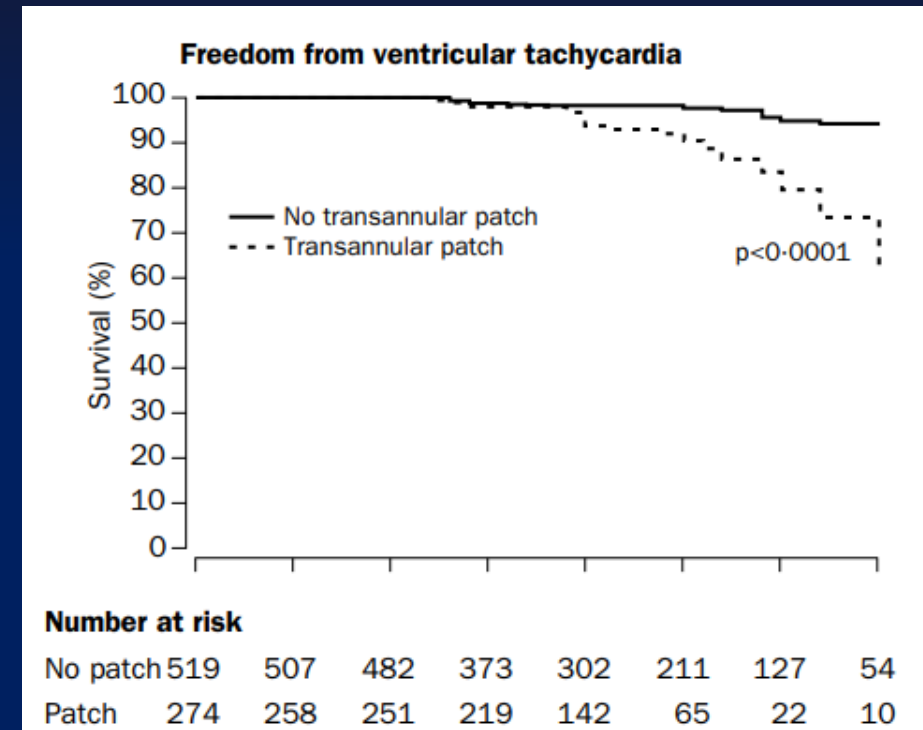
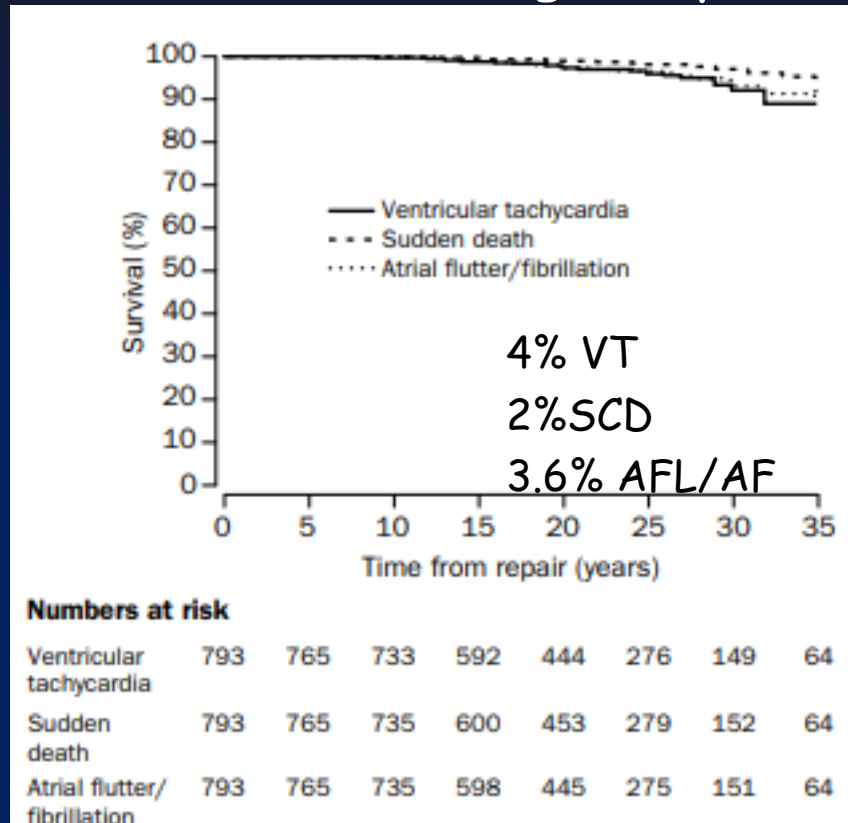


**Aritmie ventricolari nella tetralogia di Fallot:
dal pediatrico al GUCH.
Stratificazione del rischio e terapia**



Elisabetta M. Mariucci,
Cardiologia e Cardiochirurgia Pediatrica e dell'età evolutiva
IRCCS Azienda Ospedaliero-Universitaria di Bologna

Ventricular arrhythmias and SCD are important late complications
in patients with repaired TOF
with PR being the predominant haemodynamic lesion



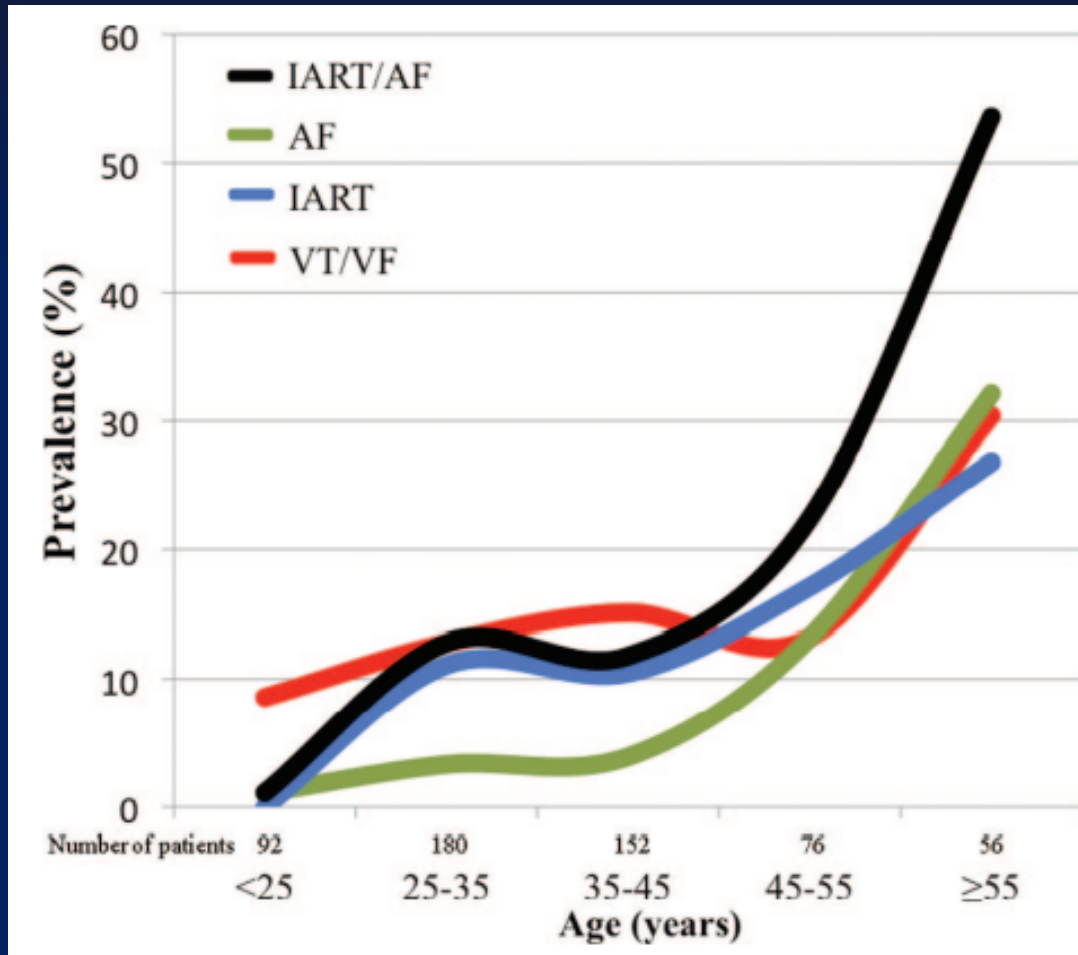
Multicentre cohort of 793 patients with repaired TDF
Mean follow-up 21 years

Gatzoulis MA, Lancet 2000; 356: 975-81

Arrhythmia Burden in Adults With Surgically Repaired Tetralogy of Fallot

A Multi-Institutional Study

Paul Khairy, MD, PhD; Jamil Aboulhosn, MD; Michelle Z. Gurvitz, MD; Alexander R. Opatowsky, MD; François-Pierre Mongeon, MD; Joseph Kay, MD; Anne Marie Valente, MD; Michael G. Earing, MD; George Lui, MD; Deborah R. Gersony, MD; Stephen Cook, MD; Jennifer Grando Ting, MD; Michelle J. Nickolaus, CRNP; Gary Webb, MD; Michael J. Landzberg, MD; Craig S. Broberg, MD; for the Alliance for Adult Research in Congenital Cardiology (AARCC)

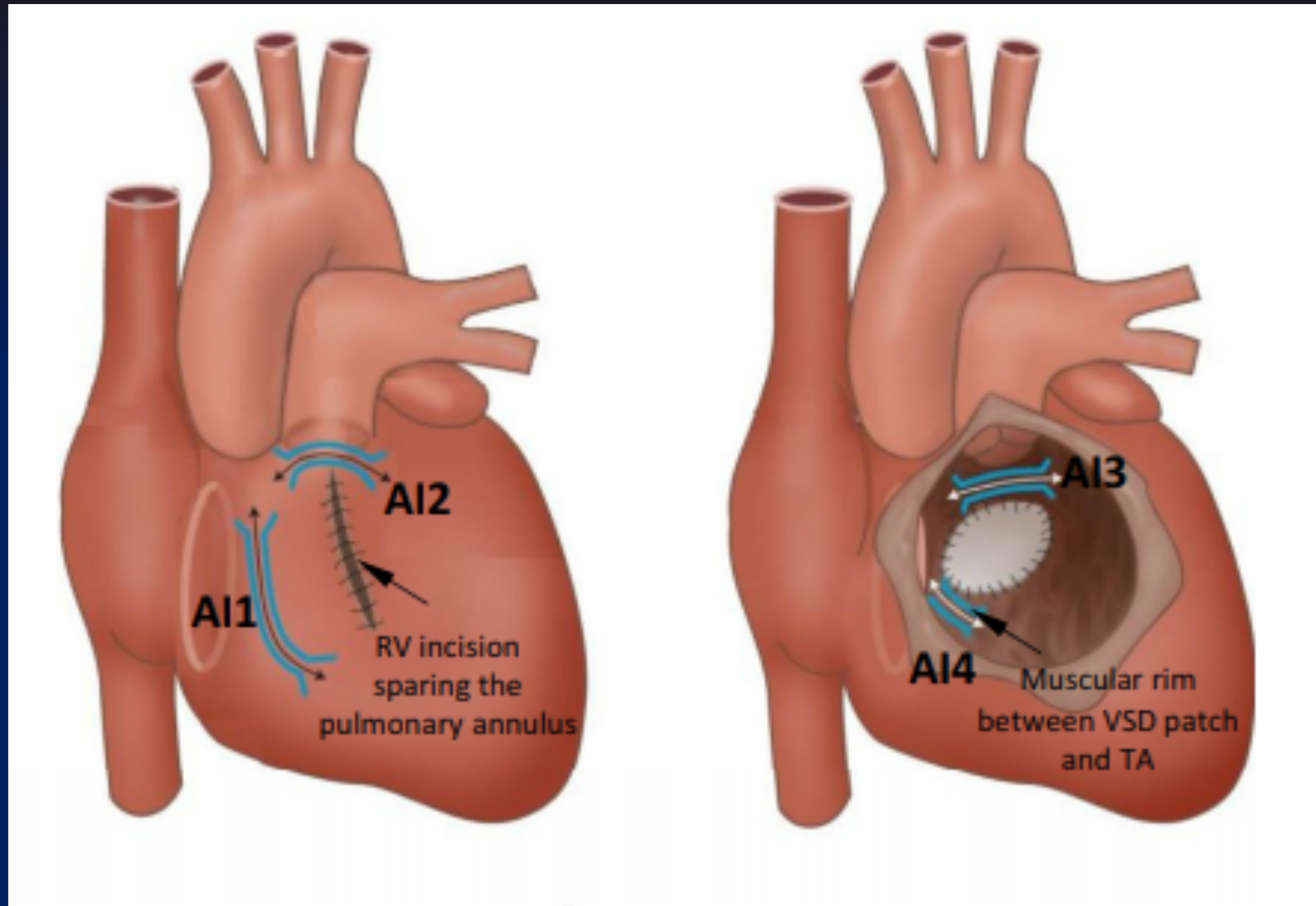


Multicenter cross-sectional study
556 rToF, mean age 37 ± 12 y
recruited from 11 centers

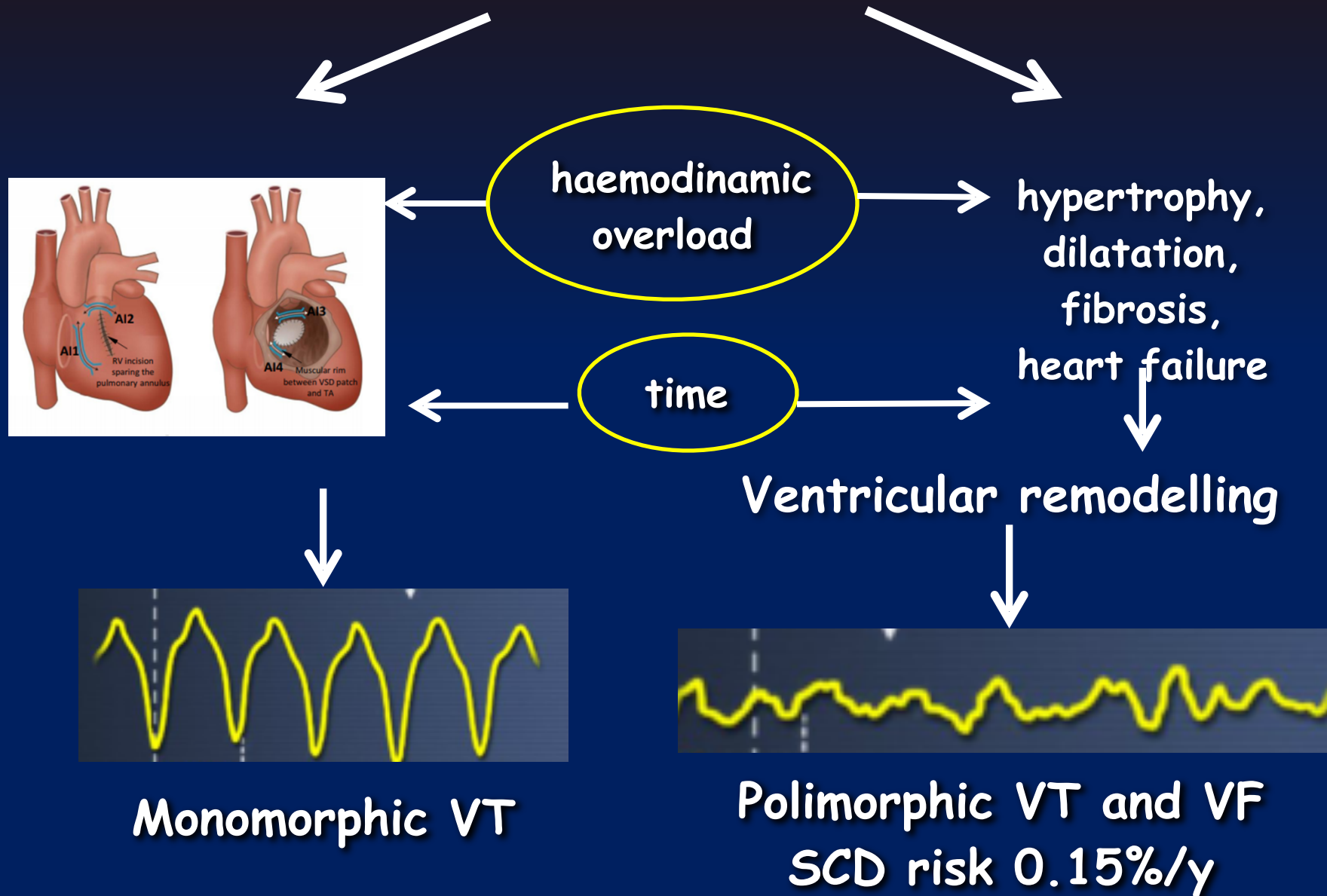
The observed prevalence of
VA 14.6%

Prevalence of VA markedly
increased
after 45 years of age

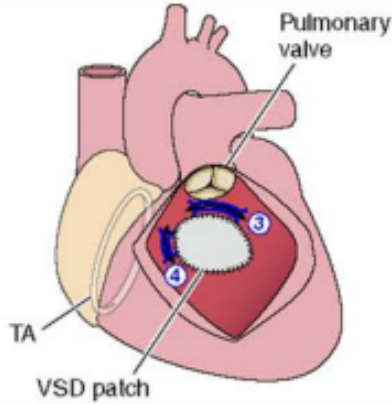
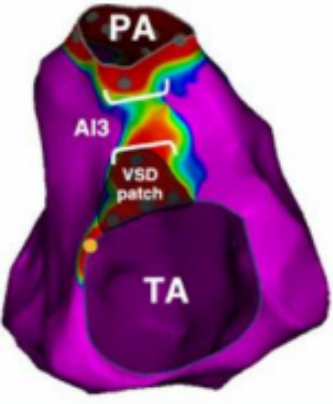
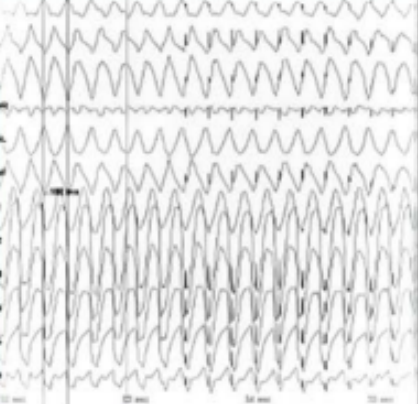
Critical VT isthmuses in ToF



VA in ToF



How to prevent VT/SCD in ToF

Substrate	Slow conduction	Triggers	Ventricular tachycardia
 Pulmonary valve TA VSD patch	 PA AI3 VSD patch TA	 m/s 10 mm/mV 1-4-2022 01:18:34	
Determined by initial anatomy and surgical repairs.	Caused by fibrosis from volume or pressure overload, dilation, hypertrophy, and aging. Associated with QRS prolongation.	Triggers (PVCs, NSVT) facilitated by diffuse fibrosis and abnormal hemodynamics. Triggers coupled with susceptible substrate can trigger VT.	Typically monomorphic and fast. Hemodynamic tolerance depends on cycle length and ventricular function.

PVR

EPS and ablation

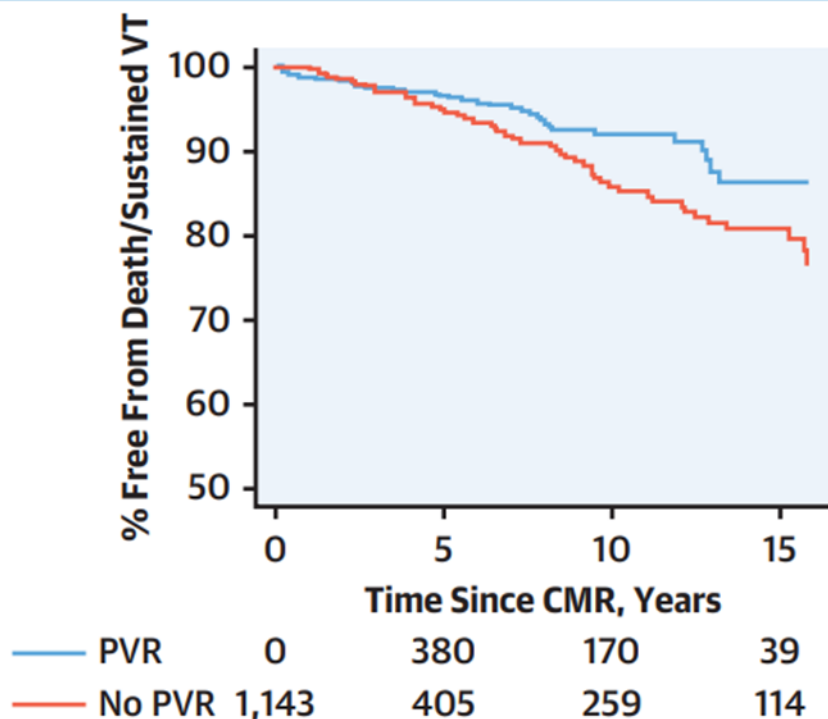
ICD

Improved Outcomes After Pulmonary Valve Replacement in Repaired Tetralogy of Fallot

Jouke P. Bokma, MD, PhD,^a Tal Geva, MD,^{b,*} Lynn A. Sleeper, ScD,^b Ji Hae Lee, BA,^b Minmin Lu, MS,^b Tehila Sompolinsky, MD,^b Sonya V. Babu-Narayan, MB, BS, BSc, PhD,^c Rachel M. Wald, MD,^d Barbara J.M. Mulder, MD, PhD,^a Anne Marie Valente, MD^{b,*}

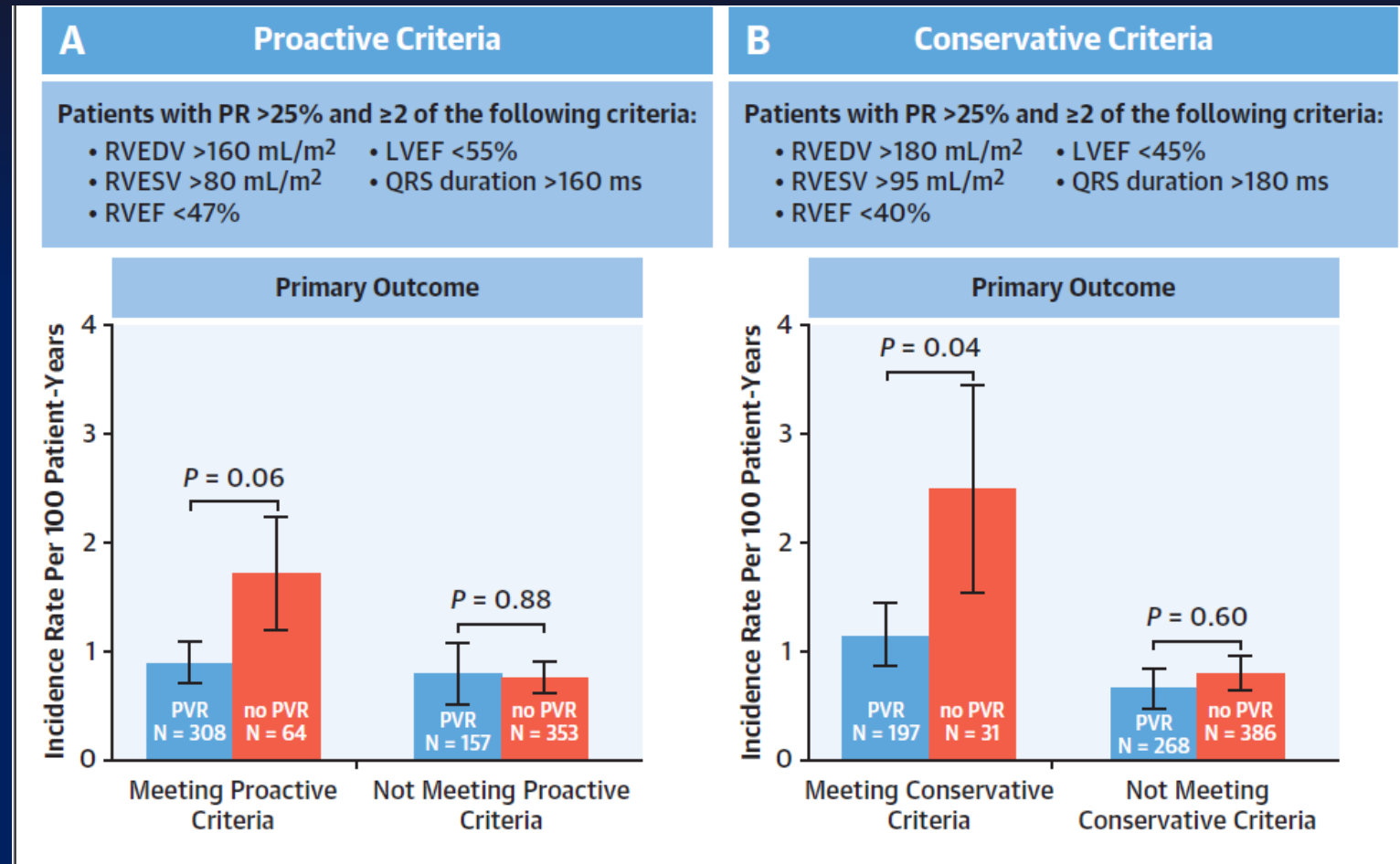
INDICATOR (International Multicenter TOF Registry).
The primary outcome was time to the earliest occurrence
of death, resuscitated SCA or sustained VT

Propensity Score-Adjusted Full Cohort



1,143 patients with rTOF (age 27 ± 14 y, f-up 8.3 ± 5.2 y),
7% experienced the primary outcome
Patients receiving PVR lower risk of death or sustained VT
HR for the primary outcome for PVR vs no-PVR was 0.41
(95% CI: 0.21-0.81; $P = 0.010$).
In patients with RV ESV index > 80 mL/m², PVR was
associated with a lower primary outcome risk
(HR: 0.32; 95% CI: 0.16-0.62; $P < 0.001$).

the protective effect of PVR both in patients who met proactive criteria (HR: 0.31; 95% CI: 0.11-0.87; P = 0.026) and conservative criteria (HR: 0.16; 95% CI: 0.03-0.82; P = 0.028).



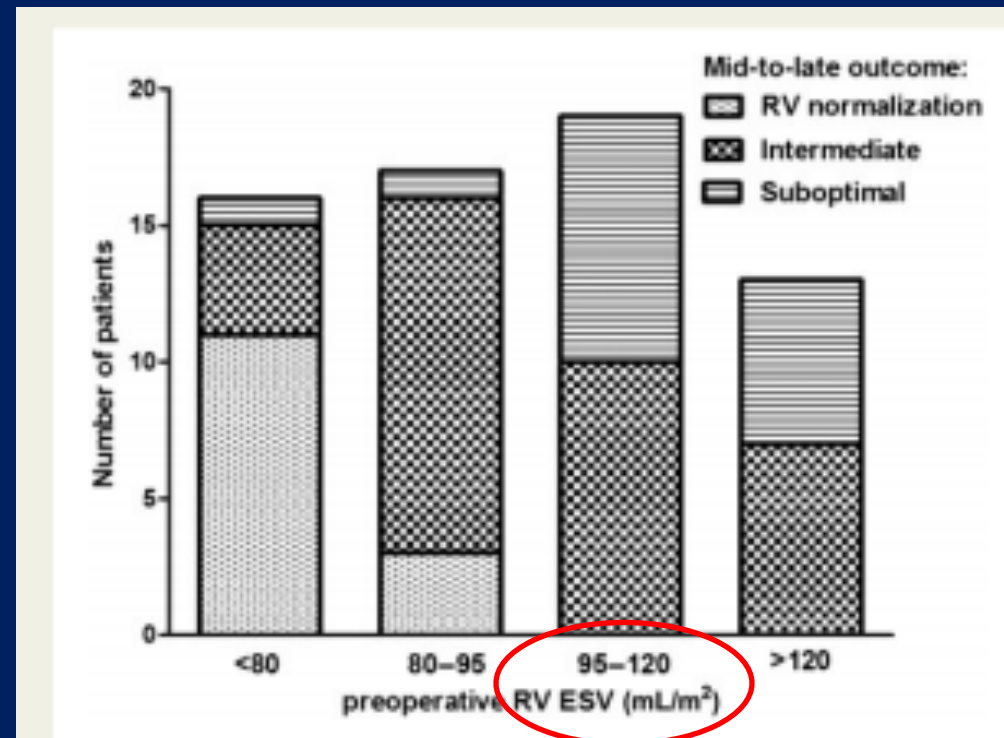
Timing PVR and VT

Preoperative thresholds for mid-to-late haemodynamic and clinical outcomes after pulmonary valve replacement in tetralogy of Fallot

best preoperative threshold for RV normalization is RVESV < 80mL/m²

Preop RV ESV > 95 mL/m² → no rev.remolding, HR 2.9

157 TOF pts
undergone PVR,
7.8±4.0 y f-up
adverse clinical
events (death,
VTs, heart
failure)



Bokma JP et al,
Eur Heart J 2016

secondary prevention of sudden cardiac death and treatment of ventricular arrhythmia

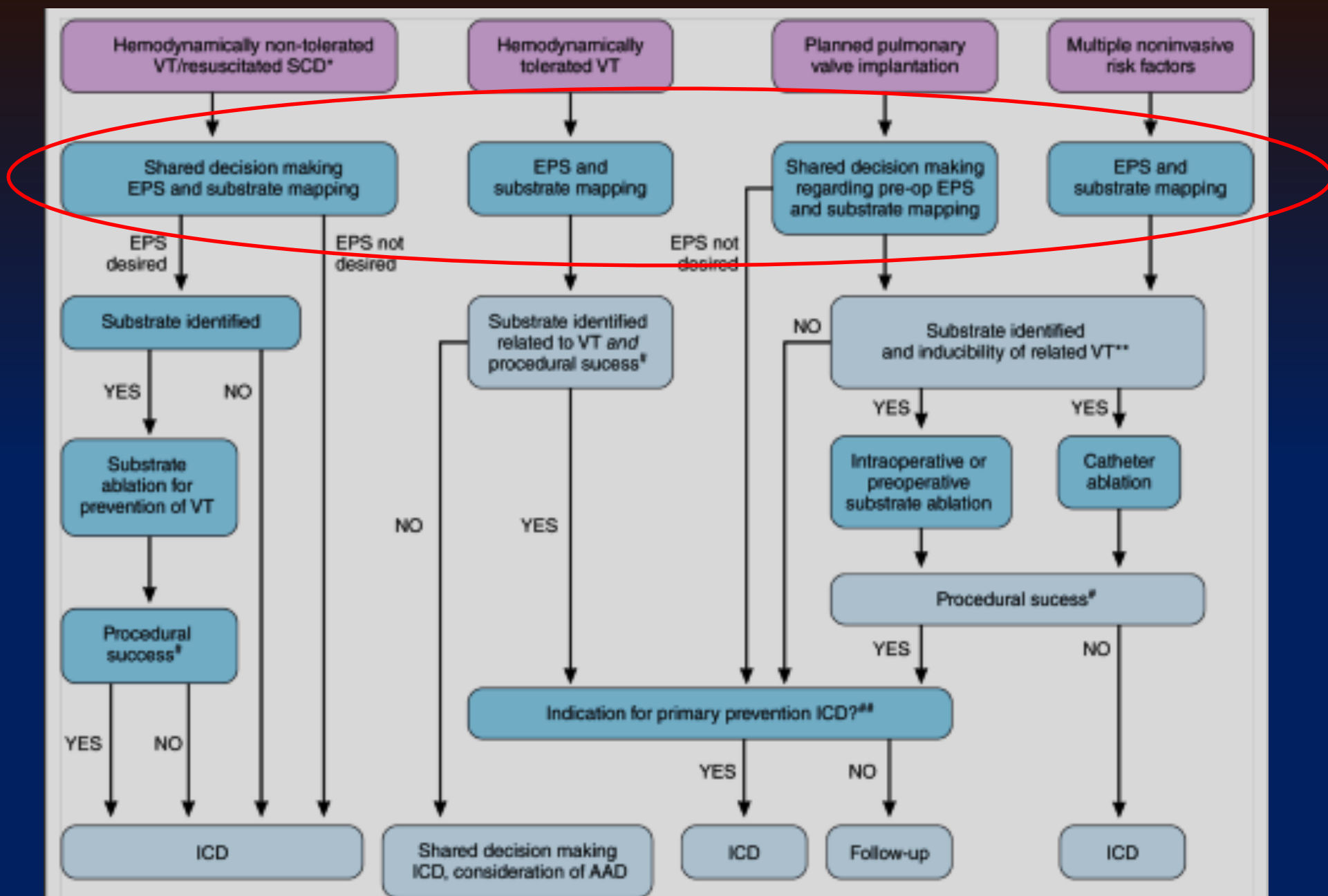
Tetralogy of Fallot		
In patients with repaired TOF who present with SMVT or recurrent, symptomatic appropriate ICD therapy for SMVT, catheter ablation performed in specialized centres is recommended. ⁸⁹⁹⁻⁹⁰¹	I	C
In patients with repaired TOF with SMVT who are undergoing surgical or transcatheter pulmonary valve replacement, pre-operative catheter mapping and transection of VT-related anatomical isthmuses before or during the intervention should be considered. ^{888,893,894}	IIa	C
In patients with repaired TOF with a preserved biventricular function and symptomatic SMVT, catheter ablation or concomitant surgical ablation performed in specialized centres may be considered as an alternative to ICD therapy. ^{899,901}	IIb	C

risk stratification and primary prevention of sudden cardiac death

Tetralogy of Fallot		
In patients after repair of TOF with arrhythmia symptoms and NSVT, electrophysiologic evaluation including PES should be considered. ^{889,903-905}	IIa	C
In patients after repair of TOF with arrhythmia symptoms and a positive PES, or a combination of other risk factors ^d and a positive PES, ICD implantation should be considered.	IIa	C
In patients after repair of TOF without arrhythmia symptoms, but with a combination of other risk factors, ^d electrophysiologic evaluation, including PES, may be considered.	IIb	C
In patients with repaired TOF undergoing surgical or transcatheter pulmonary valve replacement, pre-operative catheter mapping and transection of VT-related anatomical isthmuses before or during the intervention may be considered. ⁸⁹⁴	IIb	C

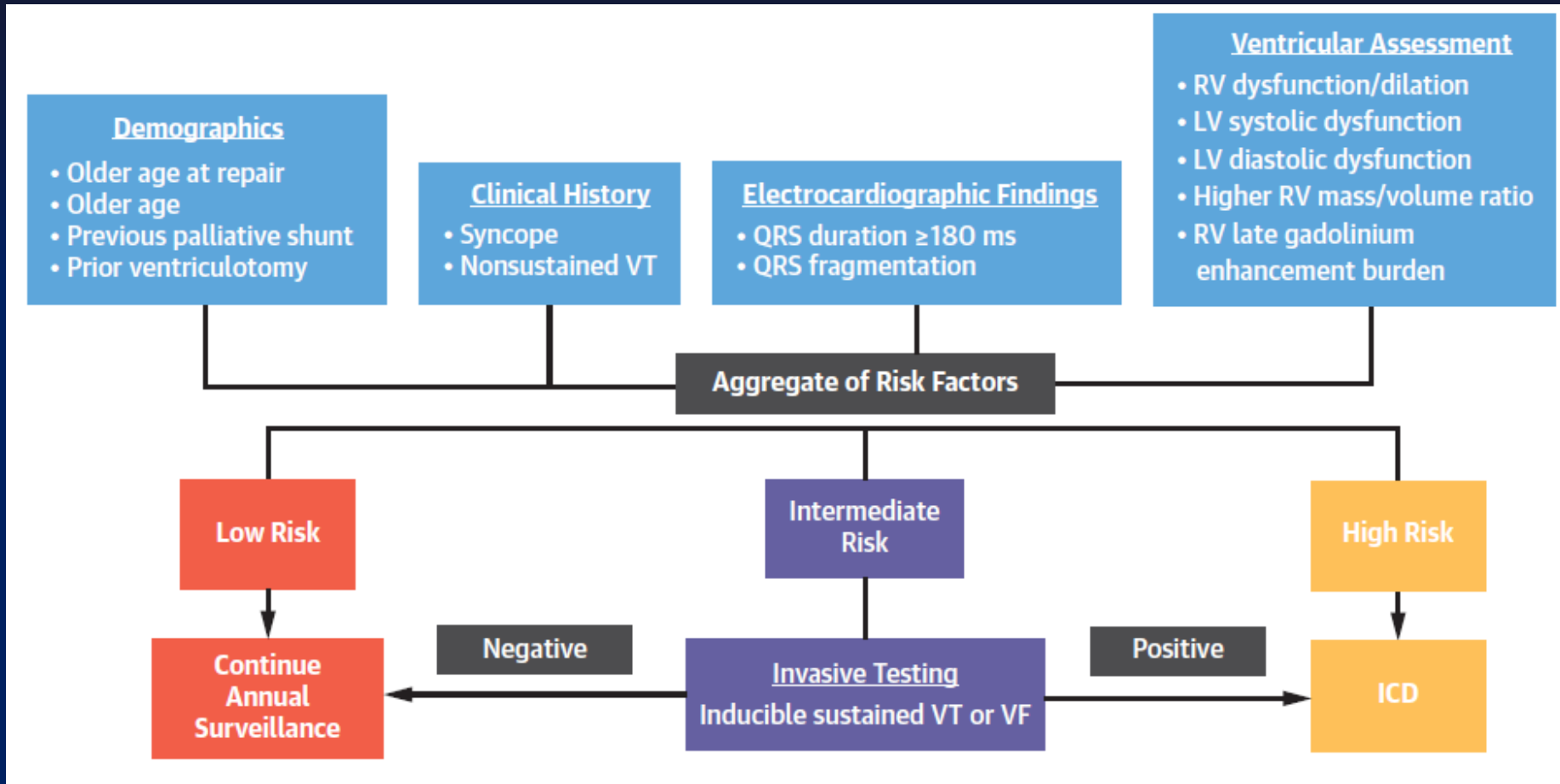
risk factors: moderate RV or LV dysf, extensive RV scarring on CMR, QRS duration ≥ 180 ms and severe QRS fragmentation

2022 ESC Guidelines for the management of patients with ventricular arrhythmias and the prevention of sudden cardiac death. European Heart Journal 2022



Arrhythmias in Repaired Tetralogy of Fallot: A Scientific Statement From the American Heart Association. *Circ Arrhythm Electrophysiol.* 2022

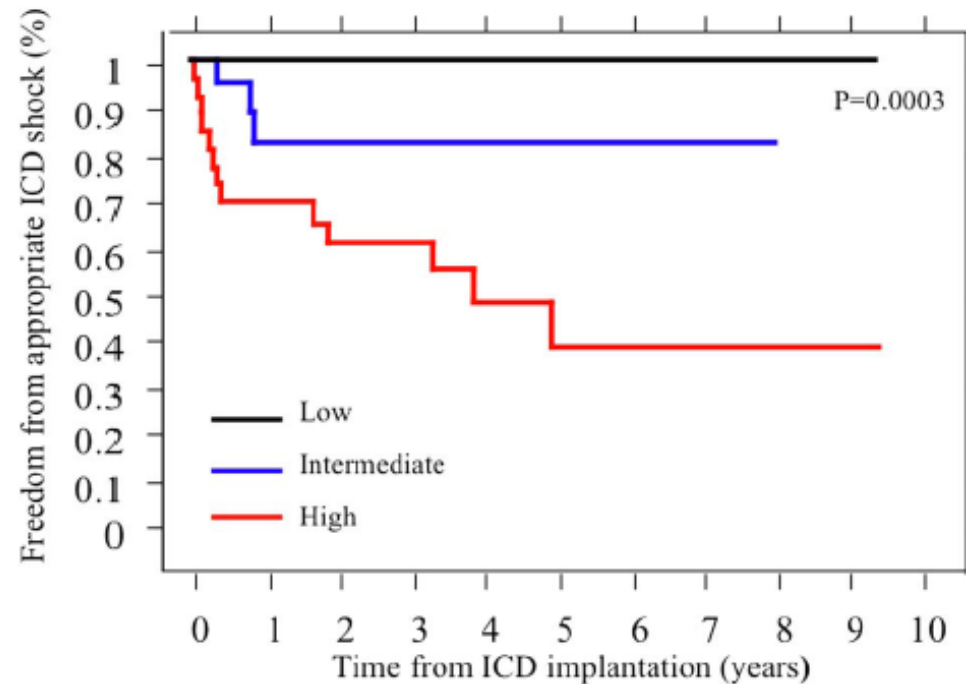
Risk stratification approach in ToF



VT/SCD risk and ToF

Table 3 Risk score for appropriate implantable cardioverter-defibrillator shocks in patients with tetralogy of Fallot

Variable	Exp(β)	Points attributed
Prior palliative shunt	3.2	2
Inducible sustained ventricular tachycardia	2.6	2
QRS ≥ 180 ms	1.4	1
Ventriculotomy incision	3.4	2
Non-sustained ventricular tachycardia	3.7	2
Left ventricular end-diastolic pressure ≥ 12 mm Hg	4.9	3
Total points		0–12



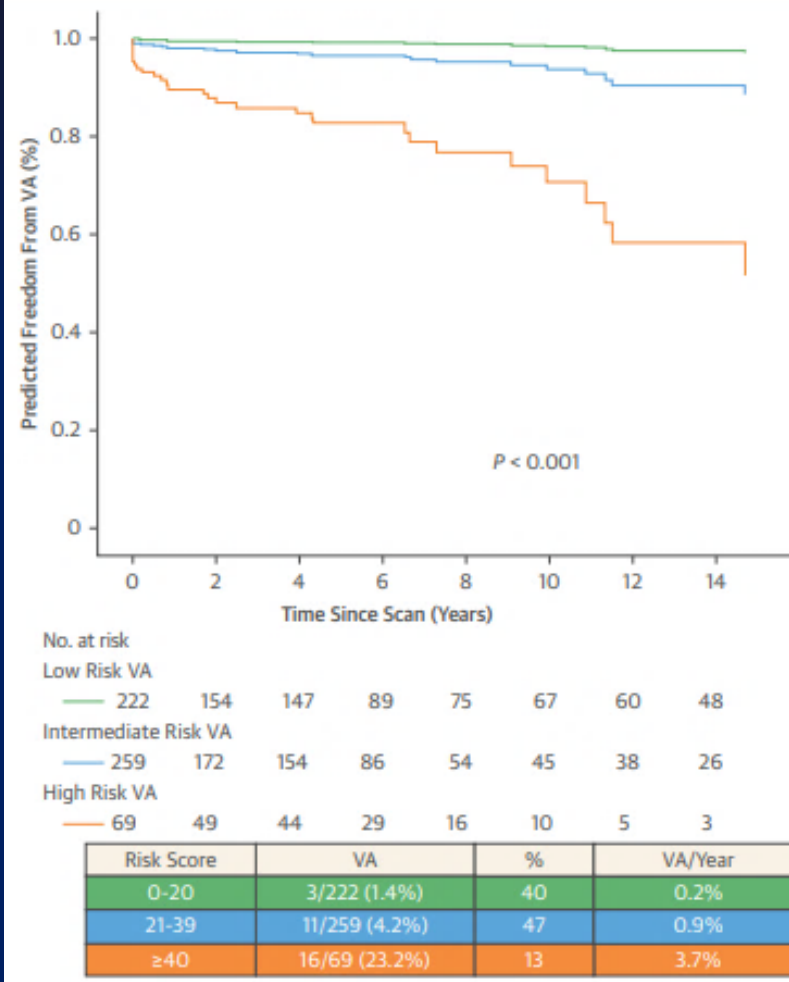
Risk score	Risk category	N	Annualized rate of appropriate shocks
0-2	Low	18	0%
3-5	Intermediate	24	3.8%
6-12	High	26	17.5%

VT/SCD risk and ToF

risk score for a better selection of high-risk patients with rTOF who may benefit from targeted therapy.

FIGURE 4 Annualized Rate of VA According to Risk Category

Ventricular Arrhythmia Risk	Exp β	Points
RVLGE extent		
Minimal/mild extent	0	0
Moderate extent	7.8	22
Severe extent	8.9	24
LVLGE present		
No		0
Yes	4	11
RV ejection fraction		
>47%		0
36-47%	2.8	8
≤35%	5.6	16
LV ejection fraction		
>55%		0
36-55%	2.2	5
≤35%	6.4	17
Peak Oxygen Uptake		
>17 ml/kg/m ²		0
≤17 ml/kg/m ²	3.2	9
B-type Natriuretic Peptide		
<127 ng/l		0
≥127 ng/l	3.2	9
Akinetic RV outflow length		
<55 mm		0
≥55 mm	2.6	9
RV systolic pressure		
<47 mm Hg		0
≥47 mm Hg	2.2	5
Total		/100



Predicting Survival in Repaired Tetralogy of Fallot

A Lesion-Specific and Personalized Approach

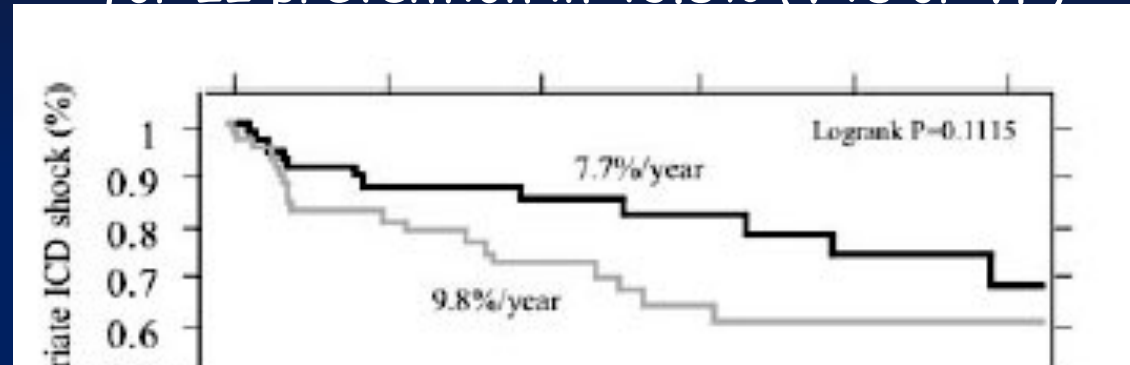
Sarah Ghonim, MB, BS, BSc, PhD,^{a,b} Michael A. Gatzoulis, MD, PhD,^{a,b} Sabine Ernst, MD, PhD,^{a,b} Wei Li, MD, PhD,^{a,b} James C. Moon, MD,^a Gillian C. Smith, PhD,^a Ee Ling Heng, MBBS, BSc, PhD,^{a,b} Jennifer Keegan, BSc, MSc, PhD,^{a,b} Siew Yen Ho, PhD,^{a,b} Karen P. McCarthy, BSc, PhD,^{a,b} Darryl F. Shore, MB CHB,^{a,b} Anselm Uebing, MD, PhD,^a Aleksander Kempny, MD, PhD,^a Francisco Alpendurada, MD, PhD,^{a,b} Gerhard P. Diller, MD, PhD,^a Konstantinos Dimopoulos, MD, MSc, PhD,^{a,b} Dudley J. Pennell, MD,^{a,b} Sonya V. Babu-Narayan, MBBS, BSc, PhD,^{a,b}

VT/SCD risk and TDF

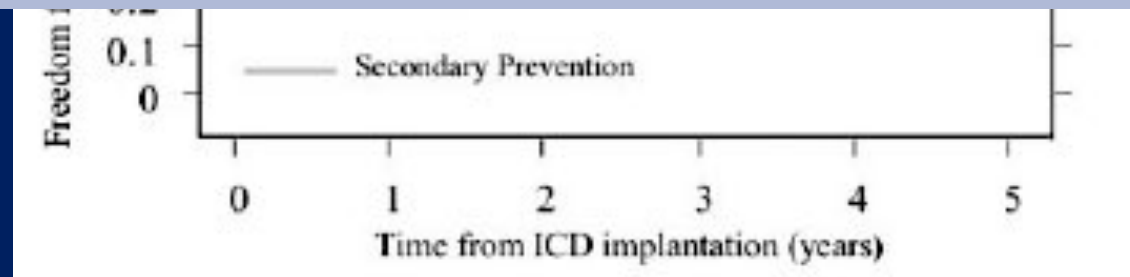
multicenter 121 repaired TDF, ICD, follow-up 3.7 y

ICDs implanted for I prevention in 56.2%

(syncope, clinical nsVT, QRS > 180 ms, severe LV sys dys, inducible VTs)
for II prevention in 43.8% (VTs or VF)



82% appropriate shock: monoVT

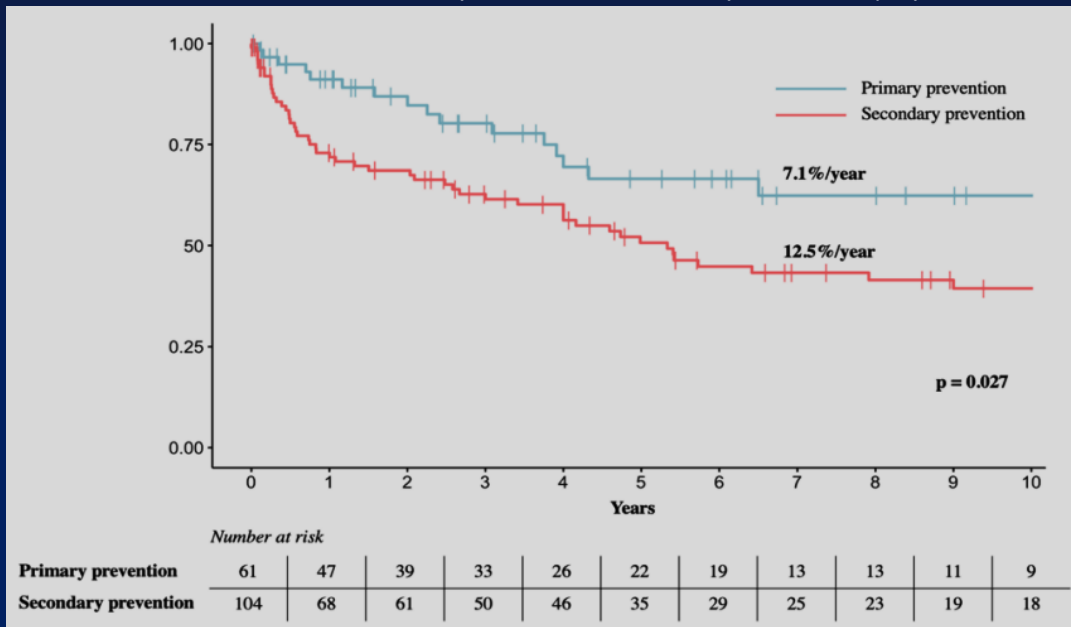


Long-Term Follow-Up of Patients With Tetralogy of Fallot and Implantable Cardioverter Defibrillator

The DAI-T4F Nationwide Registry

165 ToF (mean age 42 ± 13 y), median follow-up 6.8 y

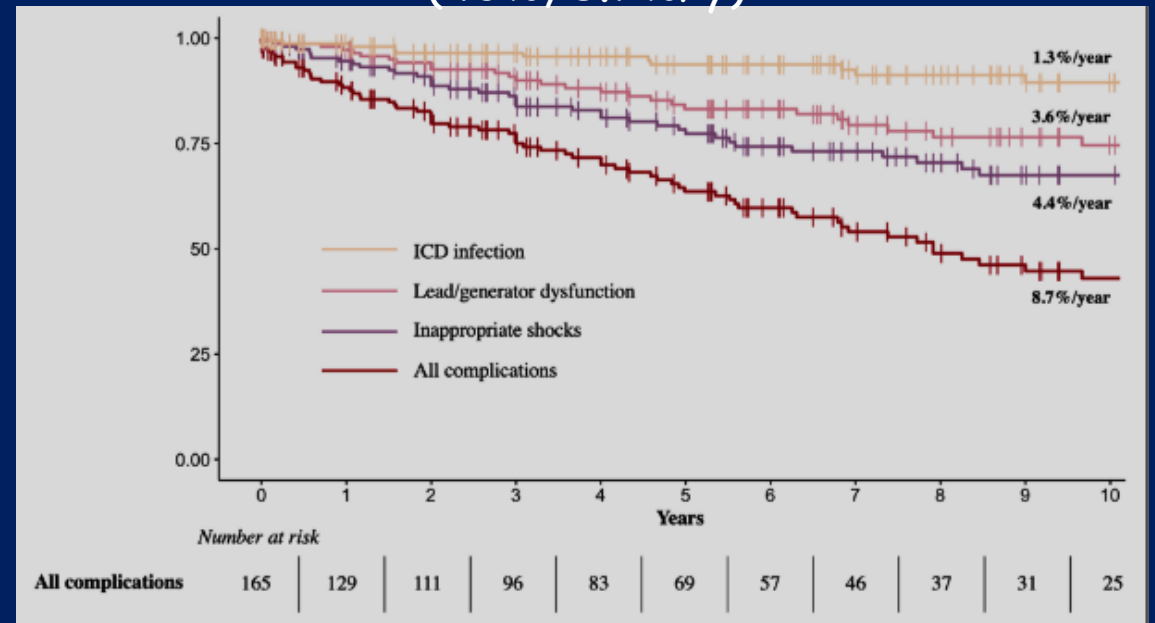
ICDs implanted for primary prevention in 37% secondary prevention in 63%



high rates of appropriate ICD therapies,
even in primary prevention

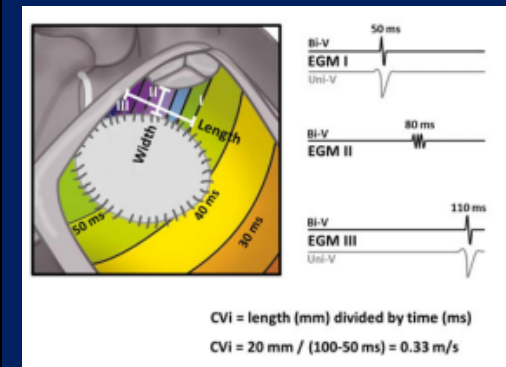
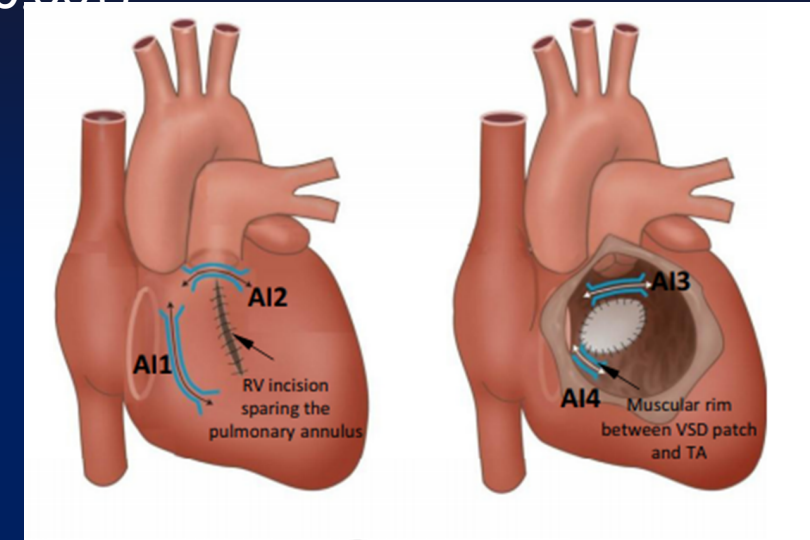
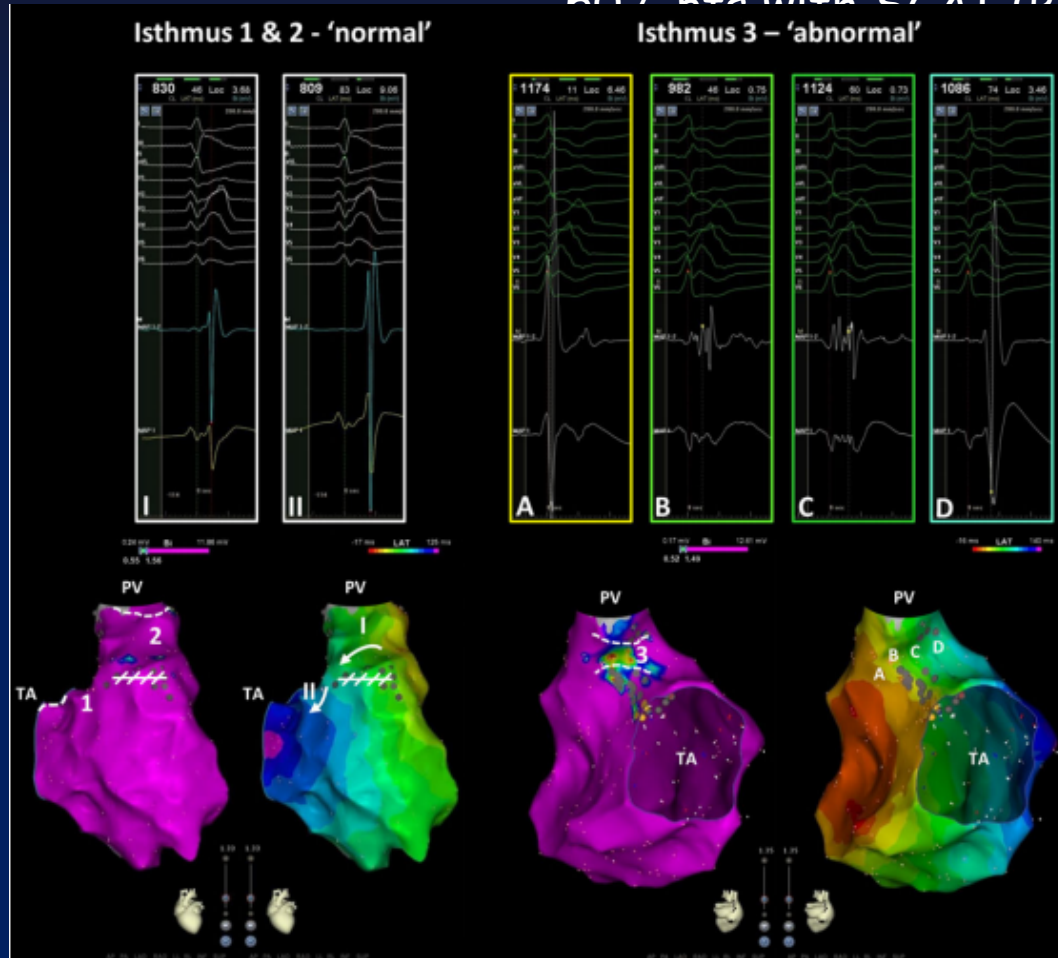
VA successfully treated with ATP in 58.7%
VF or fast VT (cycle length ≤ 250 ms) in 47.3%

considerable burden of ICD-related complications
(43%, 8.7%/y)



74 adults rTOF patients, at risk for/documented VT
2005-2013 (Leiden, Bordeaux)

AI in patients with VT were longer, narrower and had lower Cvi
follow-up (50±22 months), no patient without SCAI had any VT, which occurred in
50% pts with SCAI (P = 0.001)



Kapel JFL et al, Eur Heart J 2017

Proactive Mapping and Preventive Ablation Reduce Defibrillator Implantation Rates in Tetralogy of Fallot

Yoshitaka Kimura, MD, PhD,^{a,b,c} Justin Wallet, MD,^{a,b,c} Charlotte Brouwer, MD,^{a,b} Jouke P. Bokma, MD, PhD,^d Robin A. Bertels, MD,^{c,e} Monique R.M. Jongbloed, MD, PhD,^{a,c} Mark G. Hazekamp, MD, PhD,^{c,f} Nico A. Blom, MD, PhD,^{c,e} Katja Zeppenfeld, MD, PhD^{a,b,c}



97 rTOF patients without prior VT underwent EAM
for VT substrate identification

before PVR or as part of risk stratification

Leiden University Medical Center, 2005-2020,
mean age 35 ± 16 y

34% had SCAI and 20% inducible monoVT
(17 of 19 SCAI-dependent)

Successful SCAI transection was achieved in 87% (26 of 30 patients) in whom attempted, without complications. 13 patients

■ ICD Indication After EAM and Ablation

If 1 or more of the following criteria were met:

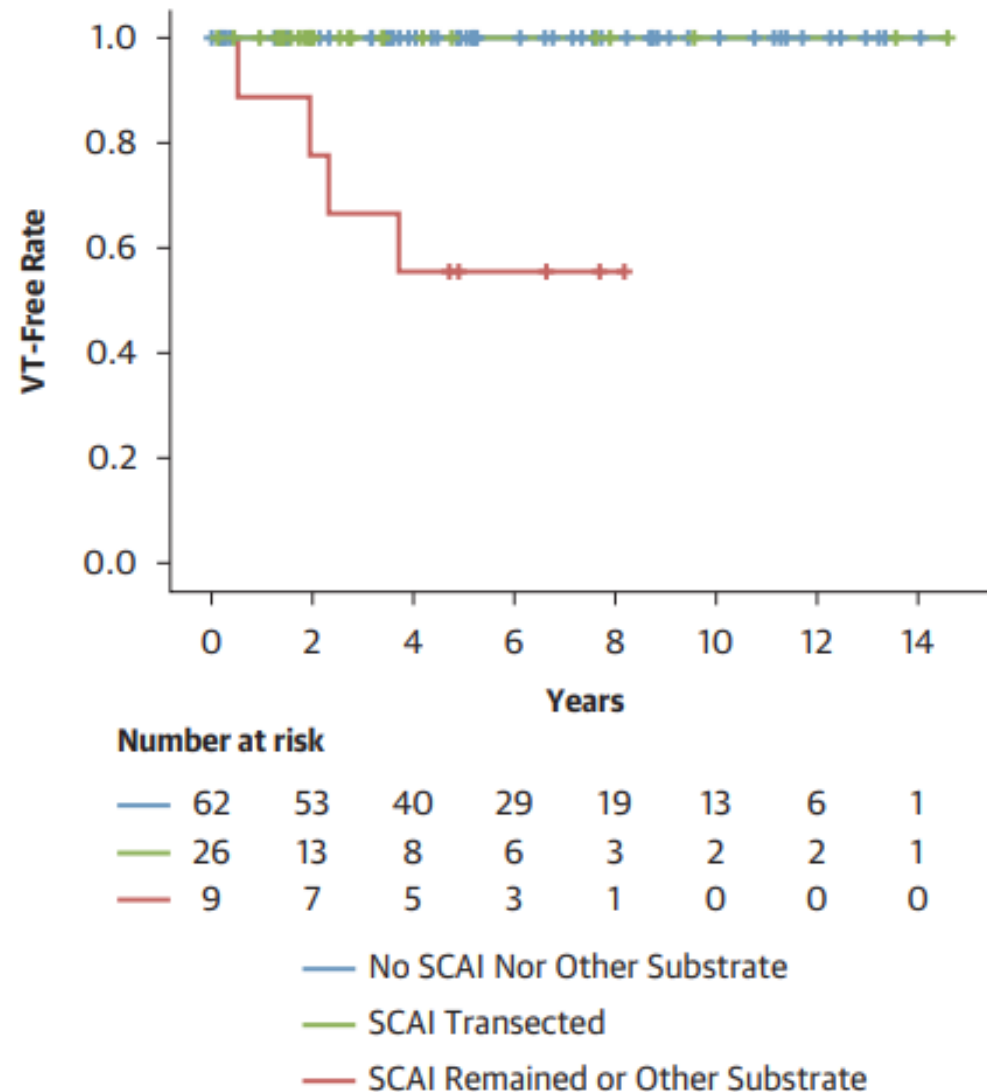
- 1) SCAI without successful ablation
- 2) VT substrate remote from AI regardless of acute ablation result
- 3) Severe RV and/or LV dysfunction

■ Transected SCAI

■ No SCAI

Kimura Y et al, JACC 2025

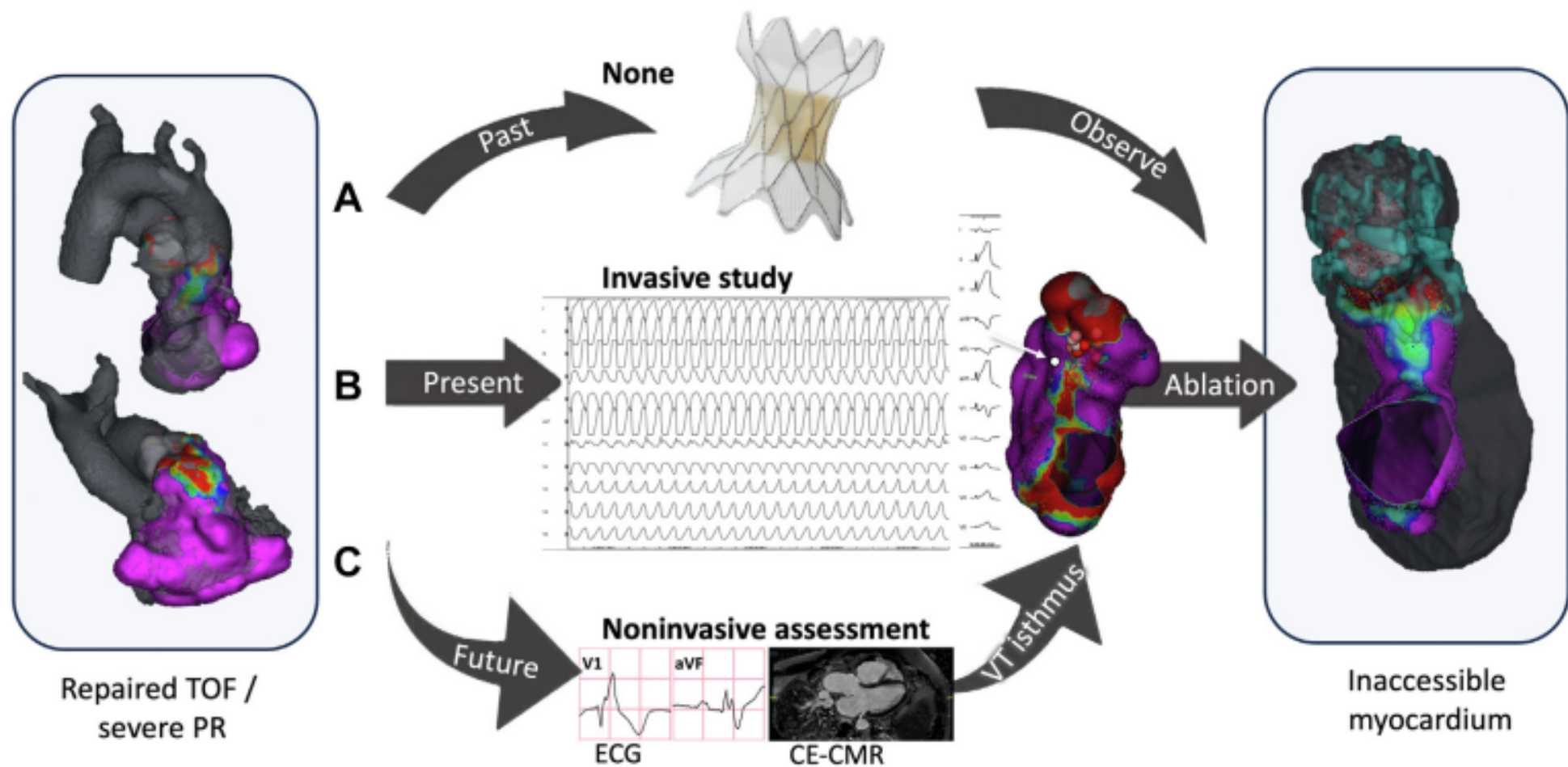
FIGURE 4 Kaplan-Meier Curve According to EAM and Ablation Results



Median follow-up 58 months,
4% VT, all after ablation failure.

According to ESC 2022
guidelines 49% would have
qualified for ICDs
After proactive mapping and
preventive ablation, 11 patients
(11%) remained ICD candidates,
including all 4 with a VT event

Pre-TPV electrophysiologic study

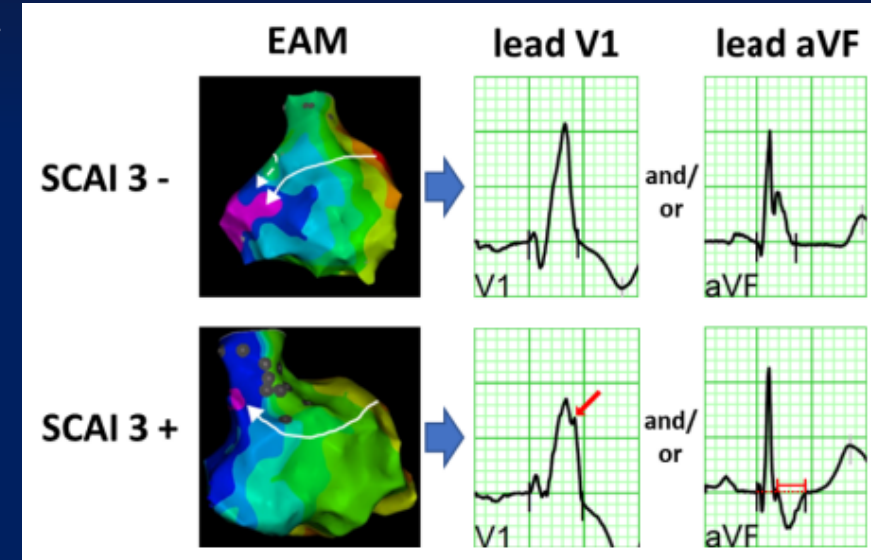
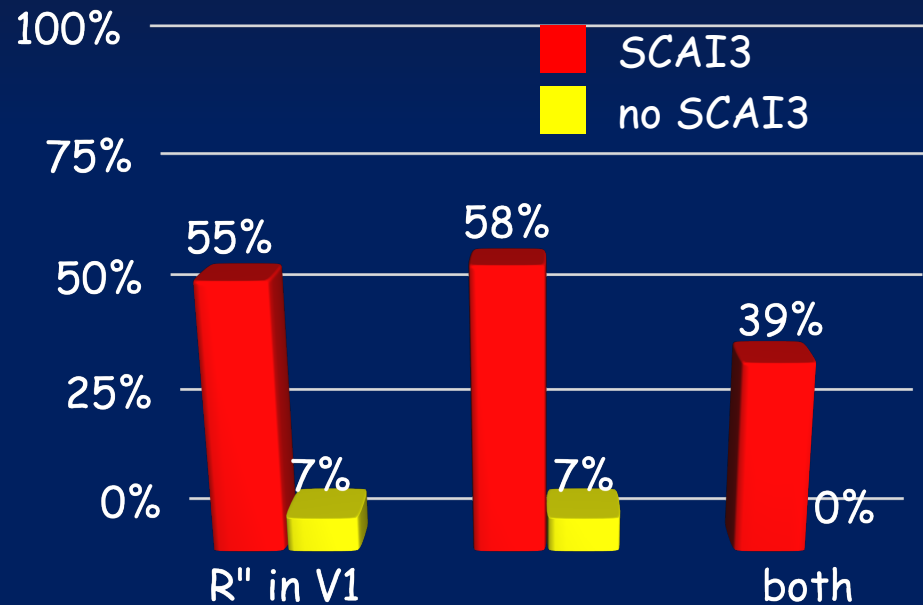


The R'' wave in V1 and the negative terminal QRS vector in aVF combine to a novel 12-lead ECG algorithm to identify slow conducting anatomical isthmus 3 in patients with tetralogy of Fallot

Justin Wallet ^{1,2,3}, Yoshitaka Kimura ^{1,2,3}, Nico A. Blom ^{3,4},
Sumche Man ^{1,2,3}, Monique R.M. Jongbloed ^{1,3,5}, and Katja Zeppenfeld ^{1,2,3*}

Wallet J et al
Europace 2023

47 rTOF aged ≥ 16 years with RBBB who underwent EAM between 2017–2022 to the Leiden University Medical Centre (LUMC)



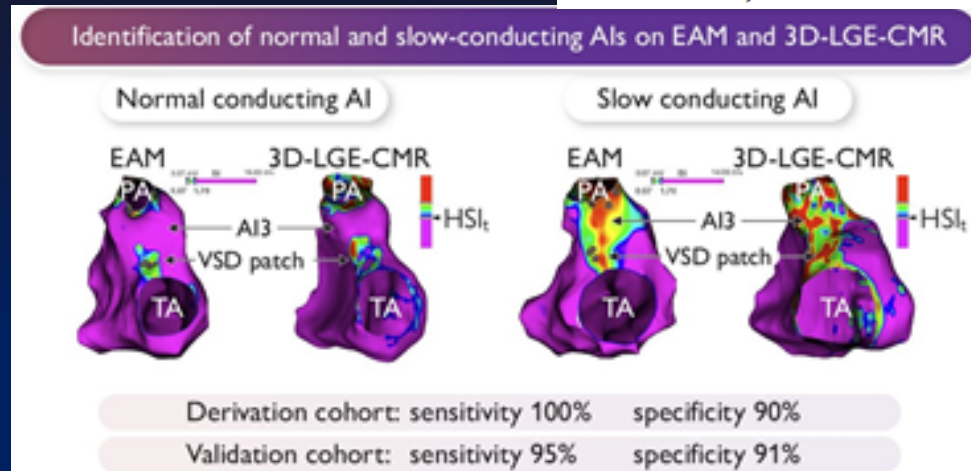
A sinus rhythm ECG-based algorithm may potentially identify patients who require transection of SCA3I before PVR and contribute to non-invasive risk stratification for VT

Three-dimensional cardiac magnetic resonance allows the identification of slow-conducting anatomical isthmuses in tetralogy of Fallot

Yoshitaka Kimura, Justin Wallet, Benjamin Bouyer, Monique R M Jongbloed, Robin Bertels, Mark G Hazekamp, Jean-Benoit Thambo, Xavier Iriart, Hubert Cochet, Frederic Sacher ... Show more

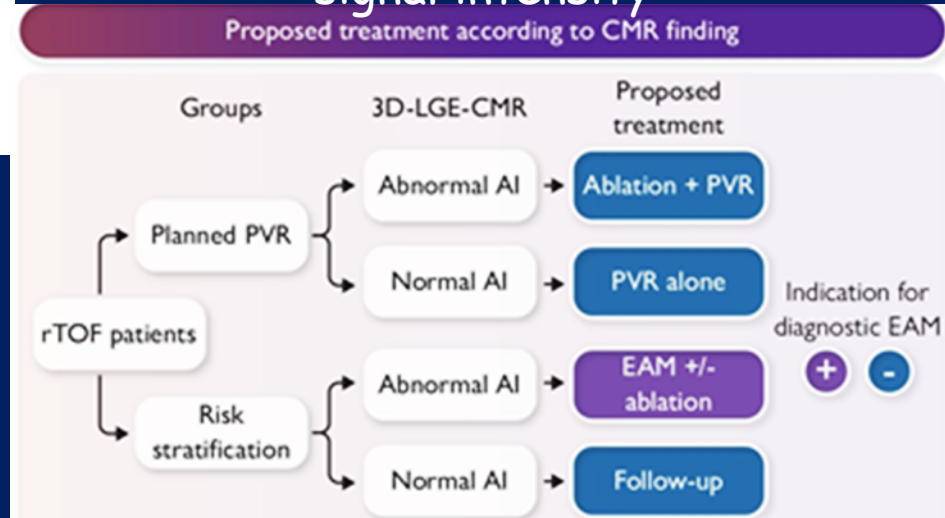
European Heart Journal, ehae268, <https://doi.org/10.1093/eurheartj/ehae268>

Published: 15 May 2024 Article history ▼



Excellent correlation between CMR and EAM (sensitivity 100%, specificity 90%, positive predictive value 78%)

The optimal CMR local intensity cut-off associated with a low bipolar voltage (<1.76 mV) was 42% of the maximum signal intensity

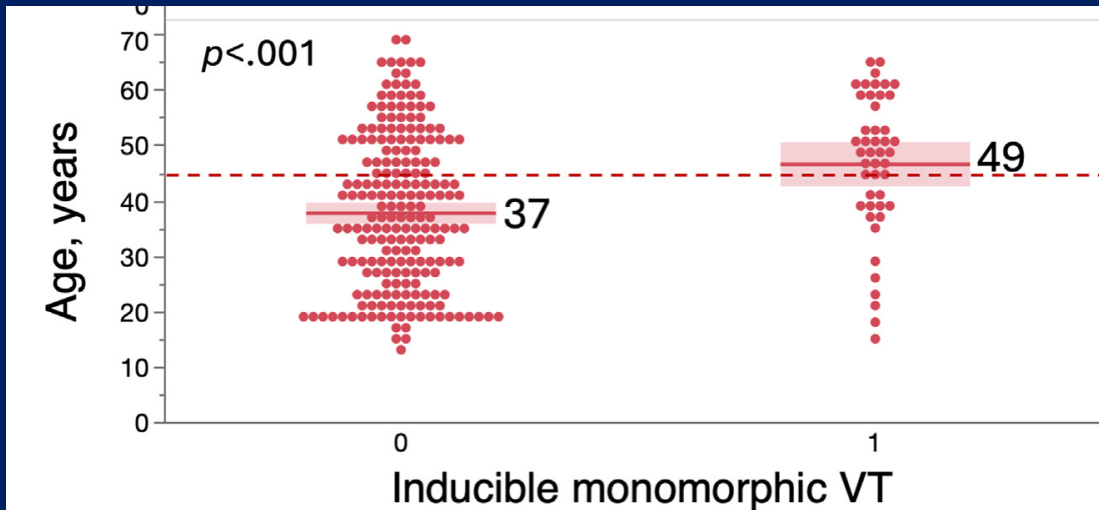
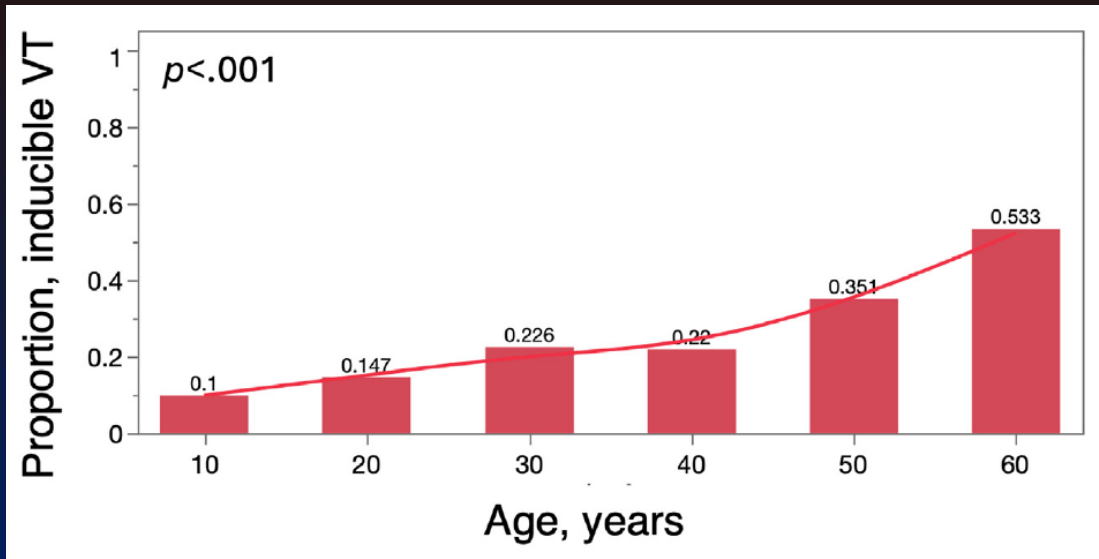


3D late gadolinium enhancement CMR can identify SCAI with excellent accuracy may guide patient selection for invasive EAM reducing diagnostic EAM by 74%

Age-Related Ventricular Tachycardia Substrate Characteristics for Repaired Tetralogy of Fallot Before Transcatheter Pulmonary Valve Placement

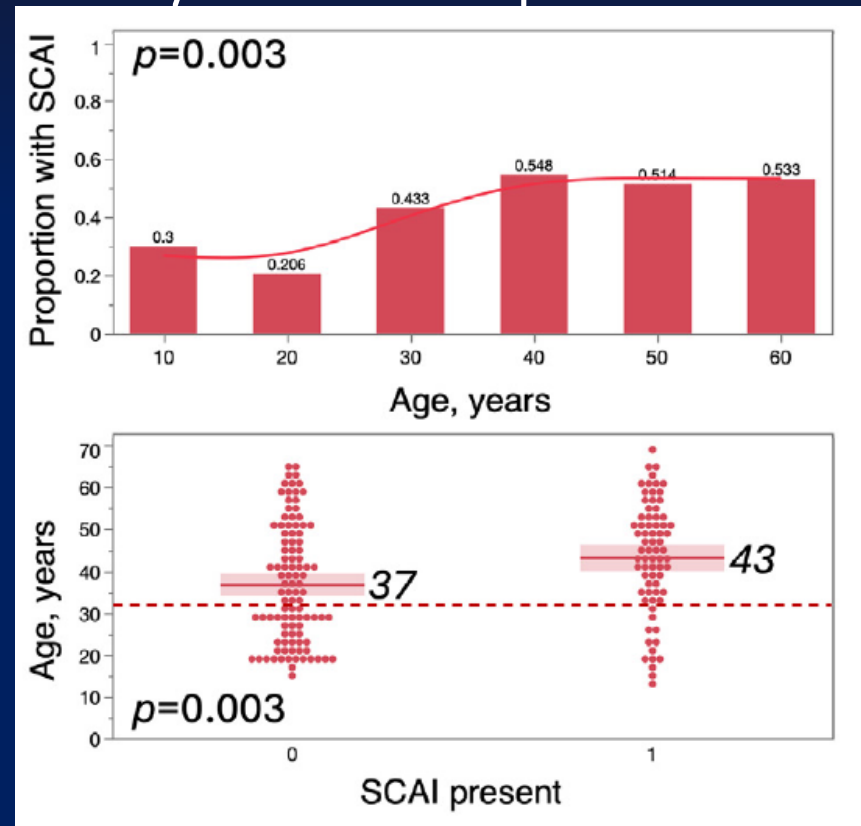
Jeremy P. Moore, MD, MS,^{a,b,c} Victor Waldmann, MD, PhD,^{d,e,f} Francis Bessière, MD, PhD,^{g,h} Nawel Babouri, MS,^{g,h} Mitchell I. Cohen, MD,ⁱ Edward T. O'Leary, MD,^j Nimesh S. Patel, MD,^k Babak Nazer, MD,^l Weiyi Tan, MD,^k Frank A. Fish, MD,^m Aarti S. Dalal, DO,^m Elisabetta Mariucci, MD, PhD,ⁿ Reina B. Tan, MD,^o Michael S. Lloyd, MD,^p Christopher J. McLeod, MBChB, PhD,^q Charles C. Anderson, MD,^r Ronald J. Kanter, MD,^{s,t} Bryce V. Johnson, MD,^l Bo Wang, MD,^p Philip M. Chang, MD,^u Claire A. Newlon, MD,^c Jonathan Su, MD,^c Kevin M. Shannon, MD,^c Jason S. Bradfield, MD,^a Kalyanam Shivkumar, MD, PhD,^a Jamil A. Aboulhosn, MD,^b Paul Khairy, MD, PhD^v

The multicenter CATAPULT-TOF (Catheter Ablation of Ventricular Tachycardia Before Transcatheter Pulmonary Valve Replacement in Repaired Tetralogy of Fallot) registry was designed to clarify the electrophysiologic characteristics and VT ablation outcomes of a large homogeneous TOF cohort beyond initial repair and before TPVR.



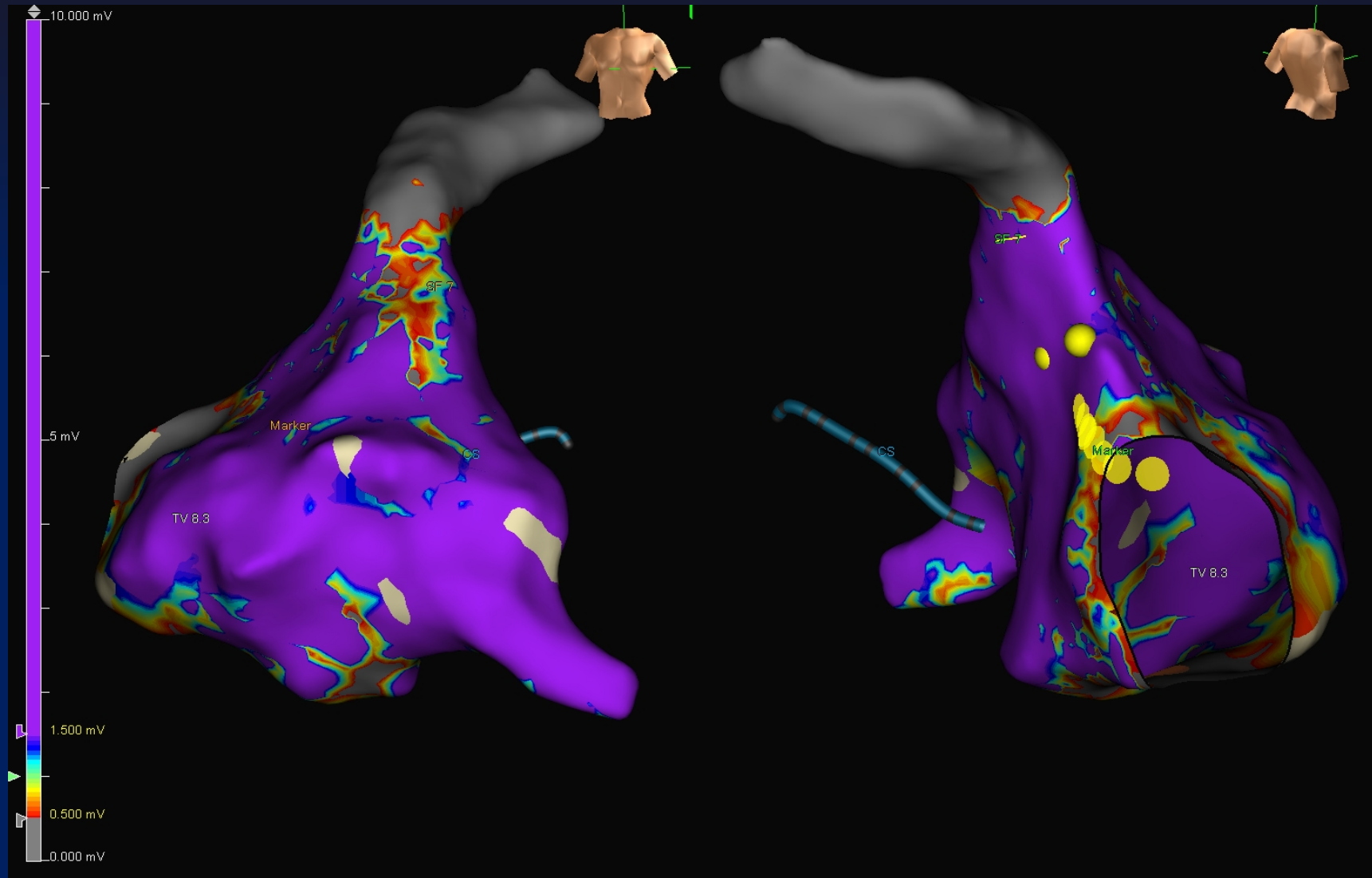
VT inducibility was strongly associated with age
The optimal age discriminator for inducible VT 45 y

Anatomic isthmus CV was negatively associated with increasing age
Detection of at least 1 SCAI was associated with age with 32 years as the optimal discriminator



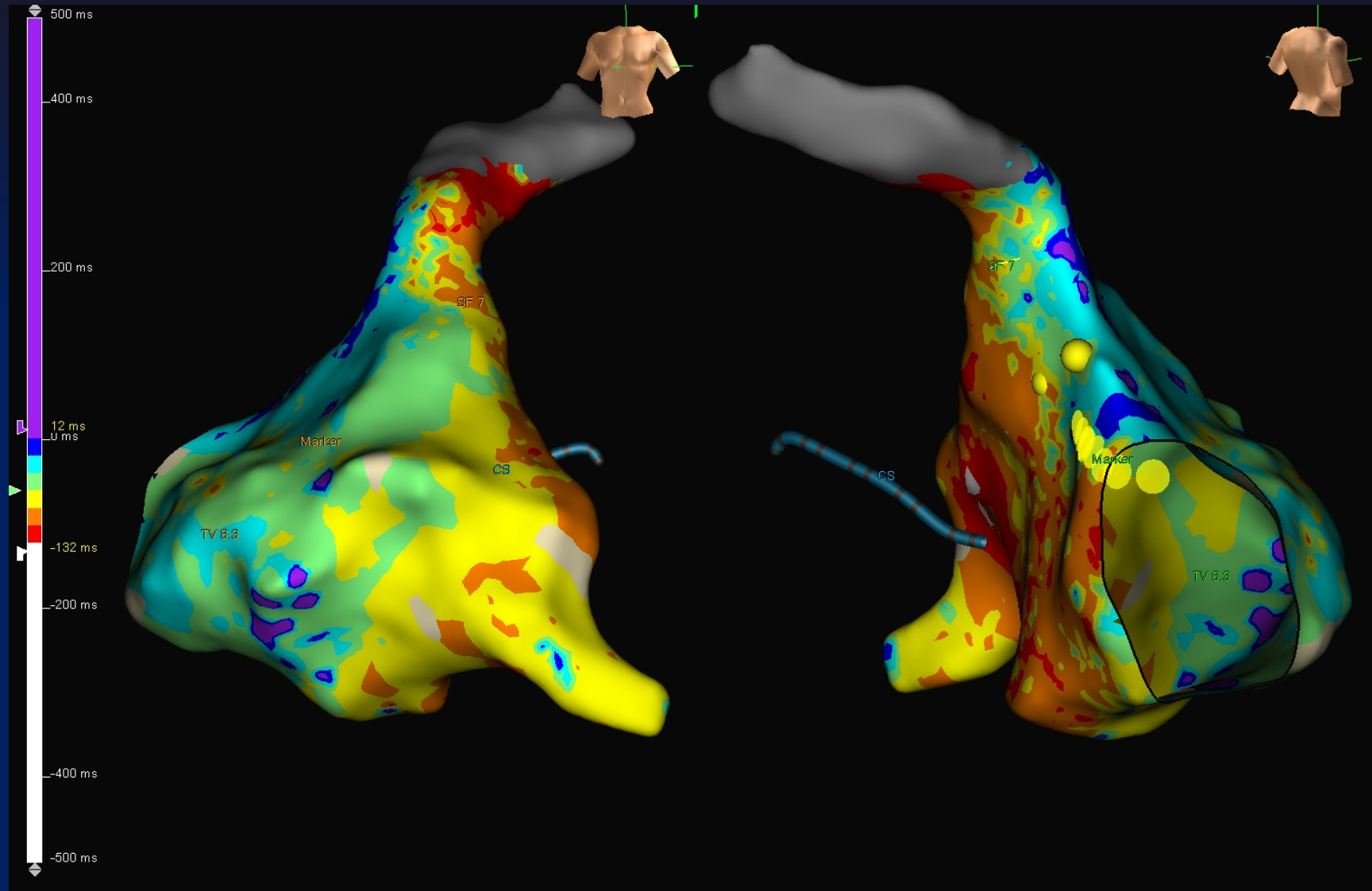
Voltage map

Caso 1:
giovane
paziente
rischio
basso



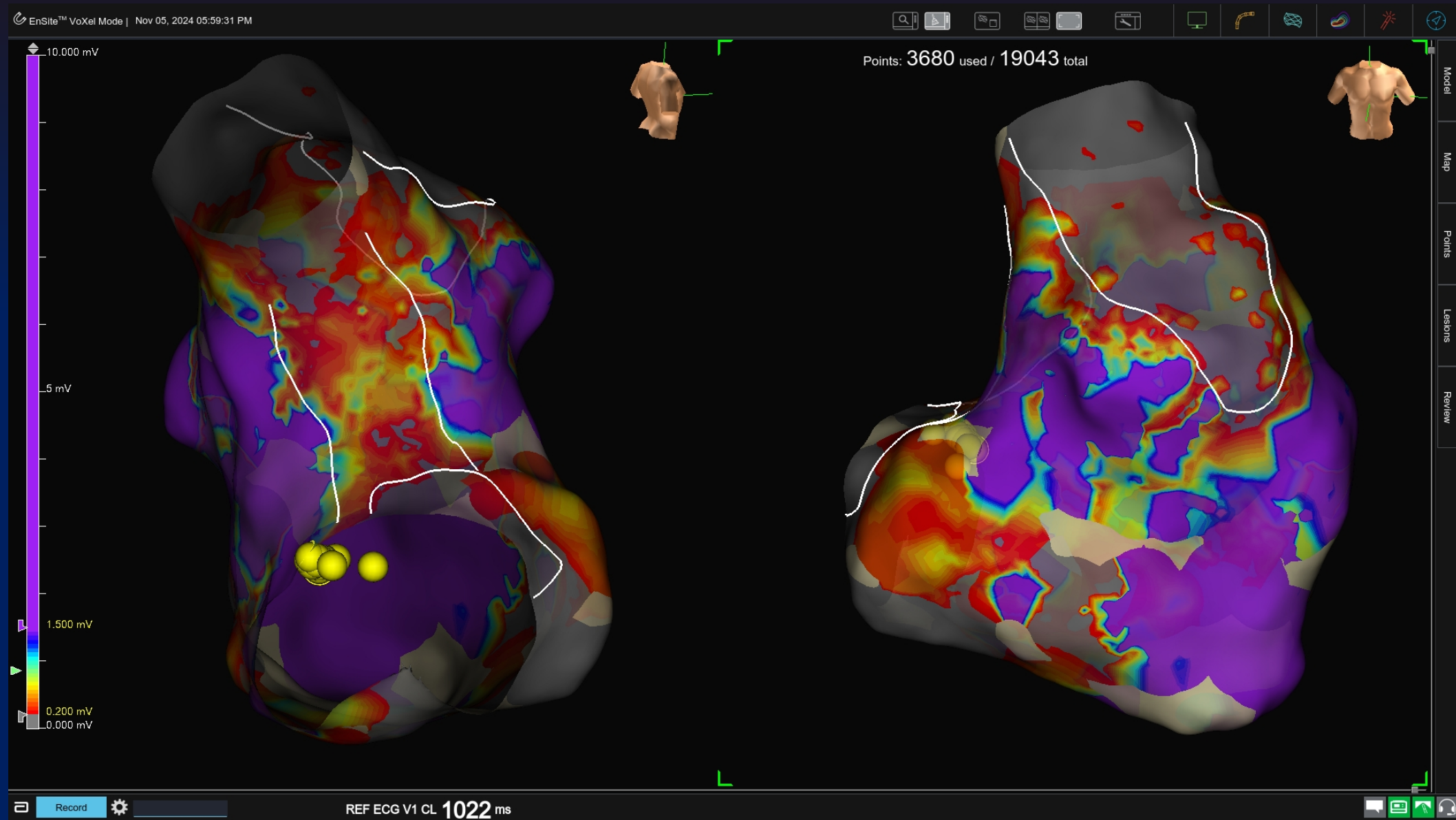
isochronal late activation mapping (ILAM)

Caso 1:
giovane
paziente
rischio
basso



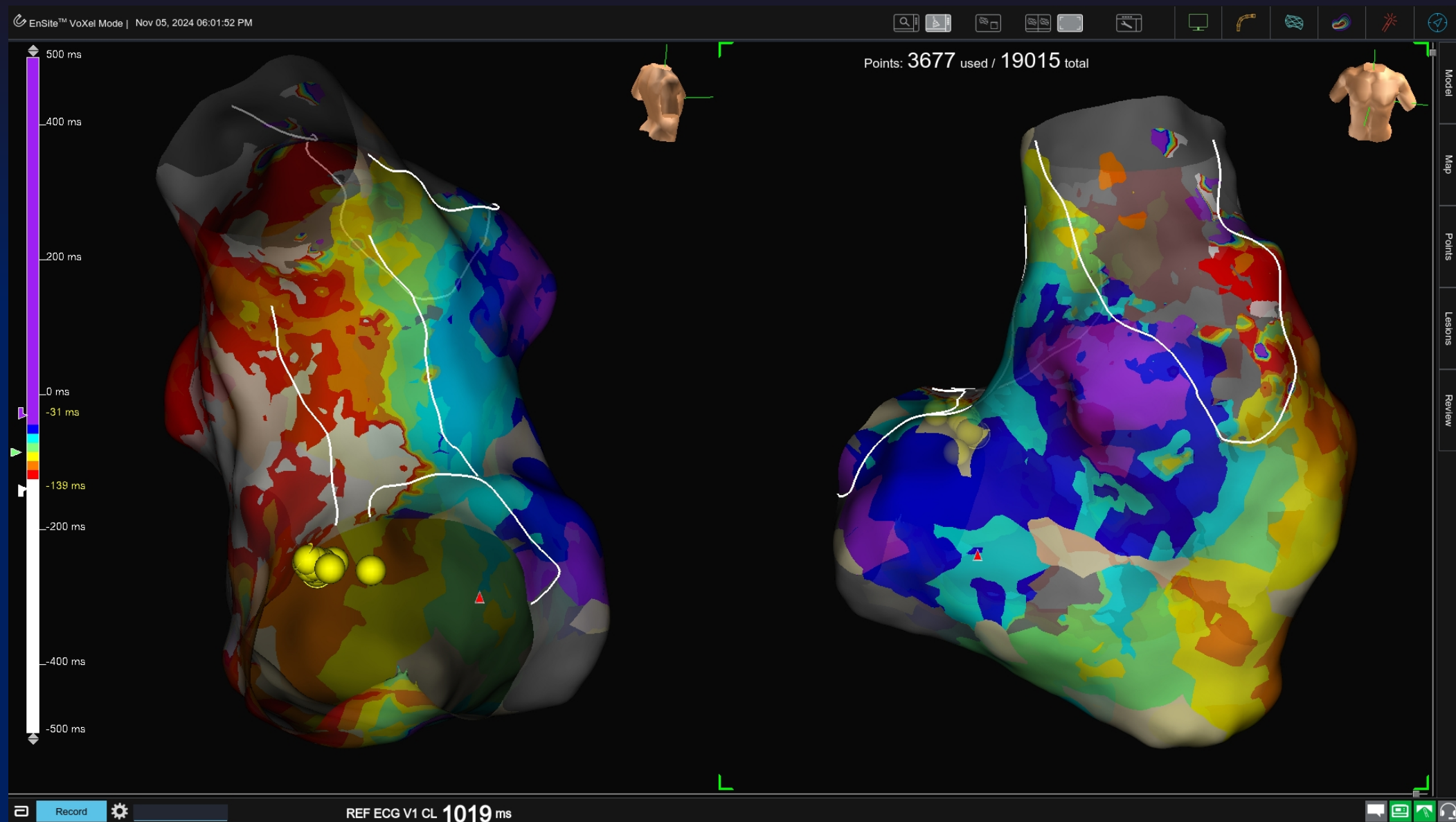
Voltage map

Caso 2
51 anni
QRS 192 msec
Rischio
intermedio

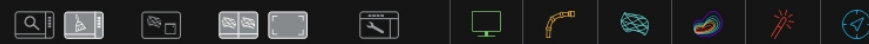


isochronal late activation mapping (ILAM)

Caso 2
51 anni
QRS 192 msec
Rischio
intermedio



Feb 16, 2024 03:00:07 PM



TV

Review: Feb 16, 2024 09:40:10 AM

VoXel AutoMap

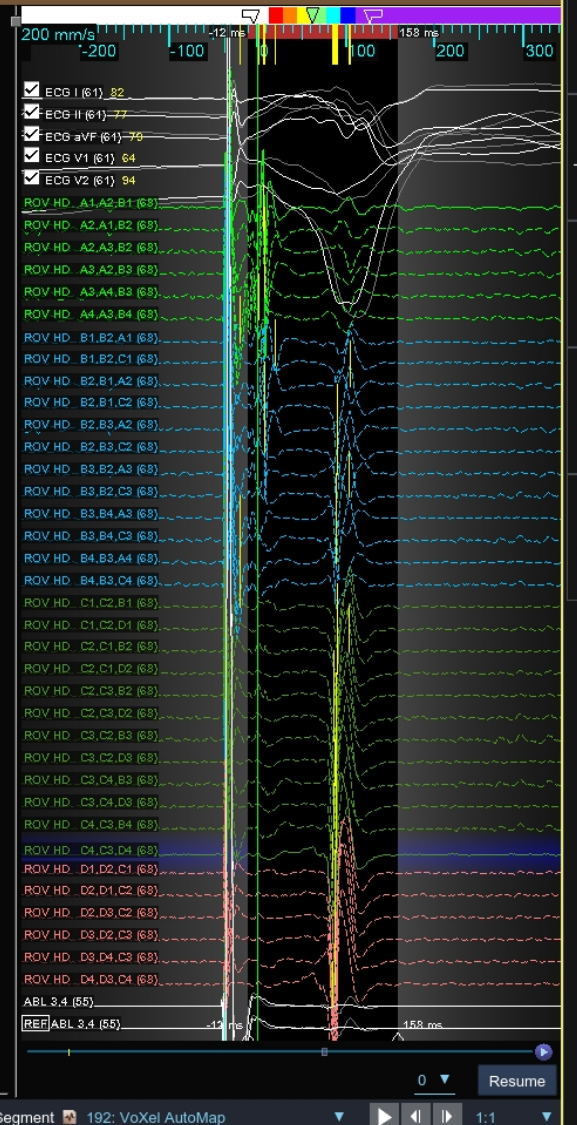
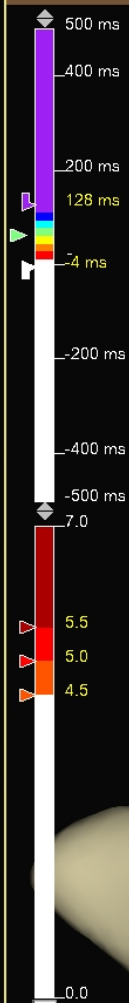
Points: 187 used / 1460 total

Marker 9.2

Marker

15 g

Marker 1.8



Segment 192: VoXel AutoMap

1:1

Caso 2
51 anni
QRS 192 msec
Rischio
intermedio

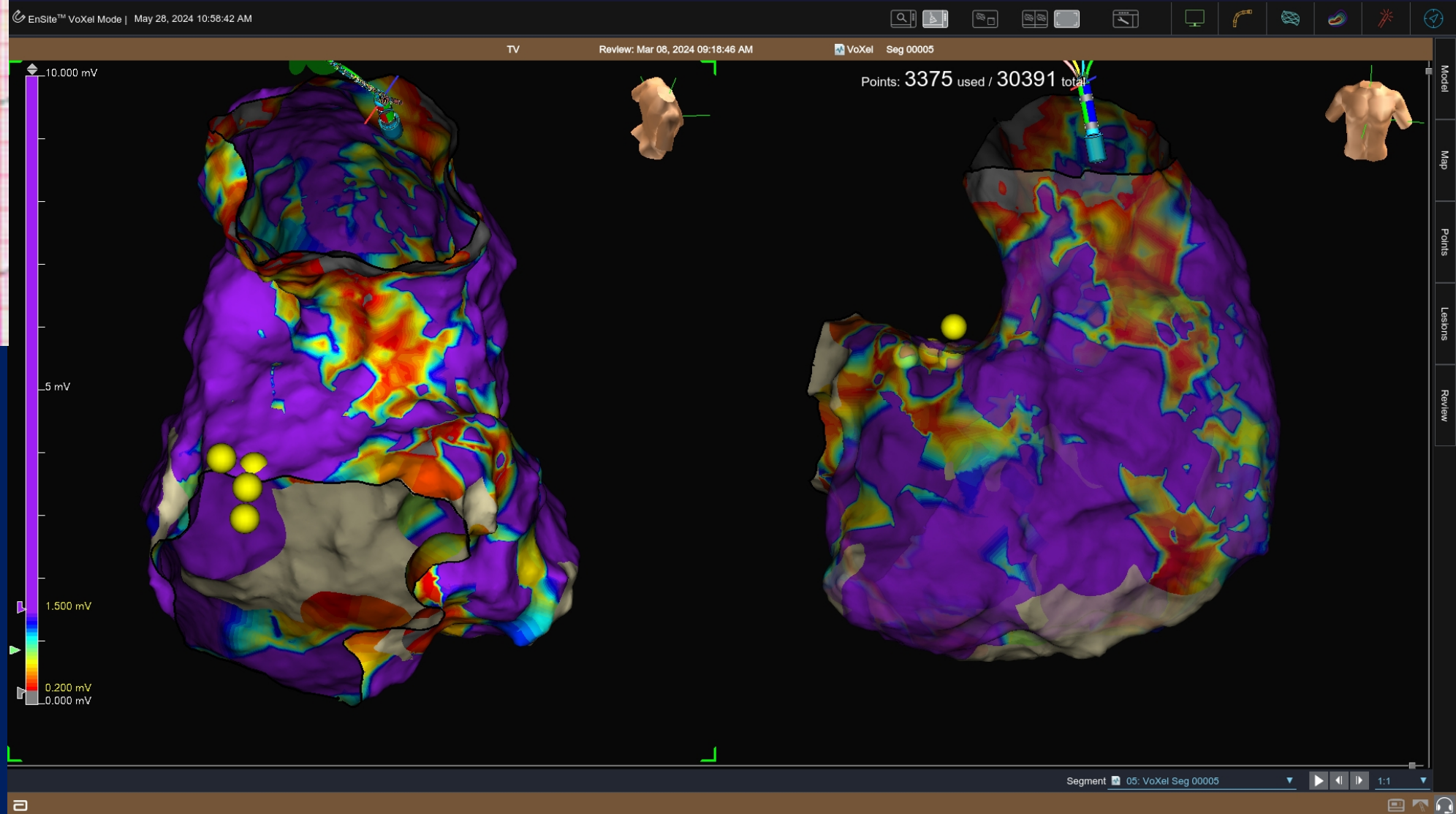
REF ABL 3,4 CL 800 ms



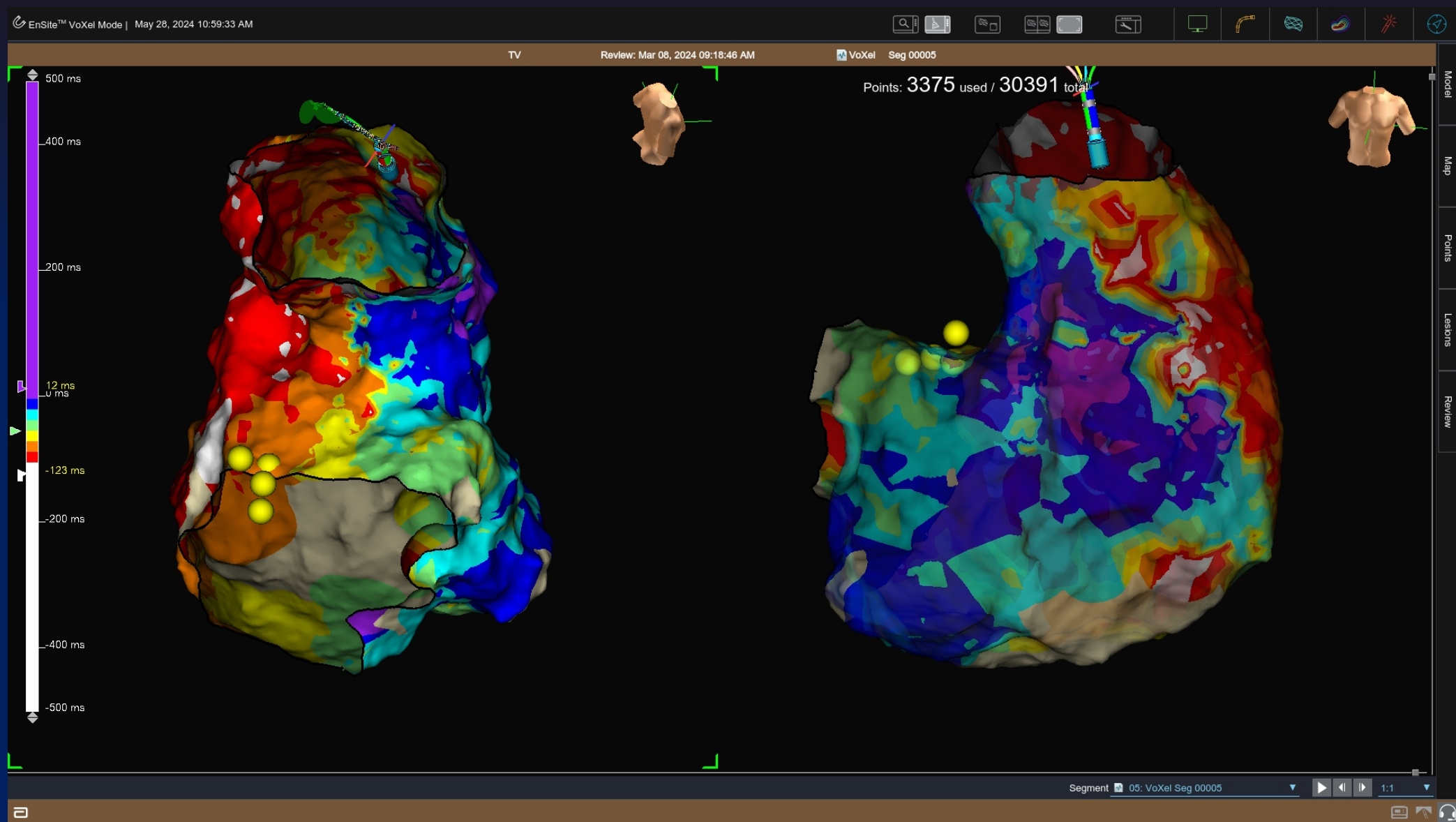
Voltage map



Caso 3
61 anni
QRS 180 msec
Rischio intermedio



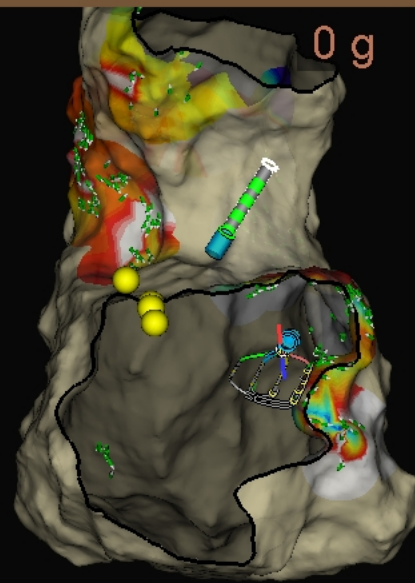
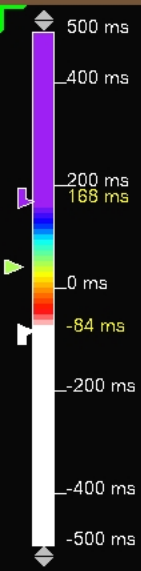
isochronal late activation mapping (ILAM)



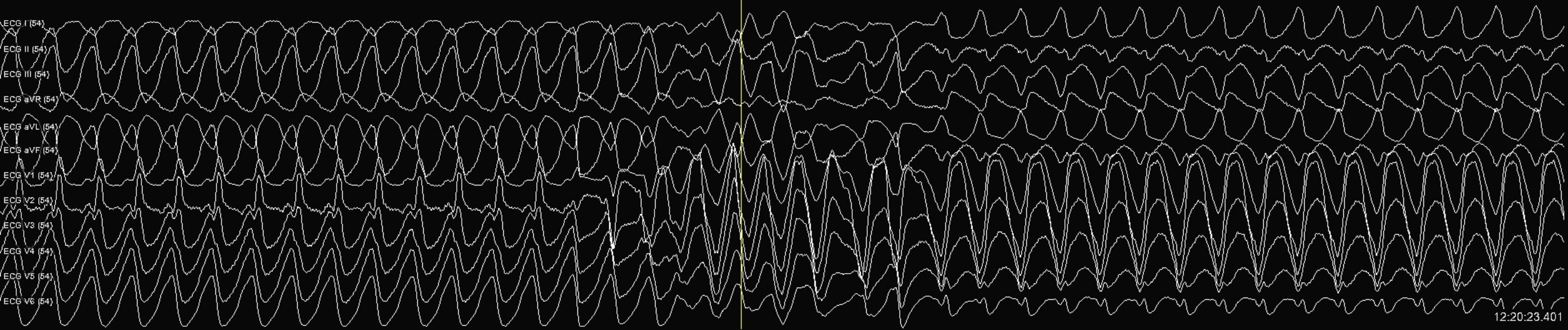
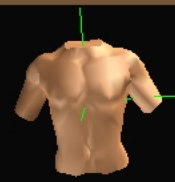
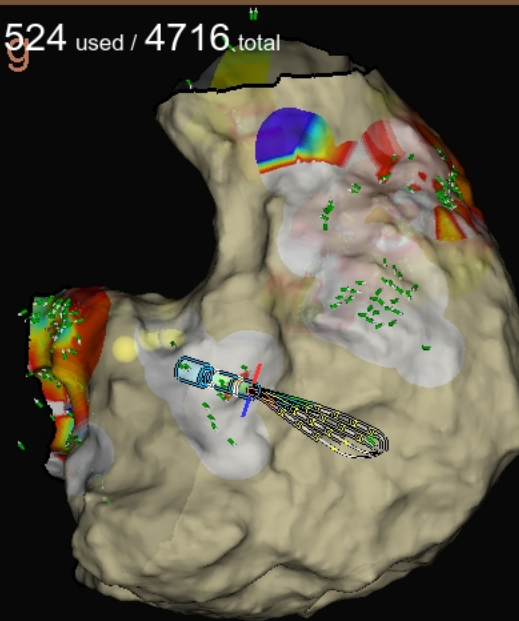
TV

Review: Mar 08, 2024 09:18:46 AM

VoXel Seg 00002



Points: 524 used / 4716 total

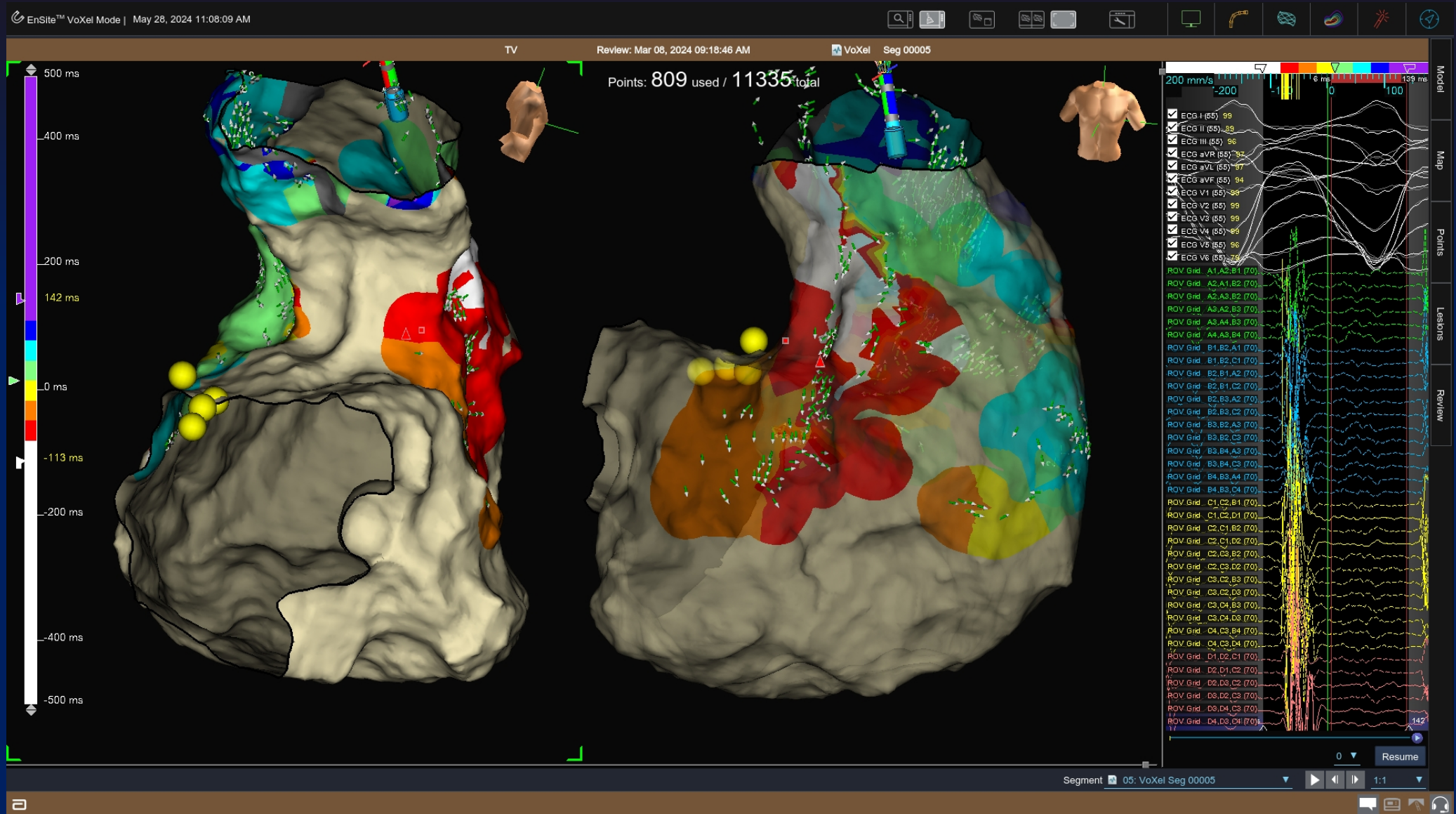


12:20:23.401

Segment 02: VoXel Seg 00002

REF CL 235 ms

VT2

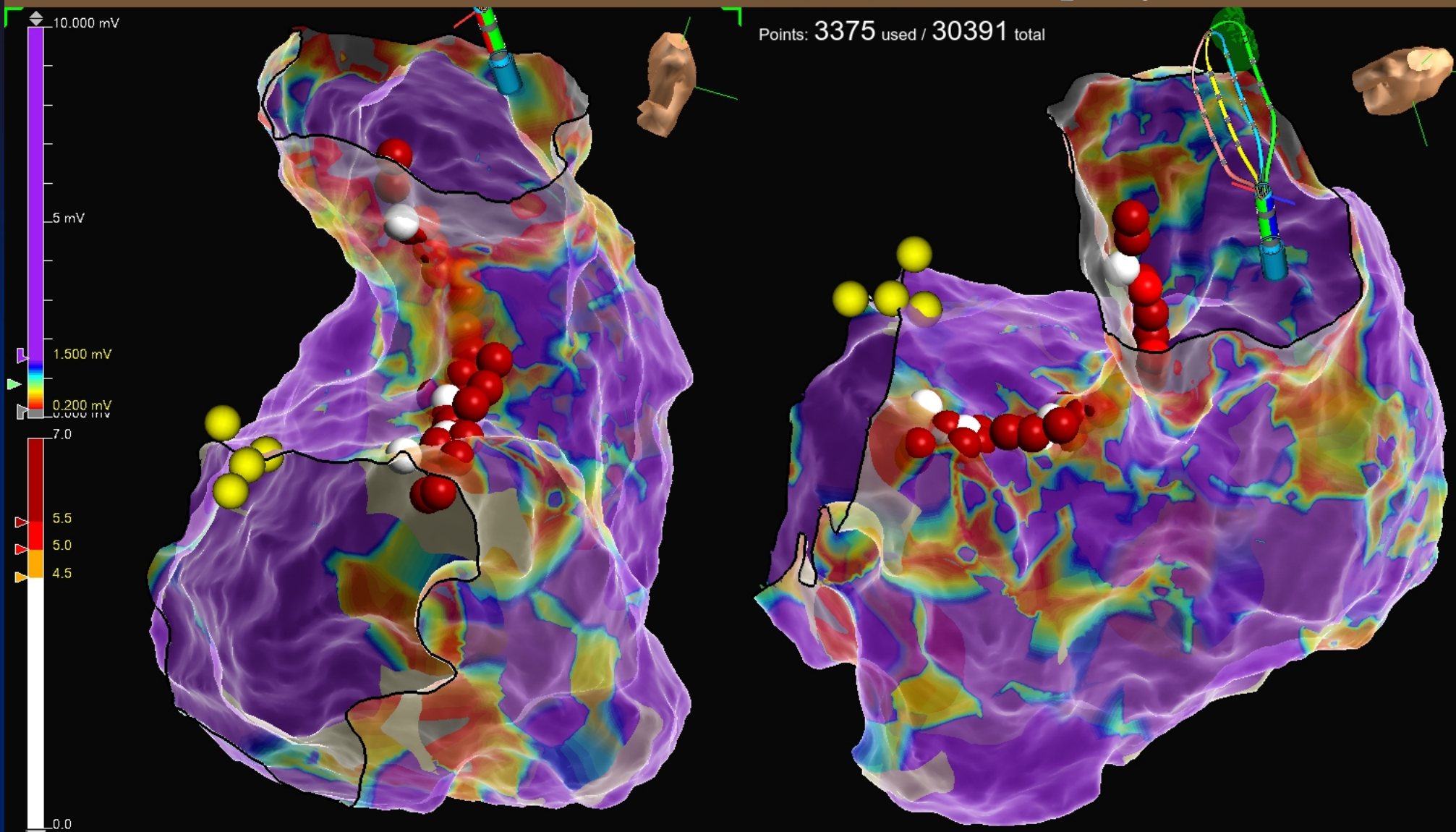


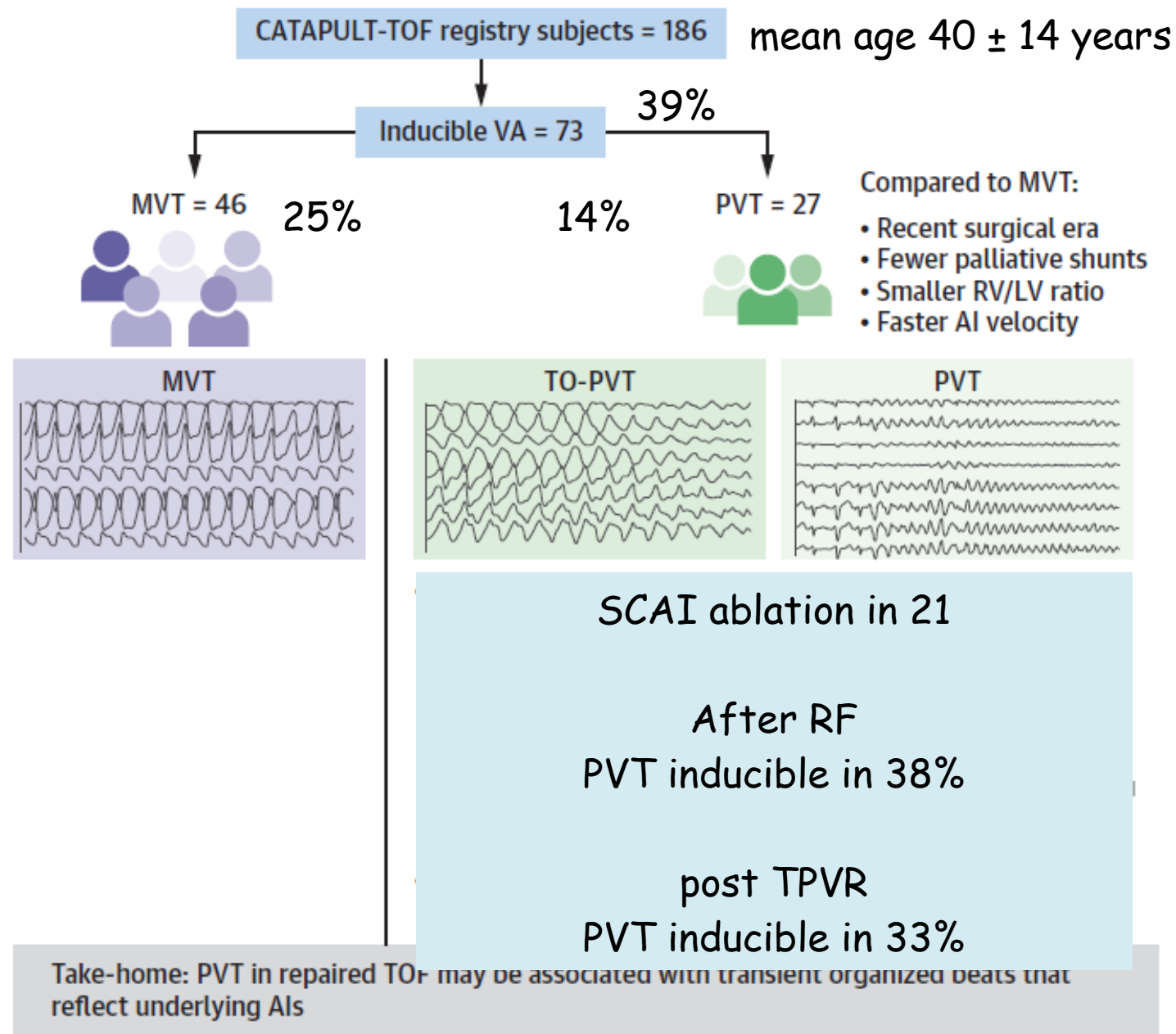
TV

Review: Mar 08, 2024 09:18:46 AM

VoXel Seg 00005

Points: 3375 used / 30391 total





Briefly organized VT before PVT in 58% and were associated with the presence of anatomical VT isthmuses. Postablation PVT was less frequent when TO were targeted with RF. During a median follow-up of 15 months, no reported cardiac events among patients with inducible PVT.

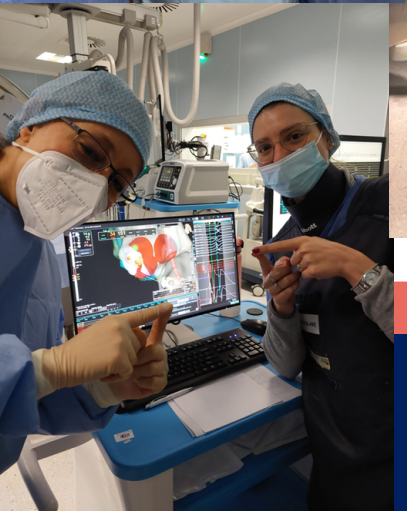
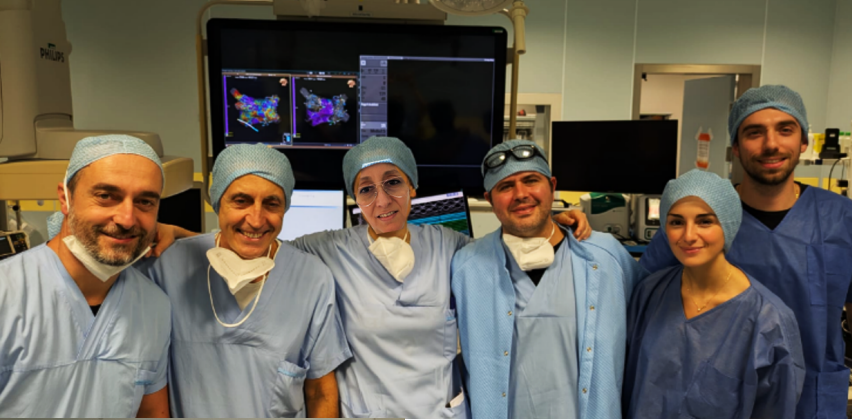
inducible PVT is a nonspecific finding. A wait-and-see approach might therefore represent the most appropriate strategy.

Moore J et al.,

JACC Clinical Electrophysiology 2025

Conclusioni

- Attualmente il rischio di VA nei rTOF è basso ma non trascurabile
- La PVR riduce in maniera significativa il rischio di VA.
- EAM per la ricerca di SCAI e l'ablazione preventiva prima che diventino inaccessibili per TPVR può essere eseguito in maniera efficace e senza complicanze di rilievo con le attuali tecnologie.
- EAM ed ablazione degli SCAI nei pazienti inducibili può ridurre gli eventi al follow-up, nei pazienti ad alto rischio può ridurre i candidati ad impianto ICD
- Dati preliminari del CATAPULT suggeriscono che l'inducibilità di PVT non sembra avere un impatto prognostico e nei casi di TO può essere ridotta trattando gli SCAI .



Pediatric Cardiology and Adult Congenital Heart Disease Program
IRCCS Azienda Ospedaliero-Universitaria di Bologna