 Months post treatment

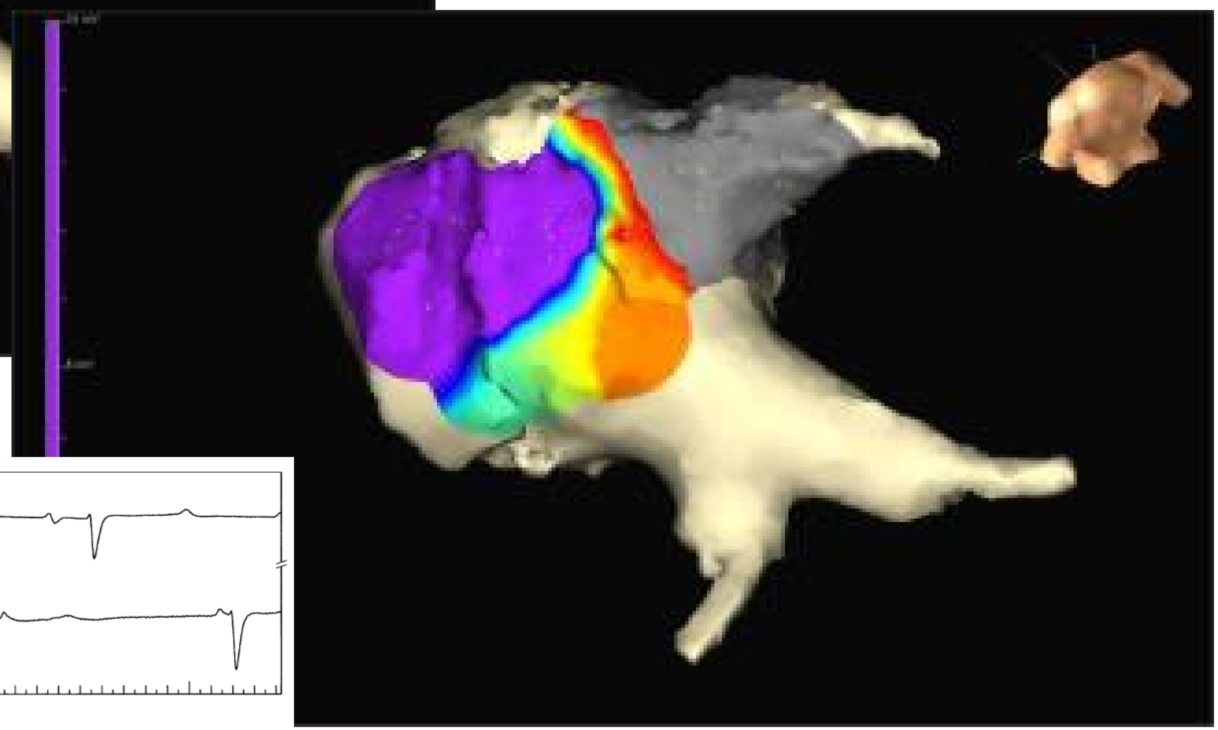
Dose-response relationship

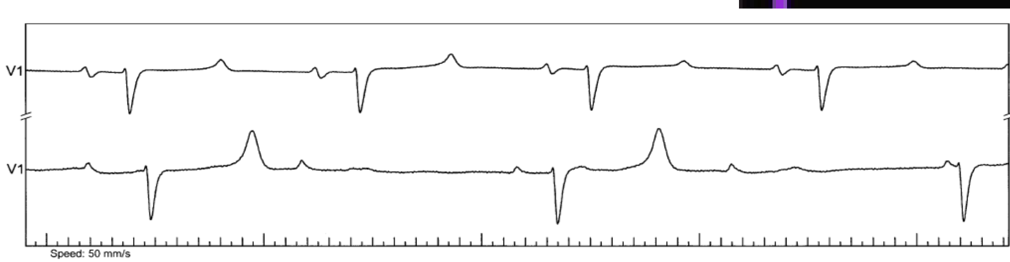
No electrophysiological signals and block with 40 Gy



Day of Treatment

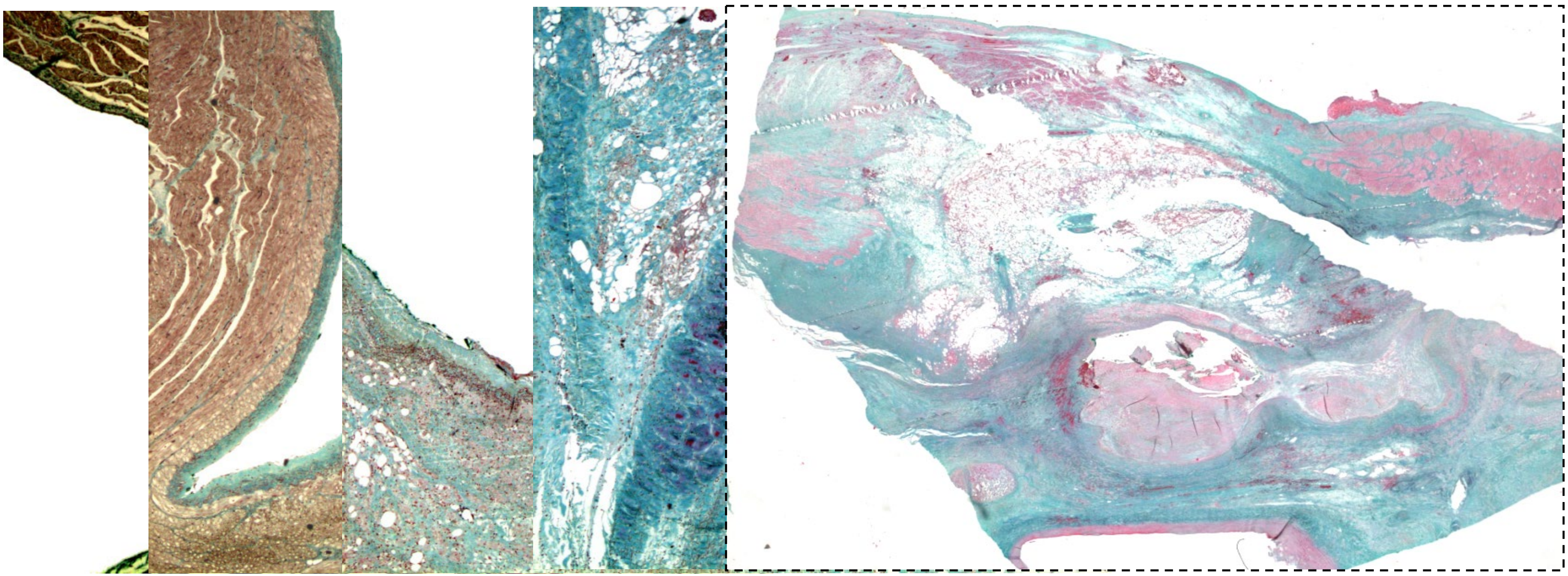
6 Months post treatment



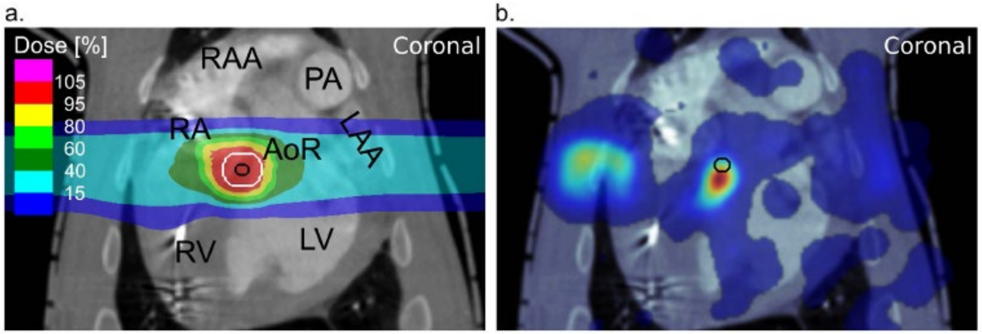


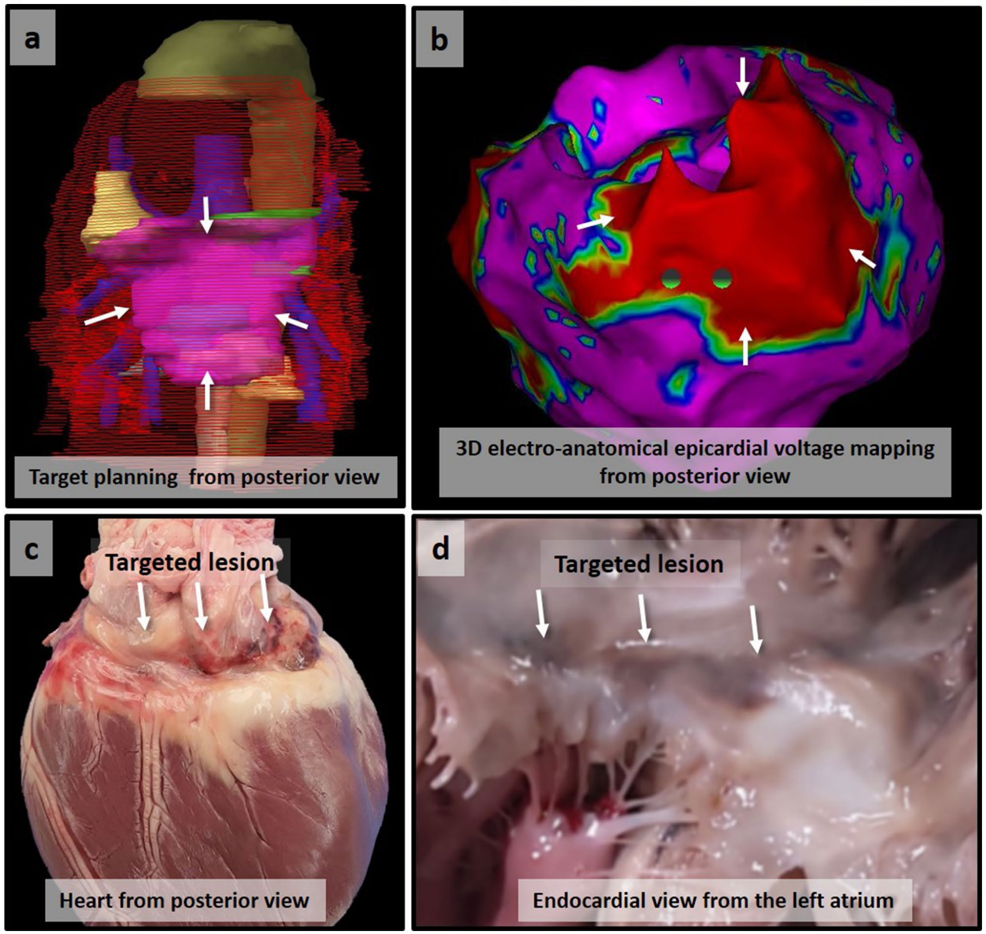
Dose-response relationship

- → Regular vein structure of control animal
- → Mild fibrosis with intermediate dose (25Gy)
- → Moderate fibrosis with intermediate to high dose (30Gy)
- → Confluent fibrosis with high dose (32.5Gy)
- → Transmural, circumferential fibrosis with stenosis (40Gy)



Dose-response relationship





SCIENTIFIC REPORTS

OPEN

Received: 08 August 2016
Accepted: 09 November 2016
Published: 20 December 2016

Feasibility Study on Cardiac Arrhythmia Ablation Using High-Energy Heavy Ion Beams

H. Immo Lehmann[1,*], Christian Graeff[2,*], Palma Simoniello[2], Anna Constantinescu[2], Mitsuru Takami[1], Patrick Lugenbiel[3], Daniel Richter[2,4], Anna Eichhorn[2], Matthias Prall[2], Robert Kaderka[2], Fine Fiedler[5], Stephan Helmbrecht[5], Claudia Fournier[2], Nadine Erbeldinger[2], Ann-Kathrin Rahm[3], Rasmus Rivinius[3], Dierk Thomas[3], Hugo A. Katus[3], Susan B. Johnson[2], Kay D. Parker[2], Jürgen Debus[6], Samuel J. Asirvatham[1], Christoph Bert[2,4], Marco Durante[2,7] & Douglas L. Packer[1]

SCIENTIFIC REPORTS

OPEN

Received: 12 October 2018
Accepted: 26 February 2019
Published online: 21 March 2019

Biological Cardiac Tissue Effects of High-Energy Heavy Ions – Investigation for Myocardial Ablation

Felicitas Rapp[1], Palma Simoniello[2], Julia Wiedemann[1], Karola Bahrami[1], Valeria Grünebaum[1], Svetlana Ktitareva[1], Marco Durante[1,3], P. Lugenbiel[4,5], D. Thomas[4,5,6], H. Immo Lehmann[7,8], Douglas L. Packer[8], Christian Graeff[1] & Claudia Fournier[1]

scientific reports

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OPEN

Feasibility study on stereotactic radiotherapy for total pulmonary vein isolation in a canine model

Ji Hyun Chang[1], Myung-Jin Cha[2,3], Jeong-Wook Seo[4], Hak Jae Kim[1,5,6], So-Yeon Park[7,8], Byoung Hyuck Kim[9], Euijae Lee[10], Moo-kang Kim[3], Hye-sun Yoon[3] & Seil Oh[3,11]

Radiation Biology Effects from STAR

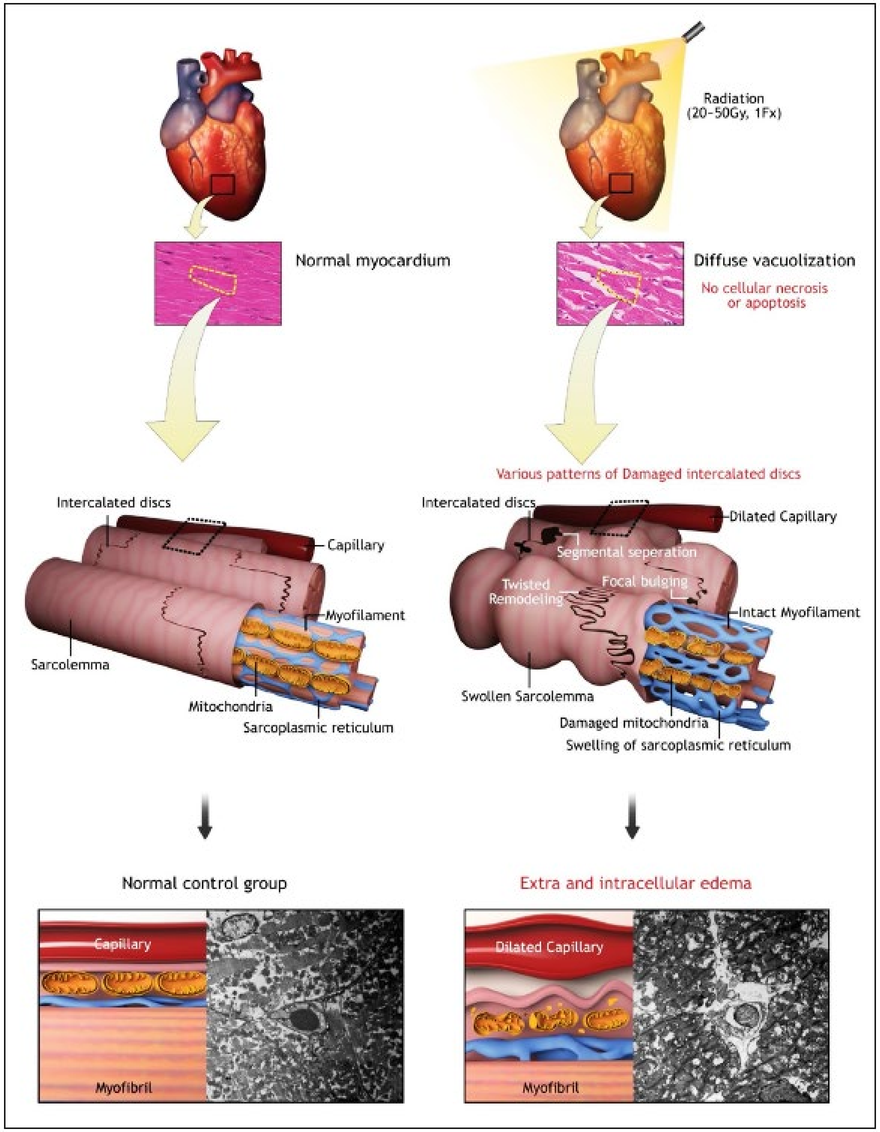
Journal of the American Heart Association

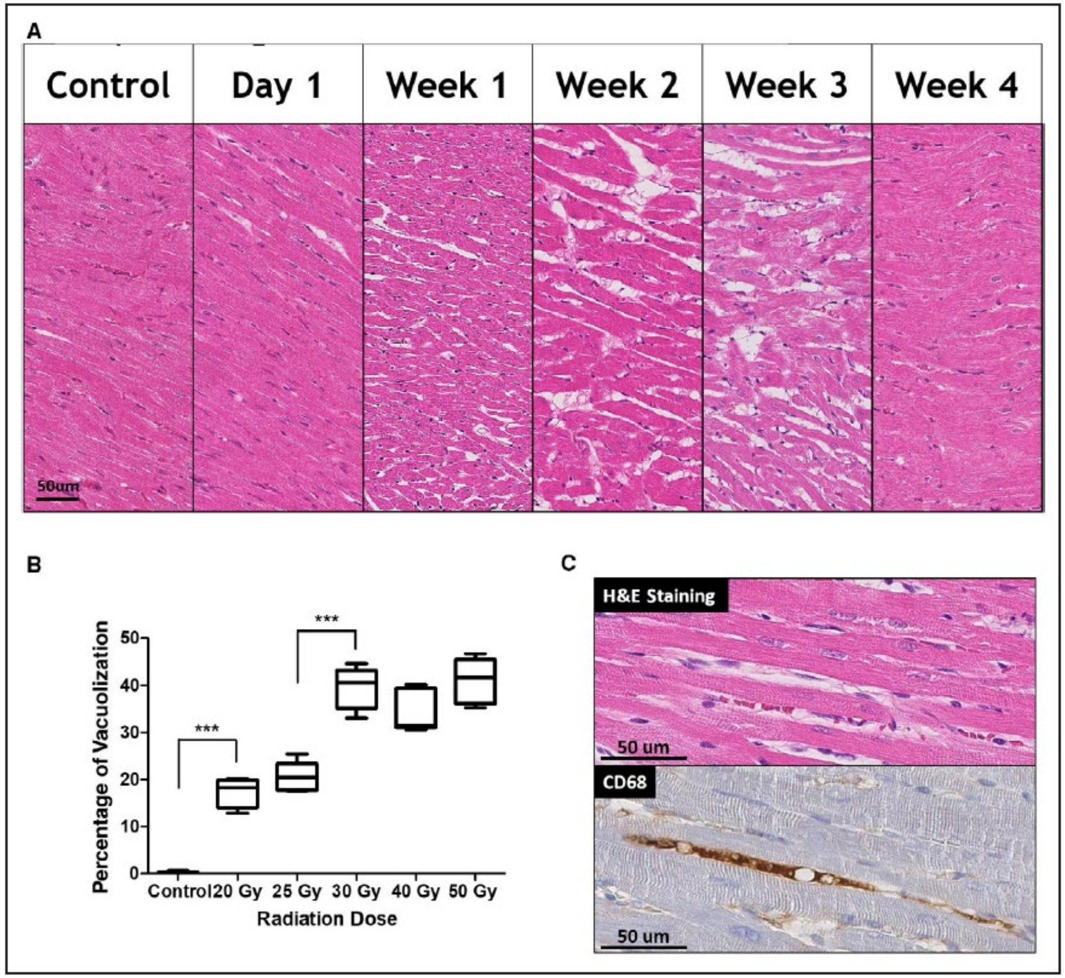
ORIGINAL RESEARCH

Early Changes in Rat Heart After High-Dose Irradiation: Implications for Antiarrhythmic Effects of Cardiac Radioablation

Myung-Jin Cha, MD, PhD; Jeong-Wook Seo, MD, PhD; Hak Jae Kim, MD, PhD; Moo-kang Kim, BS; Hye-sun Yoon, BS; Seong Won Jo; Seil Oh, MD, PhD*; Ji Hyun Chang, MD, PhD*

→ After 4-6 week we see fibrosis and cell death with doses > 30 Gy





→ In the first 4 weeks we mainly see vacuolization and edema

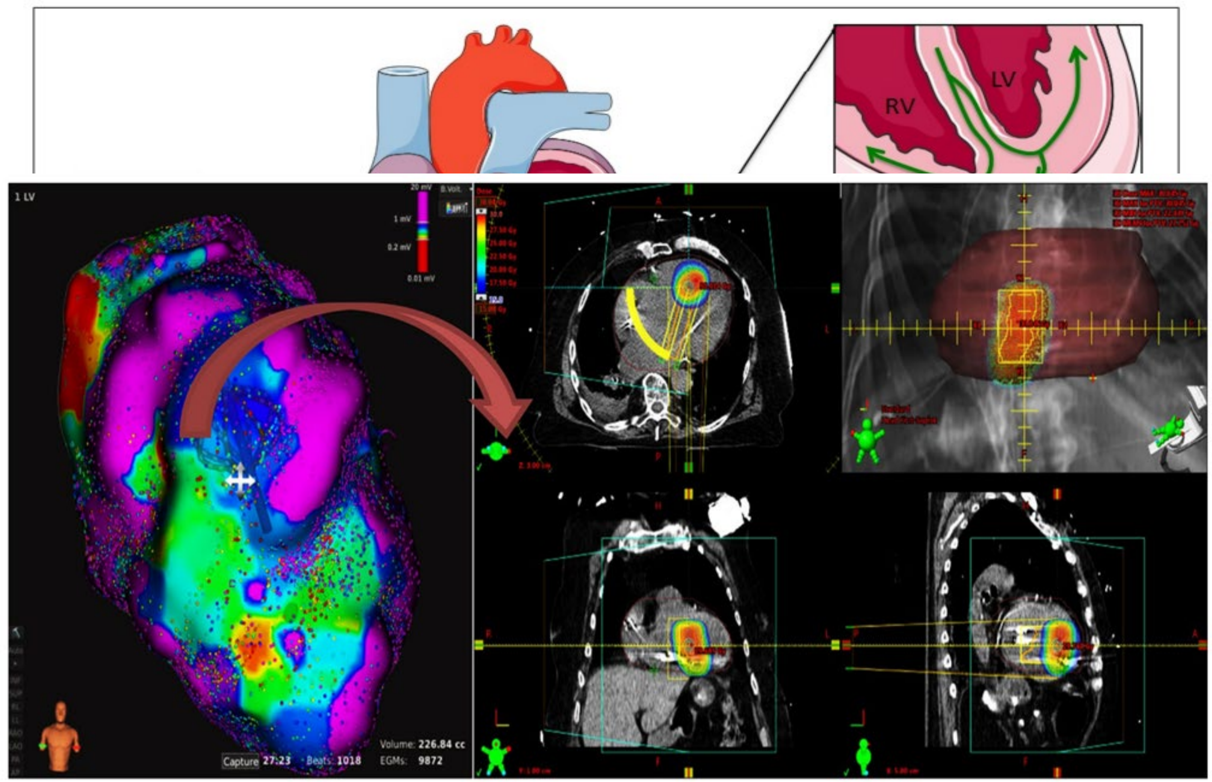
STereotactic Arrhythmia Radioablation (STAR)

- **Cardiovascular diseases** are most common cause of death
- **Ventricular Tachycardia (VT)** is associated with certain cardio-vascular diseases and the main cause for sudden cardiac death

Therapy options

- Implantation of an ICD
- Antiarrhythmic medications
- Catheter ablation

However, the recurrence rates are as high at 50% with limited options for treatment: STAR

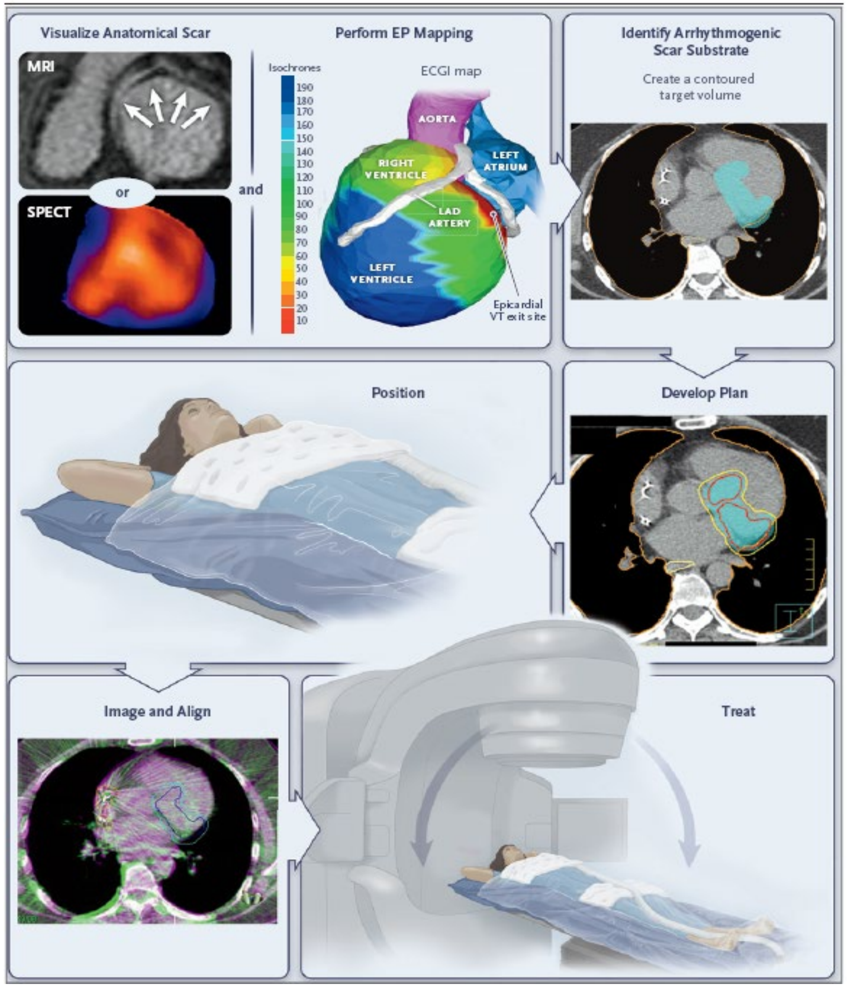


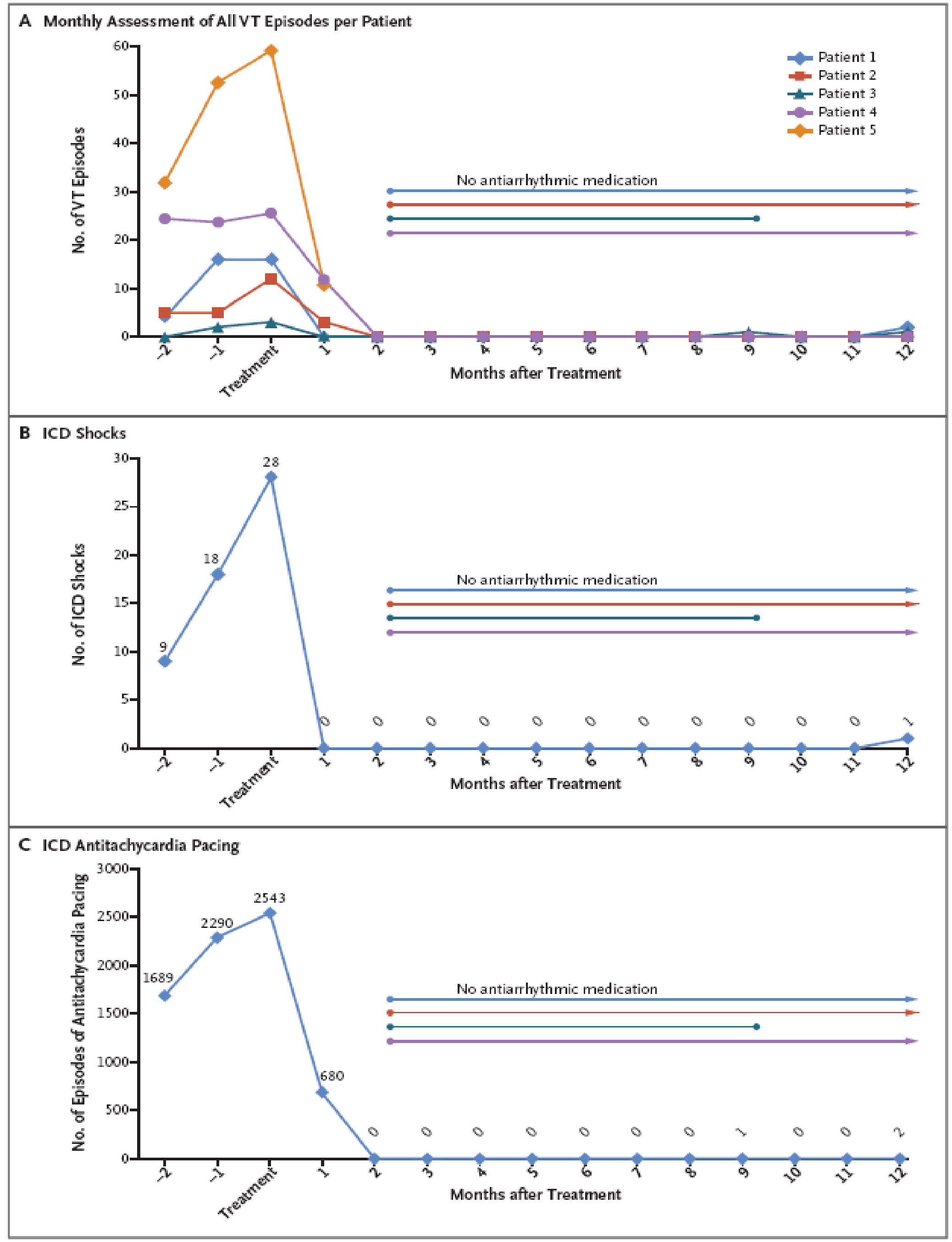
Jumeau R, Ozsahin M, Schwitter J, et al. Stereotactic Radiotherapy for the Management of Refractory Ventricular Tachycardia: Promise and Future Directions. Front Cardiovasc Med. 2020;7:108.

Why did 25 Gy work for VT?

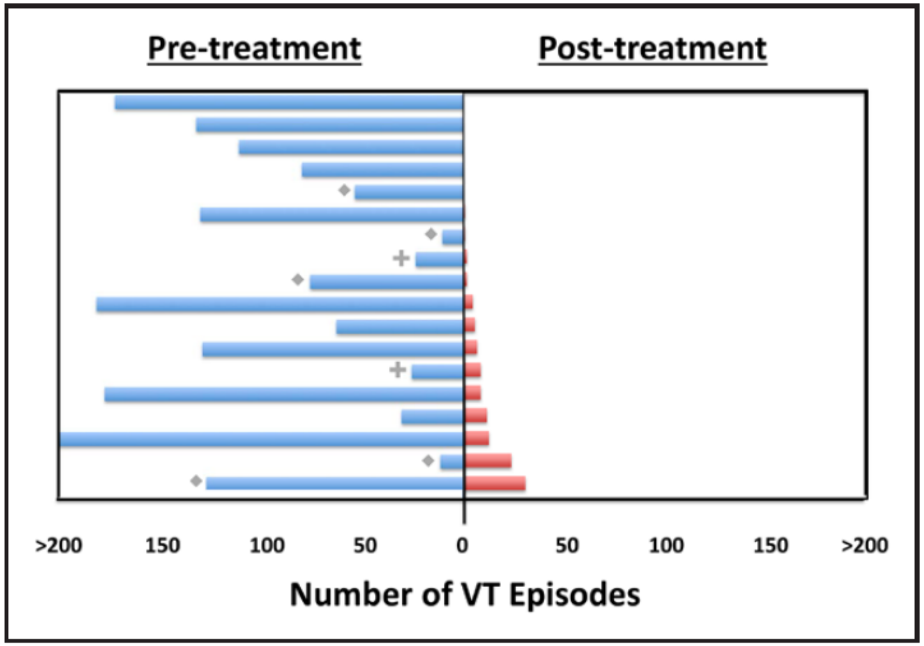
Noninvasive Cardiac Radiation for Ablation of Ventricular Tachycardia

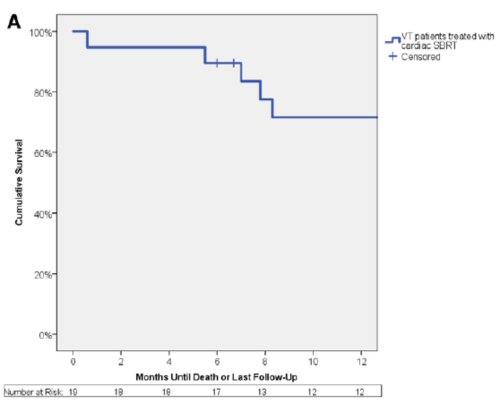
Phillip S. Cuculich, M.D., Matthew R. Schill, M.D., Rojano Kashani, Ph.D., Sasa Mutic, Ph.D., Adam Lang, M.D., Daniel Cooper, M.D., Mitchell Faddis, M.D., Ph.D., Marye Gleva, M.D., Amit Noheria, M.B., B.S., Timothy W. Smith, M.D., D.Phil., Dennis Hallahan, M.D., Yoram Rudy, Ph.D., and Clifford G. Robinson, M.D.

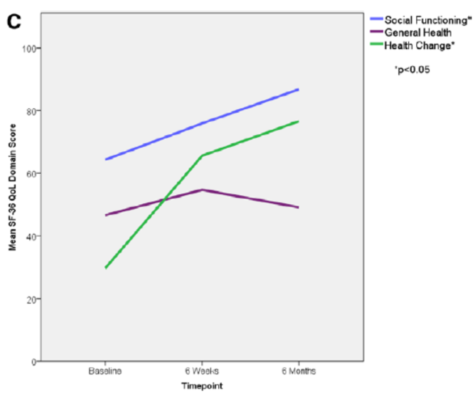




First Phase I / II Studies







Circulation

ORIGINAL RESEARCH ARTICLE

Phase I/II Trial of Electrophysiology-Guided Noninvasive Cardiac Radioablation for Ventricular Tachycardia

Editorial see p XXX

Clifford G. Robinson, MD
Pamela P. Samson, MD, MPHS
Kaitlin M.S. Moore, BS
Geoffrey D. Hugo, PhD
Nels Knutson, PhD
Sasa Mutic, PhD
S. Murty Goddu, PhD
Adam Lang, MD
Daniel H. Cooper, MD
Mitchell Faddis, MD, PhD
Amit Noheria, MBBS, SM
Timothy W. Smith, D Phil, MD
Pamela K. Woodard, MD
Robert J. Gropler, MD
Dennis E. Hallahan, MD
Yoram Rudy, PhD
Phillip S. Cuculich, MD

BACKGROUND: Case studies have suggested the efficacy of catheter-free, electrophysiology-guided noninvasive cardiac radioablation for ventricular tachycardia (VT) using stereotactic body radiation therapy, although prospective data are lacking.

METHODS: We conducted a prospective phase I/II trial of noninvasive cardiac radioablation in adults with treatment-refractory episodes of VT or cardiomyopathy related to premature ventricular contractions (PVCs). Arrhythmogenic scar regions were targeted by combining noninvasive anatomic and electric cardiac imaging with a standard stereotactic body radiation therapy workflow followed by delivery of a single fraction of 25 Gy to the target. The primary safety end point was treatment-related serious adverse events in the first 90 days. The primary efficacy end point was any reduction in VT episodes (tracked by indwelling implantable cardioverter defibrillators) or any reduction in PVC burden (as measured by a 24-hour Holter monitor) comparing the 6 months before and after treatment (with a 6-week blanking window after treatment). Health-related quality of life was assessed using the Short Form-36 questionnaire.

RESULTS: Nineteen patients were enrolled (17 for VT, 2 for PVC cardiomyopathy). Median noninvasive ablation time was 15.3 minutes (range, 5.4–32.3). In the first 90 days, 2/19 patients (10.5%) developed a treatment-related serious adverse event. The median number of VT episodes was reduced from 119 (range, 4–292) to 3 (range, 0–31; $P<0.001$). Reduction was observed for both implantable cardioverter defibrillator shocks and antitachycardia pacing. VT episodes or PVC burden were reduced in 17/18 evaluable patients (94%). The frequency of VT episodes or PVC burden was reduced by 75% in 89% of patients. Overall survival was 89% at 6 months and 72% at 12 months. Use of dual antiarrhythmic medications decreased from 59% to 12% ($P=0.008$). Quality of life improved in 5 of 9 Short Form-36 domains at 6 months.

CONCLUSIONS: Noninvasive electrophysiology-guided cardiac radioablation is associated with markedly reduced ventricular arrhythmia burden with modest short-term risks, reduction in antiarrhythmic drug use, and improvement in quality of life.

CLINICAL TRIAL REGISTRATION: URL: https://www.clinicaltrials.gov/. Unique identifier: NCT02919618.

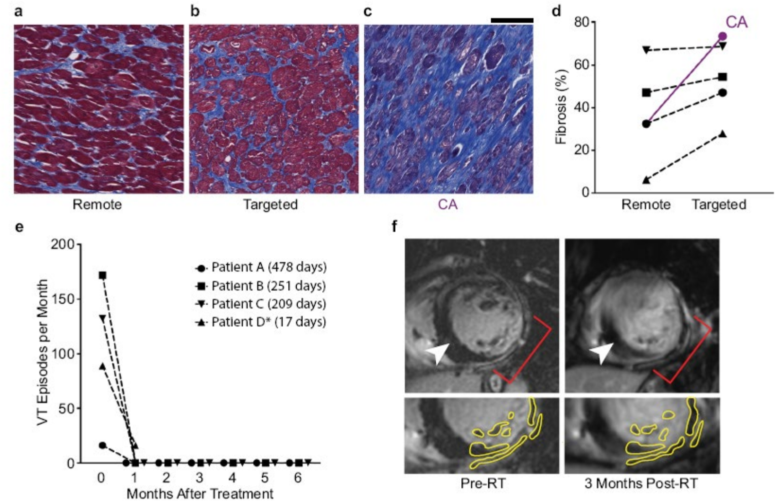
Key Words: noninvasive ■ stereotactic radiotherapy ■ ventricular tachycardia

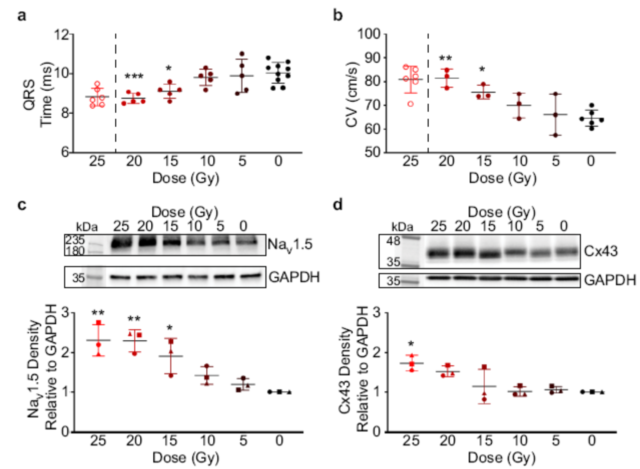
Sources of Funding, see page XXX

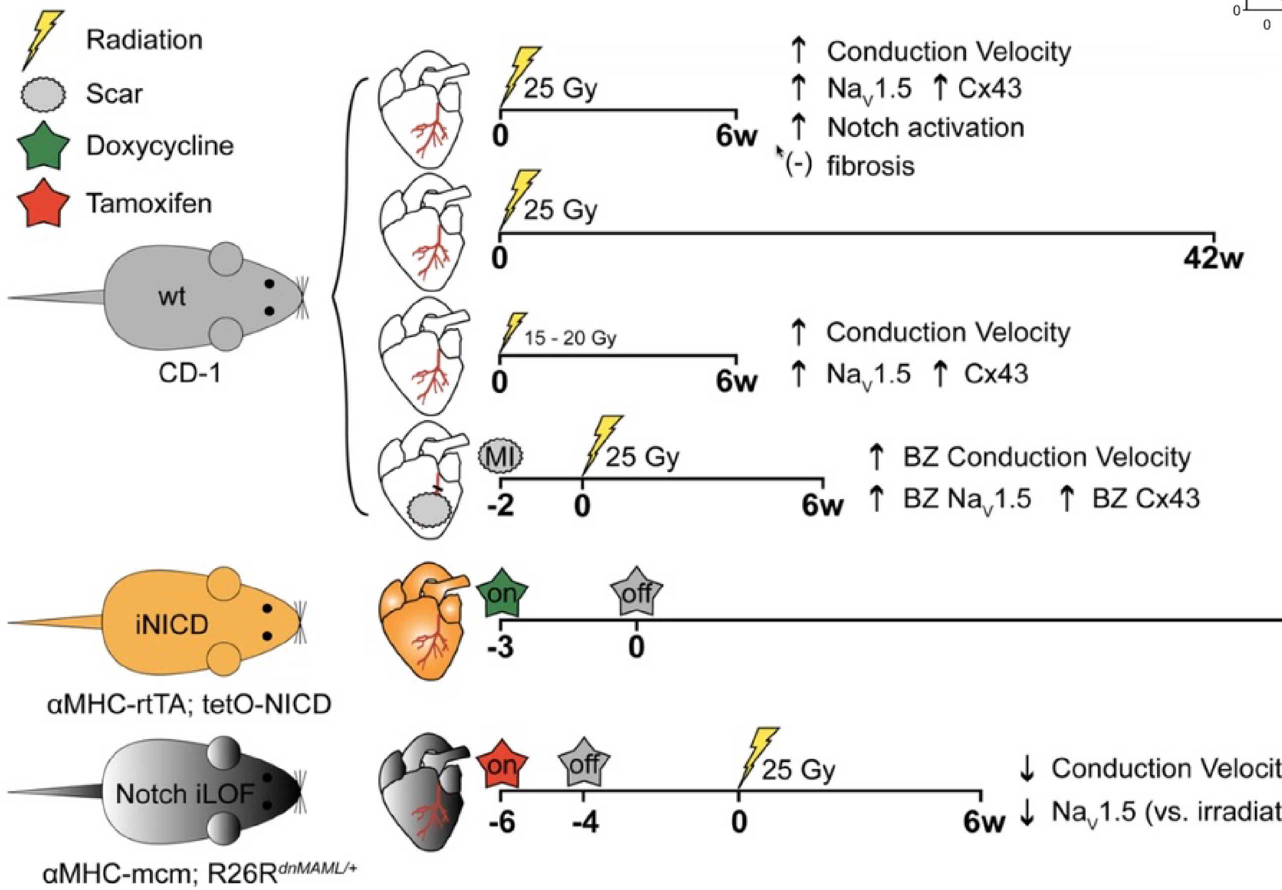
https://www.ahajournals.org/journal/circ

Radiation Biology Effects from STAR

nature COMMUNICATIONS

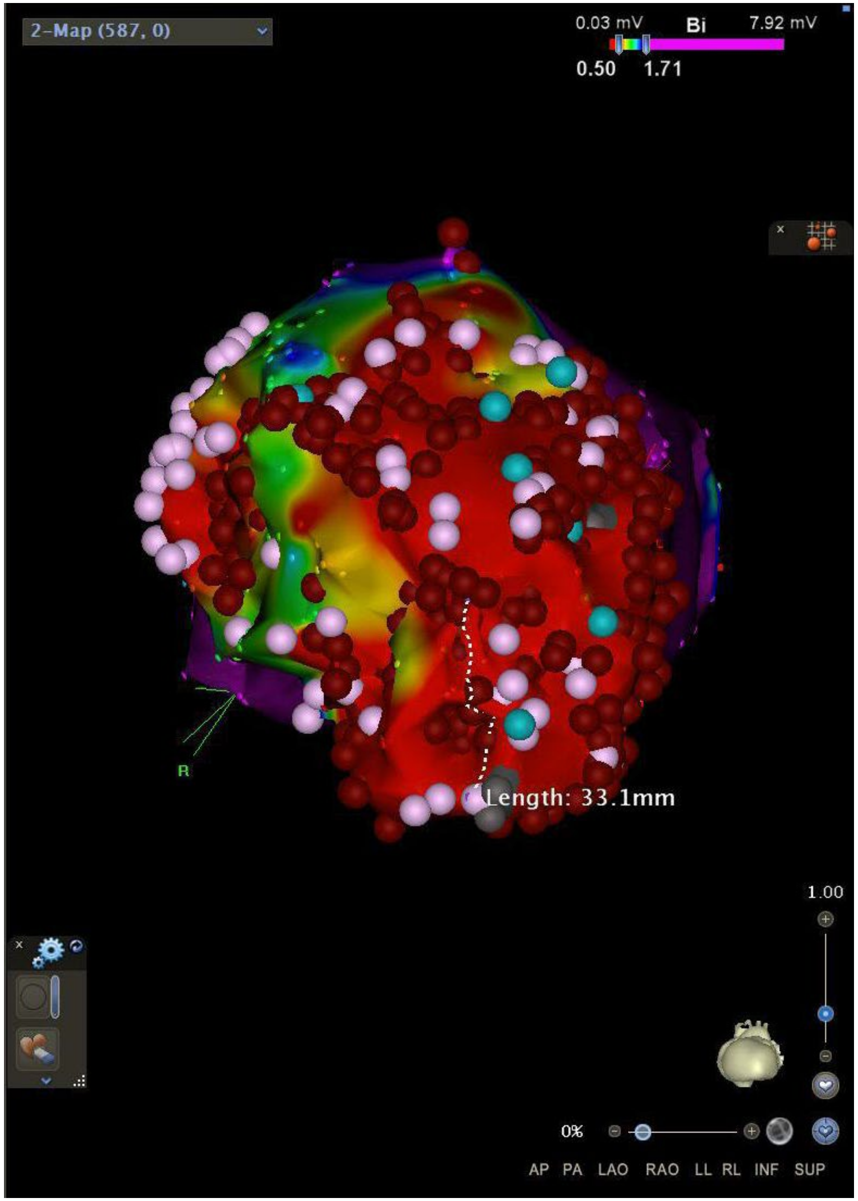


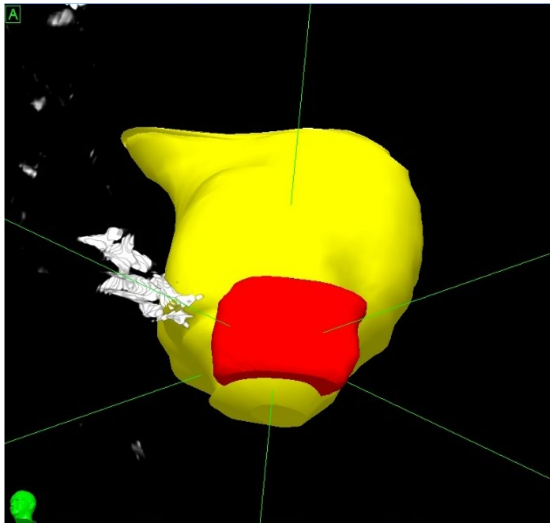


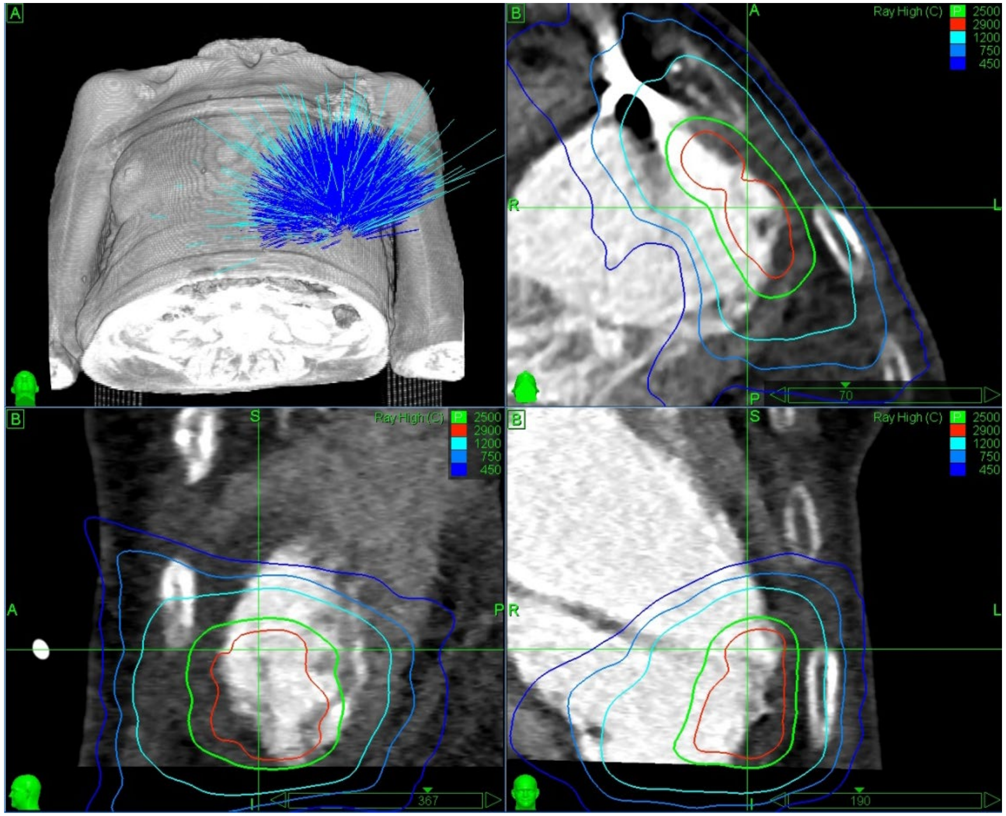


First Case in Germany

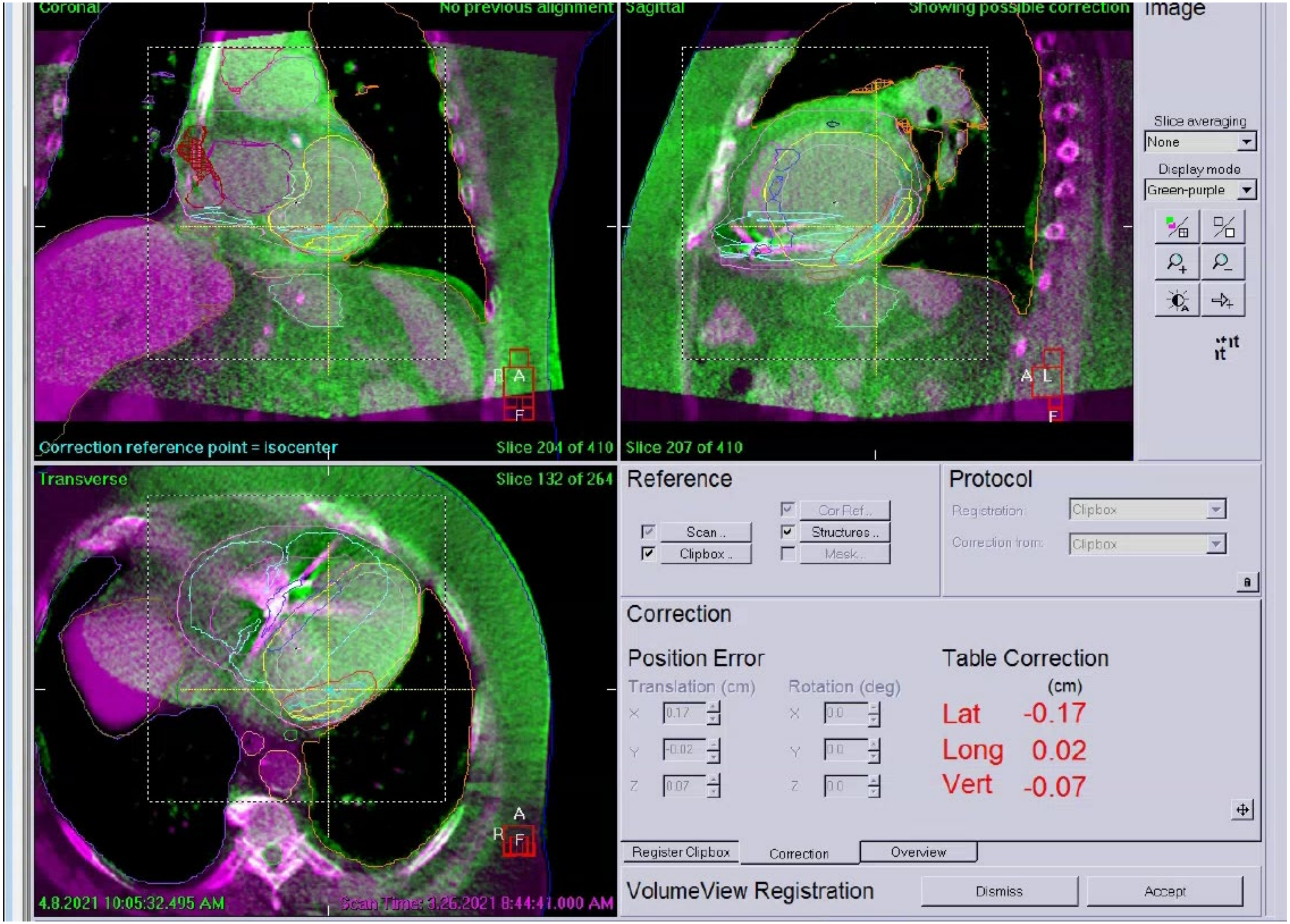
First CyberKnife Case







Example STAR with Versa HD and DIBH/Catalyst (Gating)



Performed by the best DIBH team in the world ☺

RAVENTA Study

<u>Studienprotokoll</u>

Radiochirurgie zur Behandlung therapierefraktärer ventrikulärer Extrasystolen und Tachykardien (RAVENTA)

Multizentrische einarmige Studie

Primary question

→ Feasibility and 30 days morbidity and mortality of radiosurgery in the heart

Secondary questions

→ Reduction of the occurrence of ventricular tachycardia

→ Short-term side effects up to 1 year after therapy

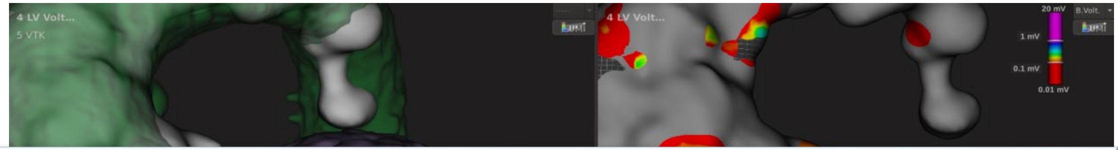
→ 20 Patients (multi-center, multi-platform)

→ Primary Ethics Committee approval

→ Federal Office for Radiation Protection approval

→ Start started 10/2019, 6 centers live, 10 patients treated

RAVENTA to STOPSTORM



10 Patients tre

Proposal Evaluation Form

EUROPEAN COMMISSION

Horizon 2020 - Research and Innovation Framework Programme

Evaluation Summary Report - Research and innovation actions

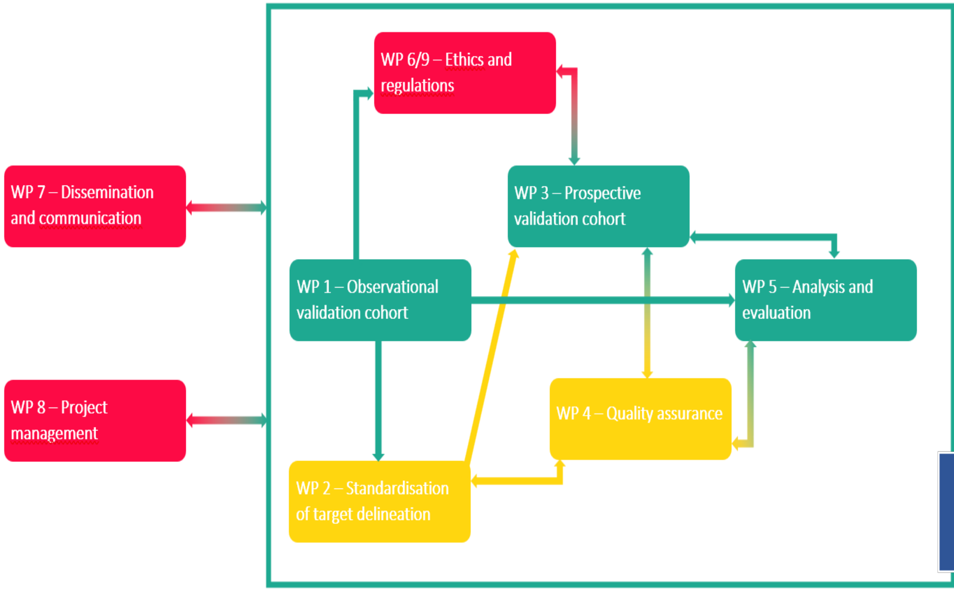
Call:	H2020-SC1-2020-Two-Stage-RTD
Type of action:	RIA
Proposal number:	945119-2
Proposal acronym:	STOPSTORM
Duration (months):	72
Proposal title:	A PROSPECTIVE EUROPEAN VALIDATION COHORT FOR STEREOTACTIC THERAPY OF RE-ENTRANT TACHYCARDIA

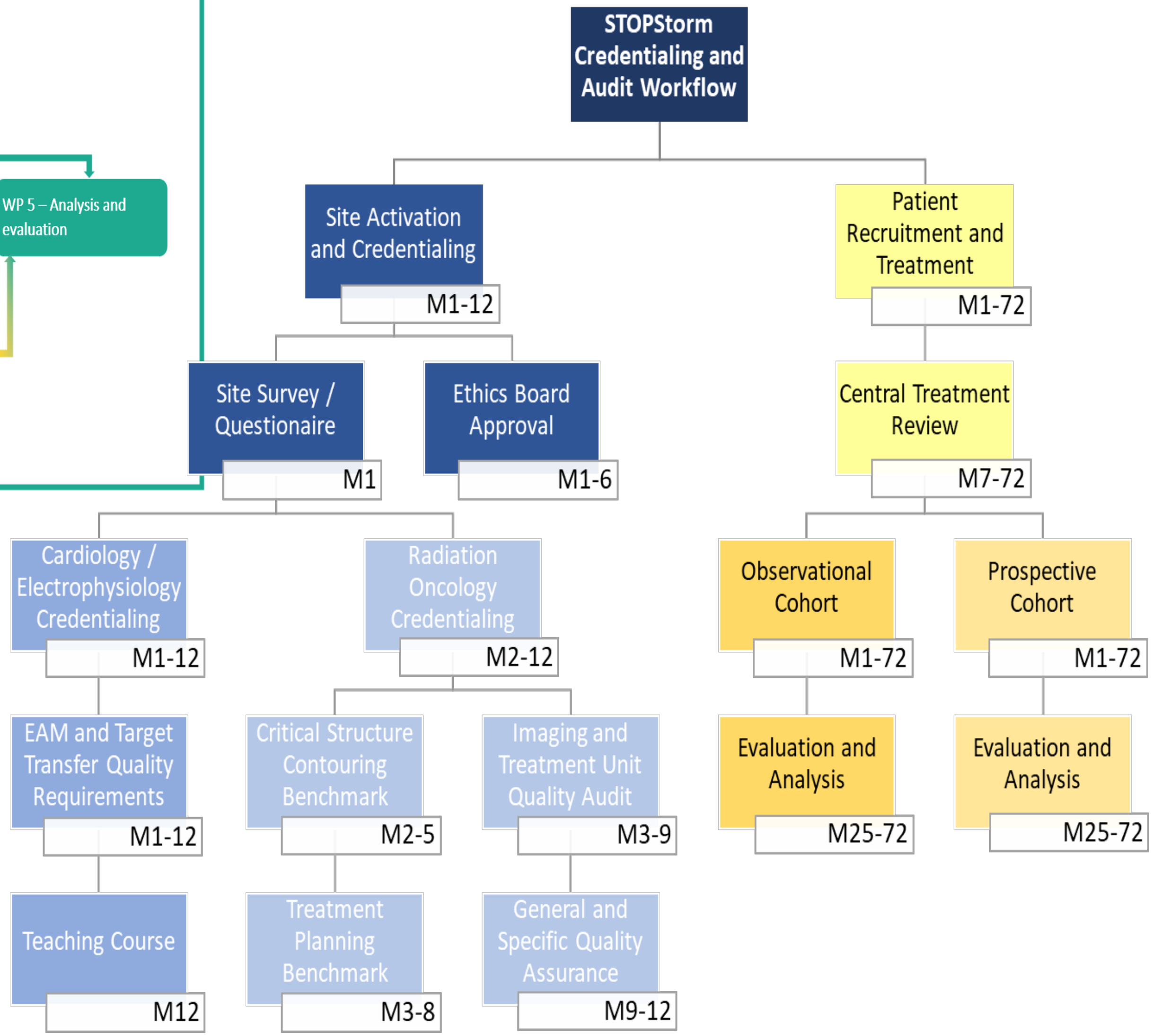
Evaluation Result

Total score: 14.00 (Threshold: 12)

RAVENTA part of EU Horizon 2020 funded STOPStorm Project

STOPSTORM: Audit and Credentialing





STereotactic Arrhythmia Radioablation (STAR): The Standardised Treatment and Outcome Platform for Stereotactic Therapy Of Re-entrant Tachycardia by a Multidisciplinary Consortium (STOPSTORM.eu) and Review of Current Patterns of STAR Practice in Europe

Melanie Grehn[1#], Stefano Mandija[2#], Marcin Miszczyk[3], David Krug[1], Bartłomiej Tomasik[4,5], Kristine E. Stickney[6], Pino Alcantara[7], Filippo Alongi[8], Matteo Anselmino[9], Ricardo Salgado Aranda[10], Brian V. Balgobind[11], Judit Boda-Heggemann[12], Leif-Hendrik Boldt[13], Nicola Bottini[14], Steen Buus Christiansen[15], Jakub Cvek[16], Olgun Elicin[17], Gaetano Maria de Ferrari[9], Rutger J. Hassink[18], Colien Hazelaar[19], Gerhard Hindricks[20], Coen Hurkmans[21], Cinzia Iotti[22], Tomasz Jadczyk[23], Otakar Jiravsky[24], Raphaël Jumeau[25], Mario Levis[26], Manuel Algara López[27], Julio Martí-Almor[28], Felix Mehrhof[29], Ditte Sloth Møller[30], Giulio Molon[31], Alexandre Ouss[32], Petr Peichl[33], Jiri Plasek[34], Pieter G. Postema[35], Aurelio Quesada[36], Tobias Reichlin[37], Roberto Rordorf[38], Boris Rudic[39], Ardan M. Saguner[40], Rachel M.A. ter Bekke[41], José López Torrecilla[42], Esther Troost[43], Viviana Vitolo[44], Nicolaus Andratschke[45], Katja Zeppenfeld[46], Slawomir Blamek[4], Martin Fast[2], Ludovica de Panfilis[47], Oliver Blanck[1], Etienne Pruvot[48§], Joost J. C. Verhoeff[2*§]

Christian-Albrechts-Universität zu Kiel
Medizinische Fakultät

STereotactic Arrhythmia Radioablation (STAR)

1) Dose-Response Relationship

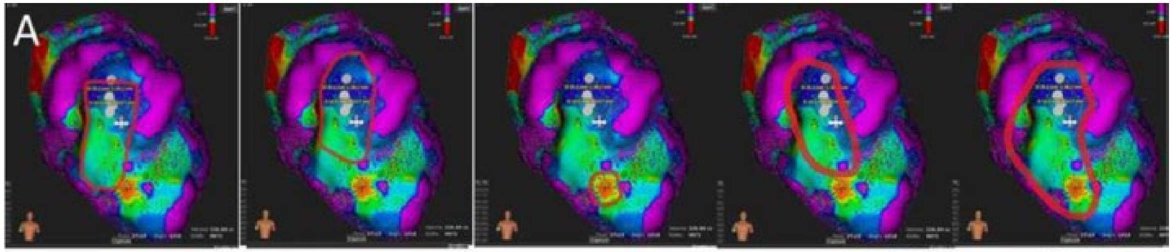
2) Target Definition and Conversion

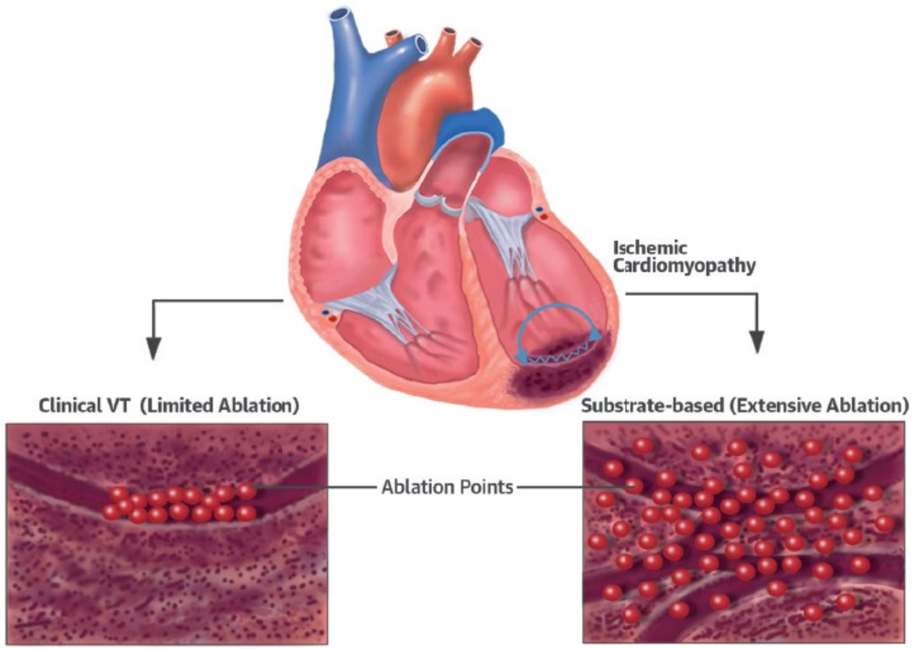
3) Motion Management

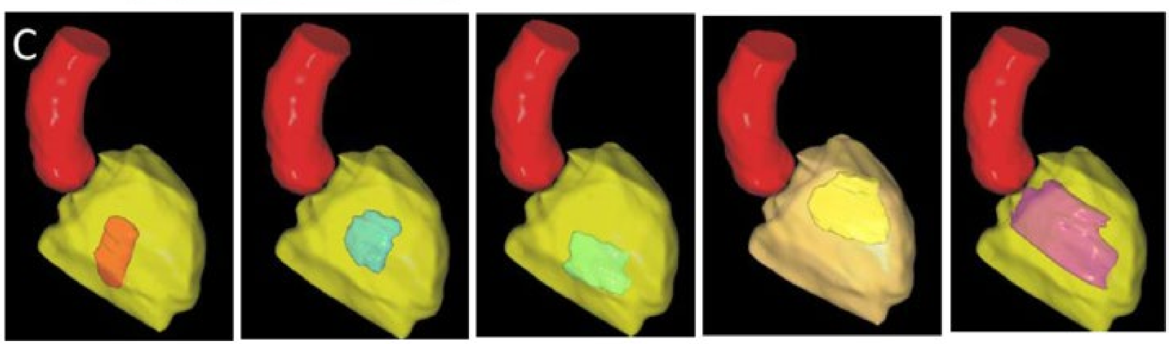
4) Treatment Planning

5) Treatment

Target Definition for Ventricular Tachycardia







Clinical Investigation

Interdisciplinary Clinical Target Volume Generation for Cardiac Radioablation: Multicenter Benchmarking for the RAdiosurgery for VENtricular TAchycardia (RAVENTA) Trial

Judit Boda-Heggemann, MD, PhD,[*] Oliver Blanck, PhD,[†]
Felix Mehrhof, MD,[‡] Floris Ernst, PhD,[§] Daniel Buergy, MD,[*]
Jens Fleckenstein, PhD,[*] Erol Tülümen, MD,[||] David Krug, MD,[†]
Frank-Andre Siebert, PhD,[†] Adrian Zaman, MD,[¶] Anne K. Kluge, PhD,[‡]
Abdul Shokor Parwani, MD,[#] Nicolaus Andratschke, MD,[**]
Michael C. Mayinger, MD,[**] Stefanie Ehrbar, PhD,[**]
Ardan M. Saguner, MD,[††] Eren Celik, MD,[‡‡] Wolfgang W. Baus, PhD,[‡‡]
Annina Stauber, MD,[§§] Lena Vogel, MD,[*] Achim Schweikard, PhD,[§]
Volker Budach, MD,[‡] Jürgen Dunst, MD,[†] Leif-Hendrik Boldt, MD,[#]
Hendrik Bonnemeier, MD,[¶] and Boris Rudic, MD[||]

2019 HRS/EHRA/APHRS/LAHRS expert consensus statement on catheter ablation of ventricular arrhythmias

Edmond M. Cronin, MB, BCh, BAO, FHRS, CCDS, CEPS-A (Chair),[1]
Frank M. Bogun, MD (Vice-Chair),[2] Philippe Maury, MD (EHRA Chair),[3]
Petr Peichl, MD, PhD (EHRA Vice-Chair),[4] Minglong Chen, MD, PhD, FHRS (APHRS Chair),[5]
Narayanan Namboodiri, MBBS, MD (APHRS Vice-Chair),[6]
Luis Aguinaga, MD, PhD, FESC, FACC (LAHRS Chair),[7]
Luiz Roberto Leite, MD, PhD, FHRS (LAHRS Vice-Chair),[8]
Sana M. Al-Khatib, MD, MHS, FHRS, CCDS,[9] Elad Anter, MD,[10]
Antonio Berruezo, MD, PhD,[11,*] David J. Callans, MD, FHRS, CCDS,[12]
Mina K. Chung, MD, FHRS,[13,†] Phillip Cuculich, MD,[14] Andre d'Avila, MD, PhD,[15,‡]
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Rakesh Latchamsetty, MD, FHRS,[2] Francis Marchlinski, MD, FHRS,[12]
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Luis C. Saenz Morales, MD,[27,¶] Pasquale Santangeli, MD, PhD,[12]
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Katja Zeppenfeld, MD, PhD, FESC, FEHRA[34,*]

Target Definition for Ventricular Tachycardia

METHOD AND ATLAS TO ENABLE TARGETING FOR CARDIAC RADIOABLATION EMPLOYING THE AMERICAN HEART ASSOCIATION SEGMENTED MODEL

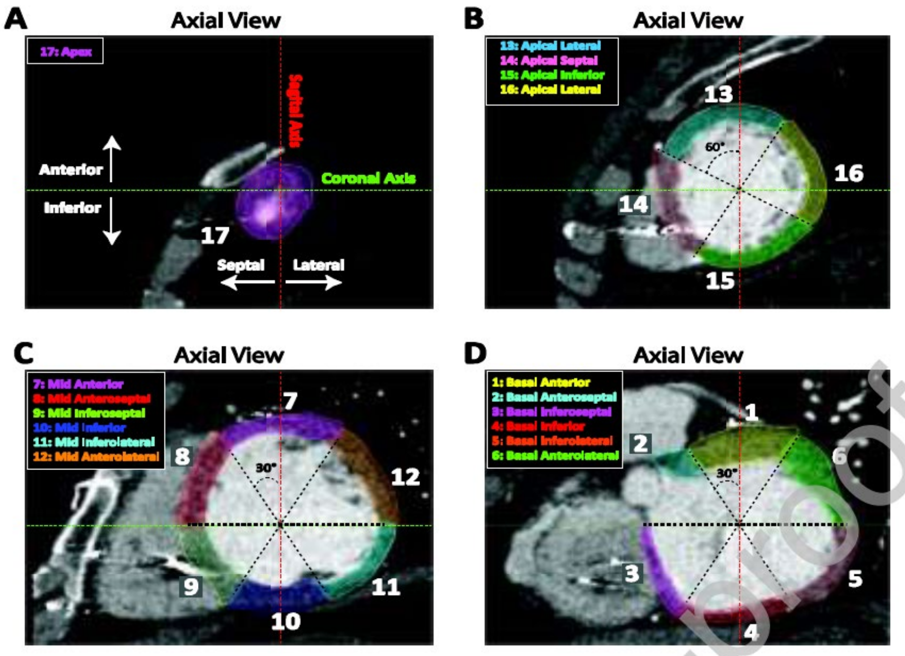
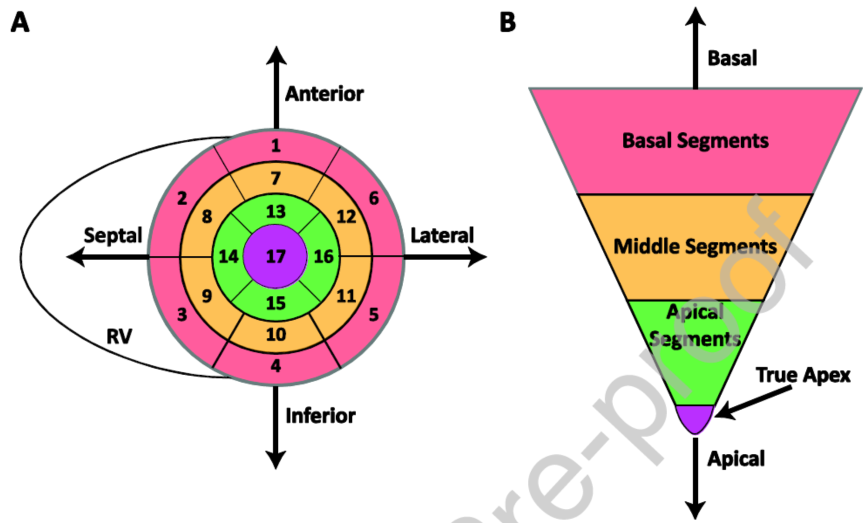
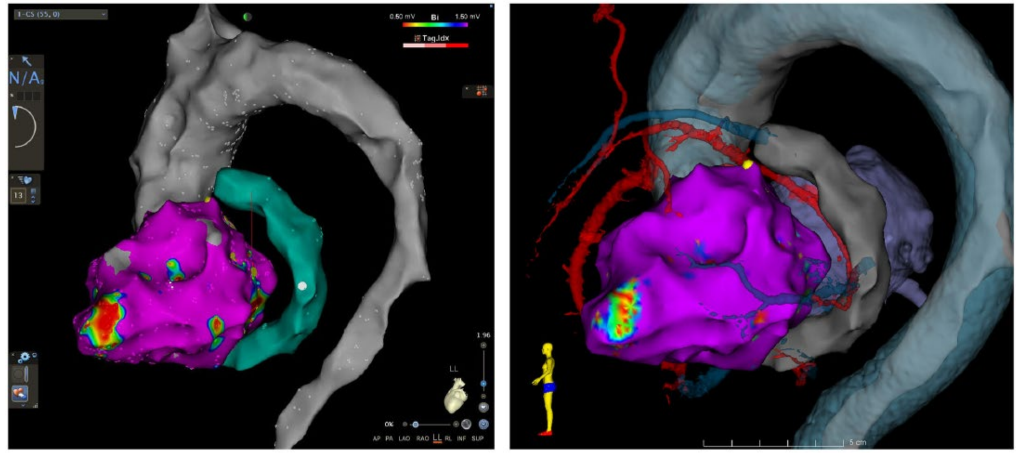


Figure 1



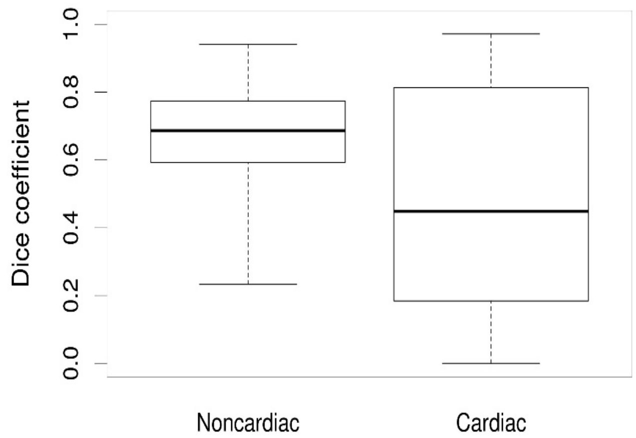
A novel open-source software-based high-precision workflow for target definition in cardiac radioablation

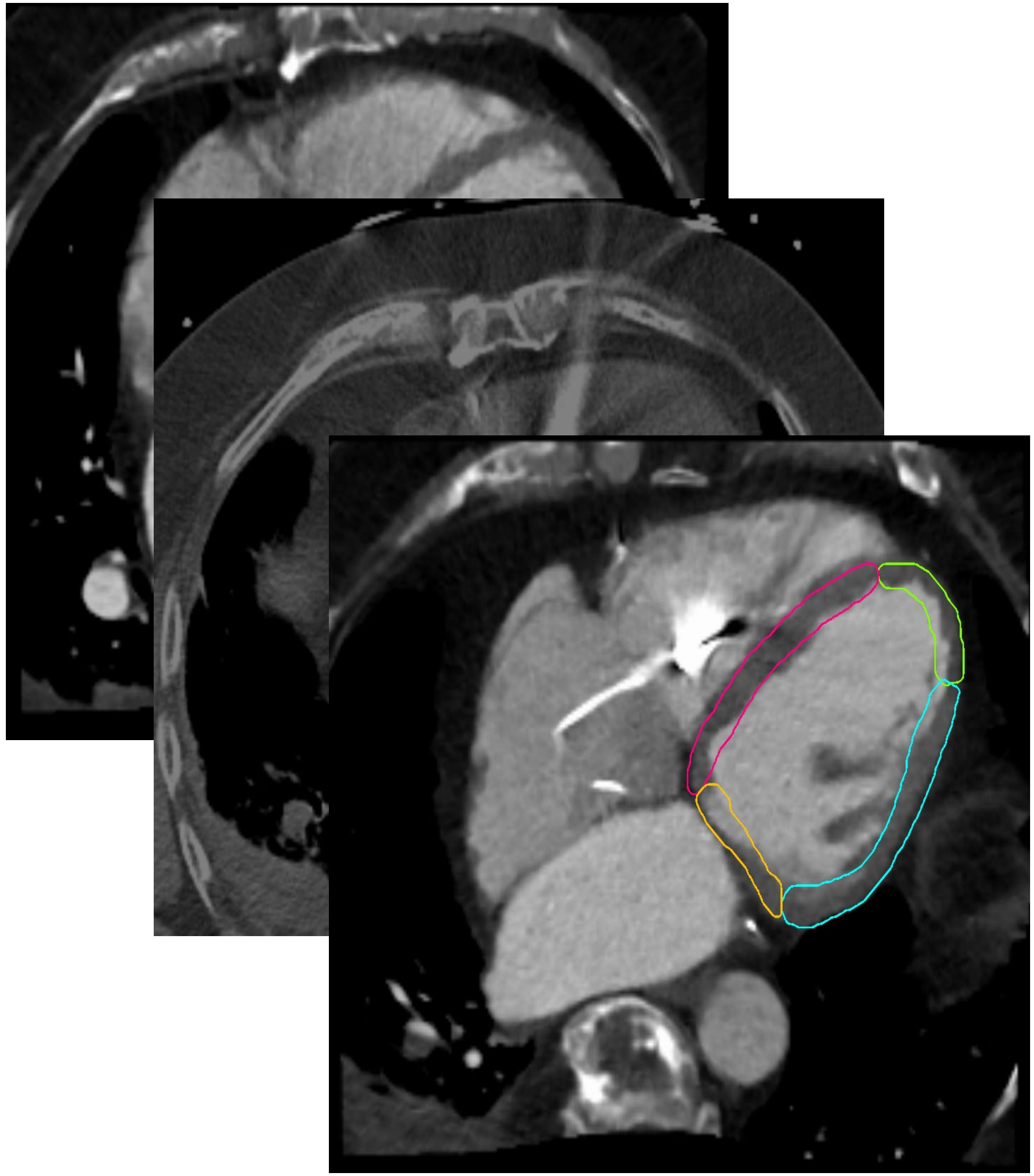


Novel Workflow for Conversion of Catheter-Based Electroanatomic Mapping to DICOM Imaging for Noninvasive Radioablation of Ventricular Tachycardia

Christopher L. Brett, MD,[a,*] Jason A. Cook, MD,[b] Asad A. Aboud, MD,[b] Rashed Karim, PhD,[c] Eric T. Shinohara, MD,[a] and William G. Stevenson, MD, FHRS[b]

STOPSTORM: Contouring Benchmark





STereotactic Arrhythmia Radioablation (STAR)

1) Dose-Response Relationship

2) Target Definition and Conversion

3) Motion Management

4) Treatment Planning

5) Treatment

Motion Management for STAR

Motion management

Requirement: *Systematic assessment and consistent consideration of periodic and non-periodic target motion during*

- *imaging for treatment planning;*
- *target volume definition;*
- *beam-delivery technique planning;*
- *dose simulation;*
- *target volume localization & repositioning; and*
- *dose application*

Strahlenther Onkol
https://doi.org/10.1007/s00066-020-01583-2

REVIEW ARTICLE

Technological quality requirements for stereotactic radiotherapy

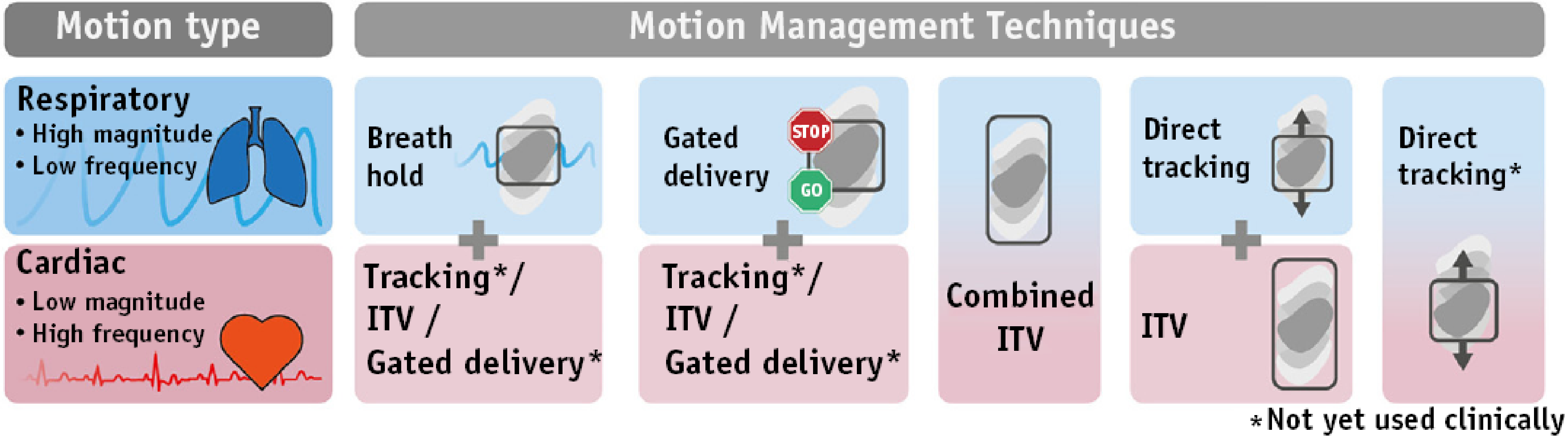
Expert review group consensus from the DGMP Working Group for Physics and Technology in Stereotactic Radiotherapy

Daniela Schmitt[1] · Oliver Blanck[2] · Tobias Gauer[3] · Michael K. Fix[4] · Thomas B. Brunner[5] · Jens Fleckenstein[6] · Britta Loutfi-Krauss[7] · Peter Manser[4] · Rene Werner[8] · Maria-Lisa Wilhelm[9] · Wolfgang W. Baus[10] · Christos Moustakis[11]

Critical Review

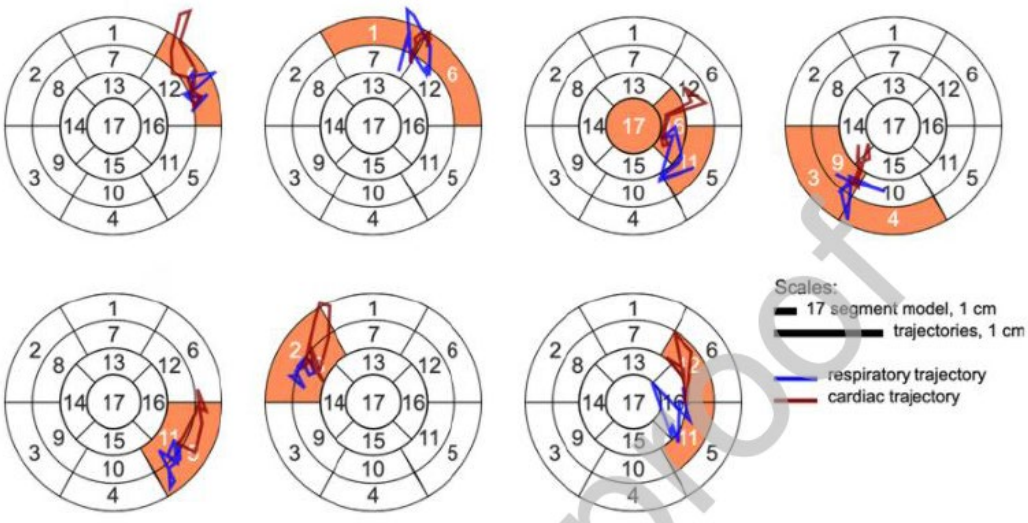
A Review of Cardiac Radioablation (CR) for Arrhythmias: Procedures, Technology, and Future Opportunities

Suzanne Lydiard, PGDip,[*,†] Oliver Blanck, PhD,[‡] Geoffrey Hugo, PhD,[§] Ricky O'Brien, PhD,[*] and Paul Keall, PhD[*]



Respiratory Motion Compensation

Evaluation of motion compensation methods for non-invasive cardiac radioablation of ventricular tachycardia



Open Access Case Report

DOI: 10.7759/cureus.190

Cardiac Radiosurgery for Malignant Ventricular Tachycardia

Jakub Cvek [1] , Radek Neuwirth [2] , Lukas Knybel [3] , Lukas Molenda [3] , Bretislav Otahal [3] , Jakub Pindor [2] , Mária Murárová [2] , Michal Kodaj [2] , Martin Fiala [2] , Marian Branny [2] , David Feltl [1]

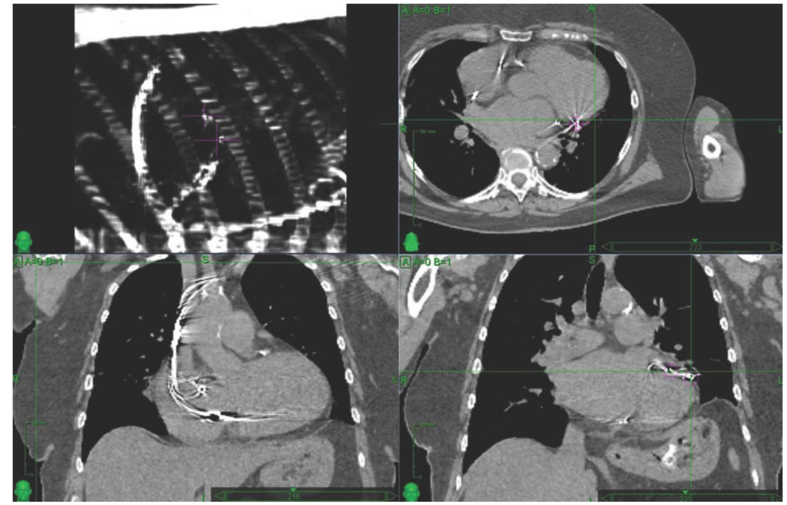


Table 3. Estimation of a gated internal target volume target expansion for each patient in three translational directions assuming the maximum value of the end exhale displacement from respiratory 4DCT and the full cardiac 4DCT to determine target motion is the driving determining factor for expansion.

	40%-60% r4DCT+ Max c4DCT		
Patient	LR (mm)	AP (mm)	SI (mm)
1	3.1	3.3	7.0
2	2.8	2.6	4.3
3	3.9	3.7	8.0
4	3.6	3.7	2.4
5	4.8	6.5	5.4
6	1.1	3.1	3.2
7	3.7	5.5	3.7
8	3.4	3.7	2.8
9	4.4	5.3	2.6
10	4.7	5.7	2.2
11	4.6	4.4	4.7
Mean	3.6	4.3	4.2
Std Dev	1.0	1.2	1.8

Table 2. Estimation of abdominal compression free-breathing internal target volume (ITV) for each patient assuming the maximum displacement between the r4DCT and c4DCT defined ITV.

	Full r4DCT+c4DCT		
Patient	LR (mm)	AP (mm)	SI (mm)
1	3.1	3.9	7.0
2	4.1	3.0	4.3
3	4.3	5.4	8.0
4	3.6	4.6	7.1
5	4.8	6.5	5.4
6	6.1	4.8	3.2
7	3.7	5.5	7.2
8	4.1	4.1	3.7
9	4.4	5.3	4.1
10	4.7	5.7	2.3
11	6.9	4.4	7.9
Mean	4.5	4.8	5.5
Std Dev	1.1	0.9	2.0

Cardiac Motion Ranges for Ventricular Tachycardia

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DOI: 10.1002/acm2.13002

RADIATION ONCOLOGY PHYSICS

WILEY

Analysis of cardiac motion without respiratory motion for cardiac stereotactic body radiation therapy

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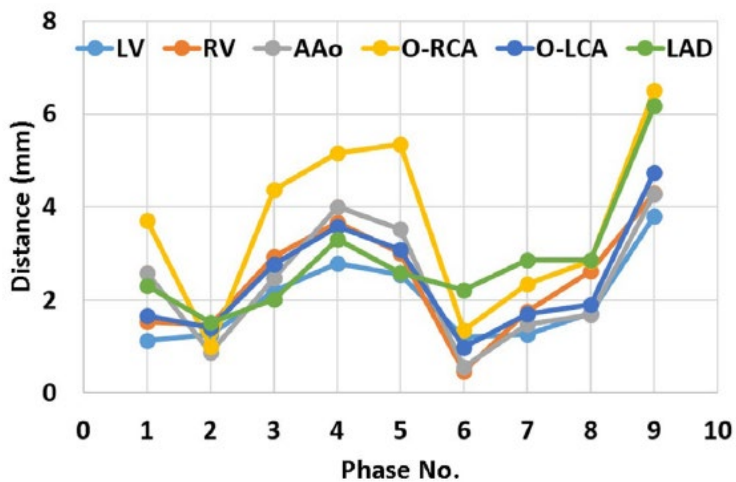
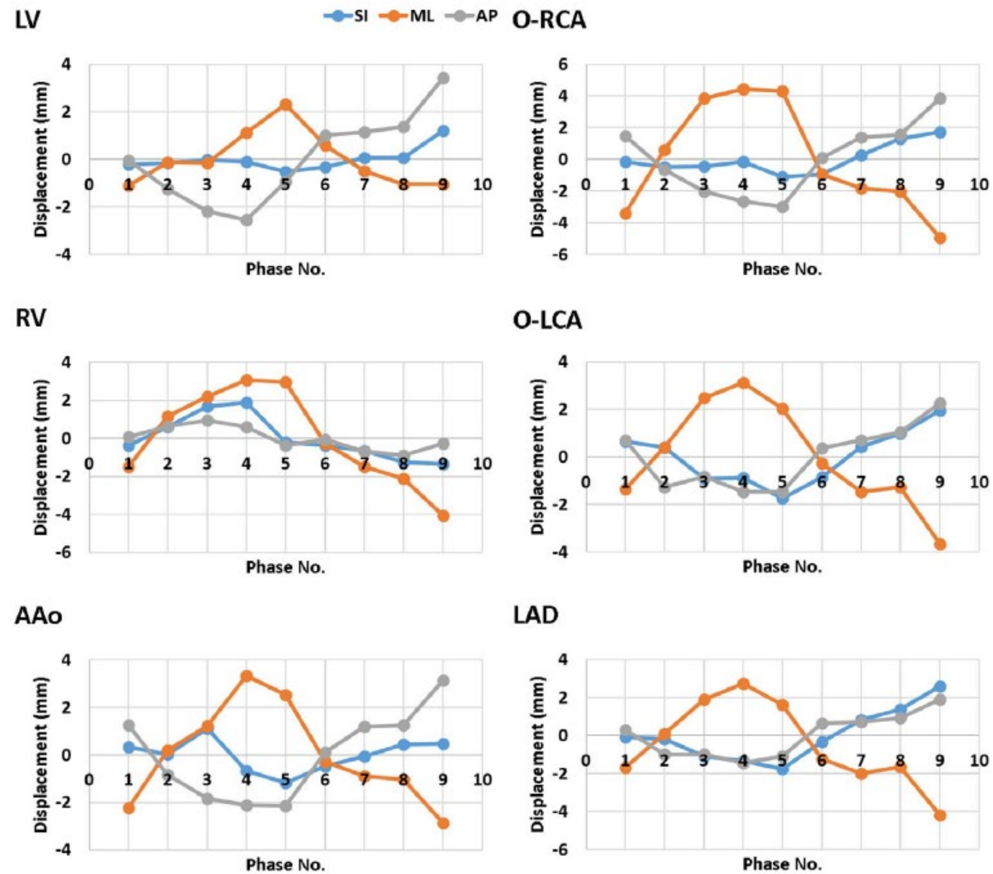
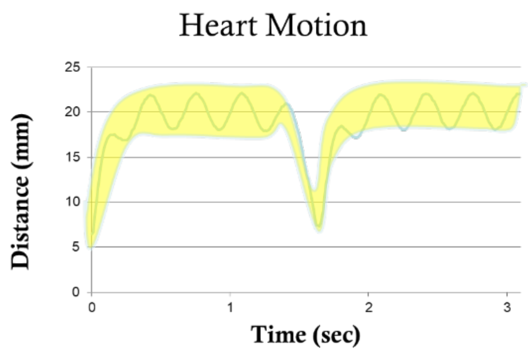


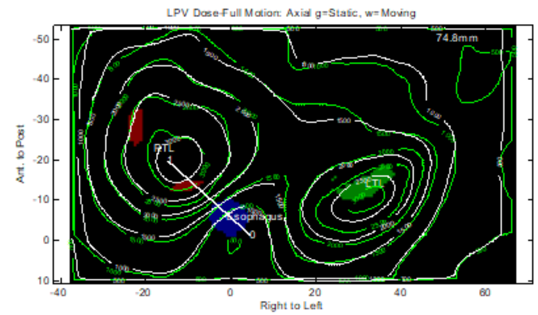


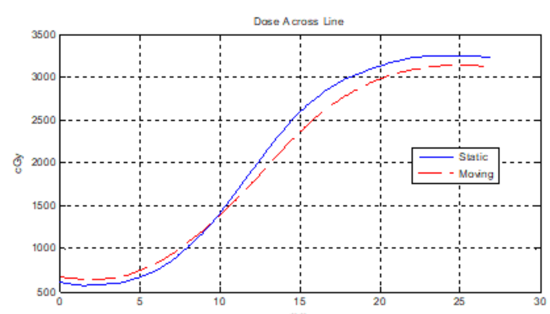
Results: For the six contoured substructures, more than 90% of the measured displacements were <5 mm. For these patients, the average volumes ranged from 191.25 to 429.51 cc for LV and from 91.76 to 286.88 cc for RV. For each patient, the ratios of maximum to minimum volumes within a cardiac cycle ranged from 1.15 to 1.54 for LV and from 1.34 to 1.84 for RV.

Dosimetric Effects on Uncompensated Cardiac Motion

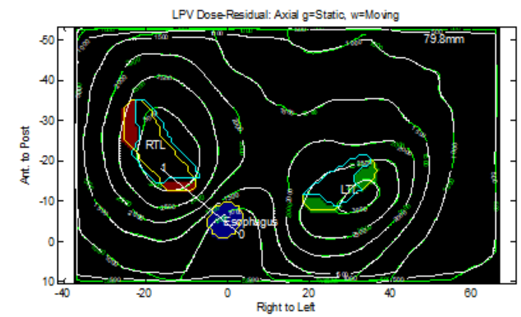
- Dominant heart motion from breathing *(compensation for STAR necessary)* but pulsing heart motion can not be compensated
- Cardiac ITV concept with respiratory motion compensation
- In phantom studies, however, it has been shown that the dosimetric effects of rapid cardiac motion < 1 cm are very low

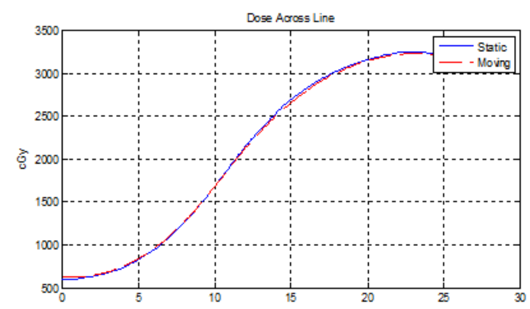






Uncompensated



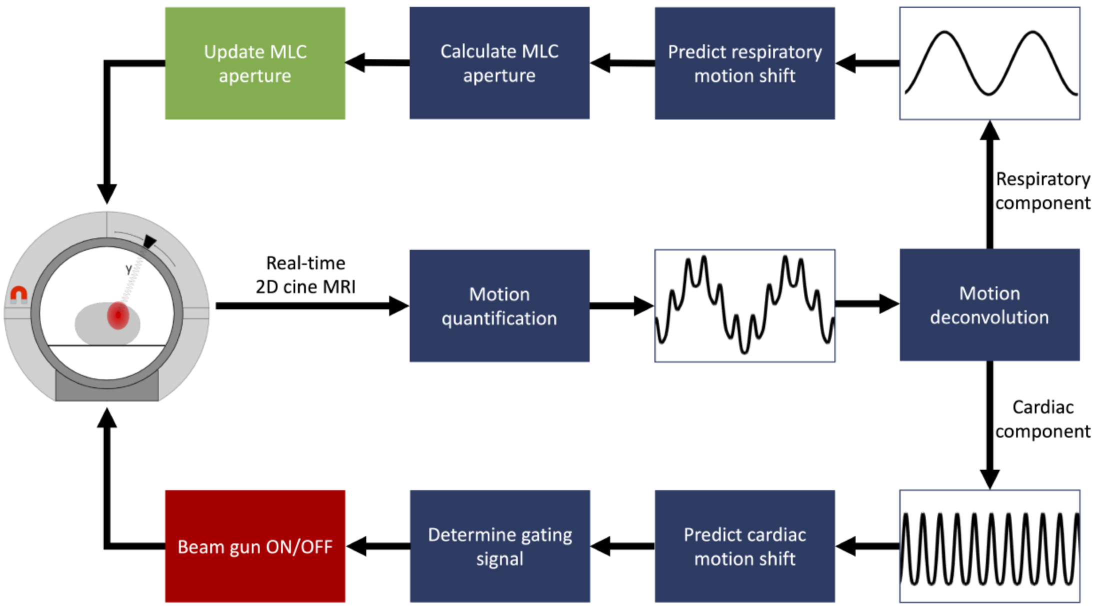


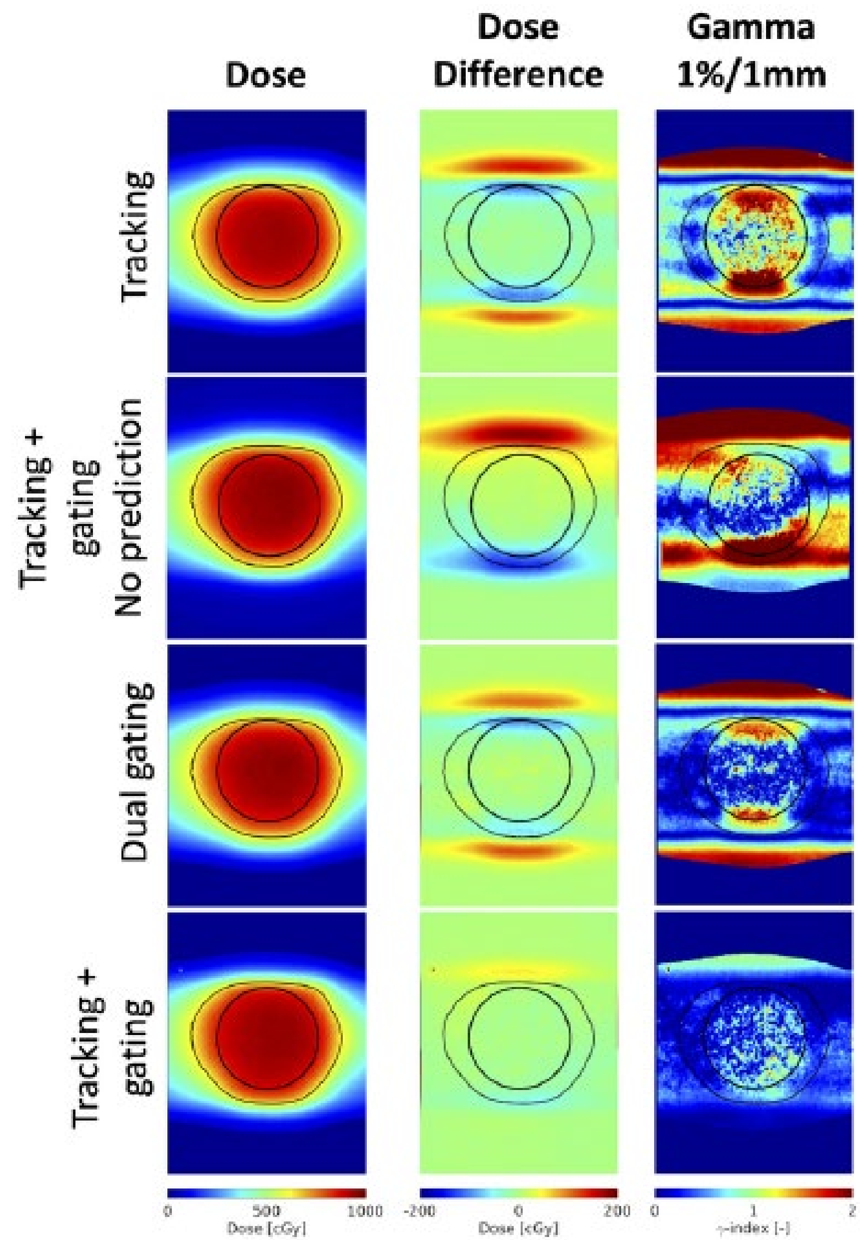
Compensated Resp.

Full Motion Compensation

Real-time cardiorespiratory motion mitigated stereotactic arrhythmia radioablation on the MR-linac

O Akdag[1*], P T S Borman[1], P Woodhead[3], P Uijtewaal[1], S Mandija[1,2], B Van Asselen1, J J C Verhoeff[1], B W Raaymakers[1], M F Fast[1]





Christian-Albrechts-Universität zu Kiel
Medizinische Fakultät

STereotactic Arrhythmia Radioablation (STAR)

1) Dose-Response Relationship

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Critical Structure Dose Limits

Organs at risk	Dose recommendations/dose limitations
Aorta	Dose limitations: $D_{max} \leq 20.0$ Gy Minor protocol deviation: 20 Gy $< D_{max} \leq 25$ Gy Major protocol violation: $D_{max} > 25$ Gy
Left coronary arteries	Dose limitations: $D_{max} \leq 14.0$ Gy Minor protocol deviation: 14 Gy $< D_{max} \leq 20$ Gy Major protocol violation: $D_{max} > 20$ Gy
Superior vena cava	Dose recommendations: $D_{50\%} \leq 0.6$ Gy
Left atrium	Dose recommendations: $D_{max} \leq 4.4$ Gy
Whole heart minus PTV	Dose recommendations: $D_{50\%} \leq 5$ Gy
Esophagus	Dose limitations: $D_{max} \leq 14.5$ Gy and $V_{9Gy} \leq 1$ ccm Minor protocol deviation: $D_{max} \leq 19$ Gy, $D_{1ccm} \leq 14.5$ Gy and $V_{9\,Gy} \leq 4$ ccm Major protocol violation: $D_{max} > 19$ Gy || $D_{1ccm} > 14.5$ Gy || $V_{9\,Gy} > 4$ ccm
Trachea	Dose limitations: $D_{max} \leq 15$ Gy and $V_{10\,Gy} \leq 1$ ccm Minor protocol deviation: $D_{max} \leq 20$ Gy, $D_{1\,ccm} \leq 15$ Gy and $V_{10\,Gy} \leq 4$ ccm Major protocol violation: $D_{max} > 20$ Gy || $D_{1\,ccm} > 15$ Gy || $V_{9\,Gy} > 4$ ccm
Bronchial tree	Dose limitations: $D_{max} \leq 15$ Gy and $V_{10Gy} \leq 1$ ccm Minor protocol deviation: $D_{max} \leq 20$ Gy, $D_{1\,ccm} \leq 15$ Gy and $V_{10\,Gy} \leq 4$ ccm Major protocol violation: $D_{max} > 20$ Gy || $D_{1\,ccm} > 15$ Gy || $V_{9\,Gy} > 4$ ccm
Spinal canal	Dose limitations: $D_{max} \leq 7$ Gy and $V_{6\,Gy} \leq 0.1$ ccm Minor protocol deviation: $D_{max} \leq 8$ Gy, $V_{6\,Gy} \leq 1$ ccm Major protocol violation: $D_{max} > 8$ Gy || $V_{6\,Gy} > 1$ ccm
Skin	Dose limitations: $D_{max} \leq 14.4$ Gy and $V_{10\,Gy} \leq 10$ ccm Minor protocol deviation: $D_{max} \leq 16$ Gy, $V_{14.4\,Gy} \leq 10$ ccm Major protocol violation: $D_{max} > 16$ Gy || $V_{14.4\,Gy} > 10$ ccm
Whole lungs	Dose limitations: $V_{100\%} - V_{7Gy} \geq 1500$ ccm ($V_{7\,Gy}$ remaining volume > 1500 ccm) and $D_{5\%} \leq 20$ Gy and $D_{50\%} \leq 3.5$ Gy Minor protocol deviation: $V_{100\%} - V_{7Gy} \geq 1000$ ccm ($V_{7\,Gy}$ remaining volume > 1000 ccm), $D_{6.5\%} \leq 20$ Gy and $D_{50\%} \leq 5$ Gy Major protocol violation: $V_{100\%} - V_{7\,Gy} < 1000$ ccm ($V_{7\,Gy}$ remaining volume < 1000 ccm), $D_{6.5\%} > 20$ Gy and $D_{50\%} > 5$ Gy
ICD (major electronics)	Dose limitations: $D_{max} \leq 0.5$ Gy and blocked from primary beam irradiation Minor protocol deviation: 0.5 Gy $< D_{max} \leq 1.0$ Gy Major protocol violation: $D_{max} > 1.0$ Gy

Clinical Research in Cardiology
https://doi.org/10.1007/s00392-020-01650-9
TRIAL DESIGN

Radiosurgery for ventricular tachycardia: preclinical and clinical evidence and study design for a German multi-center multi-platform feasibility trial (RAVENTA)

Oliver Blanck[1] · Daniel Buergy[2] · Maren Vens[3,4] · Lina Eidinger[1,5] · Adrian Zaman[5] · David Krug[1] · Boris Rudic[6] · Judit Boda-Heggemann[2] · Frank A. Giordano[2] · Leif-Hendrik Boldt[7] · Felix Mehrhof[8] · Volker Budach[8] · Achim Schweikard[9] · Denise Olbrich[3] · Inke R. König[4] · Frank-Andre Siebert[1] · Reinhard Vonthein[4] · Jürgen Dunst[1] · Hendrik Bonnemeier[5]

Radiotherapy Workflow and Dosimetric Analysis from a Phase I/II Trial of Noninvasive Cardiac Radioablation for Ventricular Tachycardia

Nels C. Knutson, PhD[1*], Pamela Samson, MD, MPHS[1*], Geoffrey Hugo, PhD[1], S. Murty Goddu, PhD[1], Francisco Reynoso, PhD[1], James Kavanaugh, MS[1], Sasa Mutic, PhD[1], Kaitlin Moore, BS[2], Jessica Hilliard, MS, CMD[1], Phillip Cuculich, MD[2], & Clifford Robinson, MD[1]

Management of Radiotherapy Patients with Implanted Cardiac Pacemakers and Defibrillators: *A Report of the AAPM TG-203**

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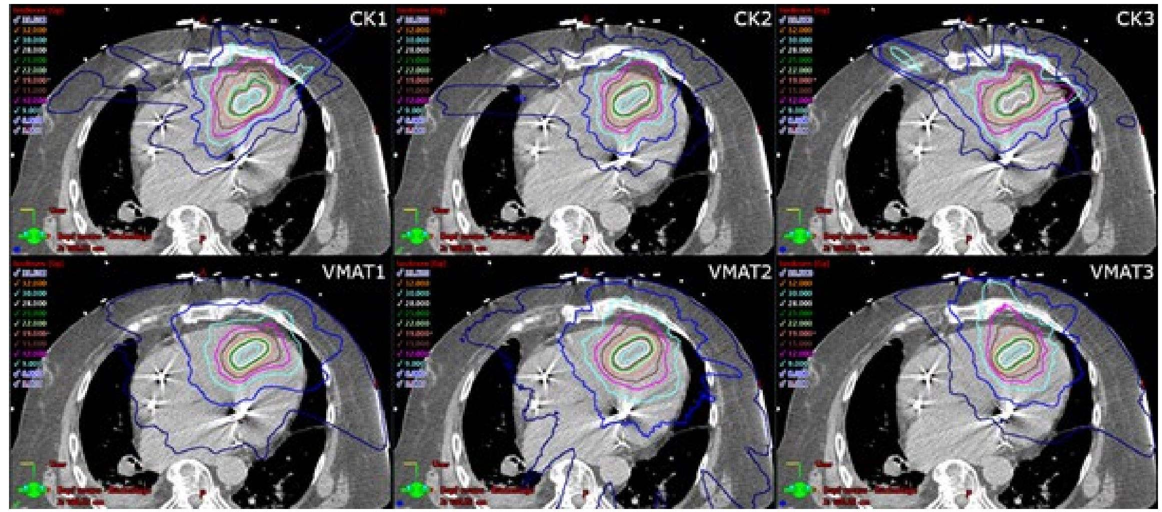
Treatment Planning for Ventricular Tachycardia

Critical Review

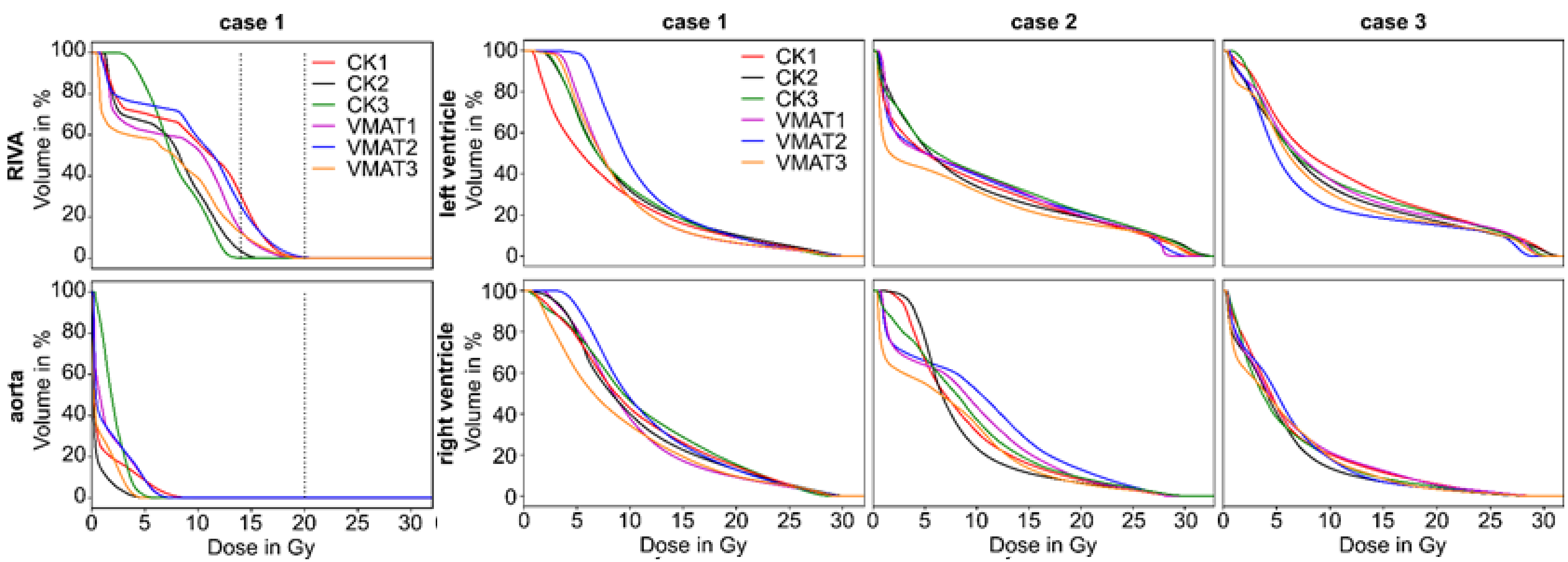
Dosimetric Multicenter Planning Comparison Studies for Stereotactic Body Radiation Therapy: Methodology and Future Perspectives

Francesca Romana Giglioli, MSc,* Cristina Garibaldi, MSc,† Oliver Blanck, PhD,‡ Elena Villaggi, Msc,§ Serenella Russo, MSc,|| Marco Esposito, PhD,|| Carmelo Marino, MSc,¶ Michele Stasi, MSc,# and Pietro Mancosu, PhD**

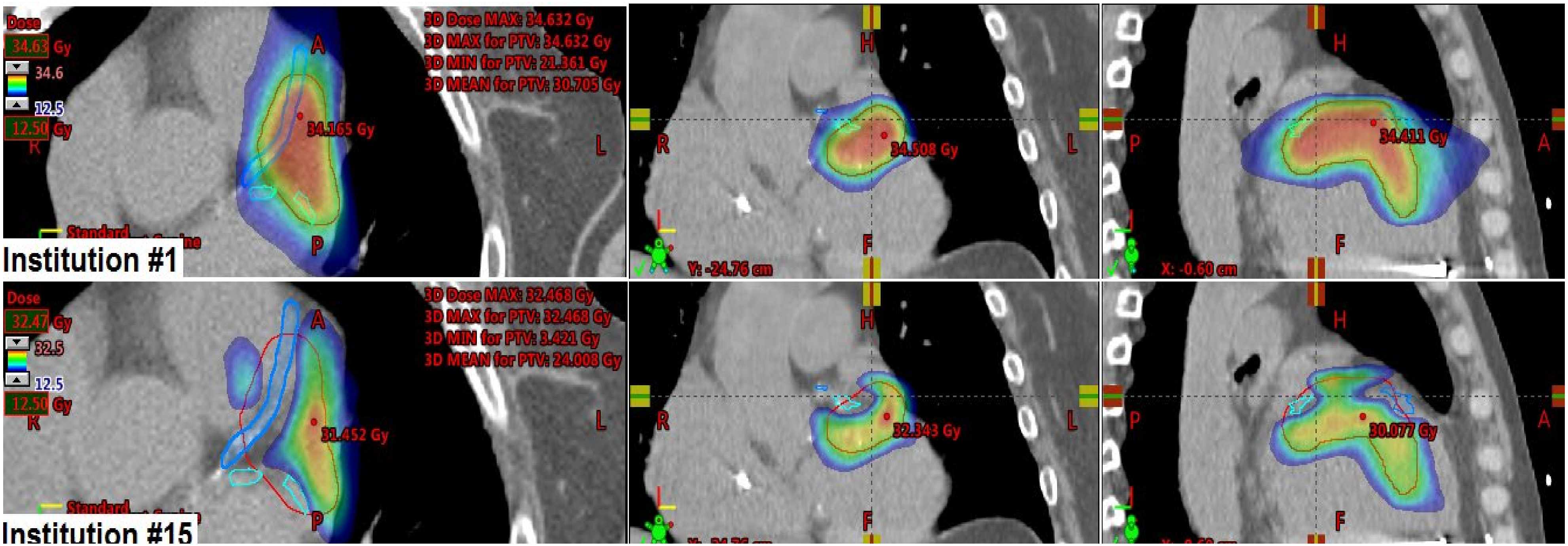


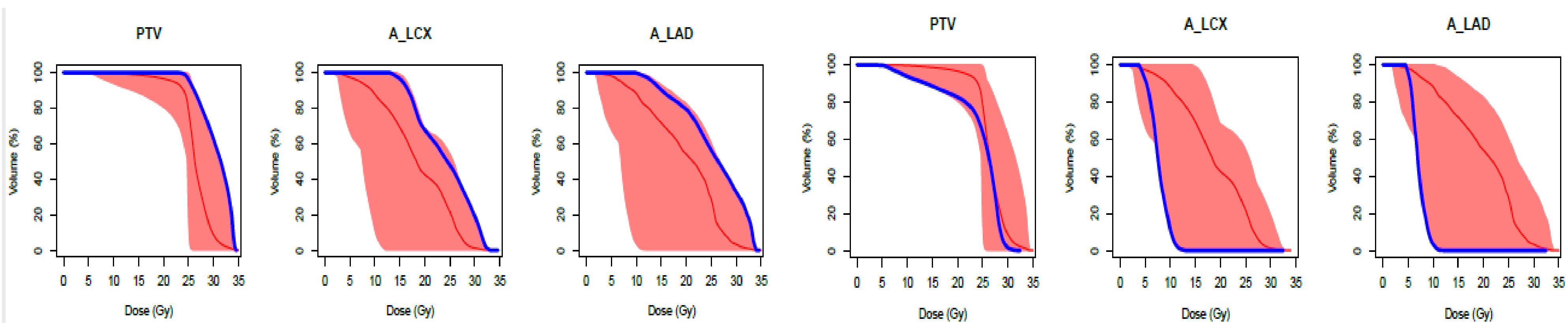
Treatment planning for cardiac radiosurgery in patients with ventricular tachycardia: benchmark study for the multi-institutional, multi-platform RAVENTA clinical trial

Kluge, Ehrbar, Grehn, Fleckenstein, Baus, Andraschke, Mayinger, Boda-Heggemann, Buergy, Krug, Saguner, Rudic, Boldt, Bonnemeier, Dunst, Budach, Blanck, Mehrhof



STOPSTORM: Treatment Planning Benchmark





STereotactic Arrhythmia Radioablation (STAR)

1) Dose-Response Relationship

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Christian-Albrechts-Universität zu Kiel
Medizinische Fakultät

STAR Treatment with CyberKnife

Critical Review

A Review of Cardiac Radioablation (CR) for Arrhythmias: Procedures, Technology, and Future Opportunities

Suzanne Lydiard, PGDip,*,† Oliver Blanck, PhD,‡ Geoffrey Hugo, PhD,§ Ricky O'Brien, PhD,* and Paul Keall, PhD*

Check for updates

Table 2: *Summary of procedural details and technology choice for human ventricular tachycardia (VT) and atrial fibrillation (AF) cardiac radioablation treatments using CyberKnife.*

Study	Number of participants	Pre-planning EP & scar imaging	Imaging for planning	Arrhythmia	Prescription	Respiratory motion management	Cardiac motion management	Treatment motion management	Treatment time
Neuwirth *et al.*, 2019	10	EAM	Contrast-enhanced 3DCT x2 (ECG gated) in expiratory breath-hold	VT	25 Gy/1 fraction	Fiducial tracking (ICD lead)	ITV based on systole & diastole ECG-gated CT	kV orthogonal oblique planar intra-fraction imaging, & fiducial tracking (Synchrony).	Mean treatment time 68 min (range 45-80 min)
Gianni *et al.*, 2020	5	EAM, ECG, contrast-enhanced CT	Contrast-enhanced cardiac CT in expiratory breath-hold	VT	25 Gy/1 fraction	Fiducial tracking (Temporary pacing lead)	Pre-defined 3mm target volume margin expansion	kV orthogonal oblique planar intra-fraction imaging & fiducial tracking (X-sight spine tracking & Synchrony)	Mean treatment times 82 min (range 71-93 min)
Loo *et al.*, 2015	1	12-lead ECG, ECHO, PET-CT	3DCT in breath-hold & fluoroscopy images of cardiac fiducials in breath-hold	VT	25 Gy/1 fraction	Fiducial tracking (Temporary pacing wire)	ITV based on breath-hold fluoroscopy of cardiac fiducials.	kV orthogonal oblique planar intra-fraction imaging & fiducial tracking (Synchrony)	90 min (approx.)
Jumeau *et al.*, 2018	1	EAM, MRI, ECHO, PET	Non-contrast CT under GA & transthoracic echocardiography	VT	25 Gy/1 fraction	Fiducial tracking (ICD lead)	Motion assessed by transthoracic echocardiography	kV orthogonal oblique planar intra-fraction imaging & fiducial tracking (Synchrony)	45 min (approx.)
Cvek *et al.*, 2014	1	EAM, CT	3DCT (pre-acquired diagnostic scan)	VT	25 Gy/1 fraction	Fiducial tracking (LC electrode of stimulation system)	ITV based on systole & diastole	kV orthogonal oblique planar intra-fraction imaging & fiducial tracking (Synchrony)	114 min
Zeng *et al.*, 2019	1	12-lead ECG and EAM	3DCT & fluoroscopy In breath-hold	VT	24 Gy/3 fractions	Fiducial tracking (Active-fixation pacing lead)	ITV based on breath-hold fluoroscopy of cardiac fiducials.	kV orthogonal oblique planar intra-fraction imaging & fiducial tracking (Synchrony) assumed	Not reported
Monroy *et al.*, 2016	1	None	CT	AF	25 Gy/1 fraction	Fiducial tracking	None (assumed as no mention)	kV orthogonal oblique planar intra-fraction imaging, & fiducial tracking	Not reported
Qian *et al.*, 2019	2	None	Contrast-enhanced cardiac CT	AF	25 Gy/1 fraction	Fiducial tracking (Active fixation lead in interatrial septum)	None (assumed as no mention)	kV orthogonal oblique planar intra-fraction imaging, & fiducial tracking	90 min (approx.)

3DCT = three-dimensional computed tomography, AF = atrial fibrillation, CT = computed tomography, EAM = electroanatomical mapping, ECG = electrocardiography, ECHO = echocardiography, GA = general anesthetic, ITV = internal target volume, kV = kilovoltage, MRI = magnetic resonance imaging, PET = positron emission tomography, VT = ventricular tachycardia

STAR Treatment with C-Arm Linear Accelerators

Table 3: *Summary of procedural details and technology choice for human ventricular tachycardia (VT) cardiac radioablation treatments using c-arm linear accelerators. No cardiac radioablation treatments for atrial fibrillation (AF) have been performed on c-arm linear accelerators.*

Study	Number of participants	Pre-planning EP & scar imaging	Imaging for planning	Arrhythmia	Prescription	Motion management	Treatment planning margins	Linac & treatment type	Immobilization	Treatment set-up /IGRT	Timeframes
*Cuculich *et al.*, 2017 *Robinson *et al.*, 2019 *Knutson *et al.*, 2019	19 (combined total)	Multi-electrode vest with CT registration, EAM, CT, contrast-enhanced MRI, ECHO, PET-CT	Contrast-enhanced 3DCT & 4DCT free-breathing	VT	25 Gy/1 fraction	Cardiac & respiratory: combined ITV. Abdominal compression used as needed.	ITV from 4DCT 5 mm ITV-PTV expansion	Varian TrueBeam or Edge 6 MV flat or FFF VMAT or IMRT	Vacuum-assisted cushion with vacuum-sealed layer or foam cushion with abdominal compression Overhead arm extension	Pre-fraction CBCT registered to respiratory-averaged planning CT, fluoroscopy to confirm shifts, 6dof couch	Simulation on average 13.5 days before treatment, mean treatment delivery time 14 min (5.4-32.3 min)
Lloyd *et al.*, 2019	10	At least 1 3D anatomical imaging and 1 EP study with EAM	Contrast-enhanced 3DCT & 4DCT free-breathing	VT	25 Gy/1 fraction	Cardiac & respiratory: combined ITV	1-5 mm scar to PTV expansion	Varian TrueBeam VMAT	Rigid immobilization consistent with Lung SBRT treatments	Pre-fraction kV planar & CBCT matched to bony anatomy and ICD leads	One hour between departure and return to clinical care unit. RT appointment 30 min
Marti-Almor *et al.*, 2019	1	Previous EAM, MRI, CT	Unclear	VT	25 Gy/1 fraction	External surrogate amplitude-based respiratory gating	Not reported	Varian TrueBeam 10FFF DCA & static fields	Vacuum assisted device	Pre-fraction CBCT	4 min treatment delivery
Bhaskaran *et al.*, 2019	1	EAM, MRI	Contrast-enhanced 3DCT & 4DCT free-breathing	VT	25 Gy/1 fraction	Cardiac & respiratory: combined ITV	ITV from 4DCT 5-8 mm margin to include adjacent myocardial tracts, 5 mm ITV-PTV expansion	Varian TrueBeam 6FFF VMAT	Supine position with external thermoplastic shoulder immobilization	Volumetric cine on day of treatment (Canon Genesis 320 slice scanner) to verify planning margins adequate & pre-fraction CBCT	5 min treatment delivery
Krug *et al.*, 2019	1	EAM, cardiac-gated CT	Non-contrast 4DCT free-breathing	VT	25 Gy/1 fraction	Cardiac & respiratory: combined ITV	ITV from cardiac-gated and free-breathing planning 4DCT, 5 mm ITV-PTV expansion	Varian TrueBeam 6FFF Co-planar DCA	Supine position with elevated arms. No vacuum bag or abdominal compression	Pre-fraction and between arcs CBCT, using ICD lead as reference for image registration	Patient positioning and setup of monitoring equipment approx. 40 min. Treatment and image guidance time approx. 15 min
Scholz *et al.*, 2019	1	EAM, coronary angiography, LV angiography	4DCT	VT	25 Gy/1 fraction	Cardiac & respiratory: combined ITV with mechanical ventilation	ITV from 4DCT, 2 mm ITV-PTV expansion	Elekta VersaHD 6FFF VMAT	Deeply sedated and mechanical ventilation	Pre-fraction 4D CBCT and kV planar	30 min treatment appointment, 5 min for image guidance, 5 min for delivery
Mayinger *et al.*, 2020	1	Contrast-enhanced MRI, non-contrast MRI, surface ECG, invasive EAM	CT & 3D MRI	VT	25 Gy/1 fraction	MRI-guided tracking of liver-dome with automatic beam gating & breath-hold	PTV 2 mm vertical and lateral, 3 mm longitudinal expansion	Hybrid MRI-Linac 6FFF IMRT	Supine position, arms raised above head	3D MRI matching GTV to planning images, 2D single-slice sagittal cine for MRI-guided tracking	Total duration 148 min; patient set-up 24 min, target localization & set-up 6 min, MR cine tracking 46min, beam on time 24 min

Summary

- STereotactic Arrhythmia Radioablation (STAR) is used for Ventricular Tachycardia (n > 150) and Atrial Fibrillation (n ≈ 5) patients with limited to no standard treatment options

- Motion Management similar to thoracic SBRT with consideration of cardiac motion (ITV)

Critical Review

A Review of Cardiac Radioablation (CR) for Arrhythmias: Procedures, Technology, and Future Opportunities

Suzanne Lydiard, PGDip,[*,†] Oliver Blanck, PhD,[‡] Geoffrey Hugo, PhD,[§] Ricky O'Brien, PhD,[*] and Paul Keall, PhD[*]

CONTEMPORARY REVIEW

Cardiac radioablation—A systematic review

Recommendations regarding cardiac stereotactic body radiotherapy for treatment refractory ventricular tachycardia

David Krug, MD,[*] Oliver Blanck, PhD,[*] Nicolaus Andratschke, MD,[†] Matthias Guckenberger, MD,[†] Raphael Jumeau, MD,[‡§] Felix Mehrhof, MD,[||] Judit Boda-Heggemann, MD,[¶] Katharina Seidensaal, MD,[#] Jürgen Dunst, MD,[*] Etienne Pruvot, MD,[**] Eberhard Scholz, MD,[††] Ardan M. Saguner, MD,[‡‡] Boris Rudic, MD,[§§] Leif-Hendrik Boldt, MD,[||||] Hendrik Bonnemeier, MD[¶¶]

- Fast delivery of 25 Gy (with potentially doses higher 30 Gy) to the VT substrate seem to be clinically effective and safe

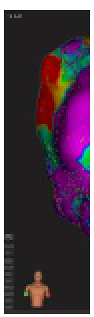
- A dedicated STAR protocol and expert guidance ideally in clinical trials or prospective registries is strongly recommended

We still have a lot to do!

Christian-Albrechts-Universität zu Kiel

Medizinische Fakultät

Unter der wissenschaftlichen Leitung der Kliniken für Elektrophysiologie



Session IV: Zukunft der Herz-Radiochirurgie Moderation: AG EP (DGK), AG RS (DEGRO)		
11:00 Uhr	Harmonisierungsansätze für die Katheterablation bei Ventrikulären Tachykardien (AG EP)	AG EP: Prof. Dr. Philipp Sommer (Bad Oeynhausen)
11:15 Uhr	Harmonisierungsansätze für die (kardiale) Stereotaktische Strahlentherapie (AG RS)	AG RS: Prof. Dr. Andrea Wittig (Jena)
11.30 Uhr	Erster Delphi-Konsensus ausgewählter deutschsprachiger Zentren	PD Dr. David Krug (Kiel)
11.50 Uhr	STOPSTORM: Aktueller Projektstand und Pattern-Of-Practice in Europa	Dr. Oliver Blanck (Kiel)
12.10 Uhr	Initiierung eines gemeinsamen Arbeitsgruppen-Konsensus	AG EP / AG RS
12.30 Uhr	Abschlussdiskussionen	Alle