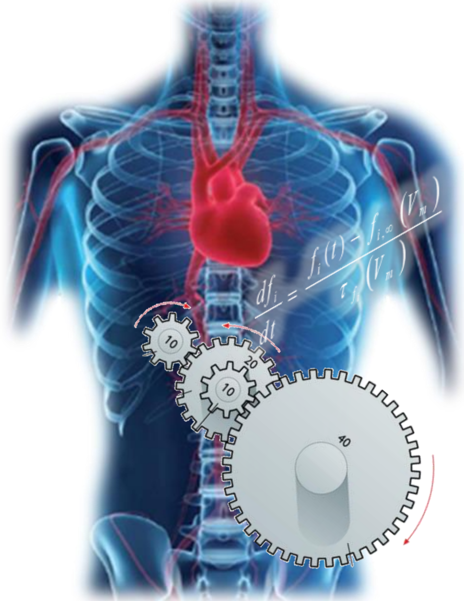
TEMA 11

MODELADO Y SIMULACIÓN DE LA ACTIVIDAD BIOELÉCTRICA DEL CORAZÓN

Chema Ferrero

Bioelectricidad

Grado en Ingeniería Biomédica



Esquema de exposición

BASE TEÓRICA: Modelos computacionales de la actividad bioeléctrica del corazón
Descripción de la isquemia aguda y el infarto

INVESTIGACIÓN: Análisis de los mecanismos arritmogénicos de la isquemia miocárdica

DESARROLLO: Simulación personalizada de ablación por RF en pacientes con infarto de miocardio

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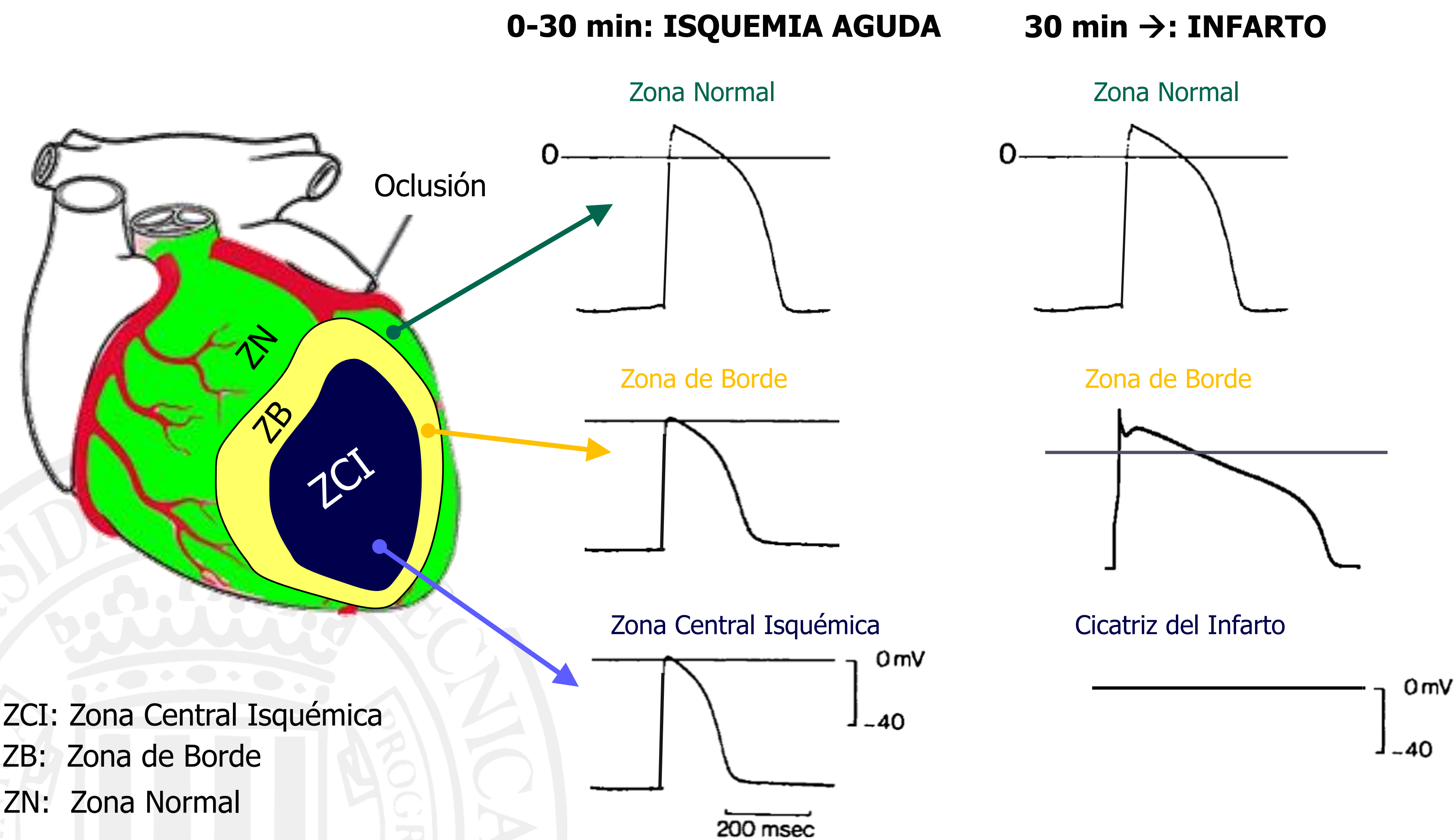
Isquemia aguda e infarto de miocardio

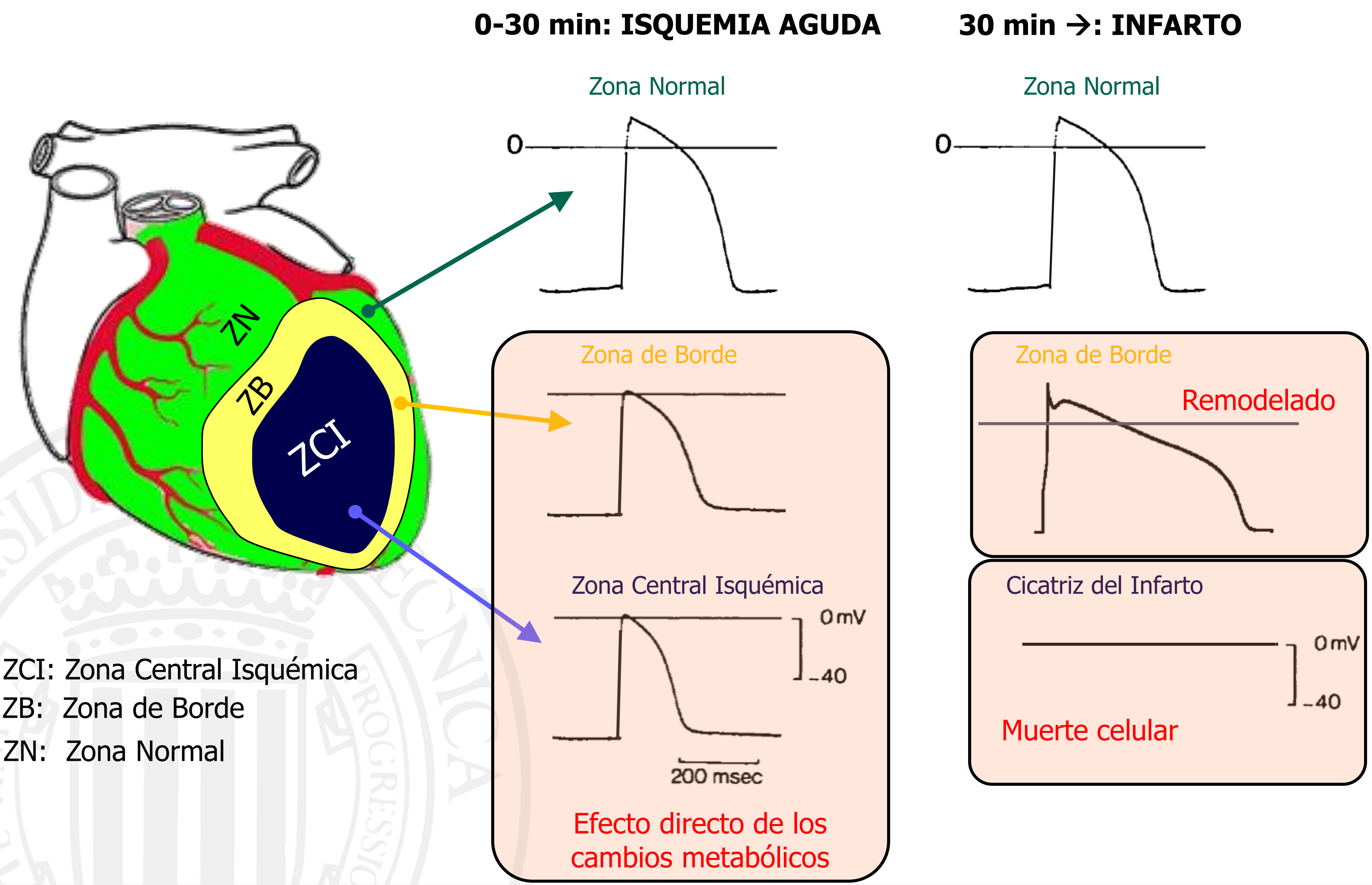


ZCI: Zona Central Isquémica

ZB: Zona de Borde

ZN: Zona Normal

Isquemia aguda e infarto de miocardio

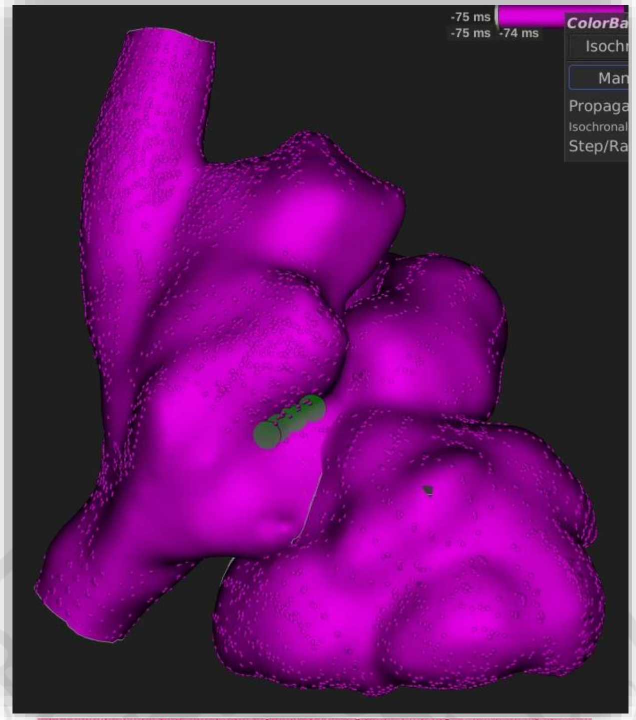


ZCI: Zona Central Isquémica
ZB: Zona de Borde
ZN: Zona Normal

Isquemia aguda e infarto de miocardio

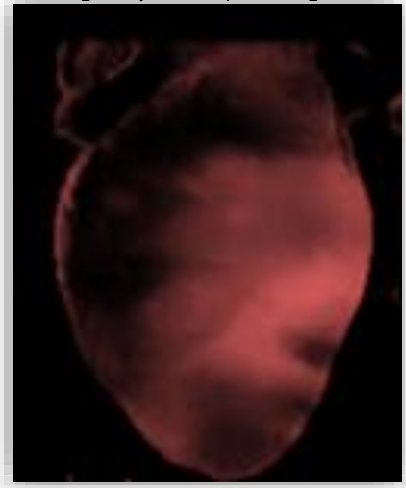
(tiempo ÷ 25)

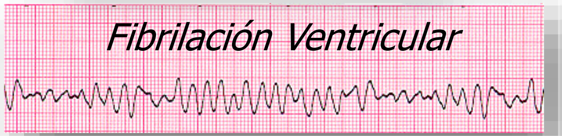
[Ferrero et al, 2018]



0-30 min: ISQUEMIA AGUDA

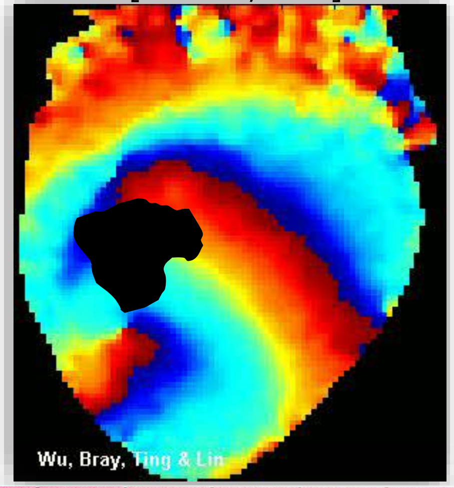
[Gray et al., 1995]

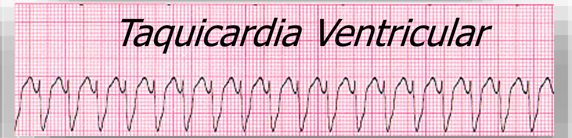




30 min →: INFARTO

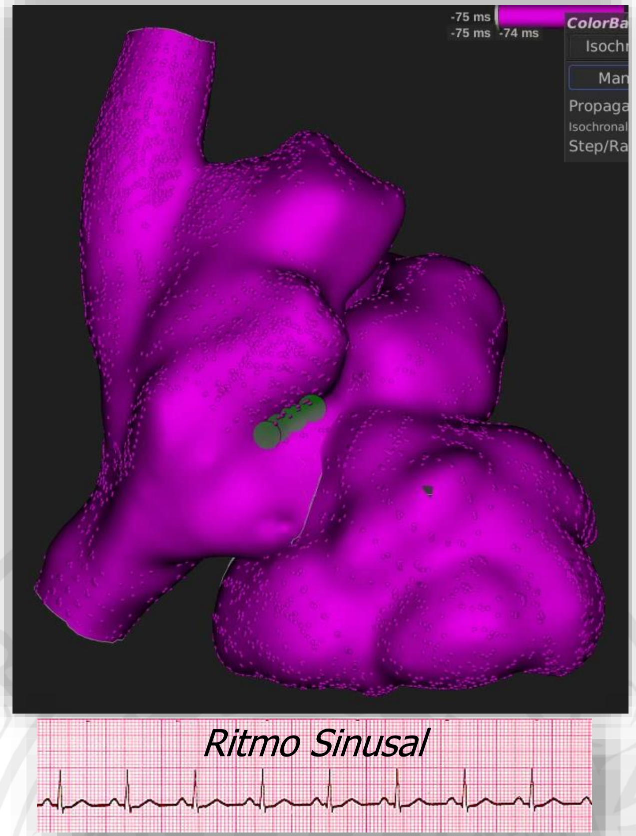
[Wu et al, 2006]





Isquemia aguda e infarto de miocardio

[Ferrero et al, 2018]



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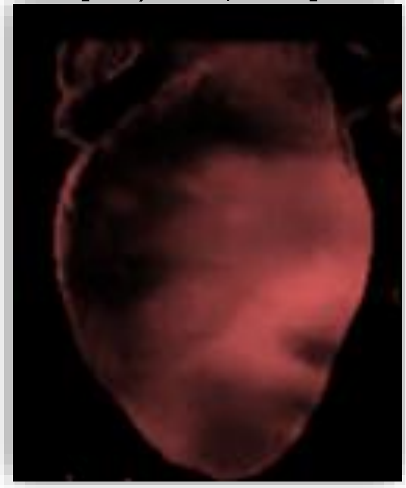
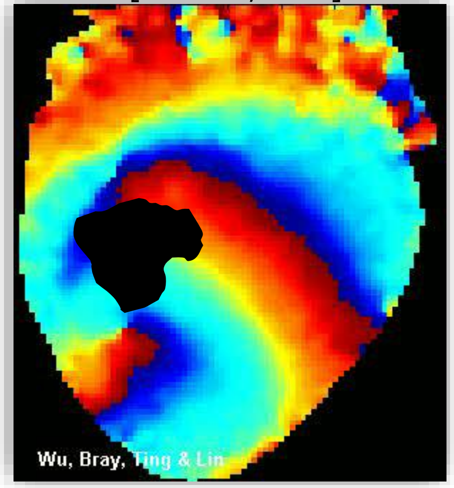
[Gray et al., 1995]



Fibrilación Ventricular

30 min →: INFARTO

[Wu et al, 2006]



Taquicardia Ventricular

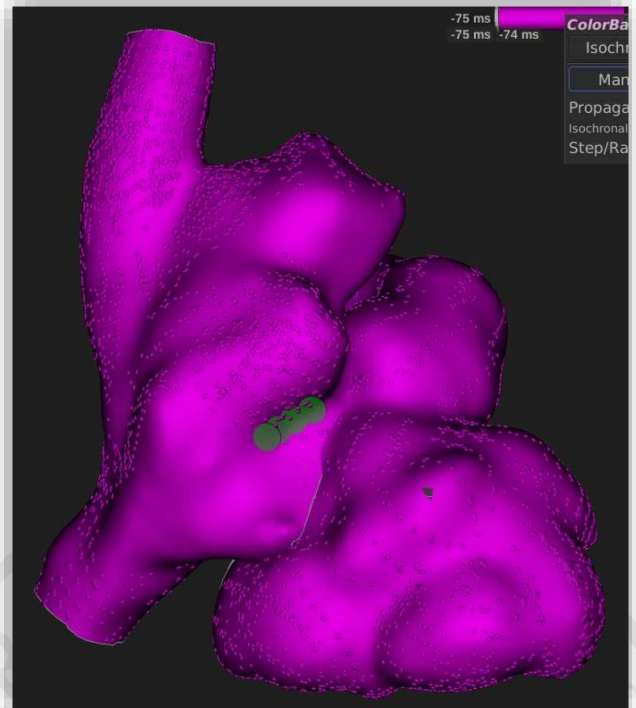
7,000,000 de muertes al año en todo el mundo

RIESGO DE SUFRIR ARRITMIAS

[Smith et al,1995]

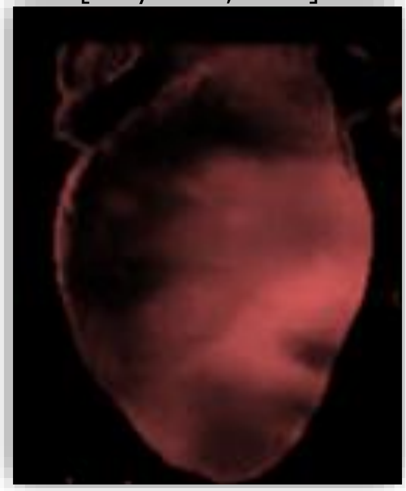
Isquemia aguda e infarto de miocardio

[Ferrero et al, 2018]



0-30 min: ISQUEMIA AGUDA

[Gray et al., 1995]



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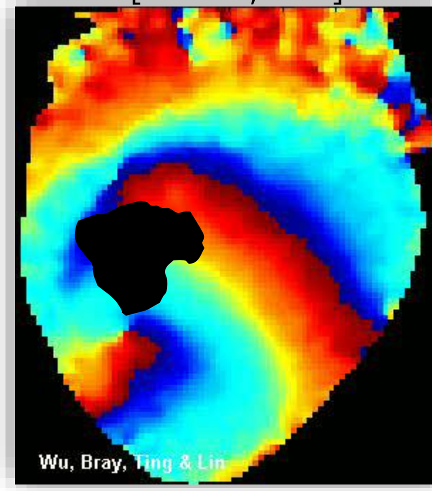
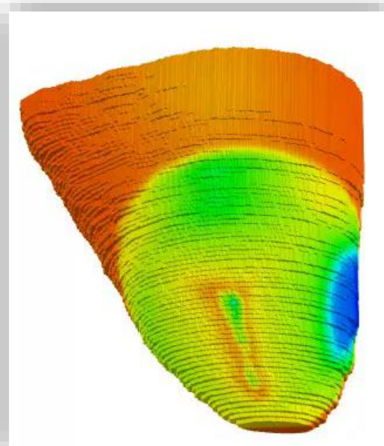
[Wu et al, 2006]



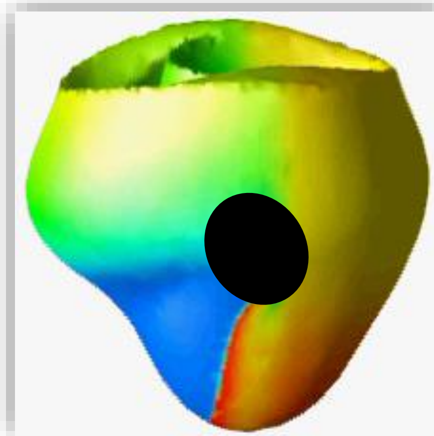
Taquicardia Ventricular

EXPERIMENTOS

SIMULACIONES



[Rodríguez & Ferrero, 2015]

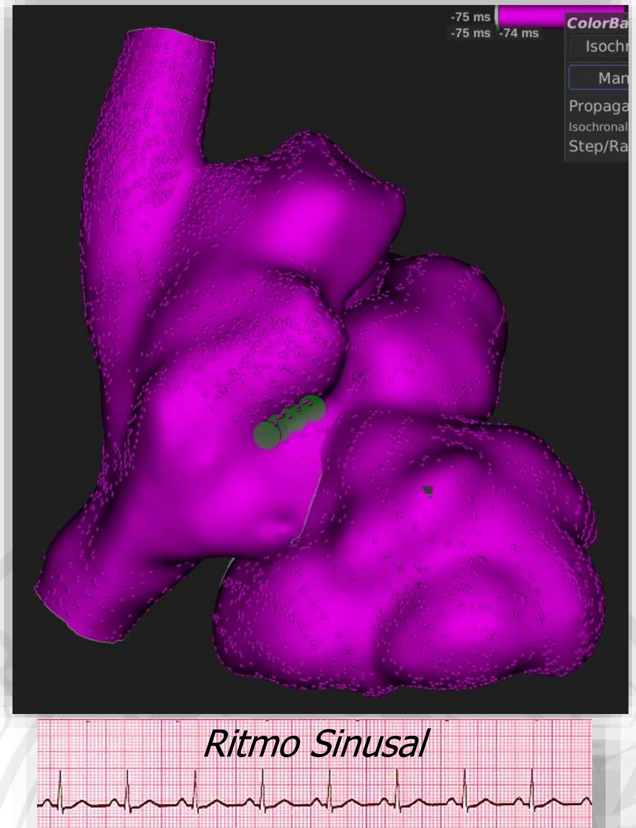


[Trayanova et al, 2006]

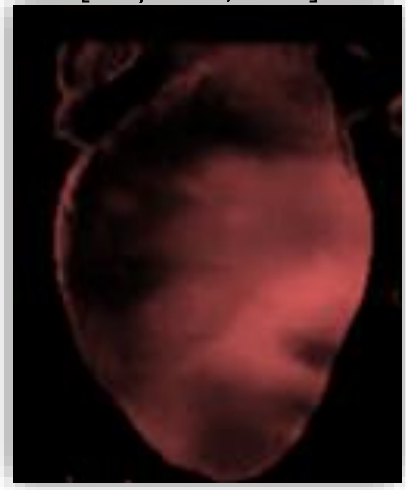
Isquemia aguda e infarto de miocardio

0-30 min: ISQUEMIA AGUDA

[Ferrero et al, 2018]

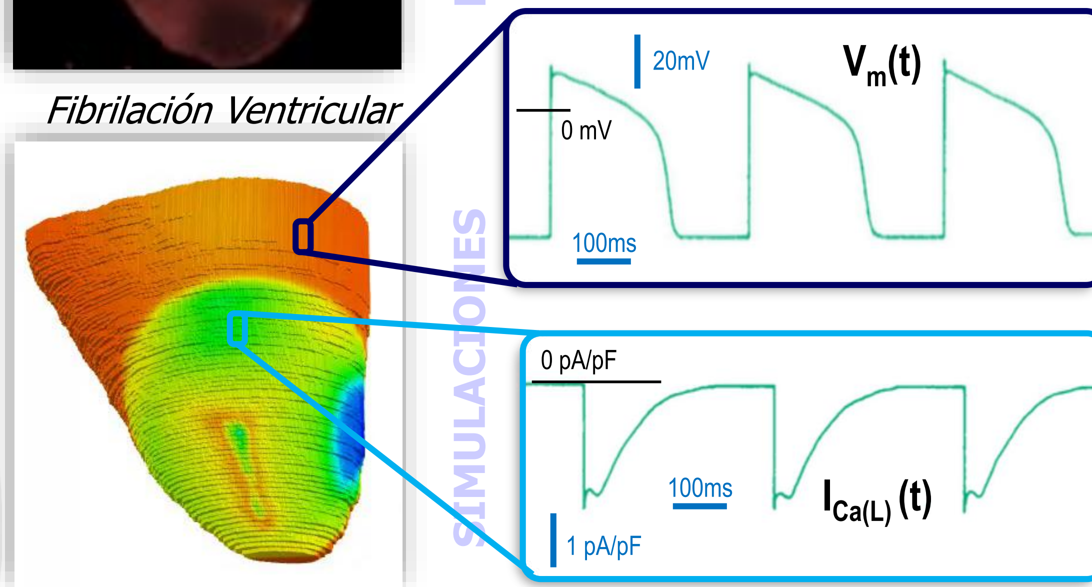


[Gray et al., 1995]



EXPERIMENTOS

Fibrilación Ventricular



SIMULACIONES

[Rodríguez & Ferrero, 2015]

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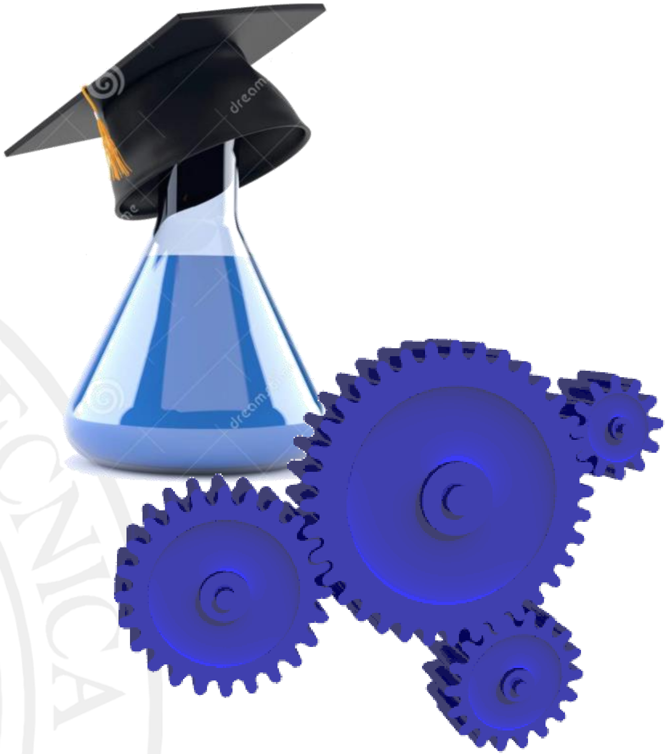
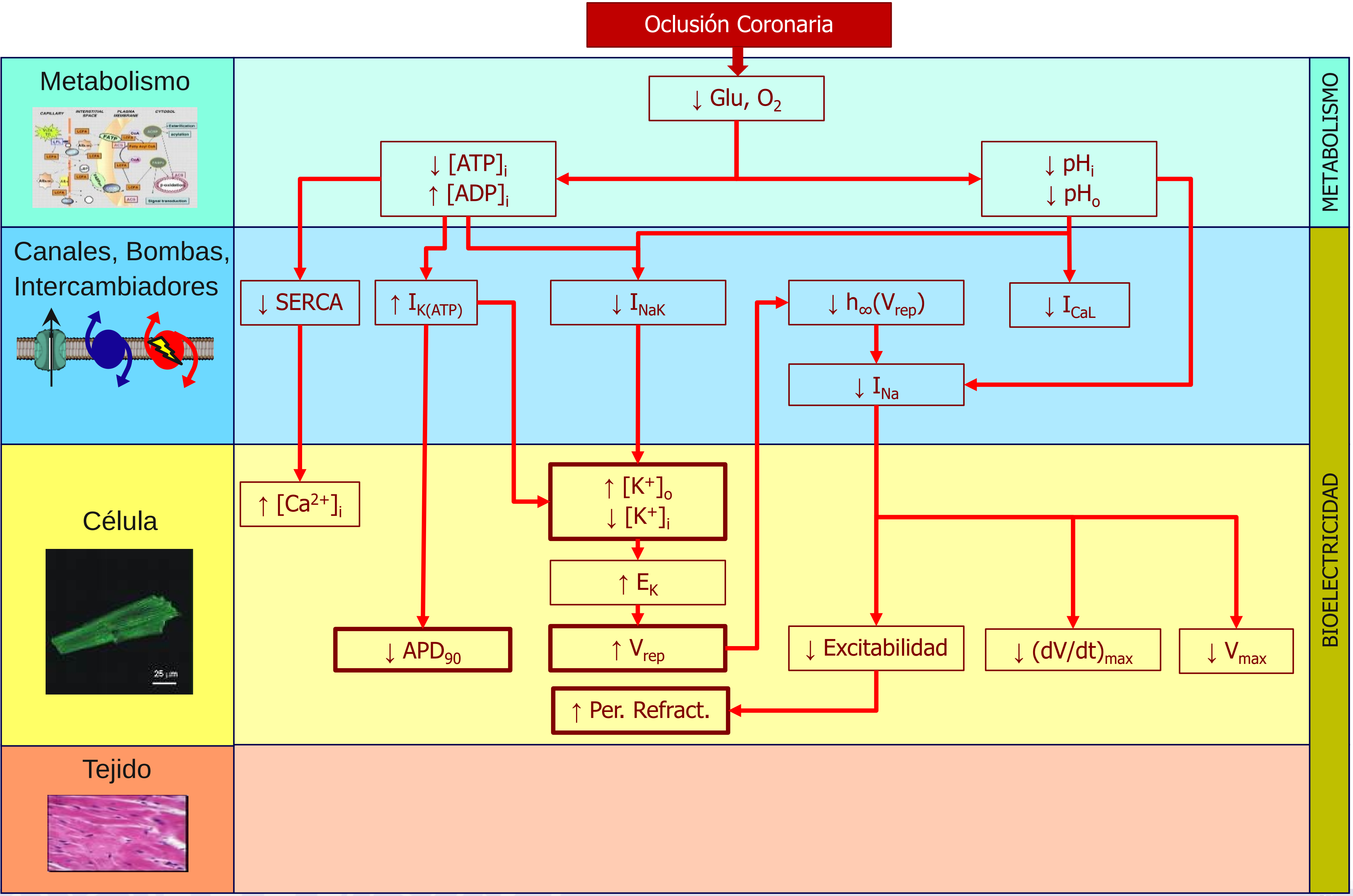


Efectos de la isquemia miocárdica aguda sobre la bioelectricidad cardiaca



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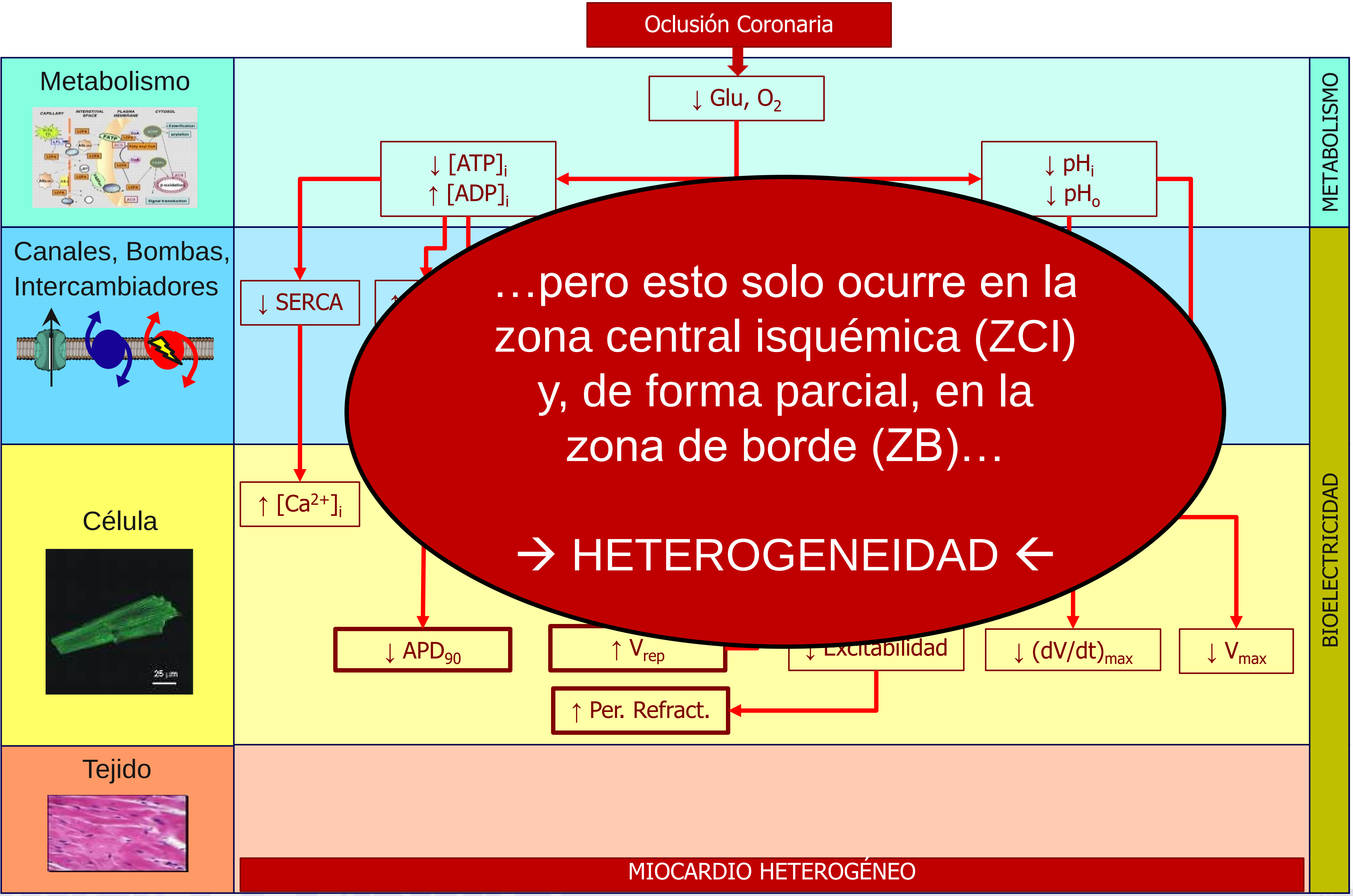
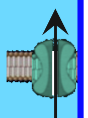
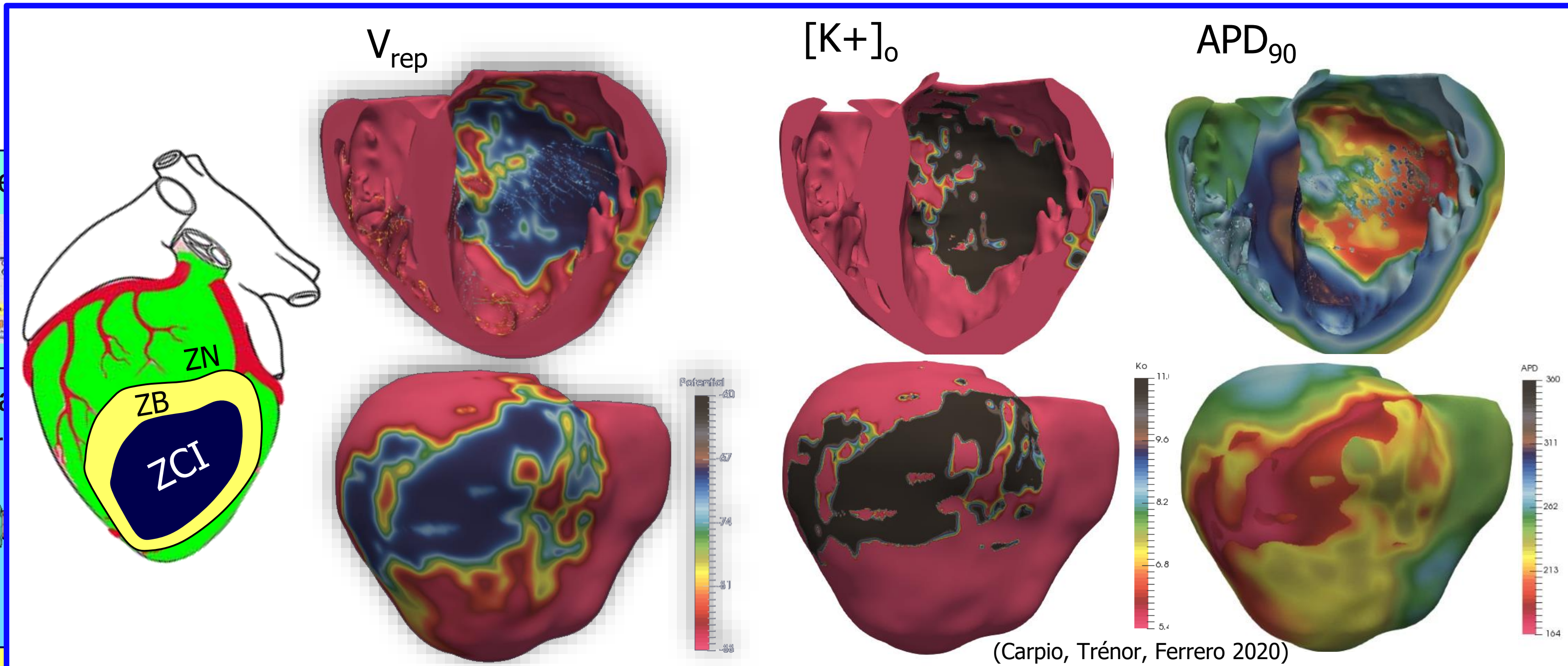


Me

Cana
Inter





(Carpio, Trénor, Ferrero 2020)

METABOLISMO

Célula

↑ $[Ca^{2+}]_i$

↑ $[K^+]_o$
↓ $[K^+]_i$

↑ E_K

↓ APD_{90}

↑ V_{rep}

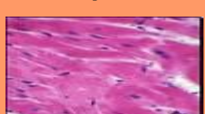
↓ Excitabilidad

↓ $(dV/dt)_{max}$

↓ V_{max}

↑ Per. Refract.

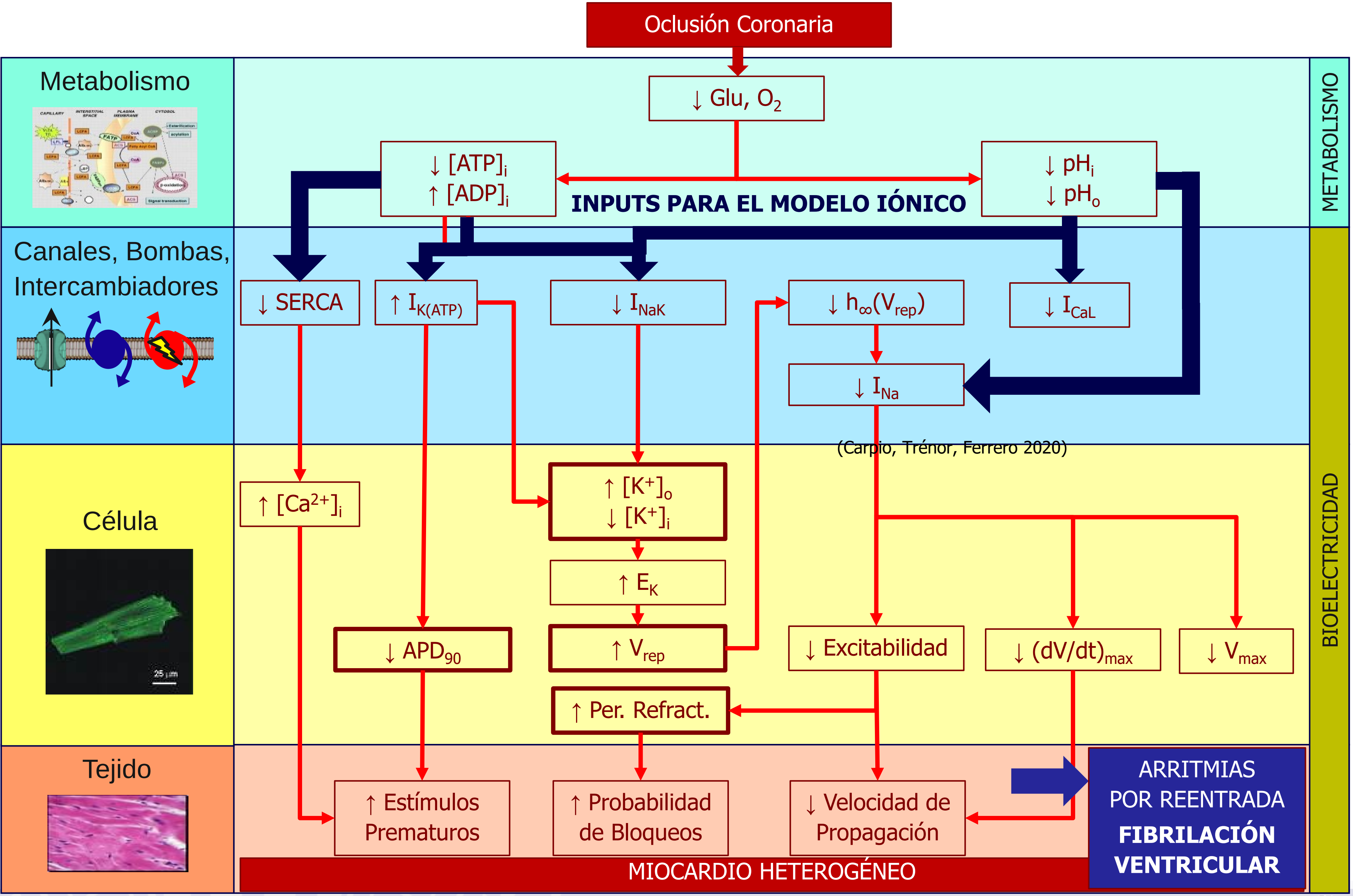
Tejido



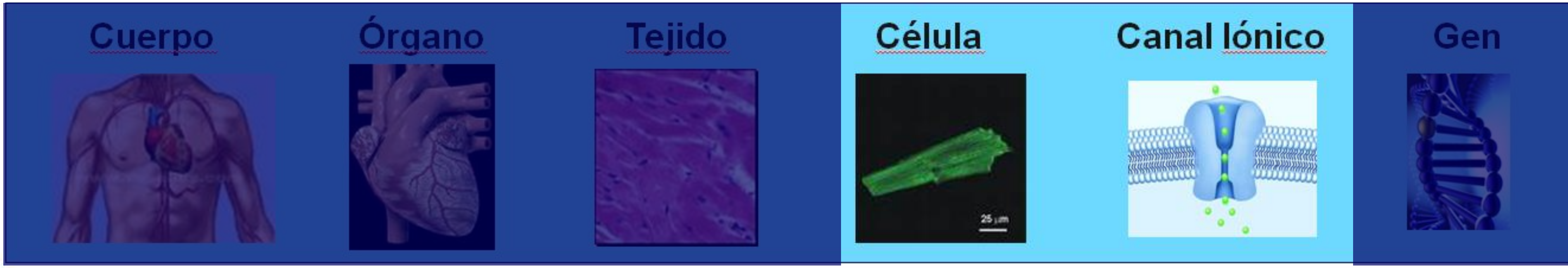
MIOCARDIO HETEROGÉNEO

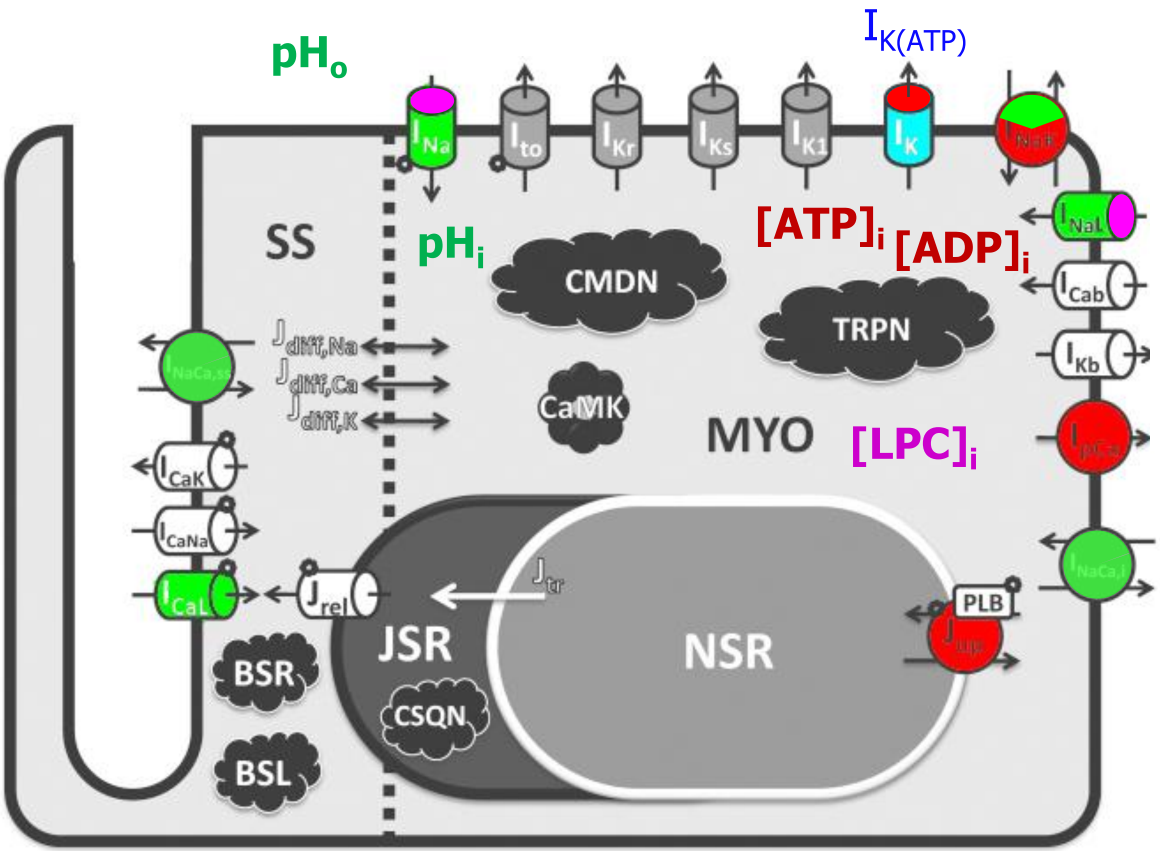
BIOELECTRICIDAD

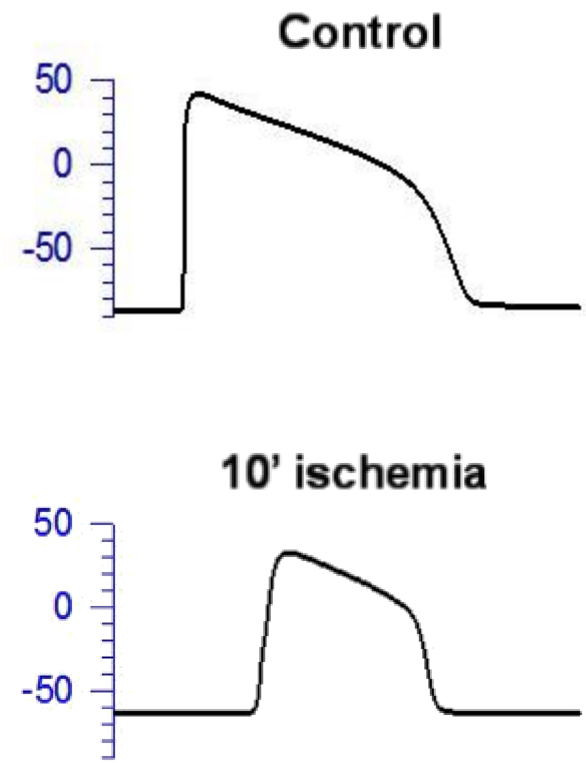
Efectos de la isquemia miocárdica aguda sobre la bioelectricidad cardiaca



Modelado multiescala de la isquemia miocárdica







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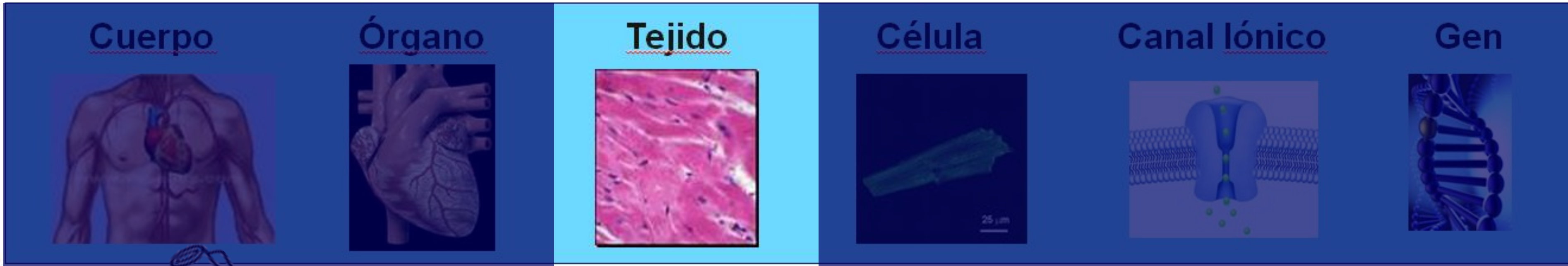
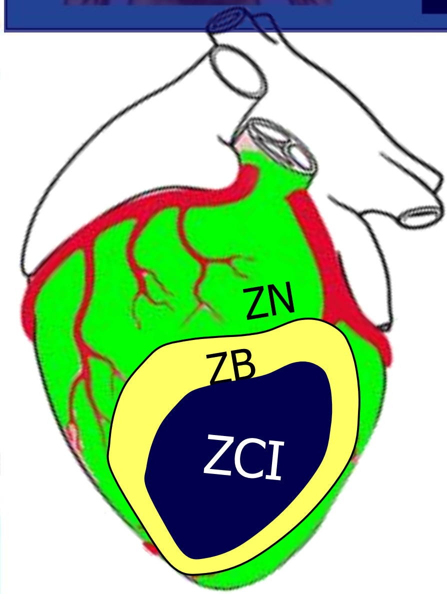
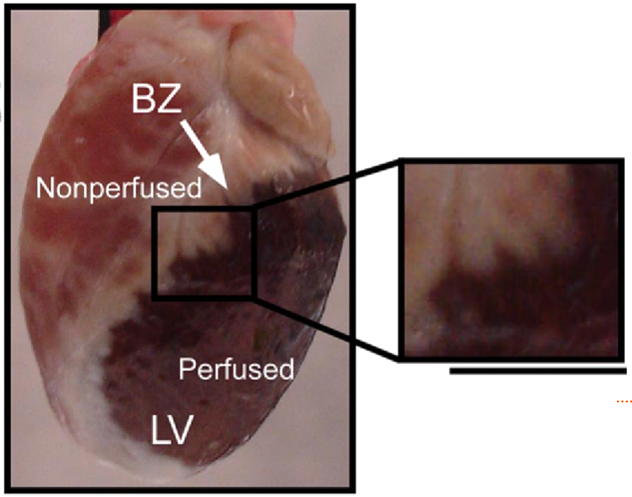
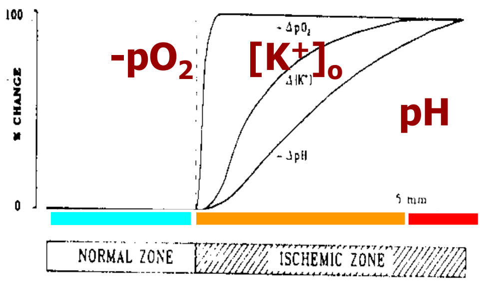
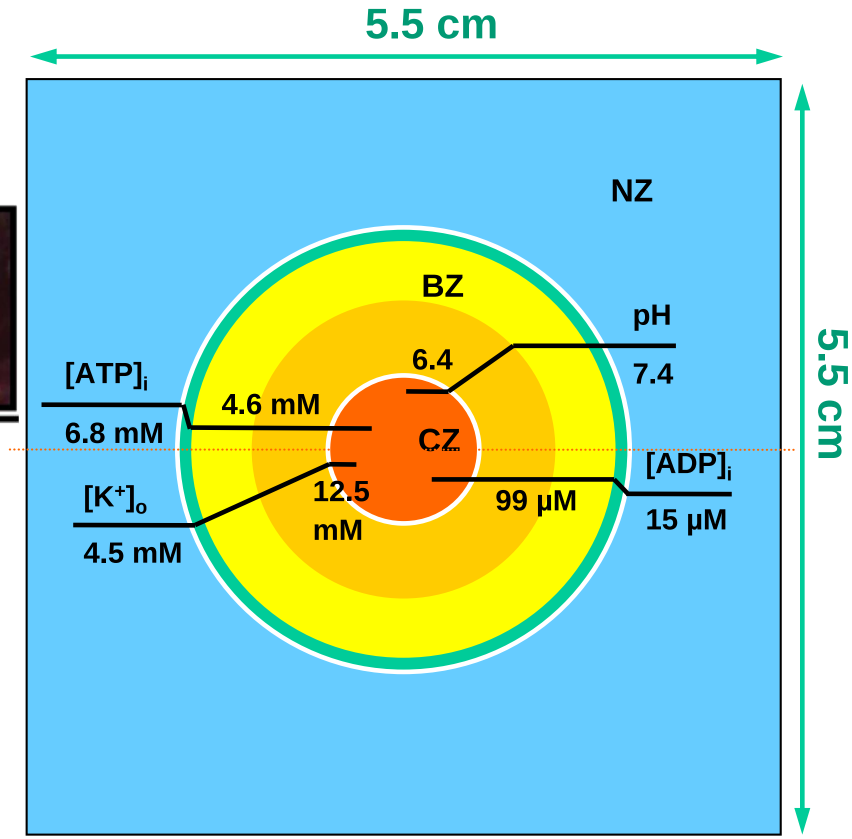








[Coronel et al, Circ Res 1988]



[Ferrero et al, *Int J Bifurcation & Chaos*, 2003]

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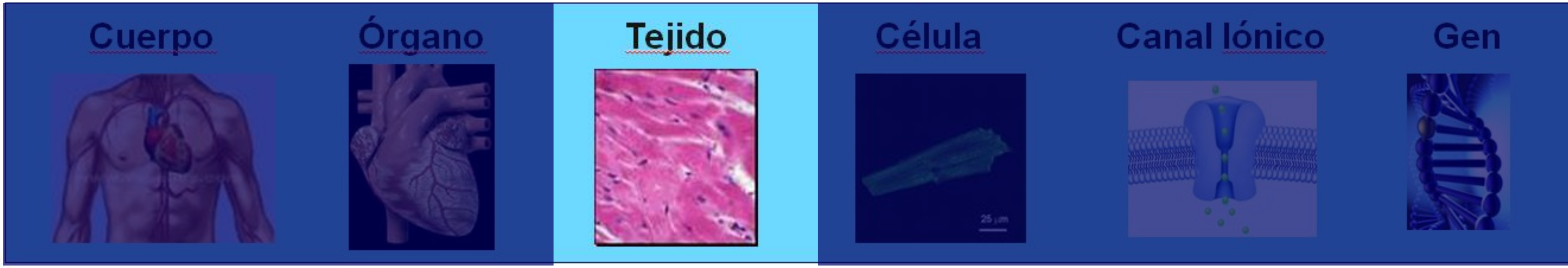

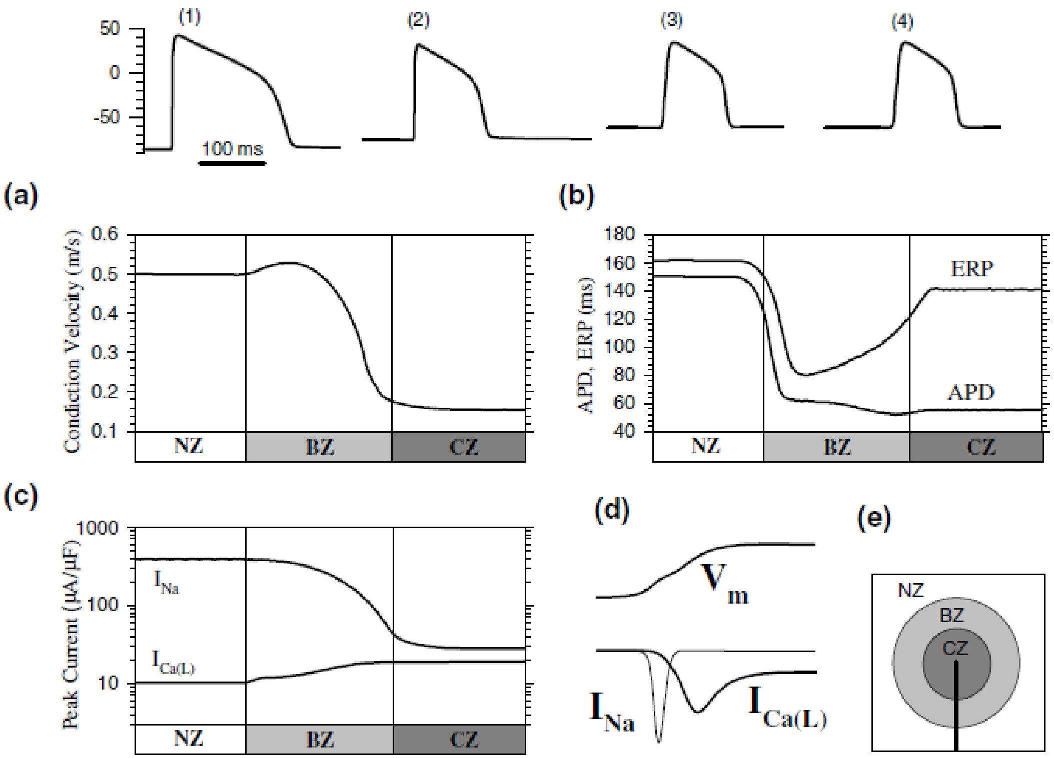

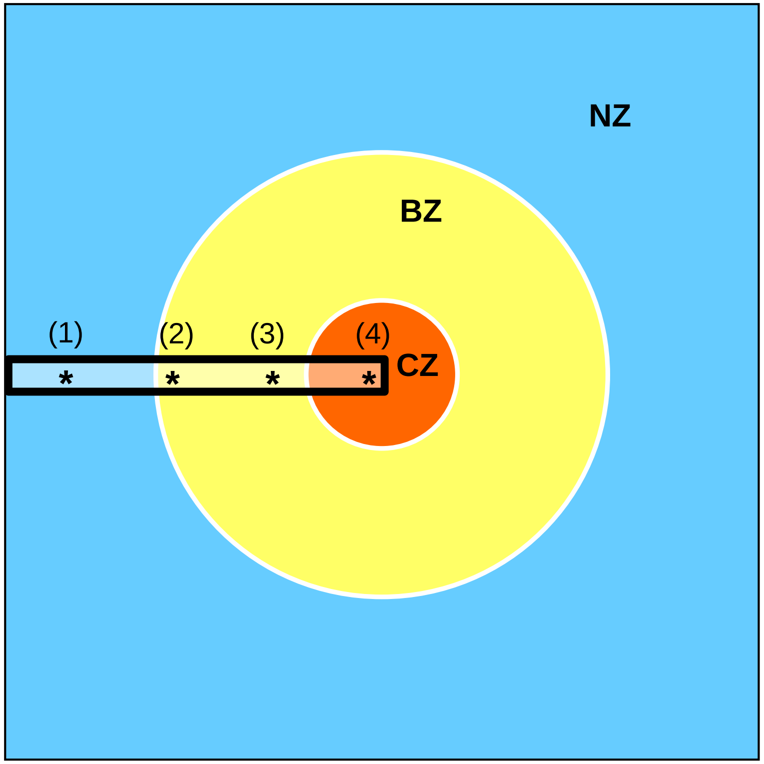

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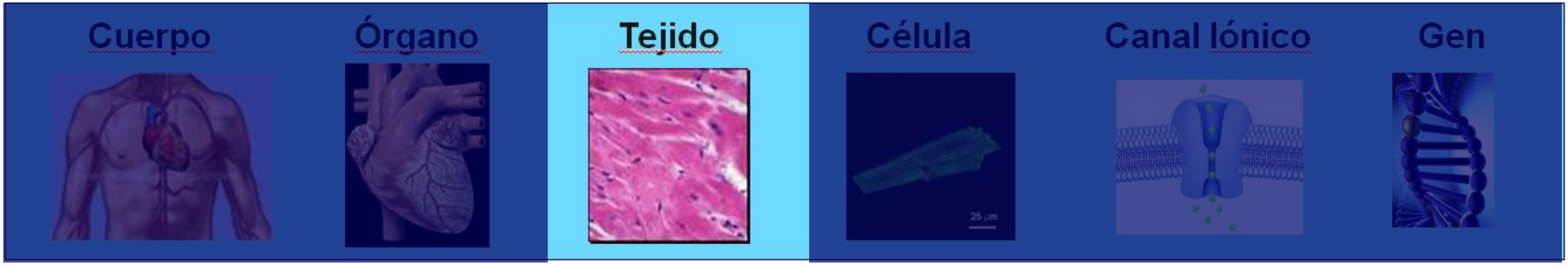

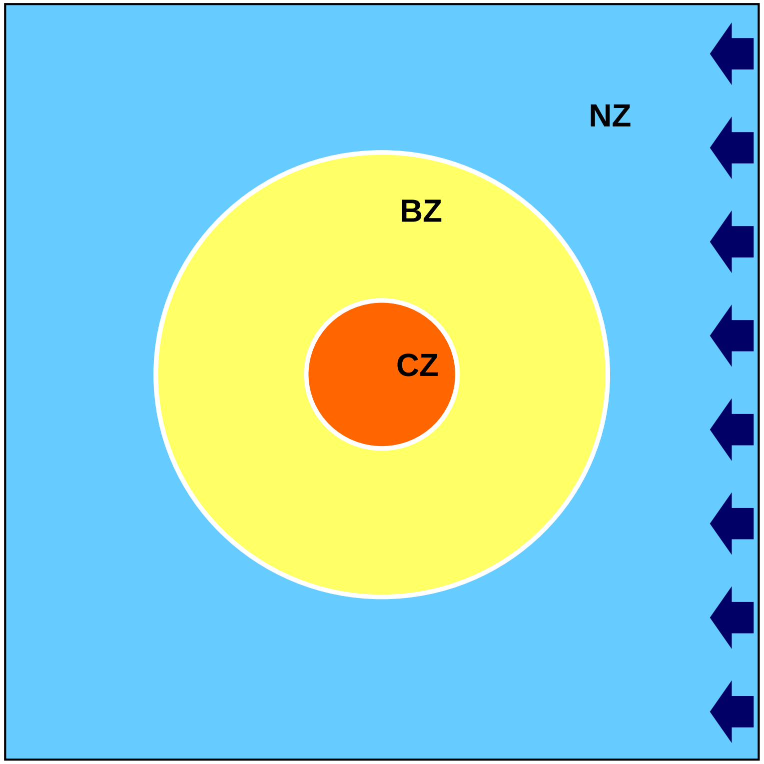

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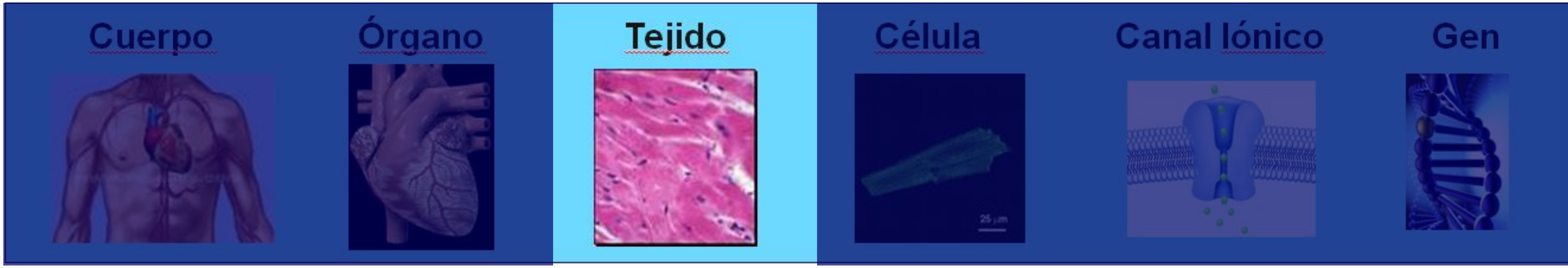

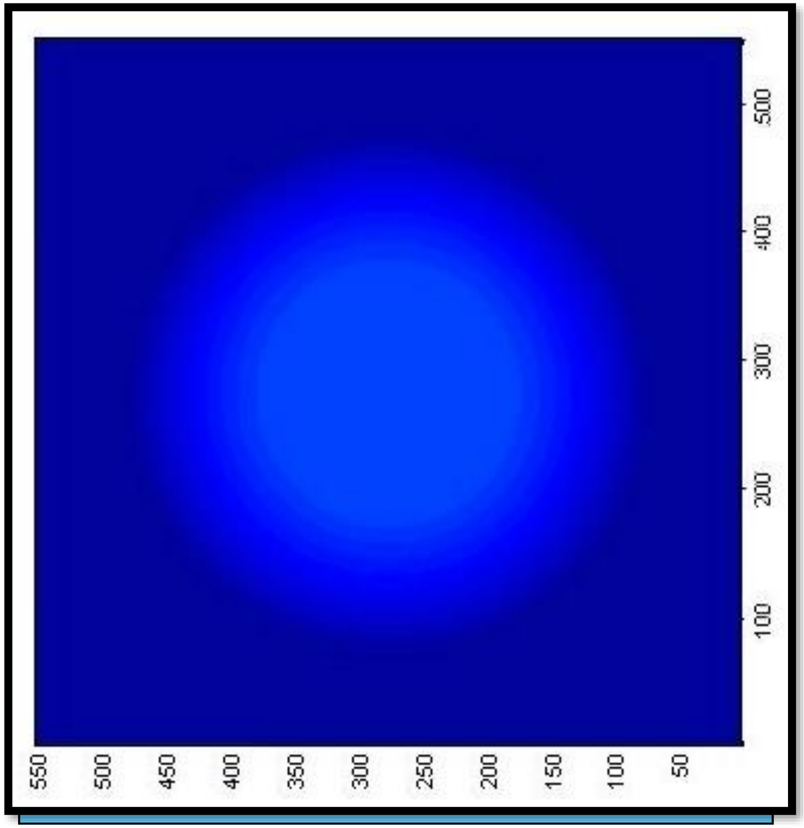

[Ferrero et al, *Int J Bifurcation & Chaos*, 2003]

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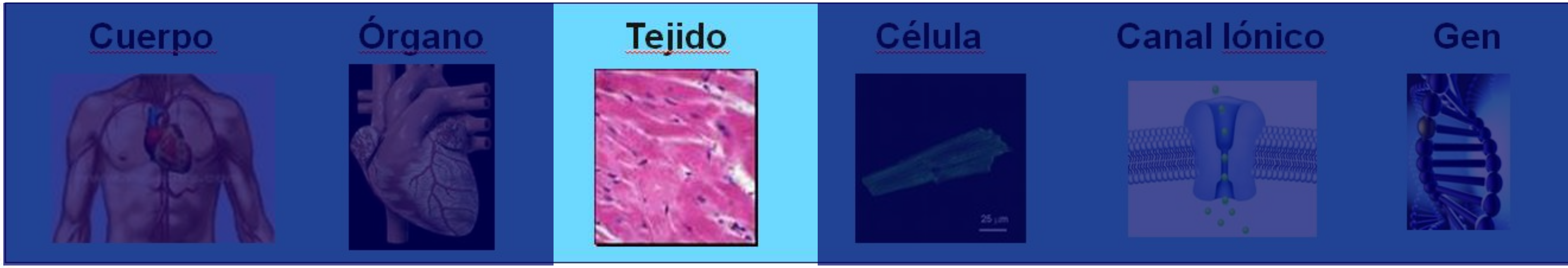
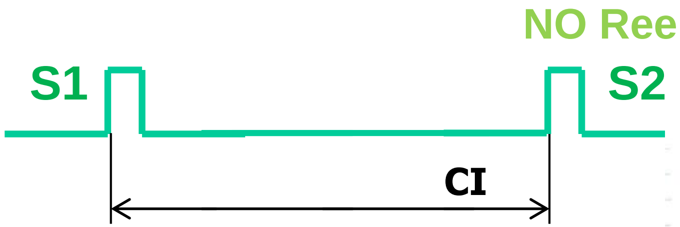
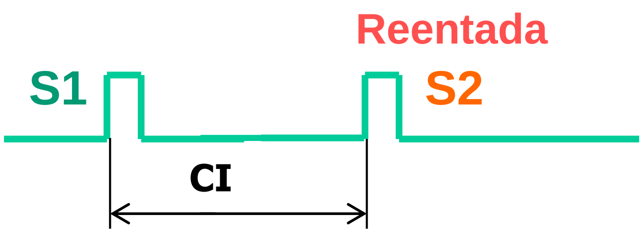
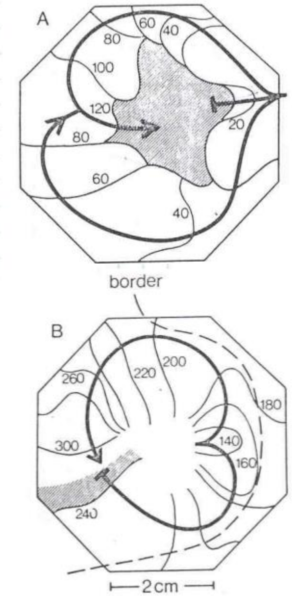
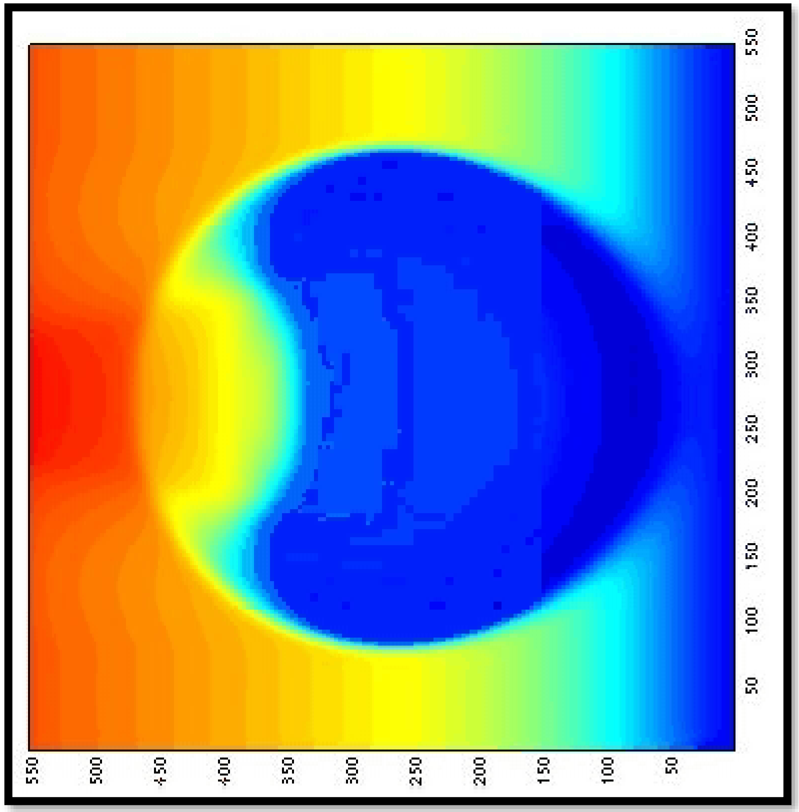








[Janse et al, *Circ Res*, 1981]



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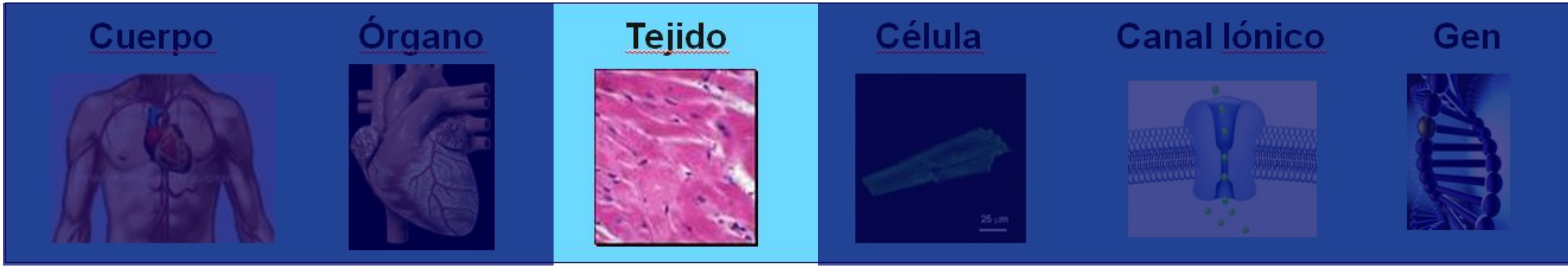

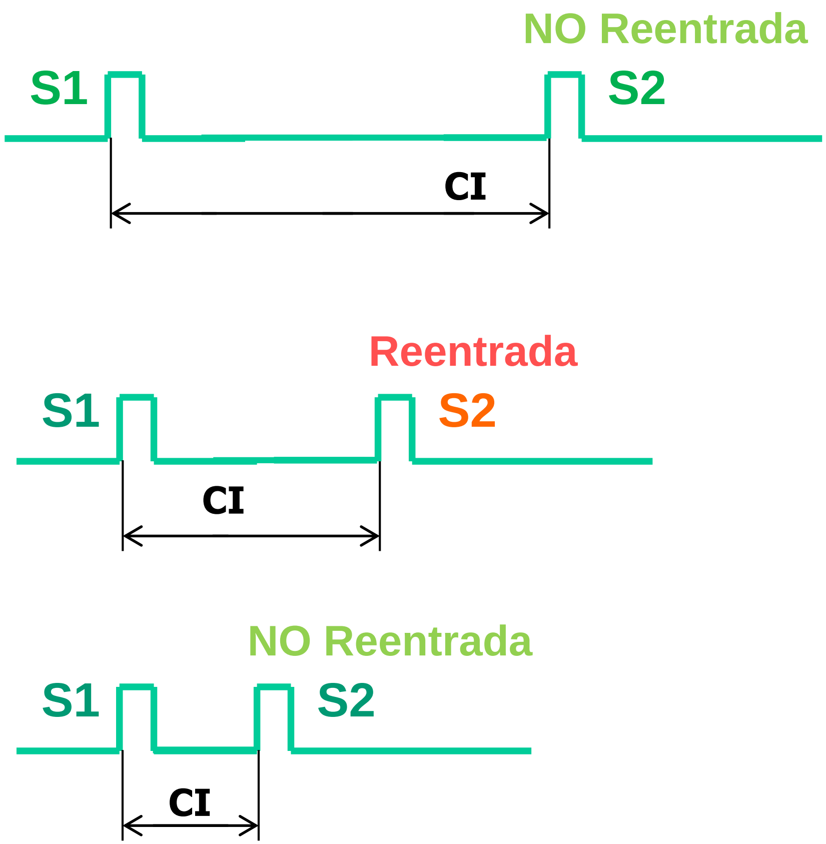

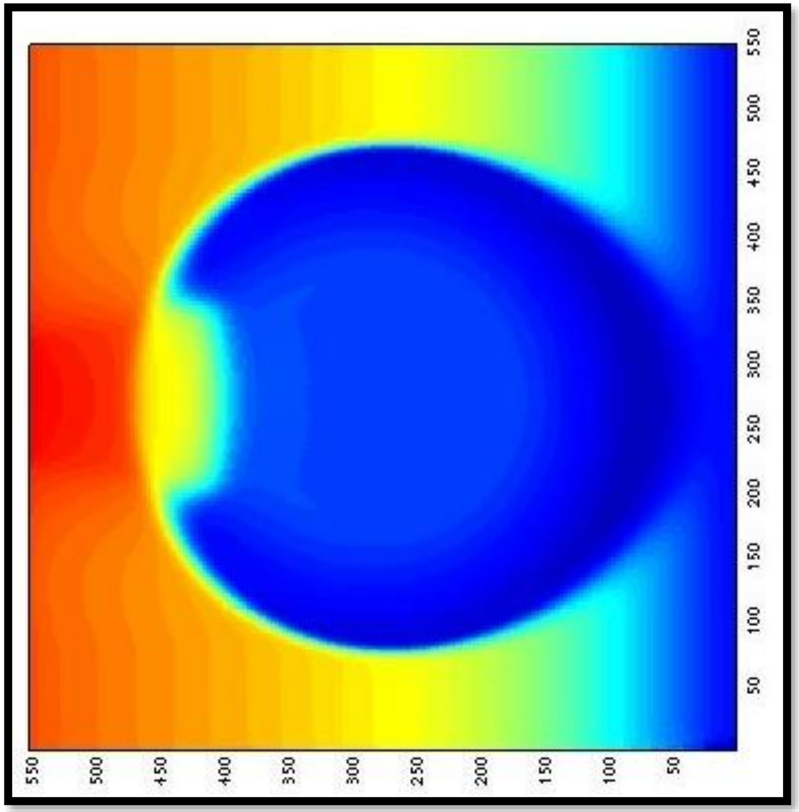

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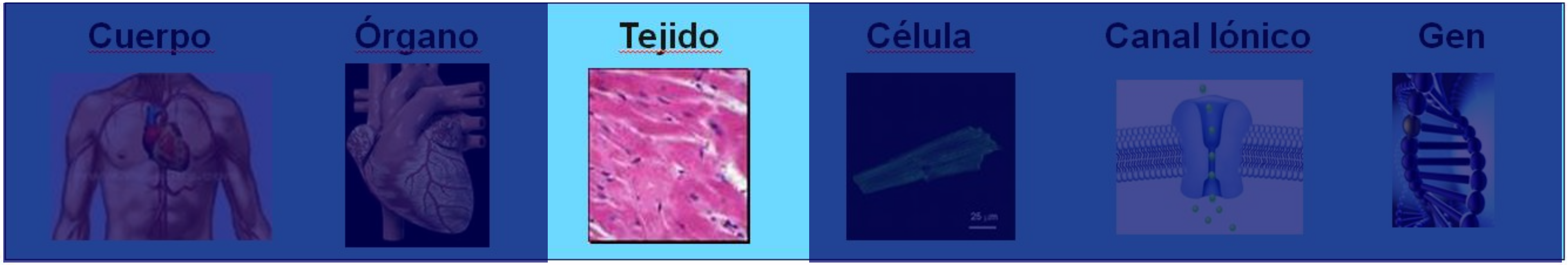

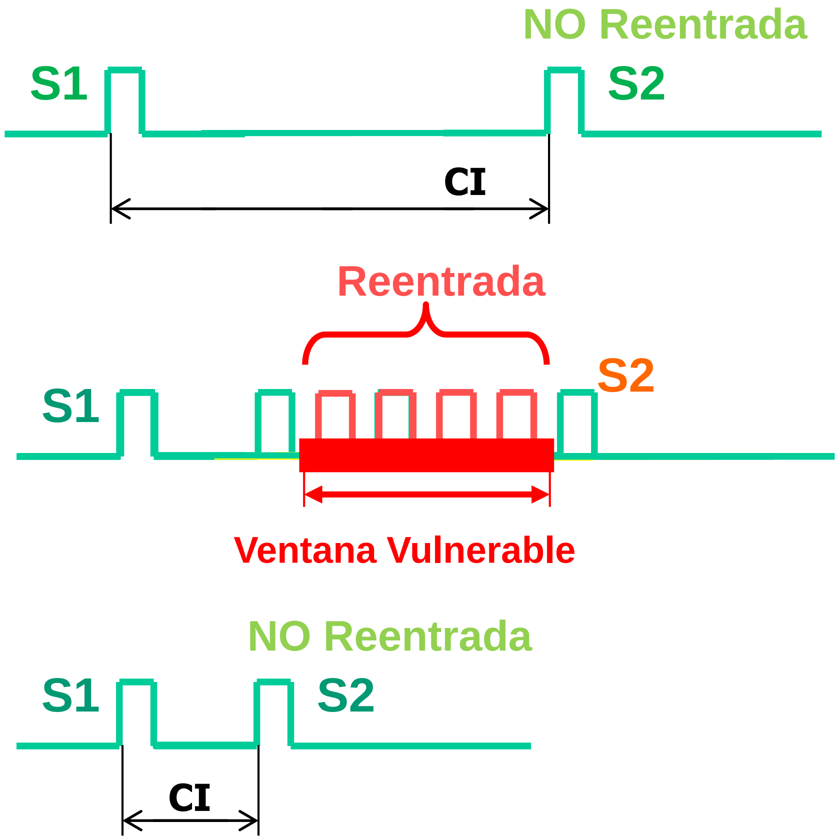

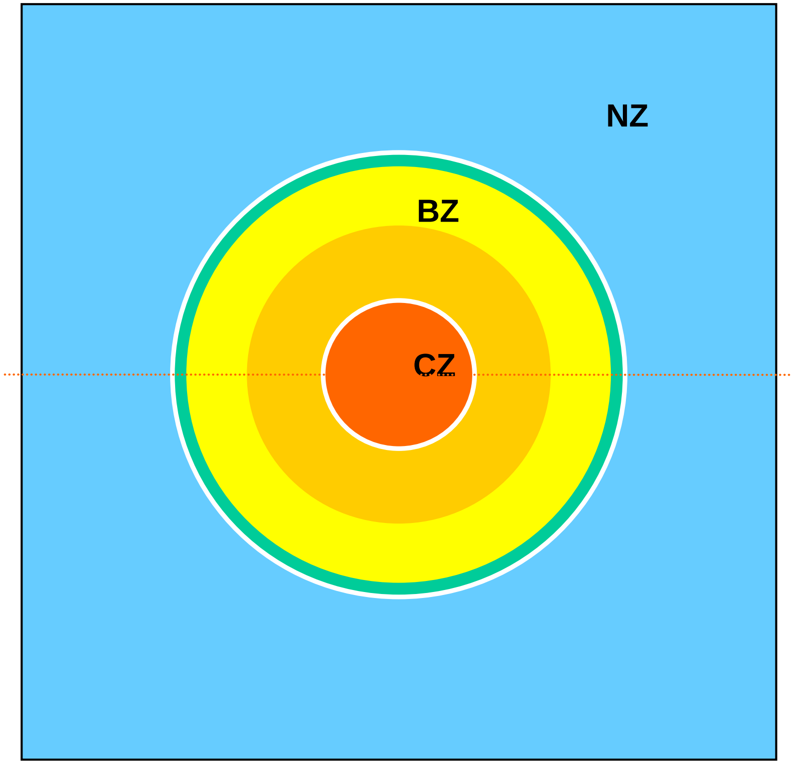

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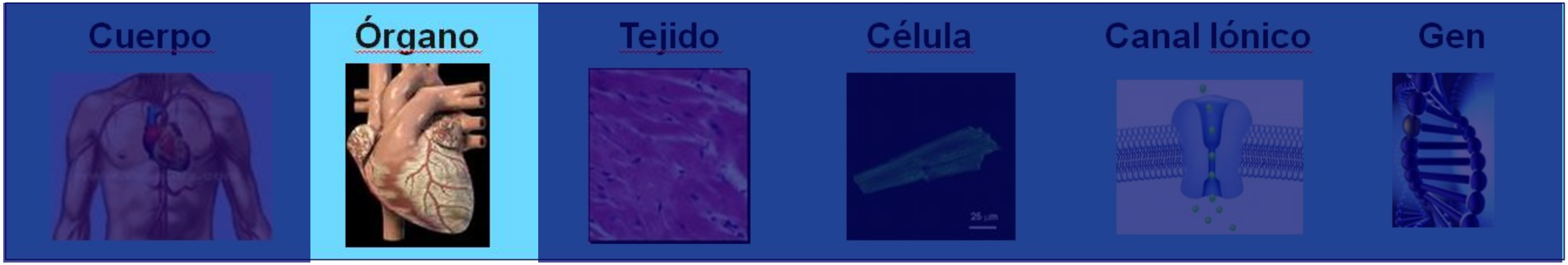

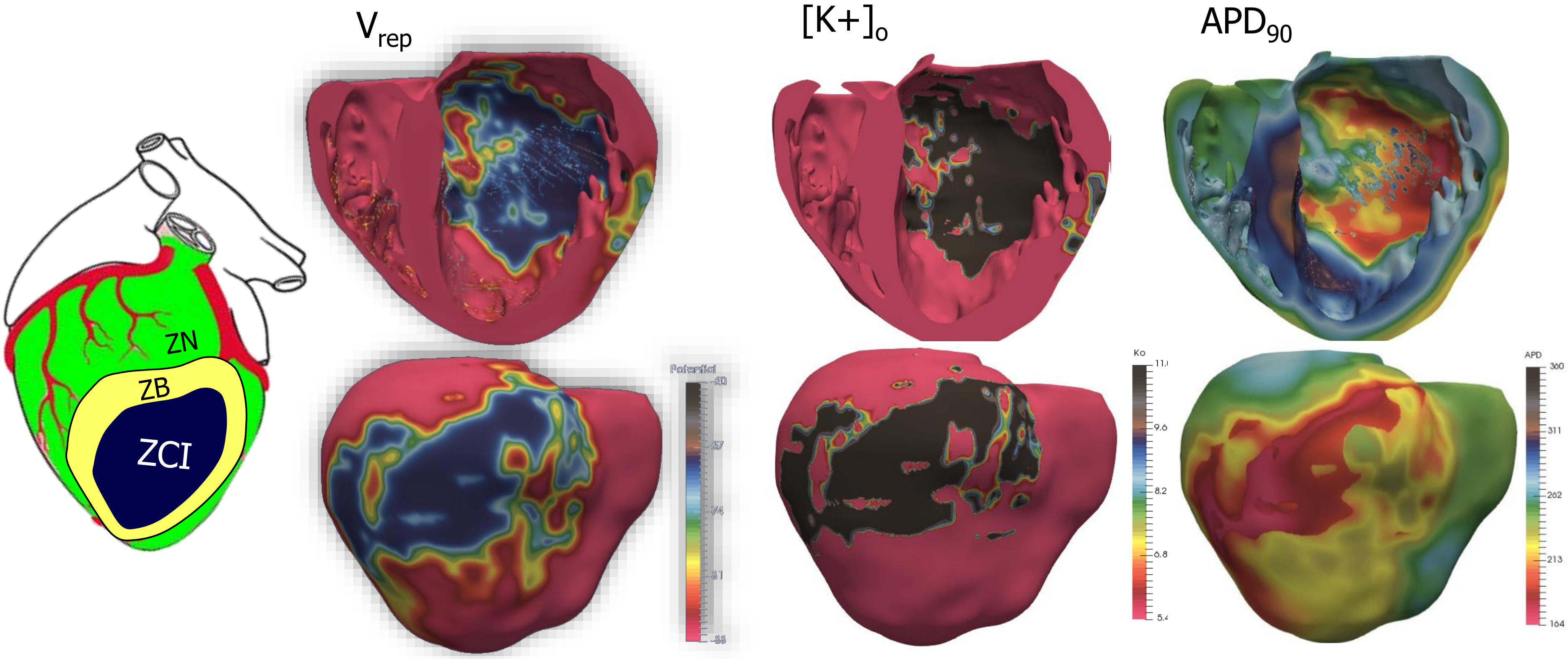

[Carpio, Trénor & Ferrero, 2020]

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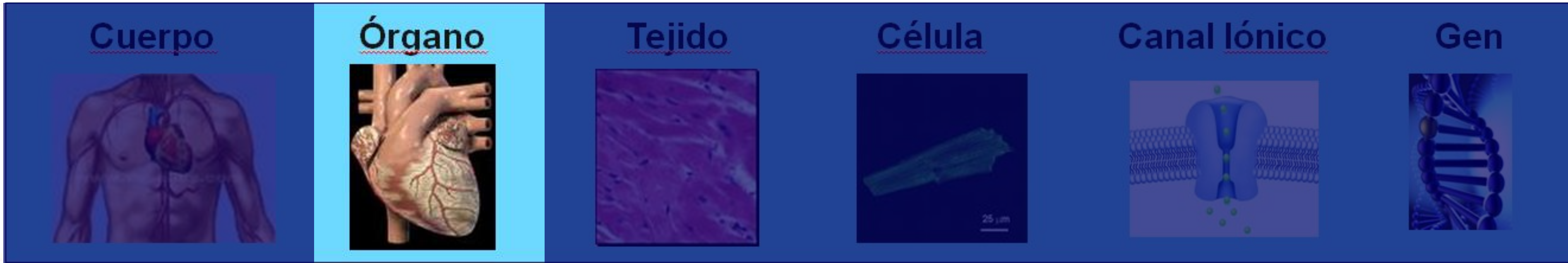

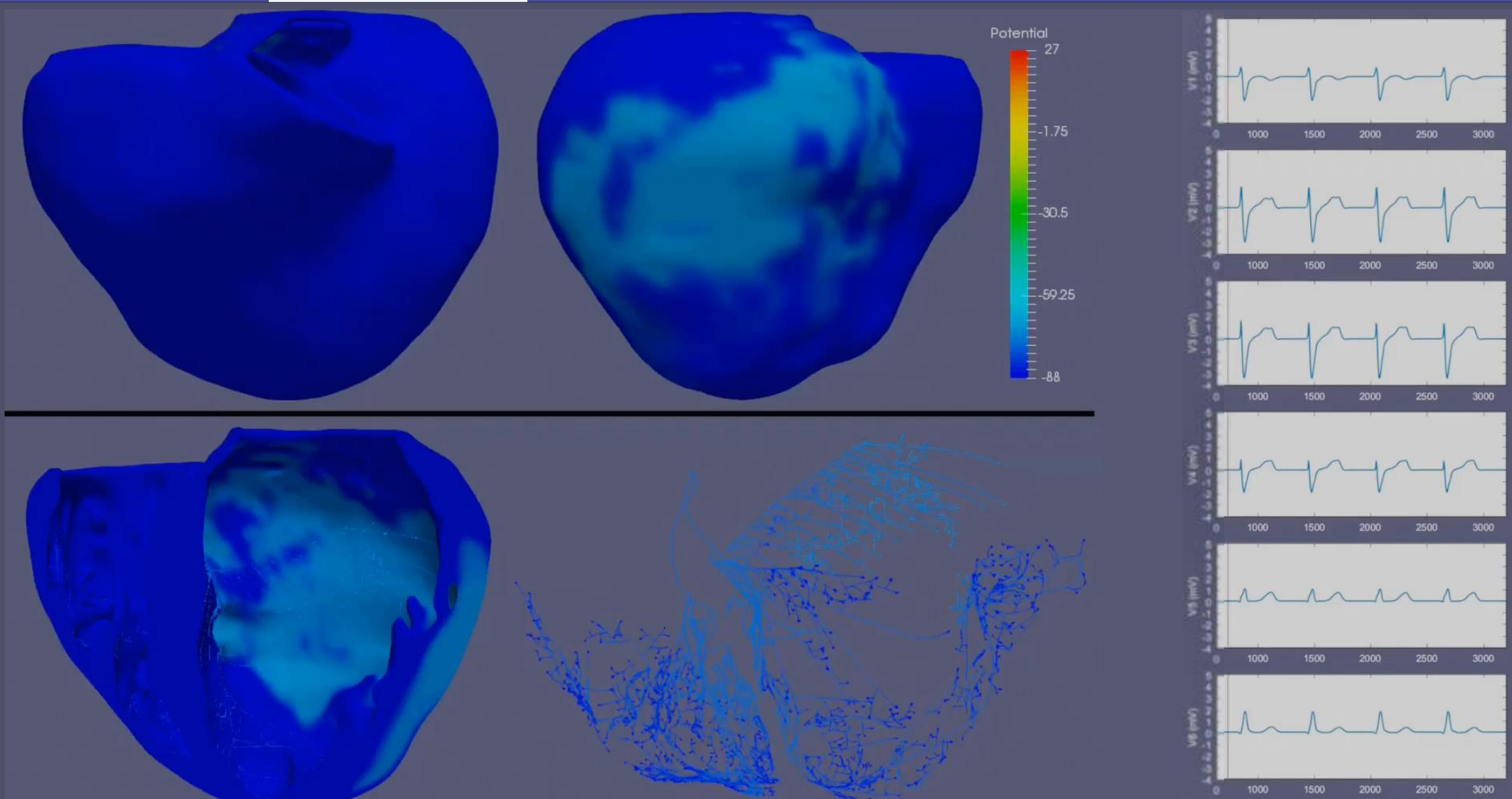

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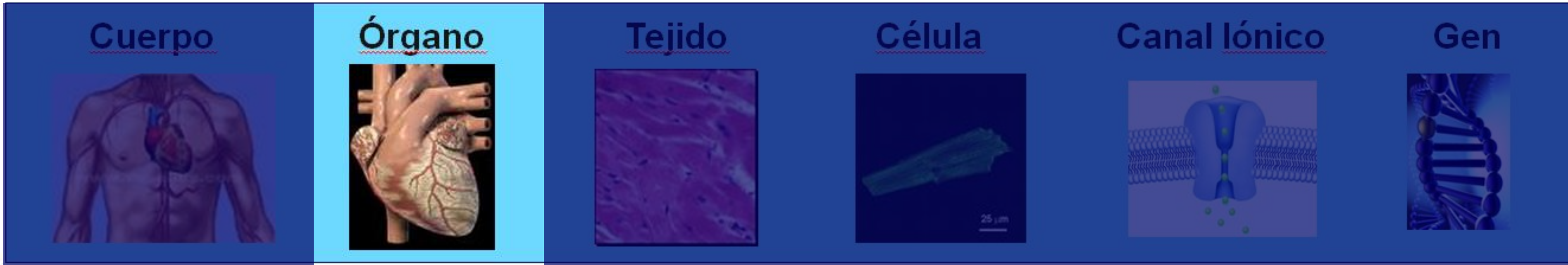

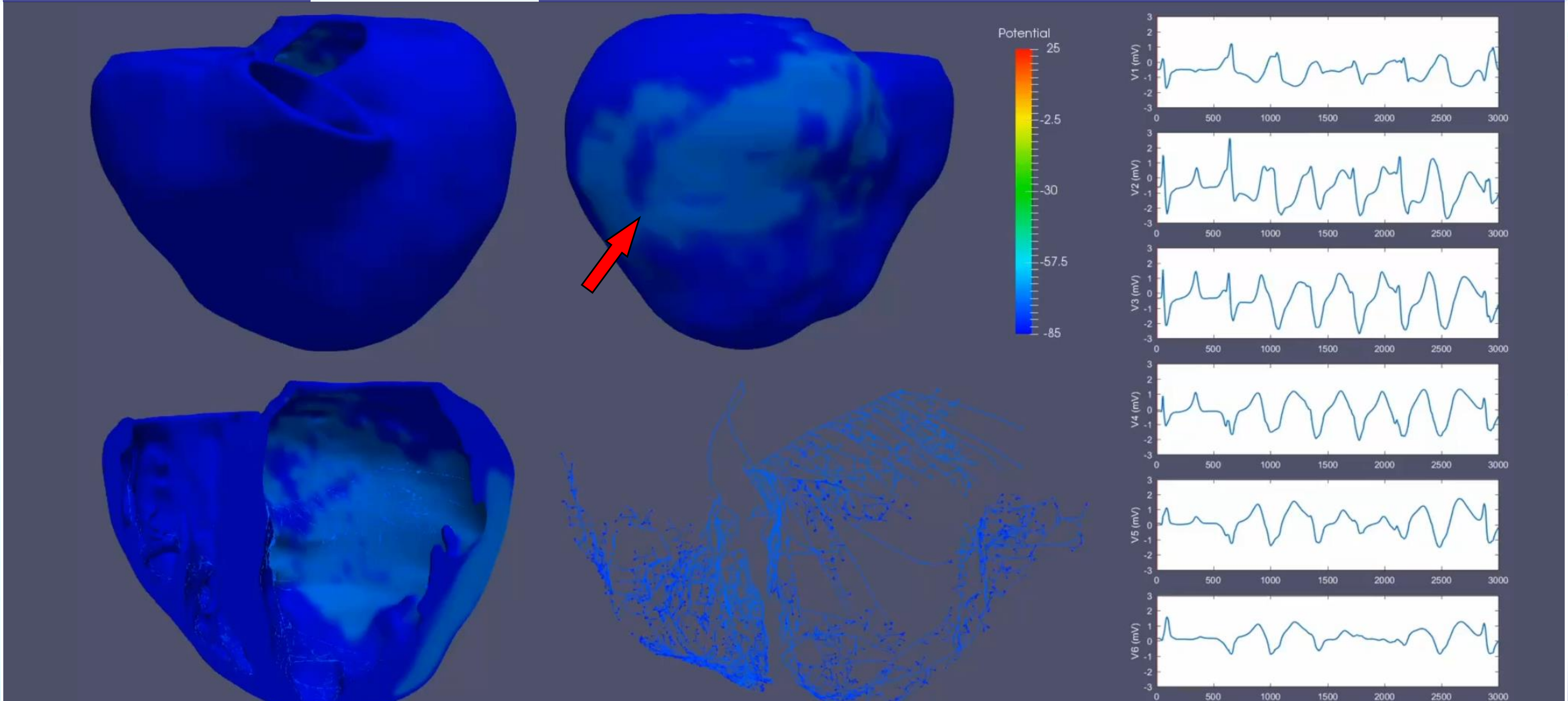

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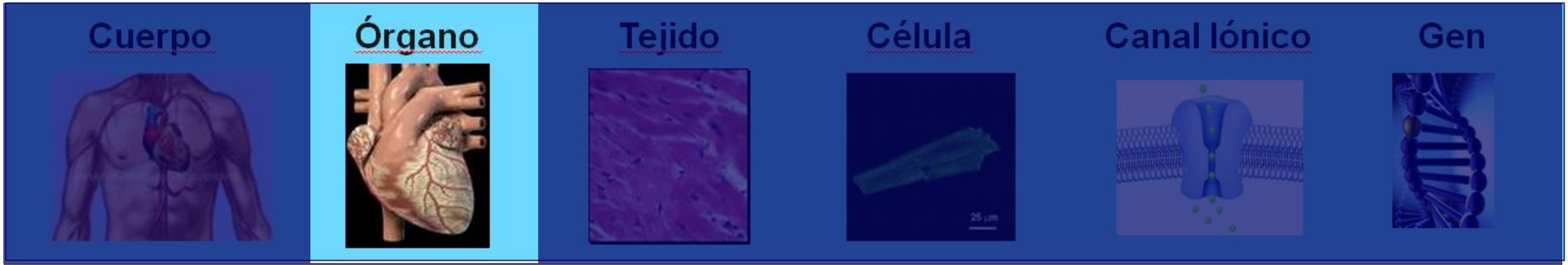

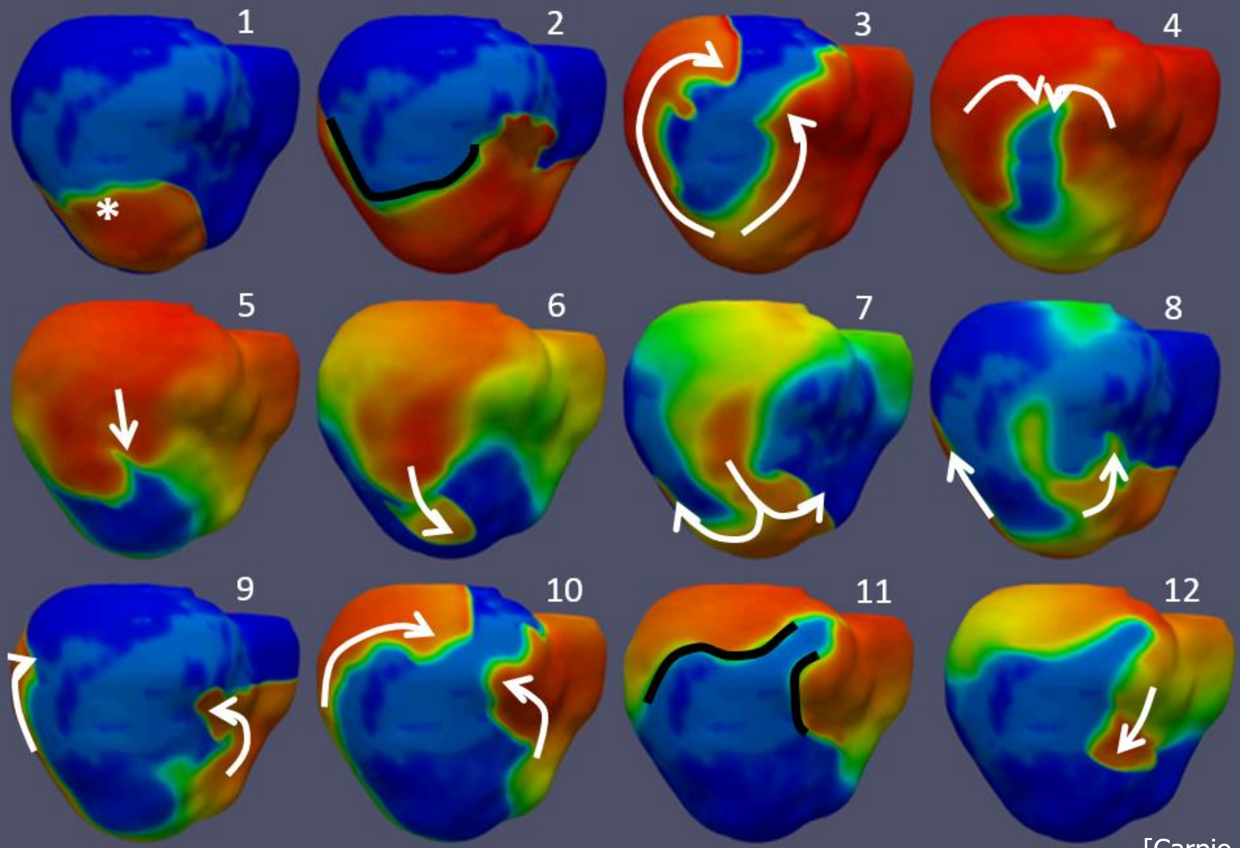

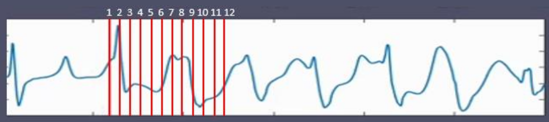

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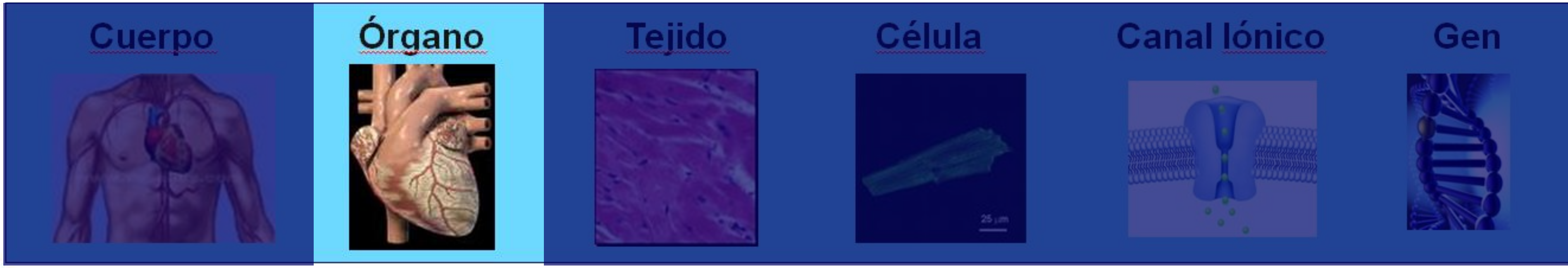
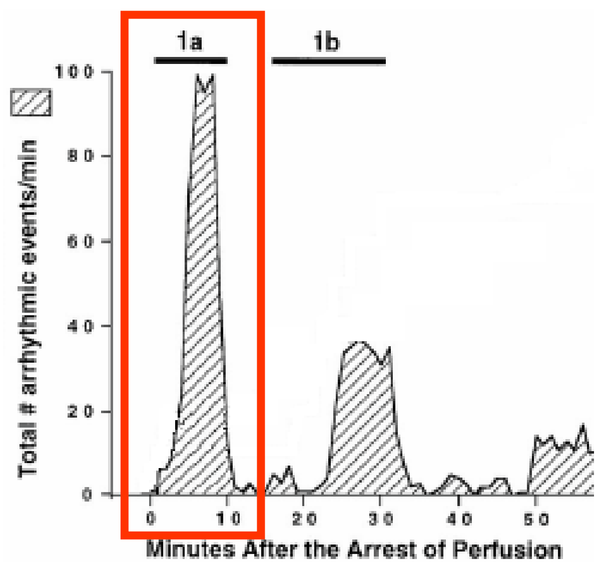
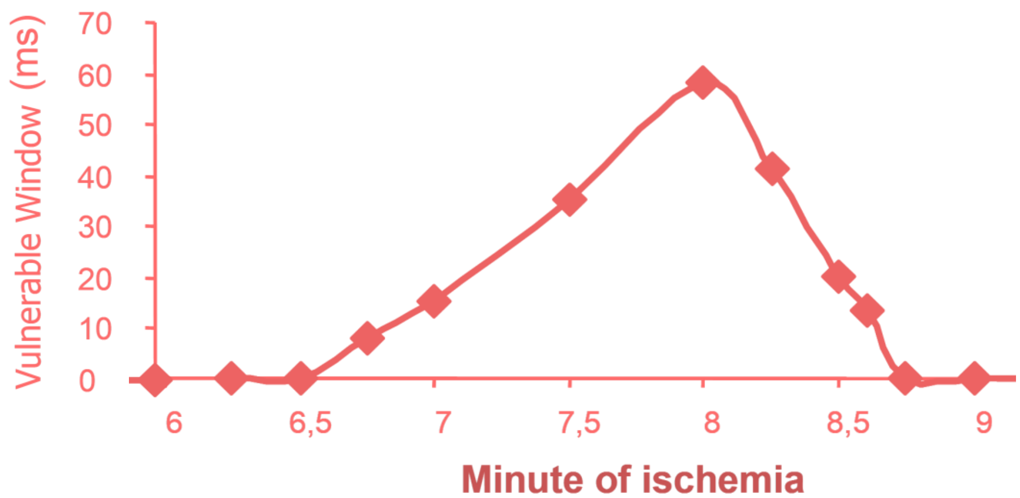


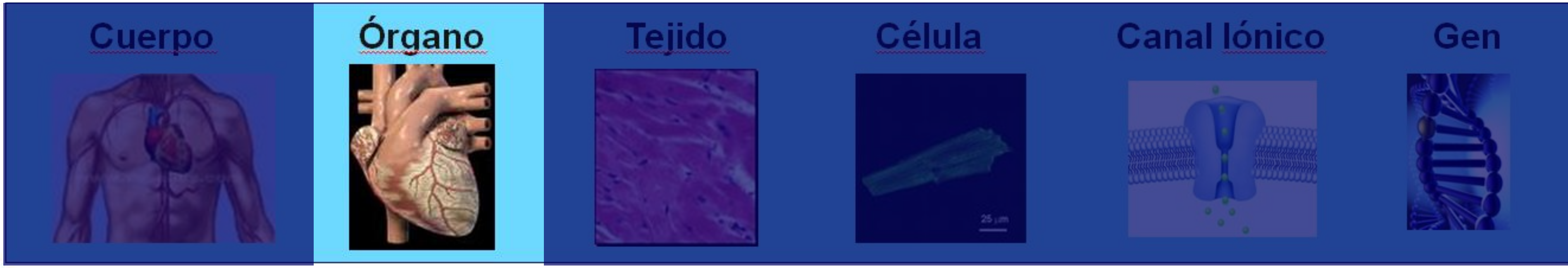


adapted from Smith *et al*. Circulation 92:3051– 60, 1995

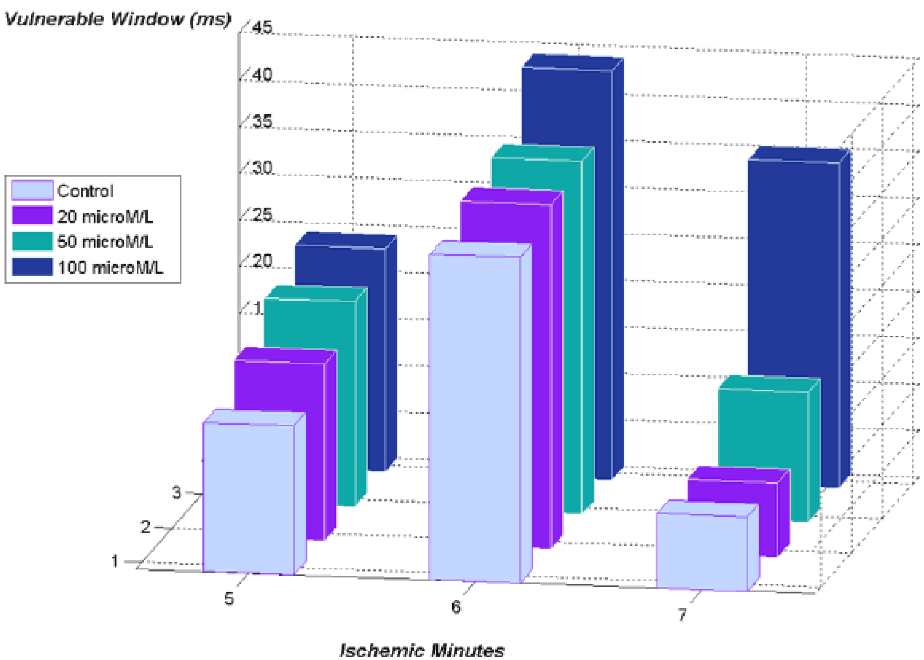


Romero, Trenor & Ferrero, Ann Biomed Eng 2009

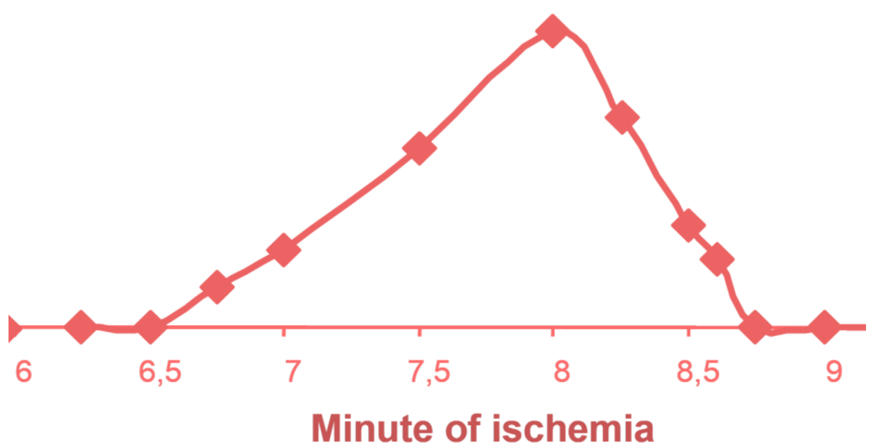
Modelado multiescala de la isquemia miocárdica



Lidocaine modulates the VW in ischemia

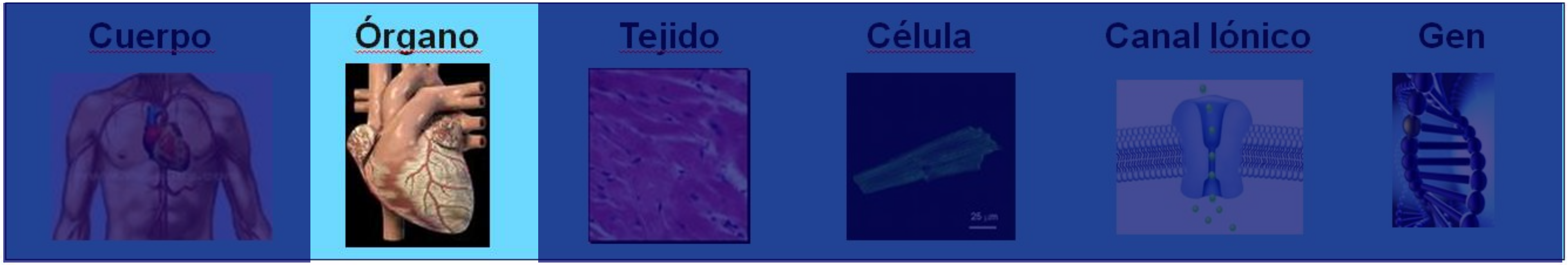


Cardona, Ferrero & Saiz Am J Physiol 2010

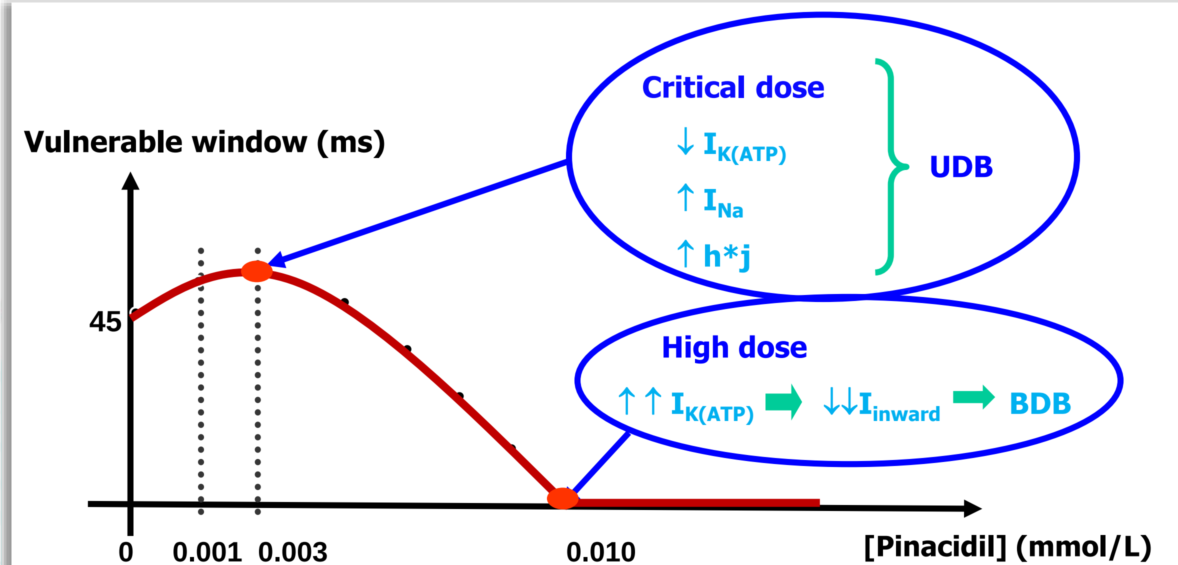


Romero, Trenor & Ferrero, Ann Biomed Eng 2009

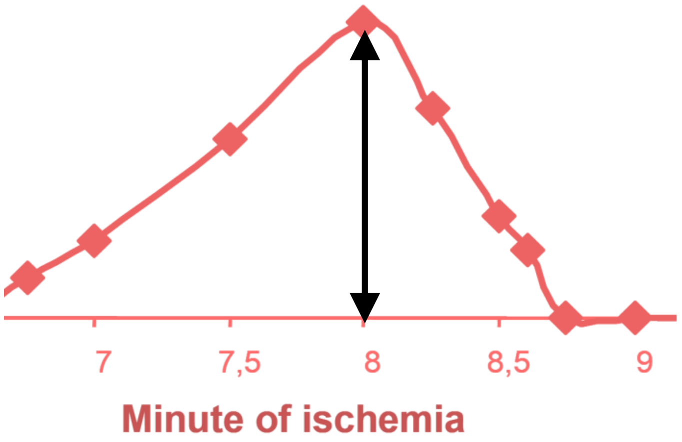
Modelado multiescala de la isquemia miocárdica



Pinacidil modulates the VW in ischemia



Trenor, Rodríguez & Ferrero, Ann Biomed Eng 2009



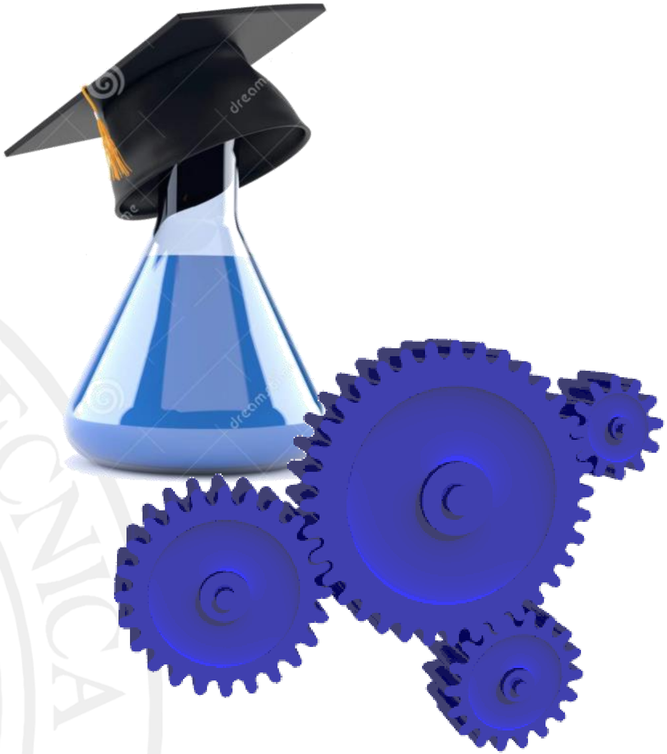
Romero, Trenor & Ferrero, Ann Biomed Eng 2009

Esquema de exposición

BASE TEÓRICA: Modelos computacionales de la actividad bioeléctrica del corazón

INVESTIGACIÓN: Análisis de los mecanismos arritmogénicos de la isquemia miocárdica

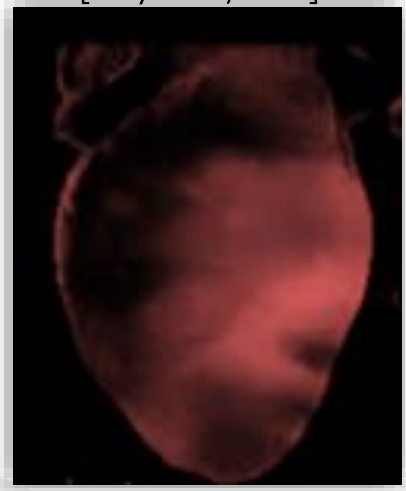
DESARROLLO: Simulación personalizada de ablación por RF en pacientes con infarto de miocardio



Isquemia aguda e infarto de miocardio

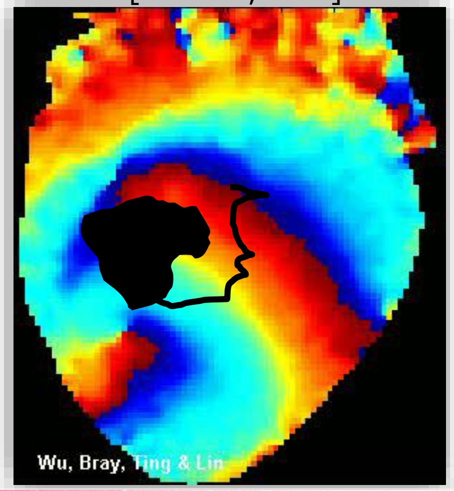
0-30 min: ISQUEMIA AGUDA

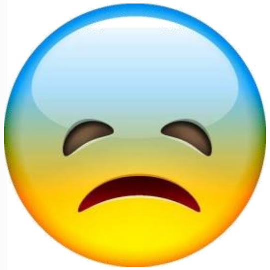
[Gray et al., 1995]

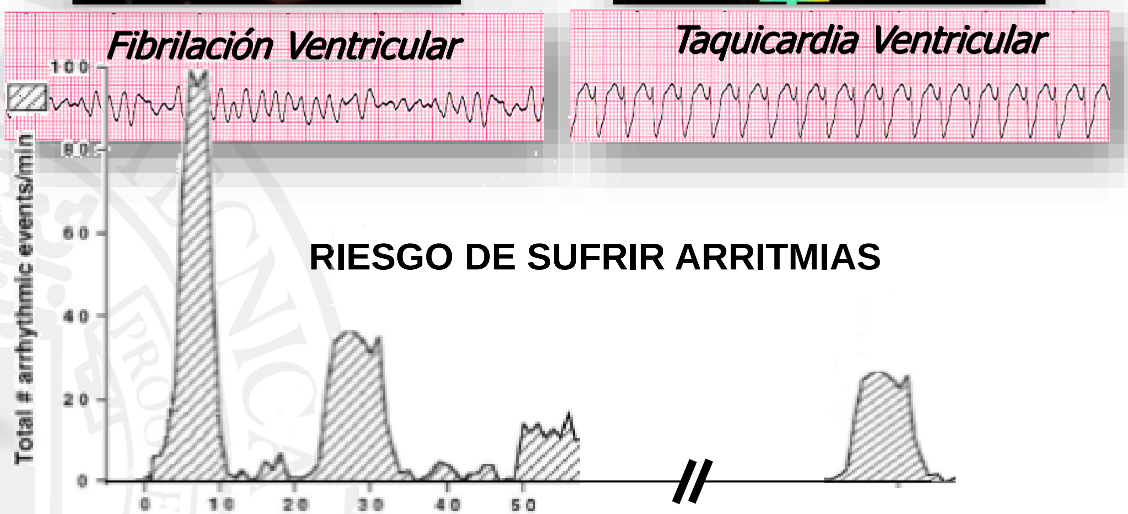


30 min →: INFARTO

[Wu et al, 2006]

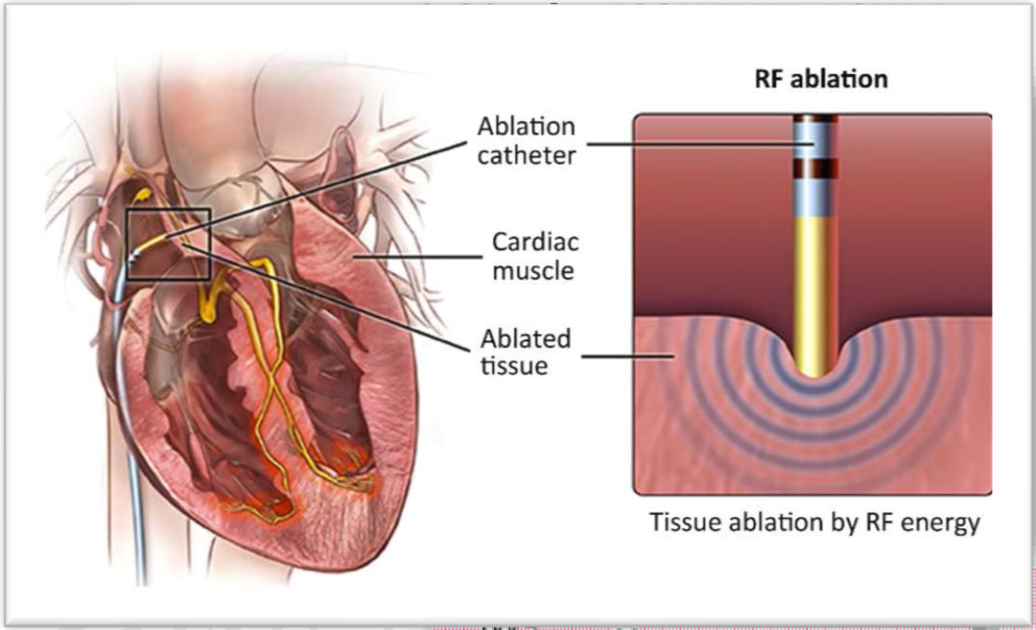






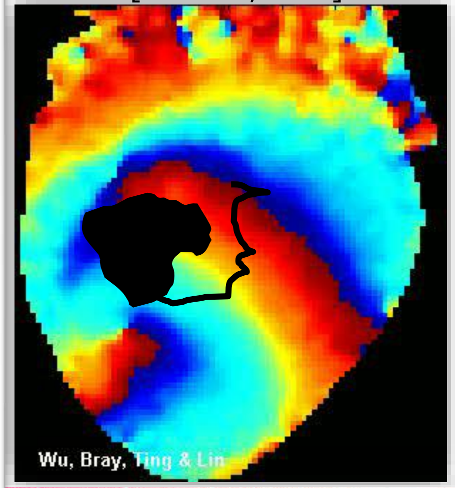
[Smith et al,1995]

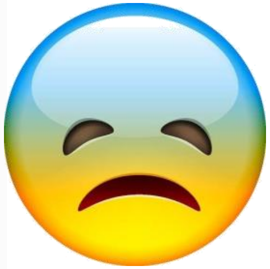
Isquemia aguda e infarto de miocardio

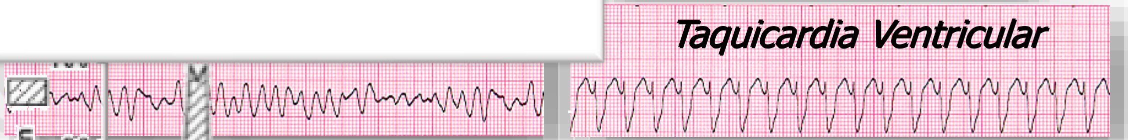


30 min →: INFARTO

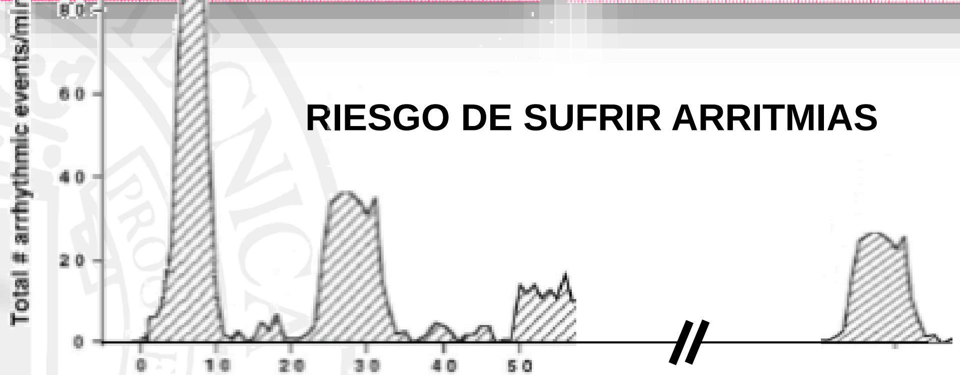
[Wu et al, 2006]







RIESGO DE SUFRIR ARRITMIAS

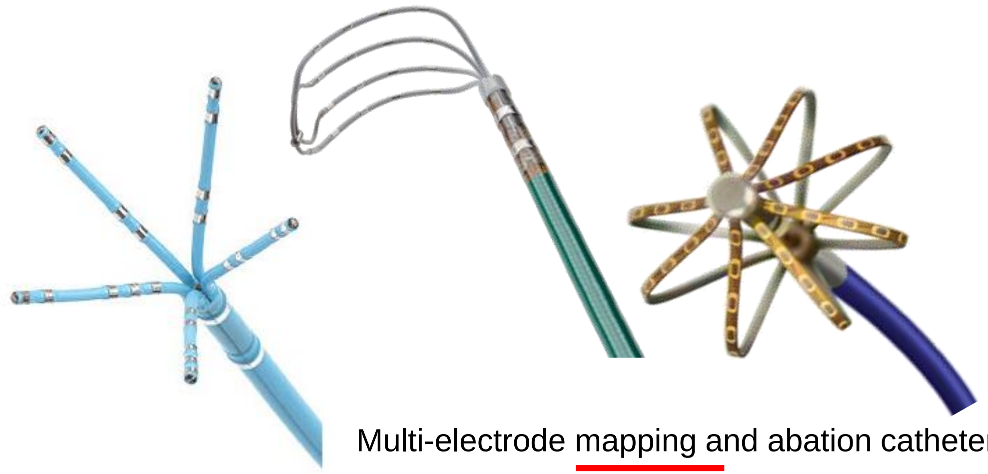


minutos

horas, días, meses, años…

[Smith et al,1995]

Radiofrequency ablation in patients with chronic myocardial infarction suffering ventricular tachycardia

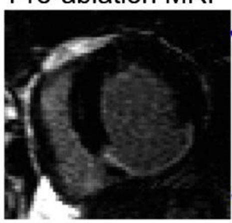


Multi-electrode mapping and abation catheters

(Johnson & Johnson, St. Jude, Boston Sc.)

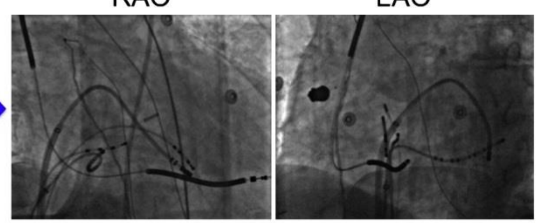
Referral for VT ablation

Pre-ablation MRI



Invasive EPS Ablation

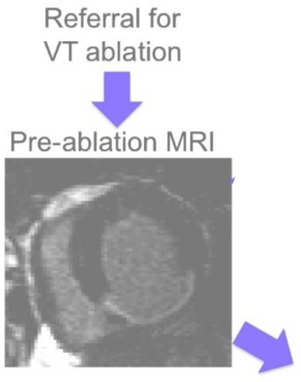
RAO LAO

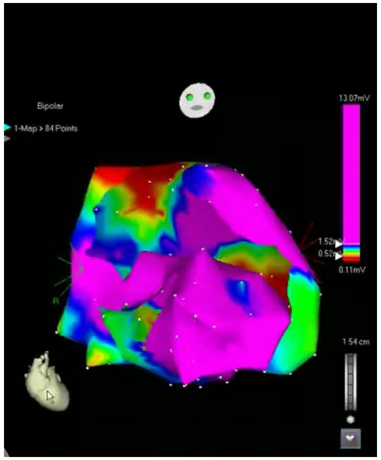


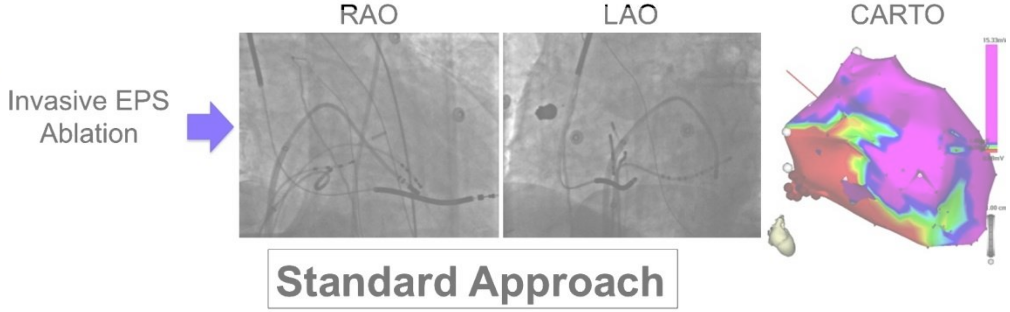
Standard Approach

[adapted from Ashikaga et al, *Heart Rhythm* 2013]

Radiofrequency ablation in patients with chronic myocardial infarction suffering ventricular tachycardia





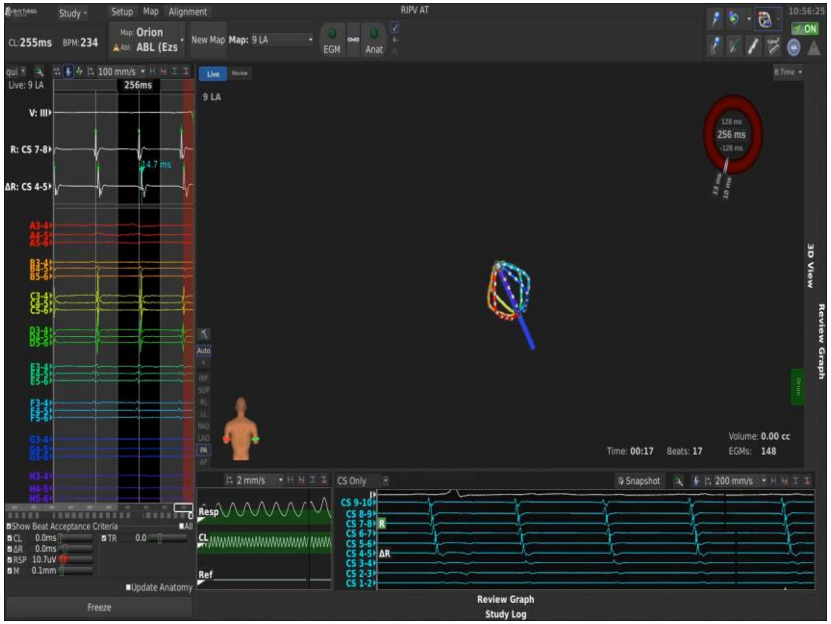


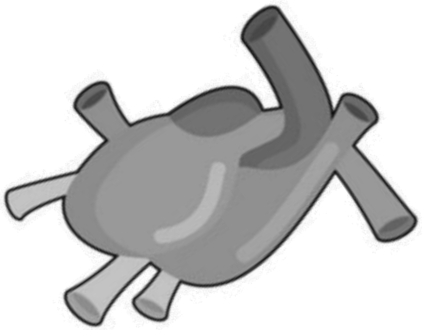
[adapted from Ashikaga et al, *Heart Rhythm* 2013]

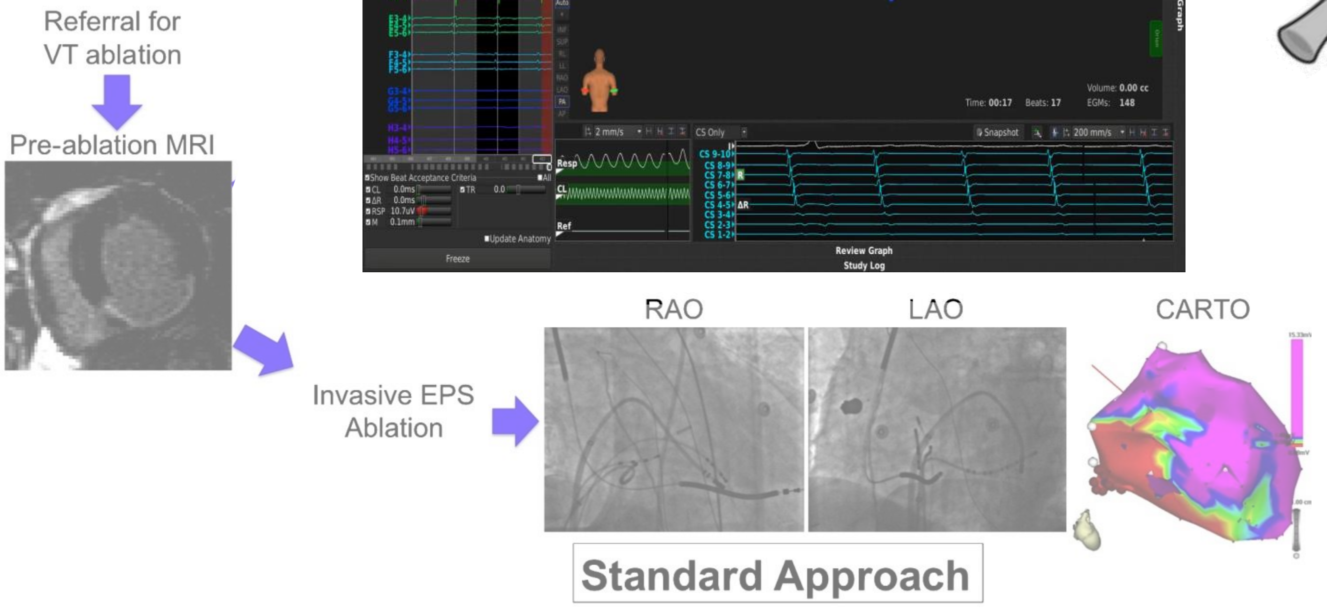
Radiofrequency ablation in patients with chronic myocardial infarction suffering ventricular tachycardia

INTELLA MIFI (Boston Sci.)

[courtesy of Dr. Ángel Ferrero, Hospital Clínic de Valencia]



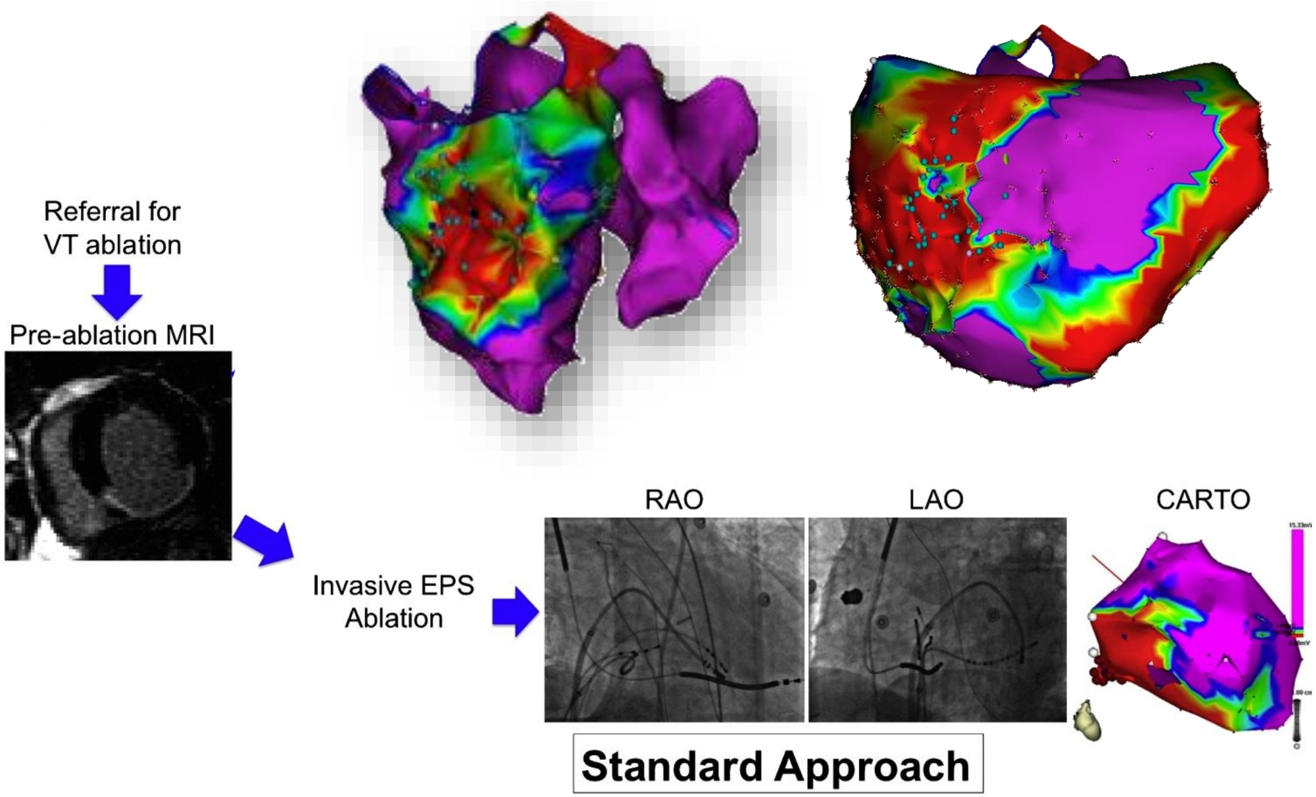




[adapted from Ashikaga et al, *Heart Rhythm* 2013]

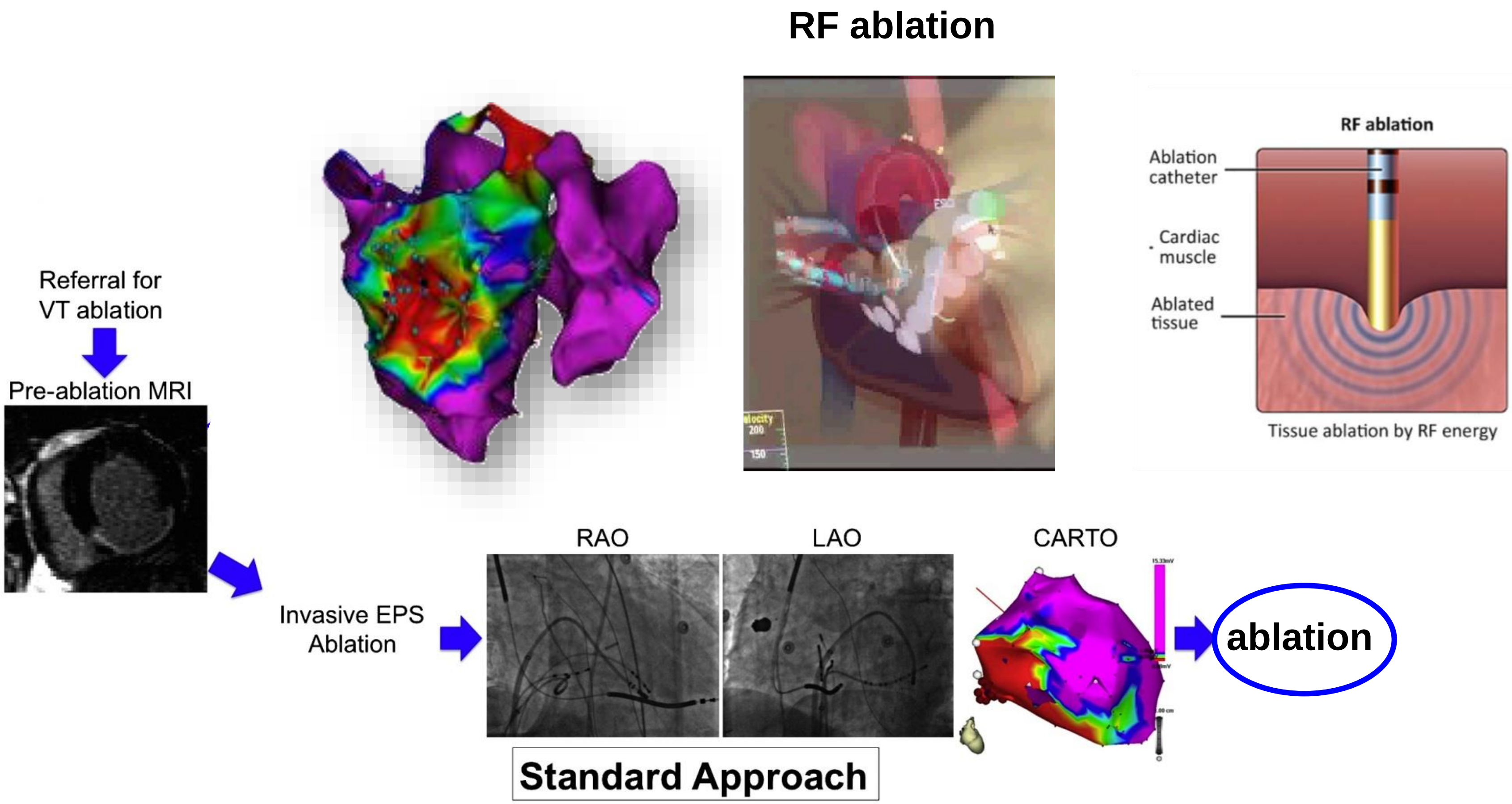
Radiofrequency ablation in patients with chronic myocardial infarction suffering ventricular tachycardia

Electroanatomical map of the endocardium…
… and the epicardium!



[adapted from Ashikaga et al, *Heart Rhythm* 2013]

Radiofrequency ablation in patients with chronic myocardial infarction suffering ventricular tachycardia



[adapted from Ashikaga et al, *Heart Rhythm* 2013]

Radiofrequency ablation in patients with chronic myocardial infarction suffering ventricular tachycardia

Personalized Cardiac Computational Models: From Clinical Data to Simulation of Infarct-Related Ventricular Tachycardia

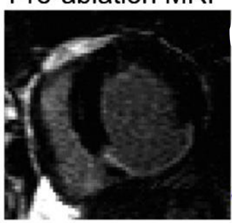
frontiers in Physiology

Alejandro Lopez-Perez [1], Rafael Sebastian [2], M. Izquierdo [3,4], Ricardo Ruiz [3,4], Martin Bishop [5] and Jose M. Ferrero [1]*

In the chronic stage of myocardial infarction, a significant number of patients develop life-threatening ventricular tachycardias (VT) due to the arrhythmogenic nature of the remodeled myocardium. Radiofrequency ablation (RFA) is a common procedure to isolate reentry pathways across the infarct scar that are responsible for VT. Unfortunately, this strategy show relatively low success rates; up to 50% of patients experience recurrent VT after the procedure. In the last decade, intensive research in the field of computational cardiac electrophysiology (EP) has demonstrated the

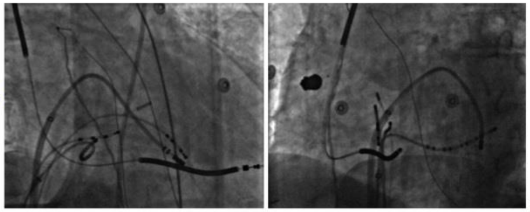
Referral for VT ablation

Pre-ablation MRI

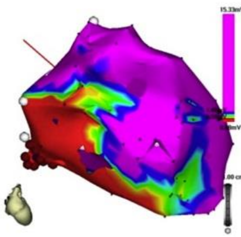


Invasive EPS Ablation

RAO LAO



CARTO



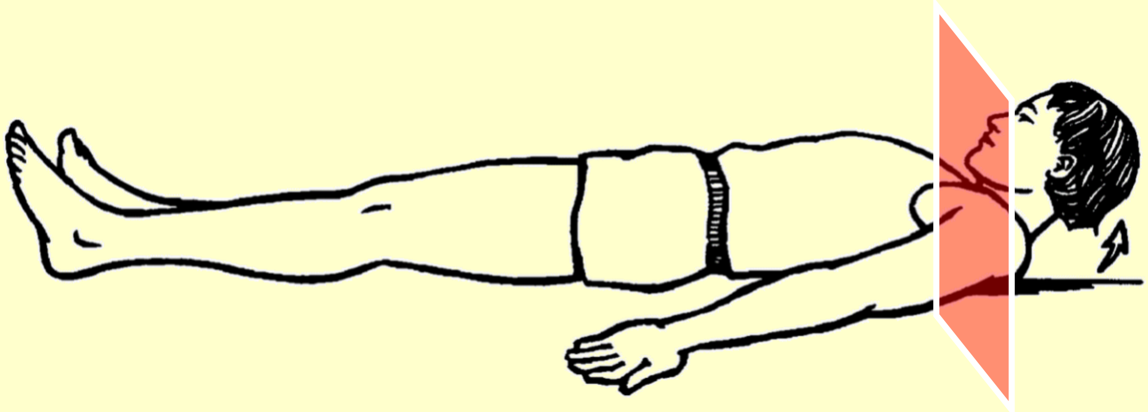
optimal ablation

Standard Approach

[adapted from Ashikaga et al, *Heart Rhythm* 2013]

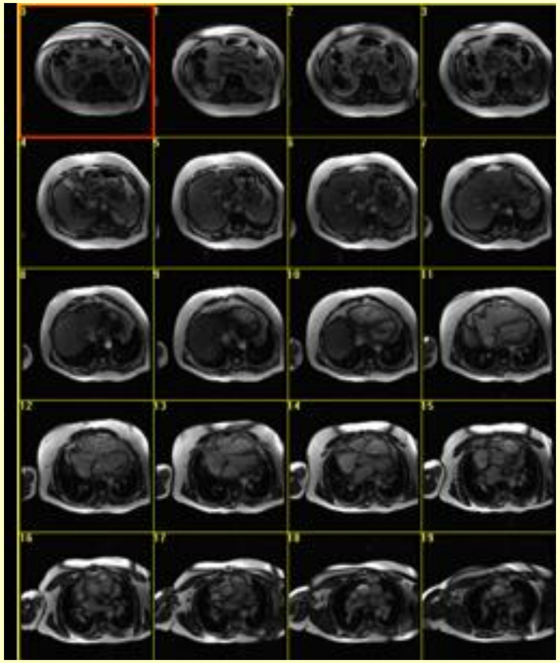
… the computational model must be personalized (i.e. patient-specific)

1. Geometría del corazón



Resonancia Magnética Nuclear (RMN – MRI)

Imágenes de MRI



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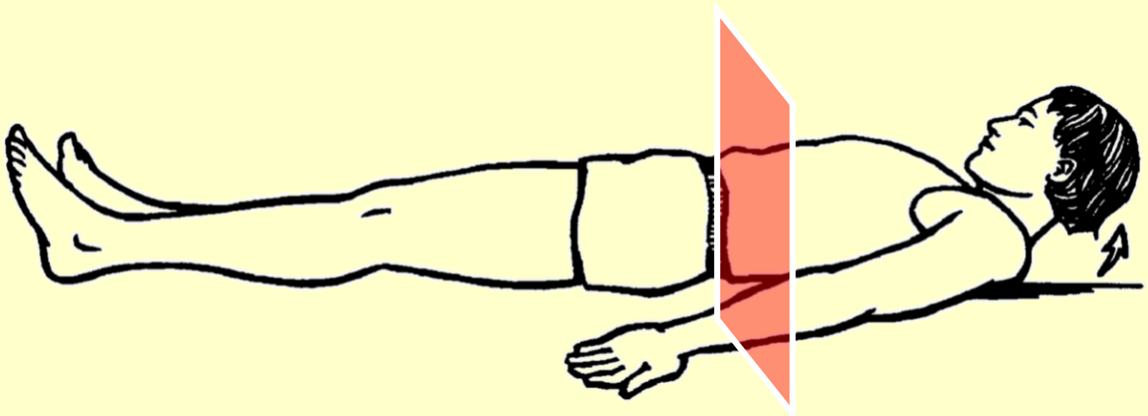
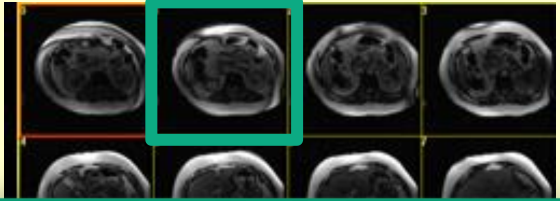
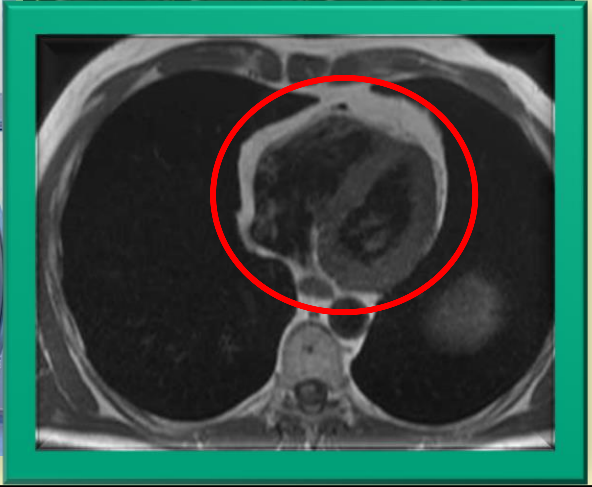


Imágenes de MRI

Resonancia
Magnética Nuclear
(RMN – MRI)





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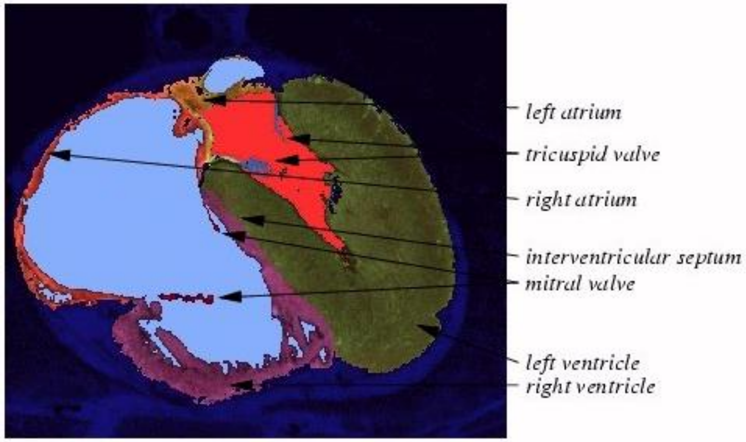
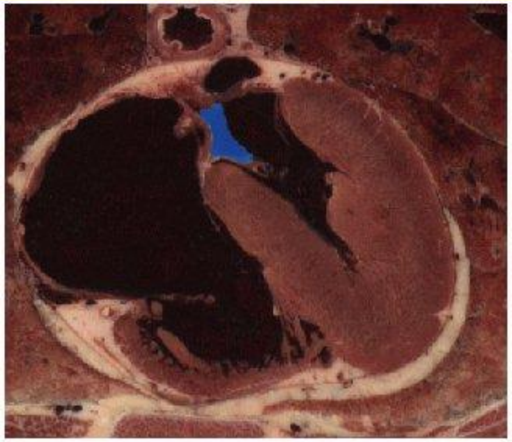
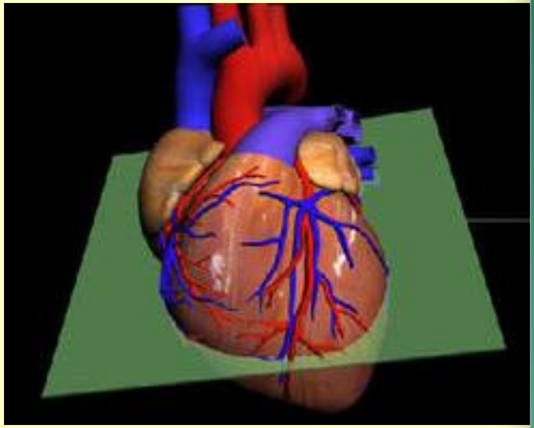
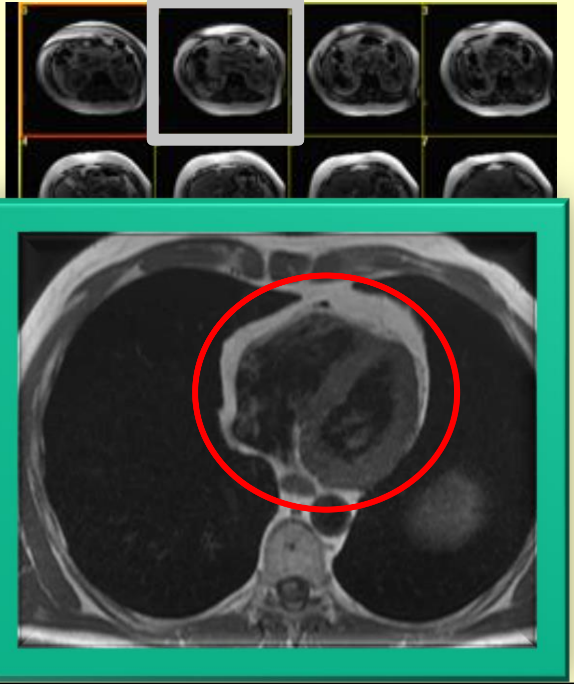




Imágenes de MRI

Resonancia Magnética Nuclear (RMN – MRI)





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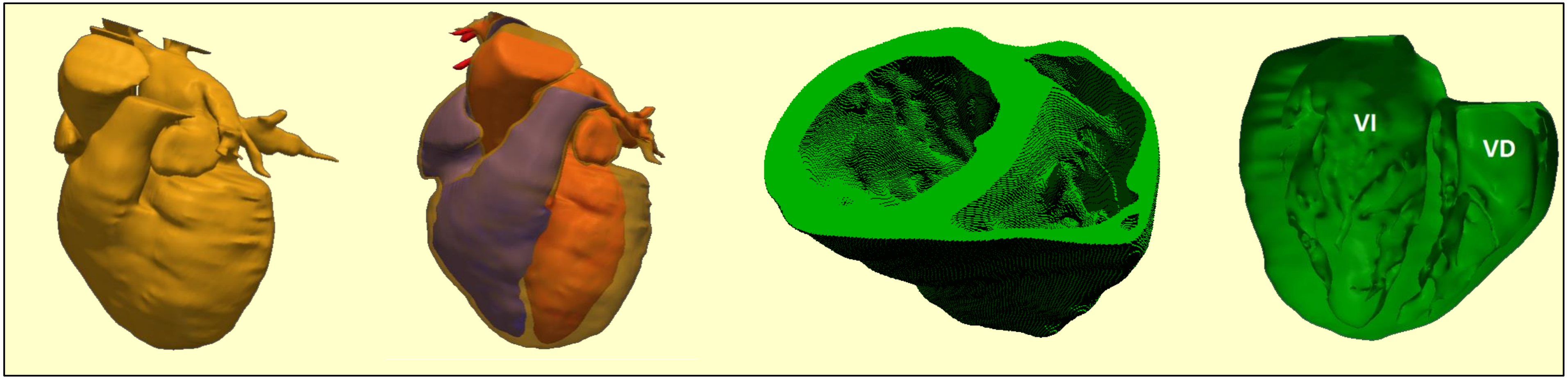
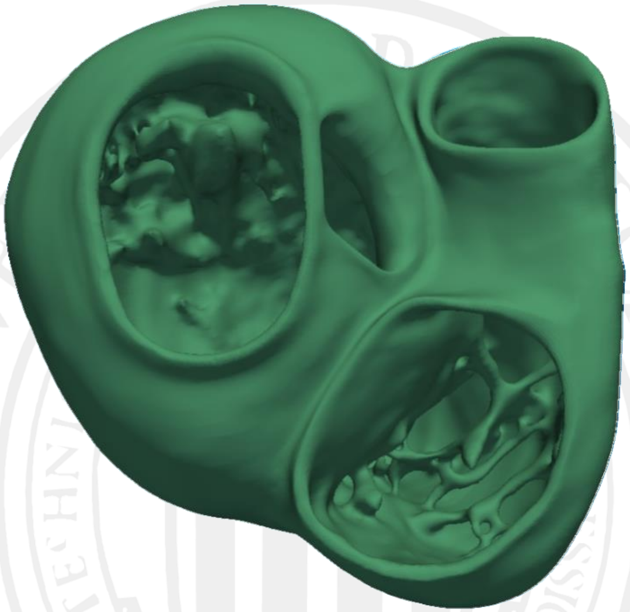
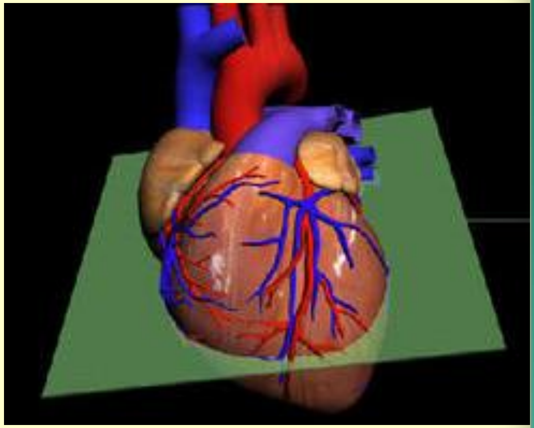
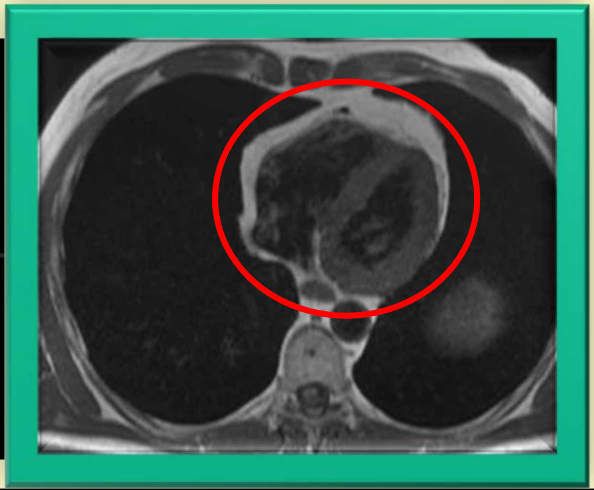


Endocardio "detallado"

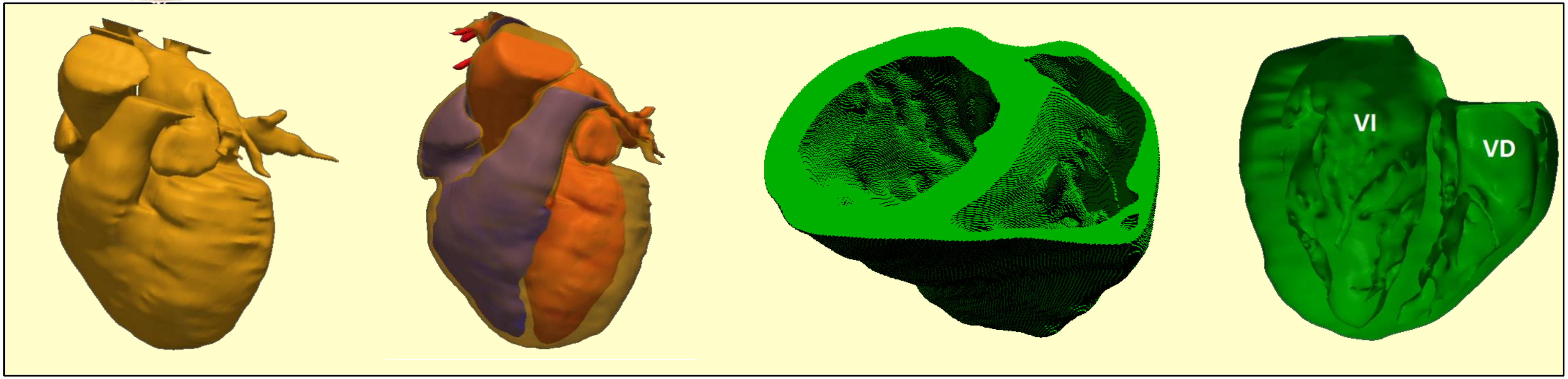


Imágenes de MRI

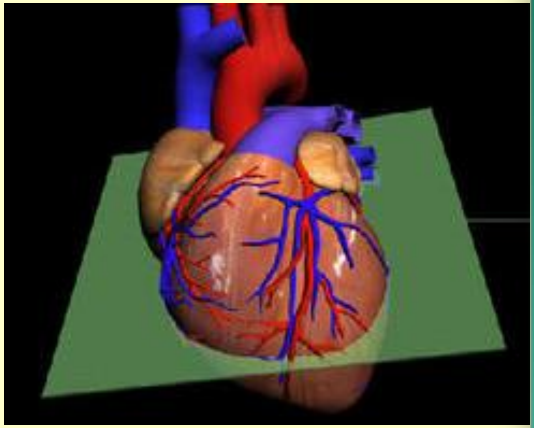


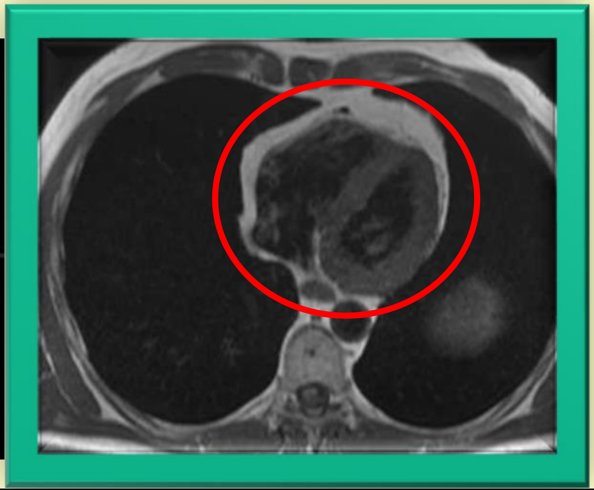


1. Geometría del corazón

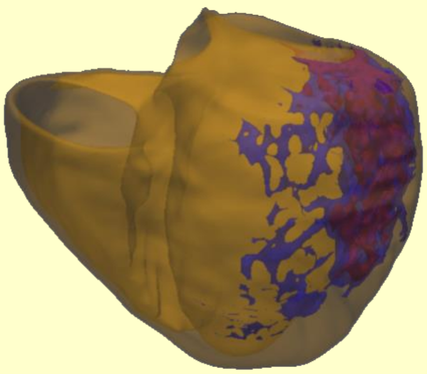
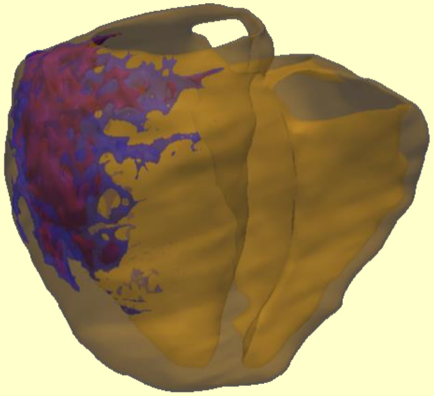
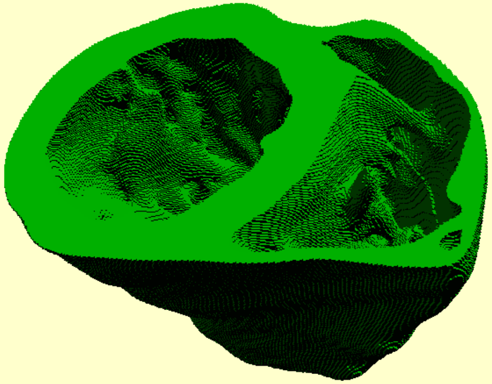
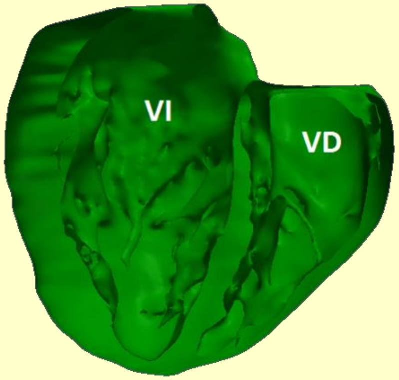


Imágenes de MRI

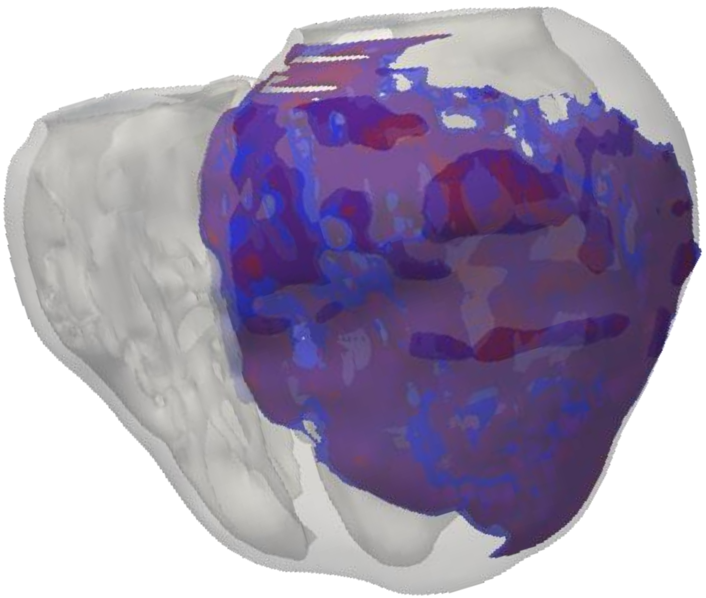




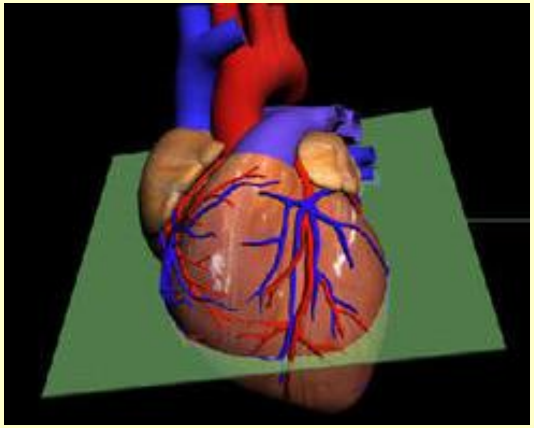
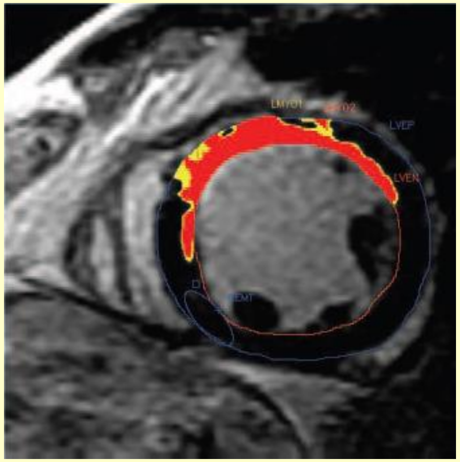
2. Cicatriz del infarto (núcleo + zona de borde)

Cicatriz



Imágenes de MRI (Delay enhancement)

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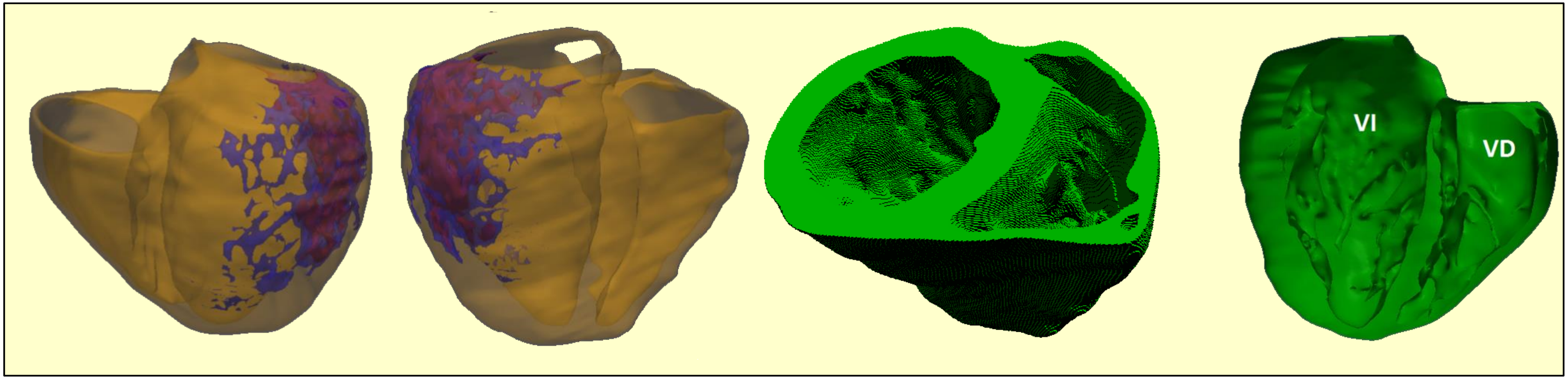
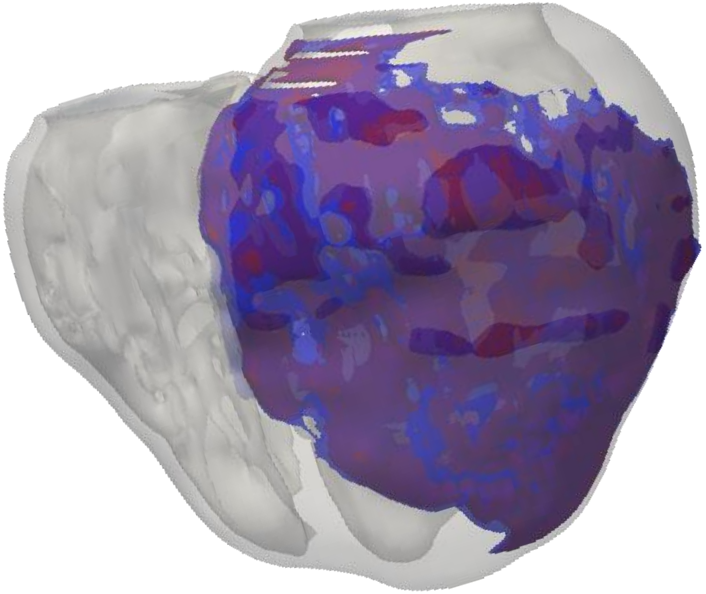
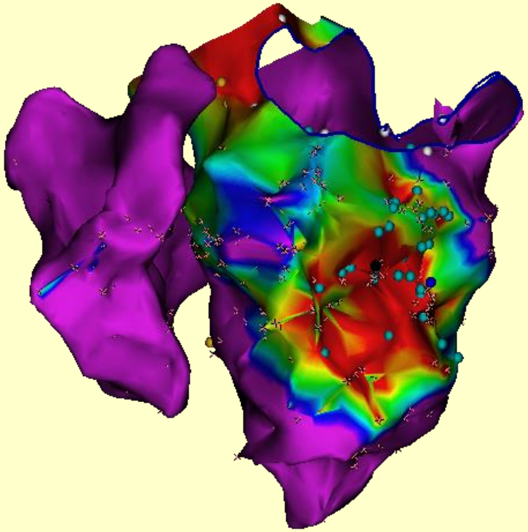


Cicatriz



Mapa electro-anatómico (CARTO)



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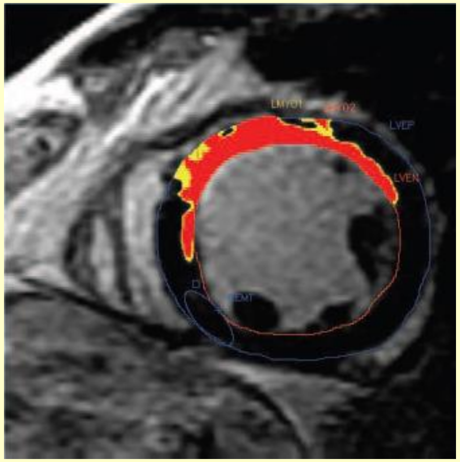

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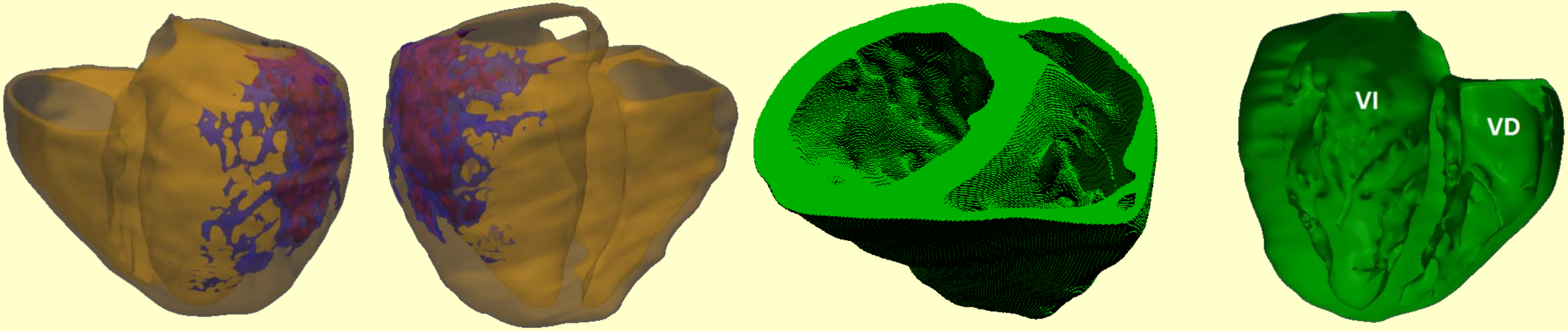

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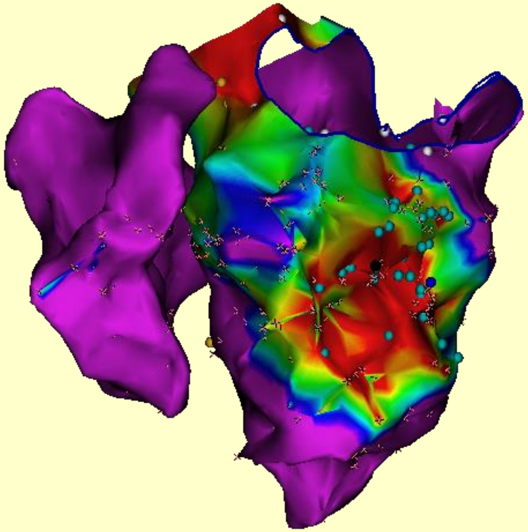
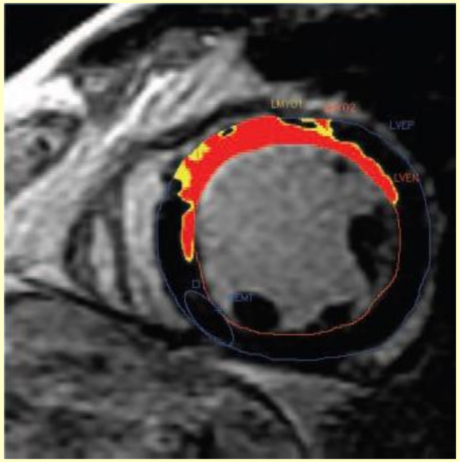
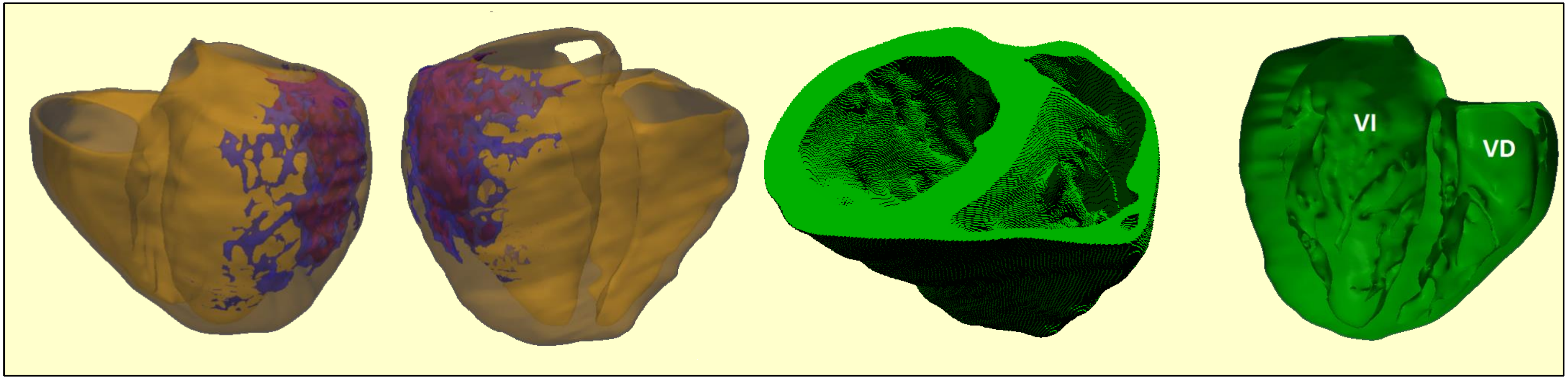
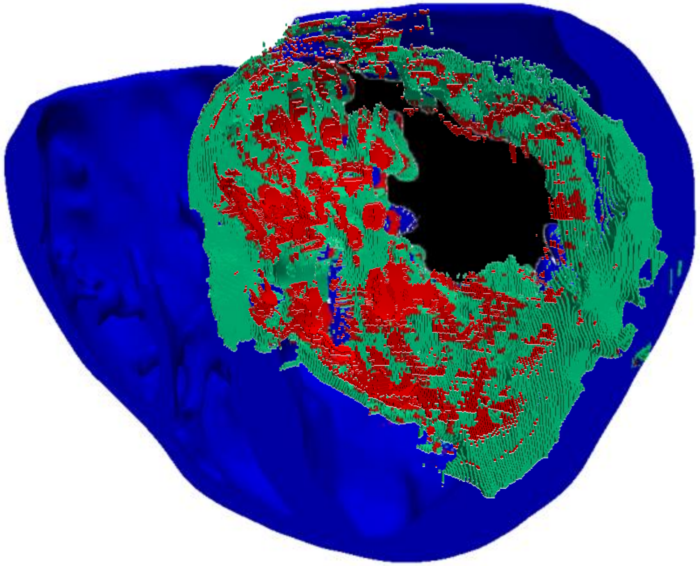


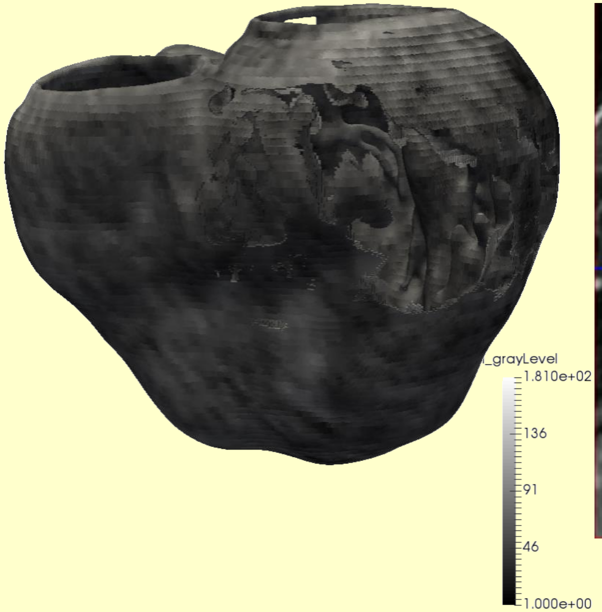
Imágenes de MRI (Delay enhancement)



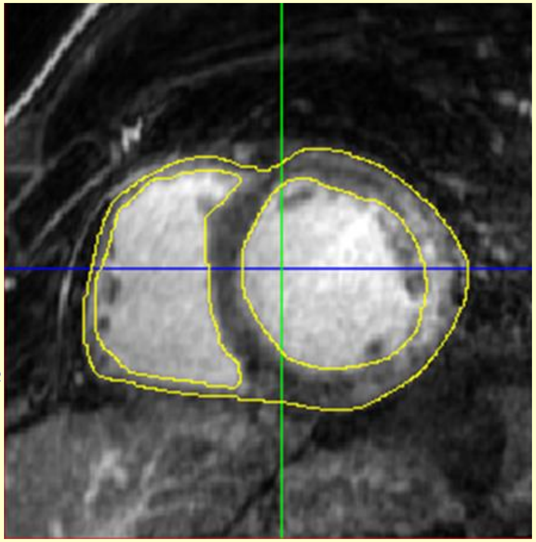
3. Fibrosis en la zona del infarto



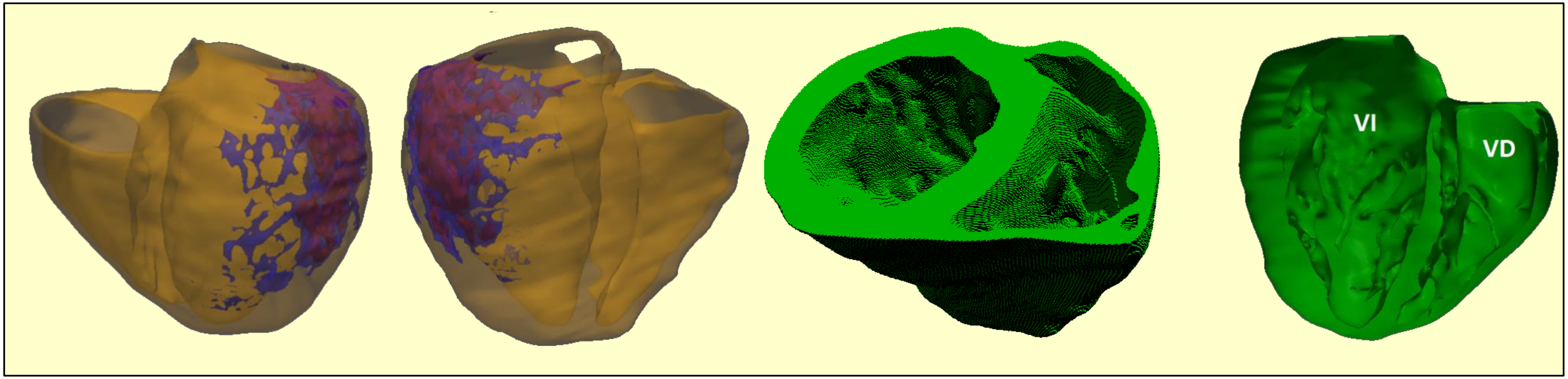


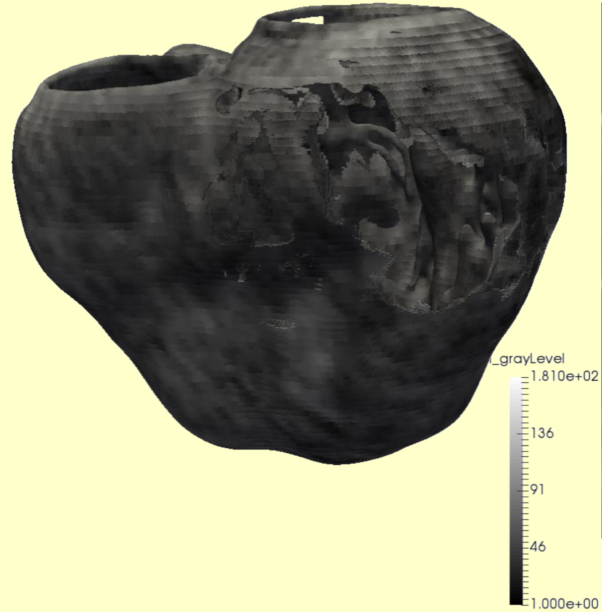


Imágenes de MRI: nivel de gris

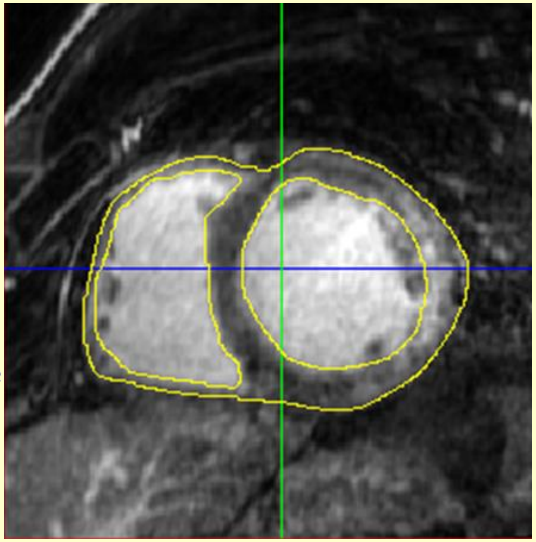


3. Fibrosis en la zona del infarto

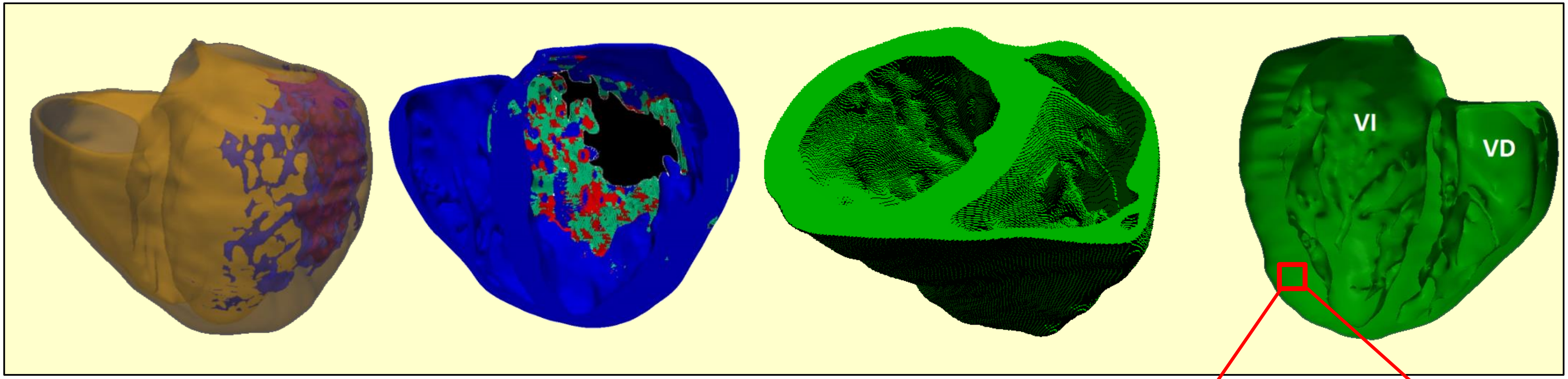




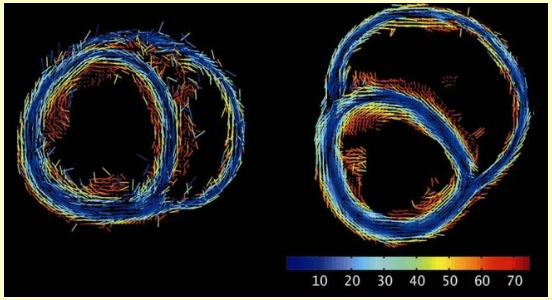
Imágenes de MRI:
nivel de gris

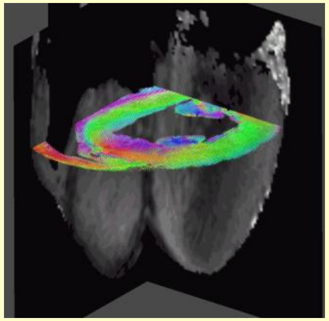


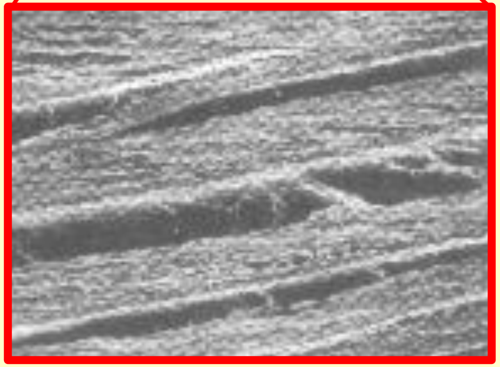
4. Estructura del miocardio (orientación de fibras)



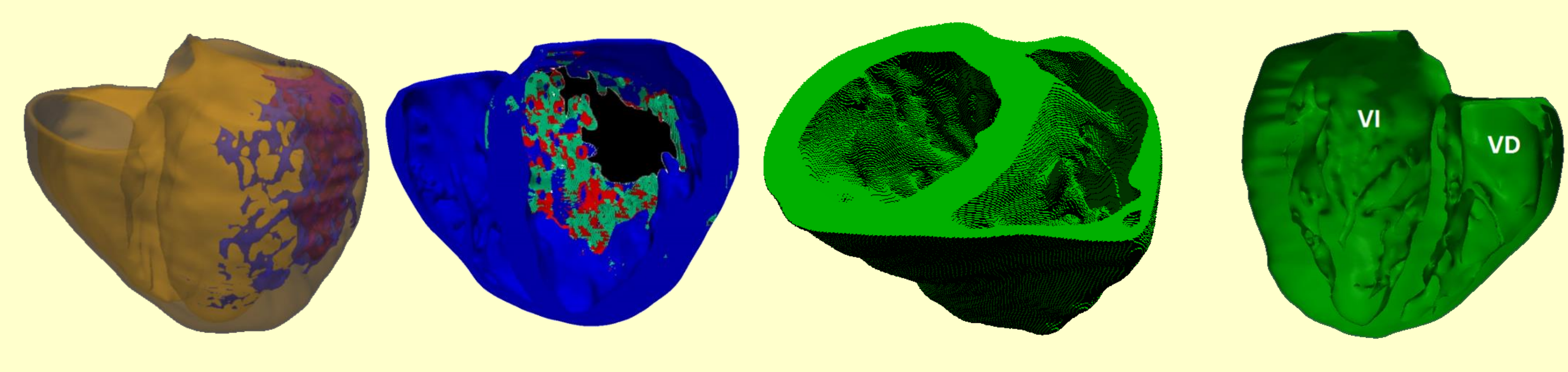
MRI-DTI (*Diffusion Tensor Imaging*)



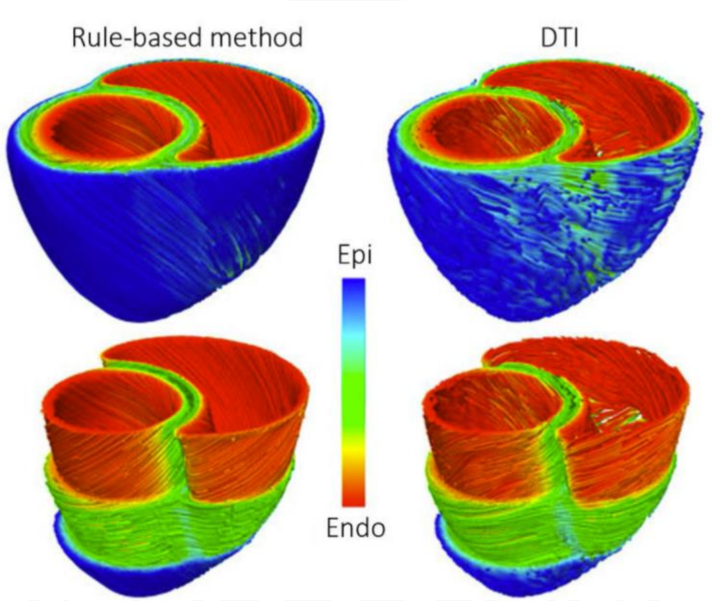




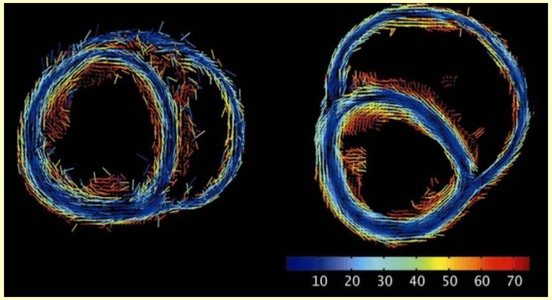
4. Estructura del miocardio (orientación de fibras)

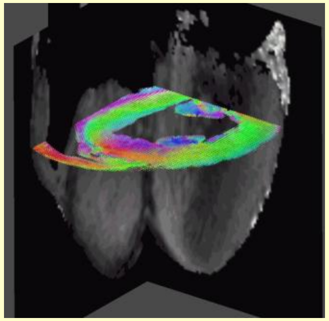


Orientación de fibras: estimación

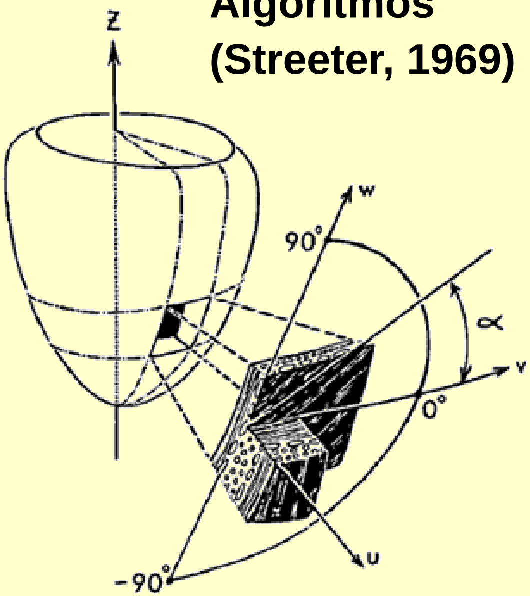


MRI-DTI (*Diffusion Tensor Imaging*)

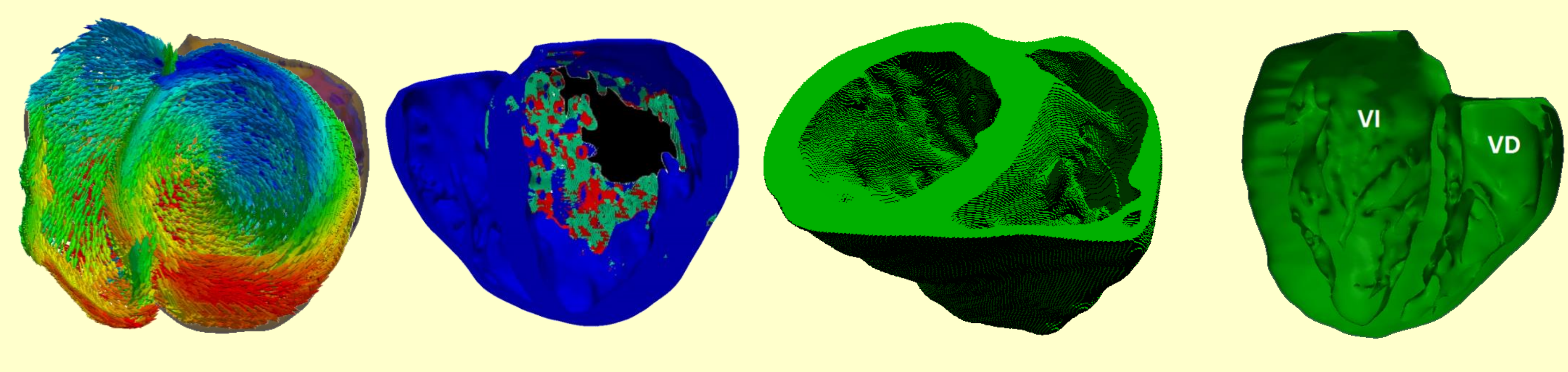




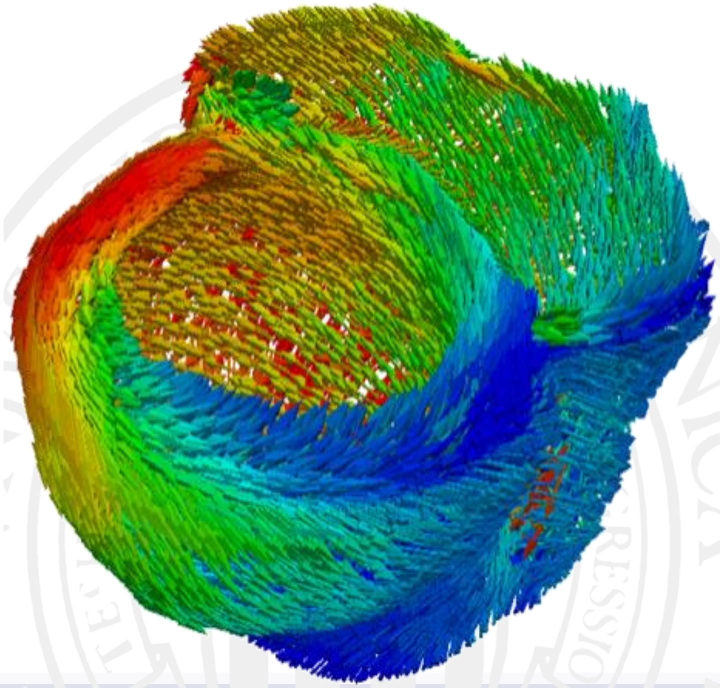
Algoritmos (Streeter, 1969)



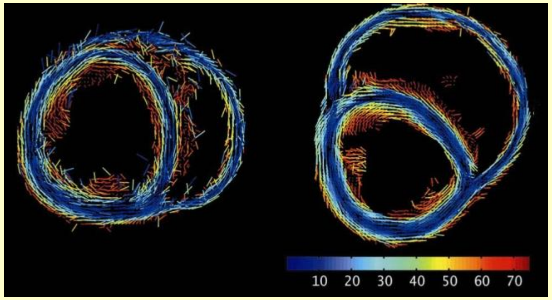
4. Estructura del miocardio (orientación de fibras)

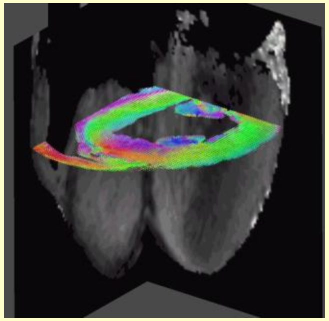


Estimación de la orientación de fibras

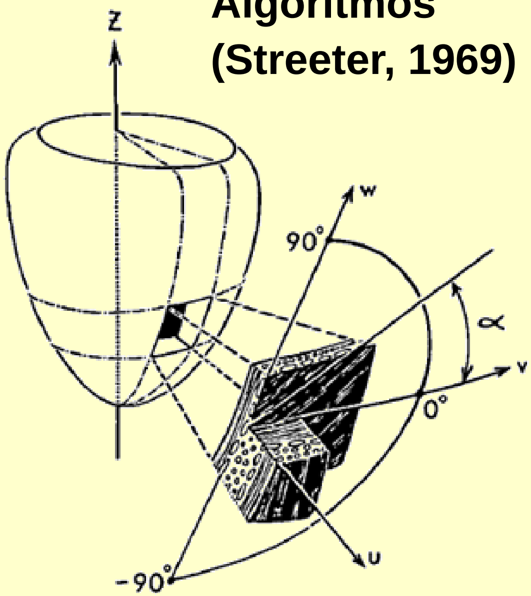


MRI-DTI (*Diffusion Tensor Imaging*)

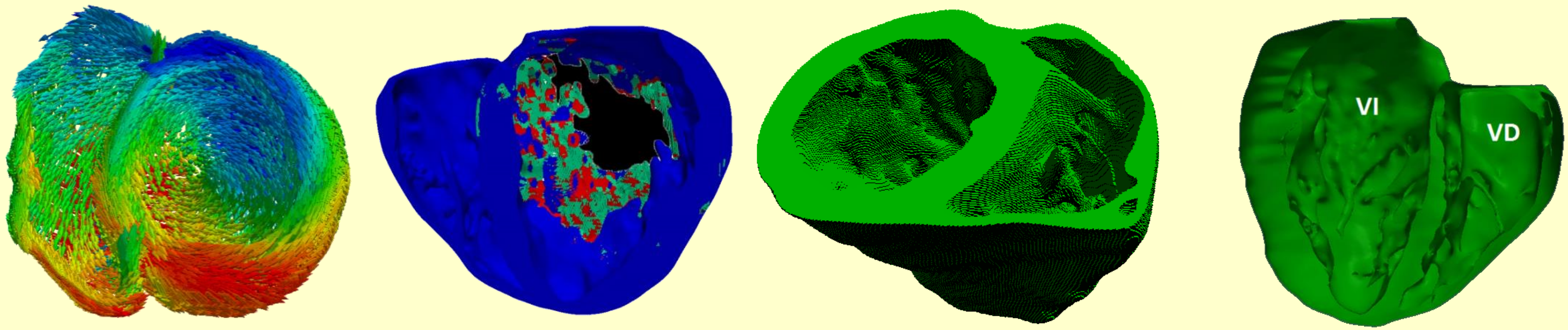




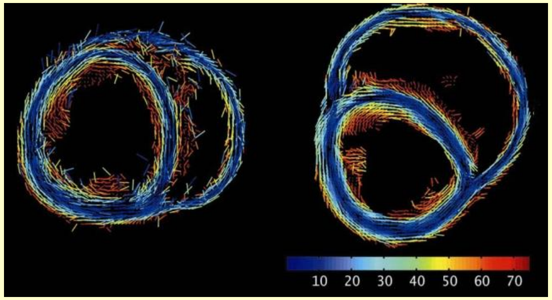
Algoritmos (Streeter, 1969)

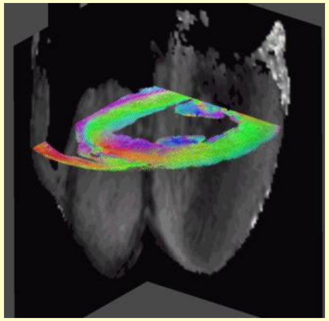


4. Estructura del miocardio (orientación de fibras)

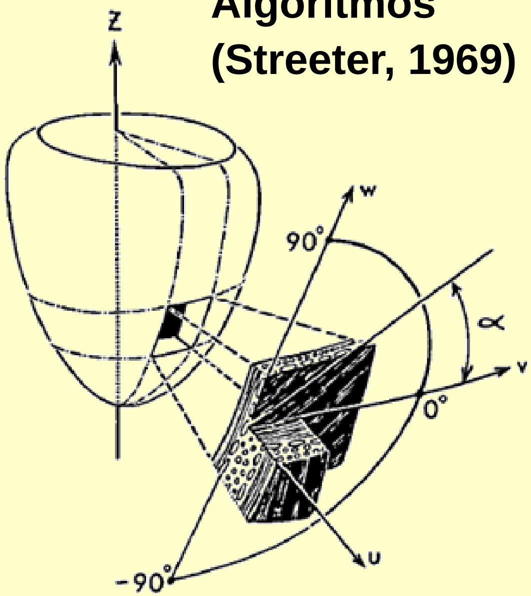


MRI-DTI (*Diffusion Tensor Imaging*)

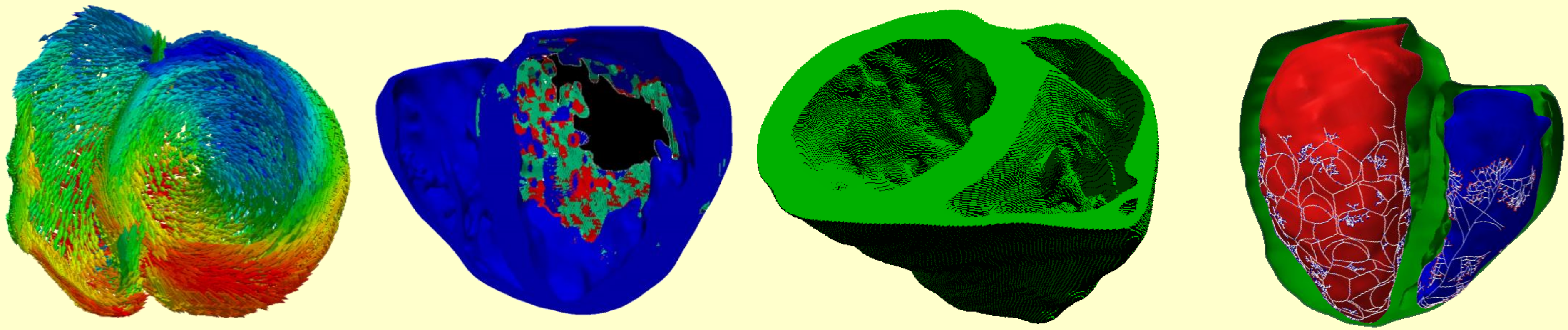




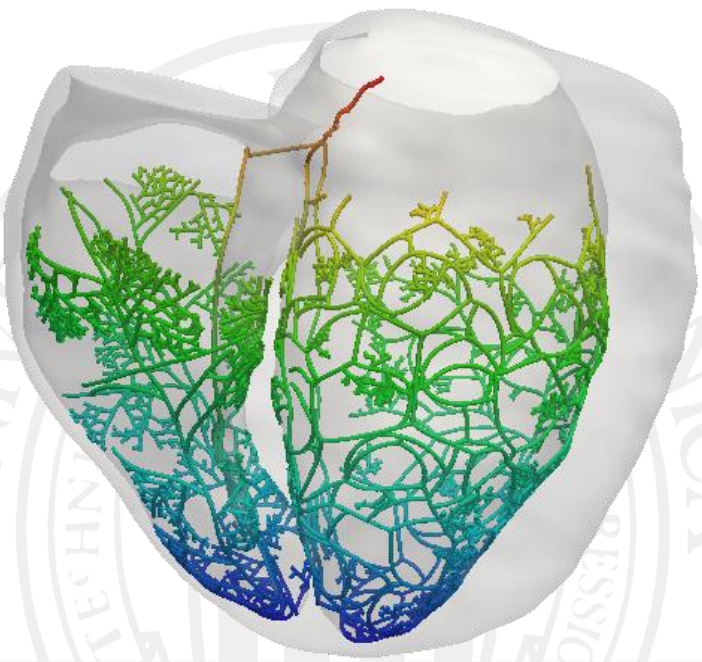
Algoritmos (Streeter, 1969)



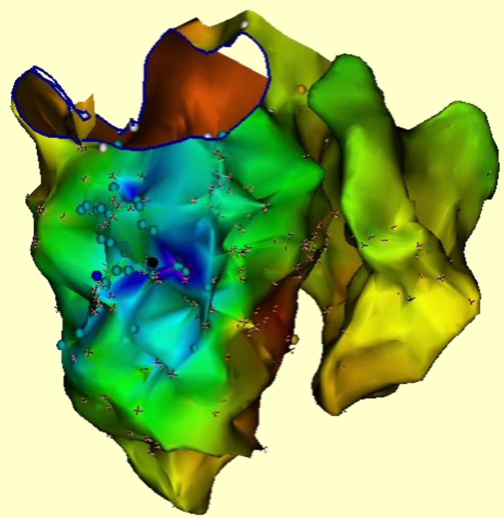
5. Sistema de conducción (His-Purkinje)



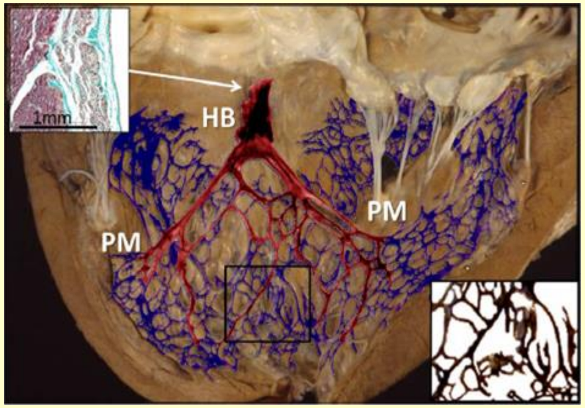
Estimación inversa del árbol de Purkinje



Mapa electro-anatómico (CARTO) [LAT]



Fotografías/Atlas



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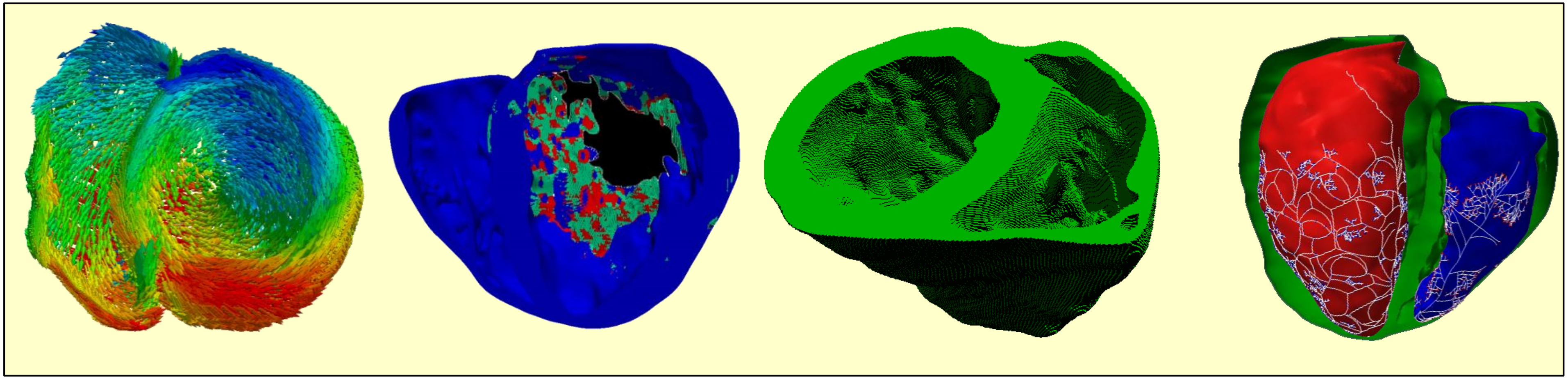
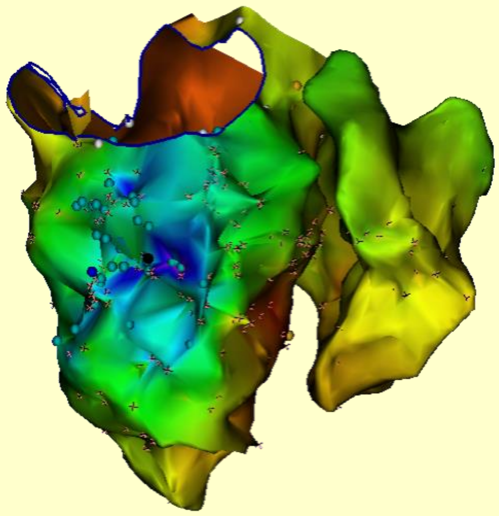
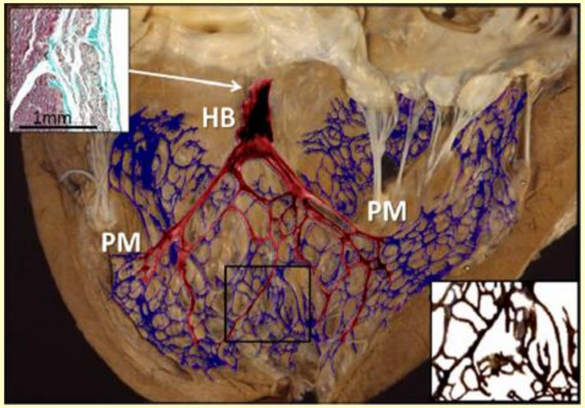


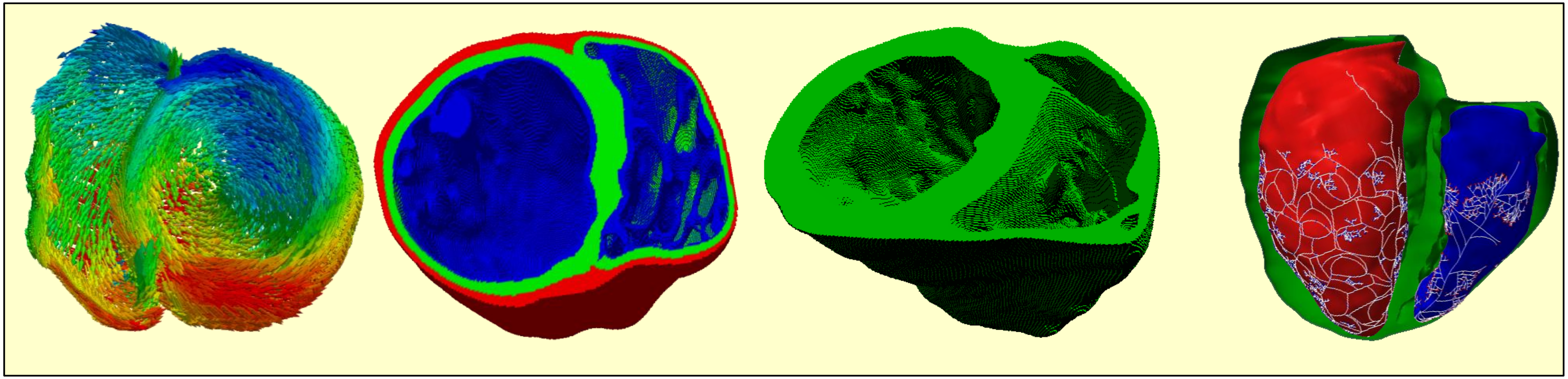
Mapa electro-anatómico (CARTO) [LAT]

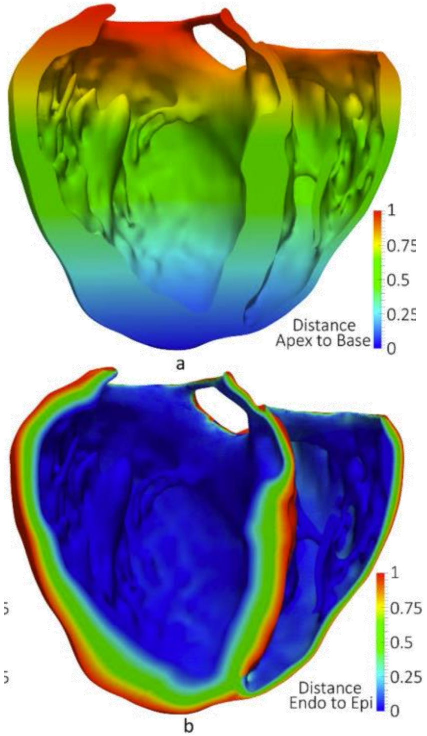


Fotografías/Atlas

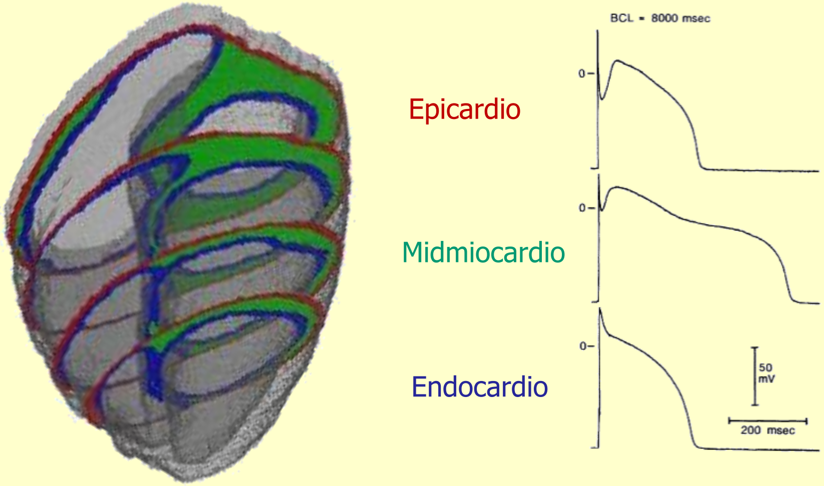


6. Heterogeneidad electrofisológica



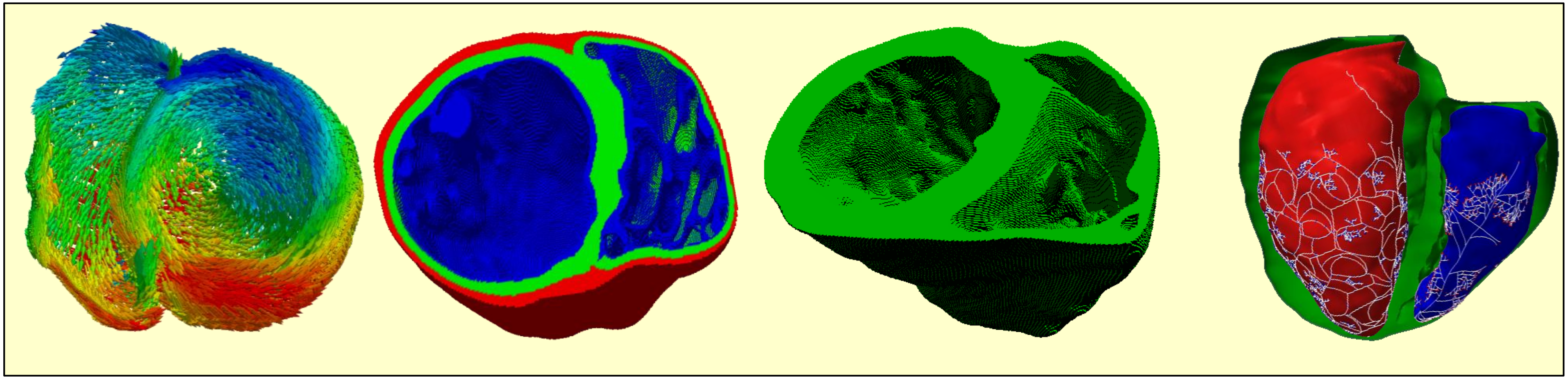


Heterogeneidad transmural

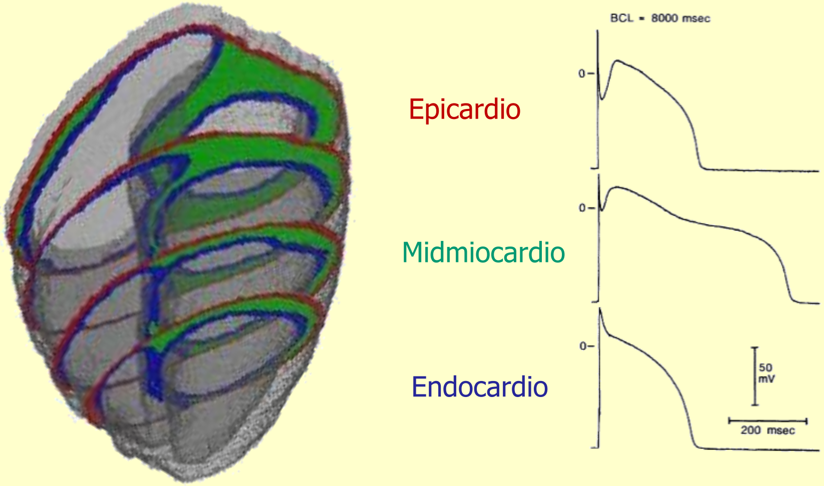


(Liu & Antzelevitch 1993)

6. Heterogeneidad electrofisológica

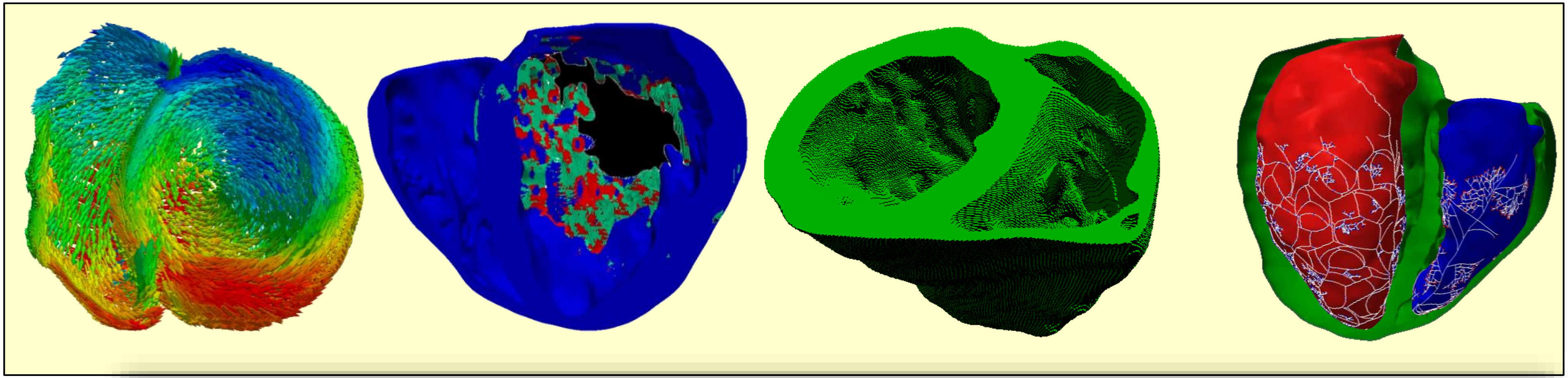


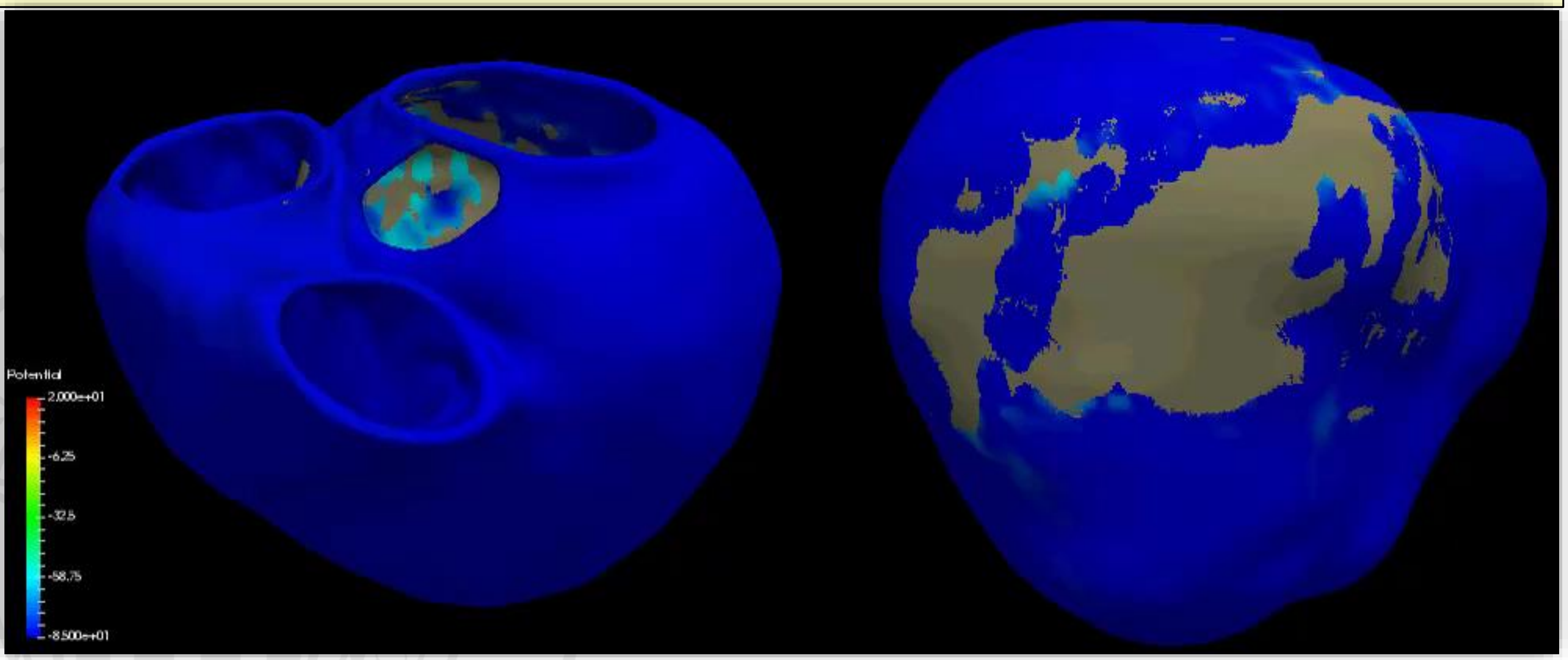
Heterogeneidad transmural



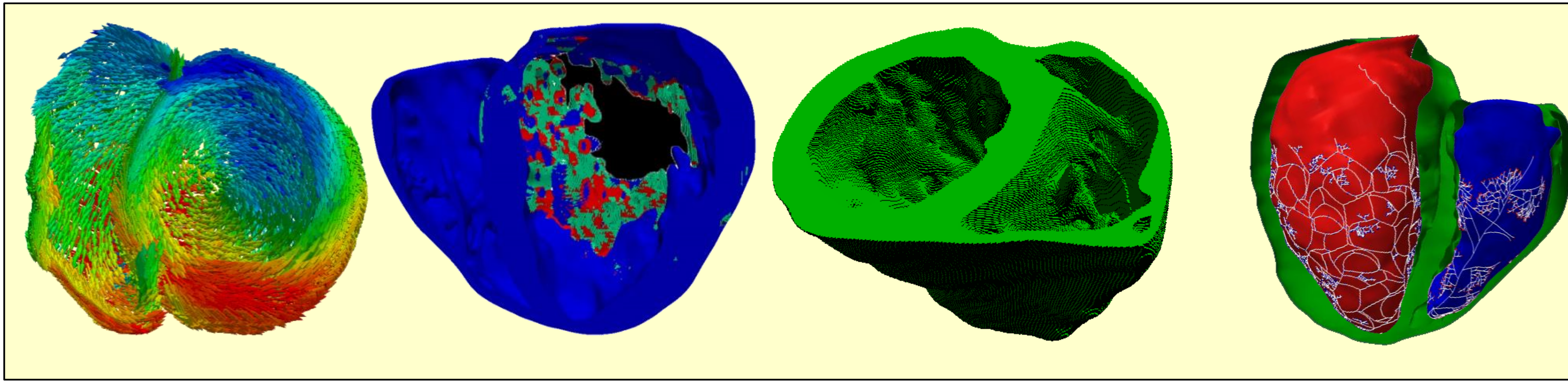
(Liu & Antzelevitch 1993)

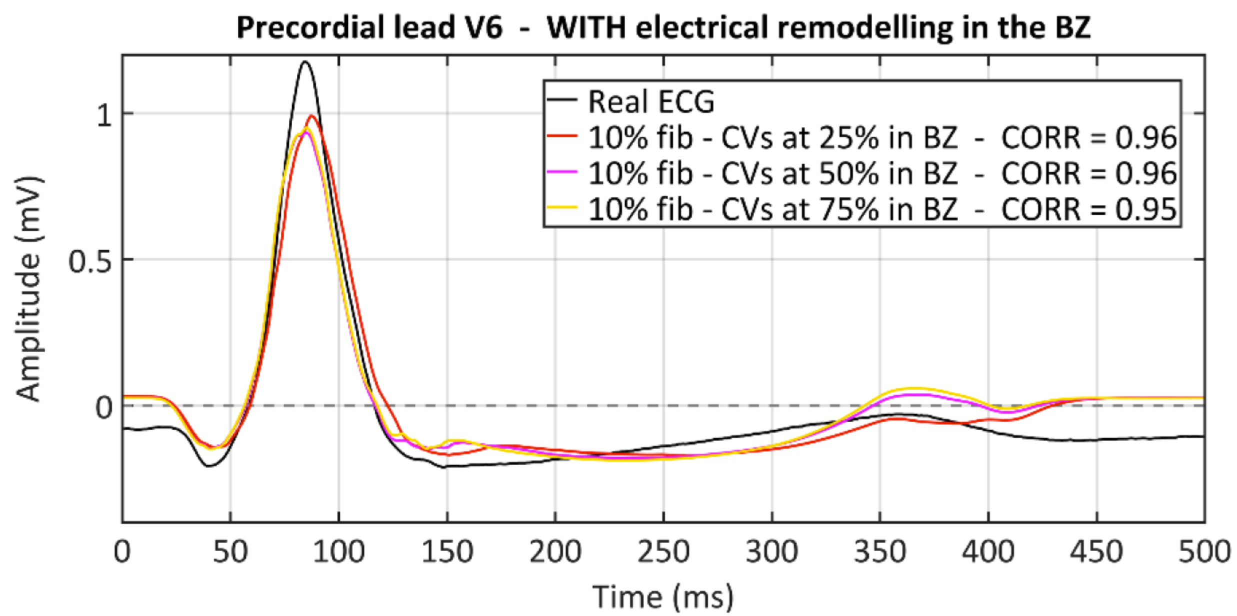
Simulación (ritmo sinusal → taquicardia ventricular)





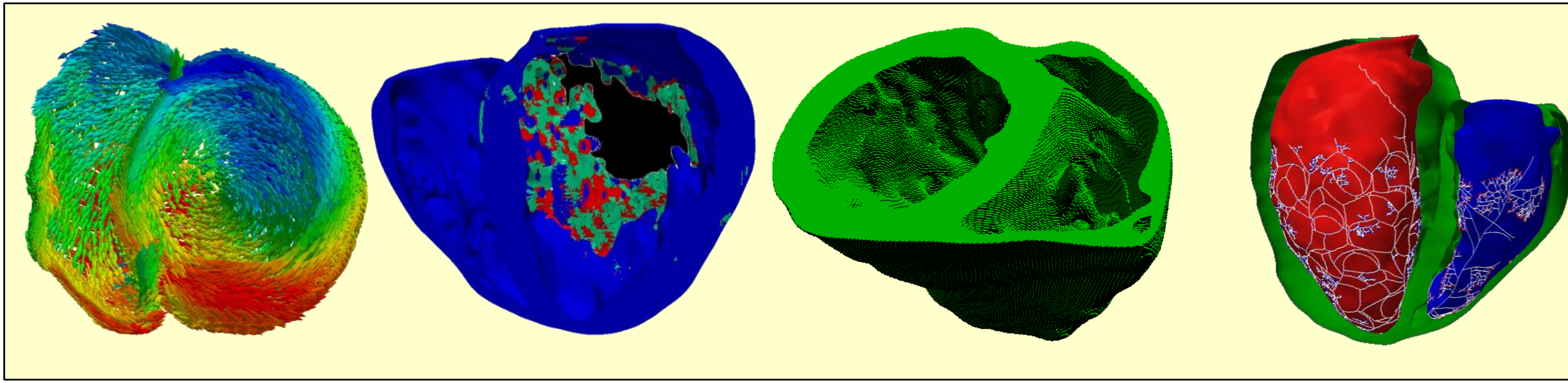
Simulación (corazón infartado, ritmo sinusal) [ECG]

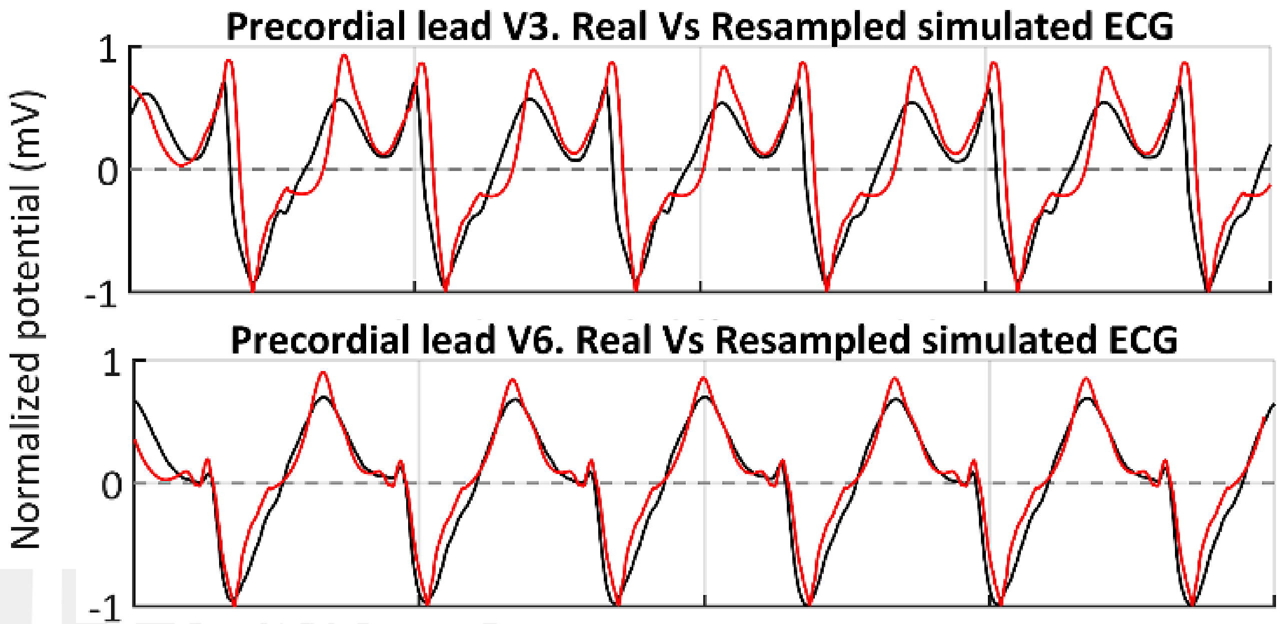




López-Pérez, Sebastián, Izquierdo, Ruiz, Bishop & Ferrero, ***Front. In Physiol. (Frontiers in Physiology*, 2019)**

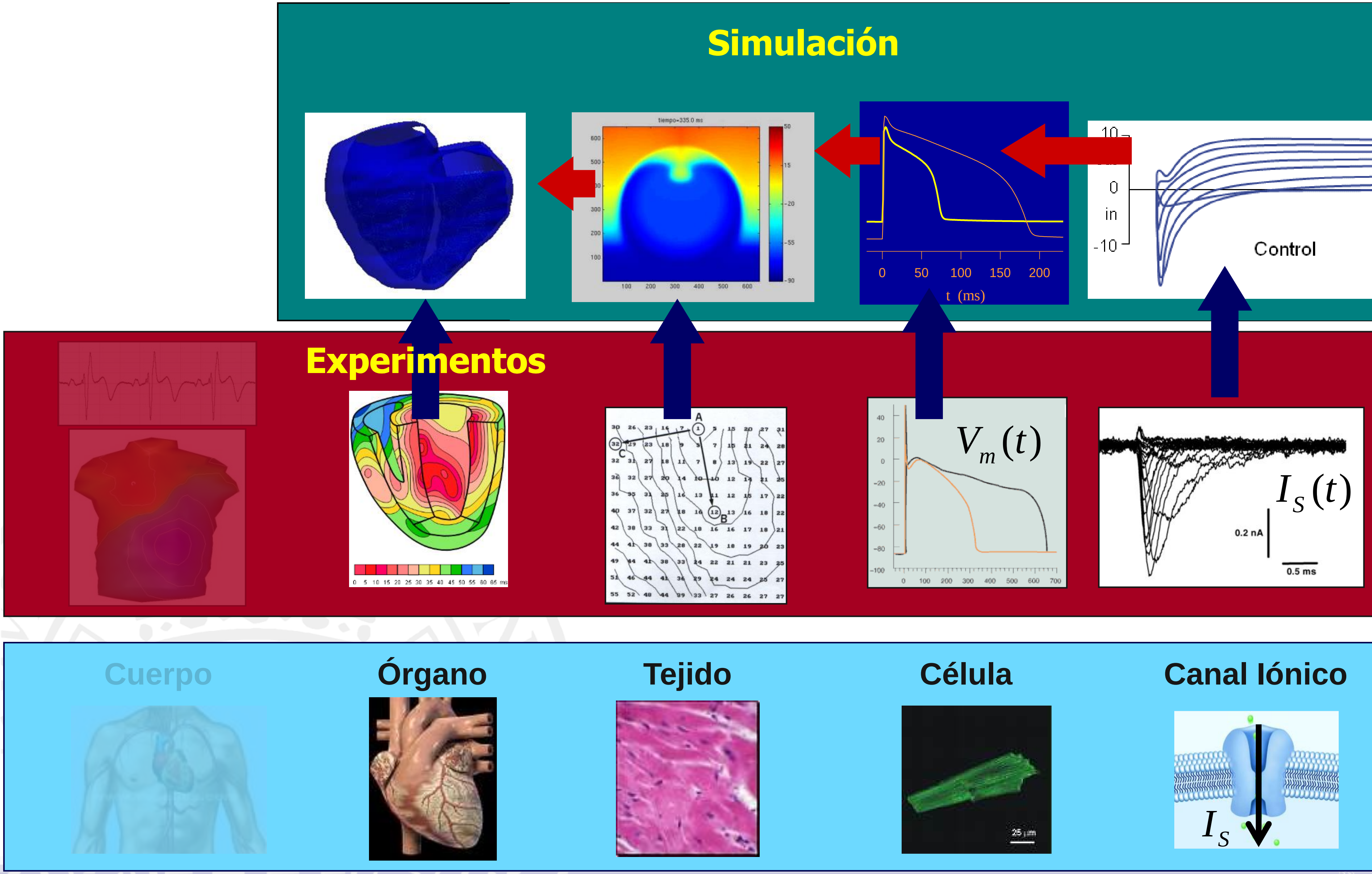
Simulación (corazón infartado, taquicardia ventricular)





López-Pérez, Sebastián, Izquierdo, Ruiz, Bishop & Ferrero, ***Front. In Physiol. (Frontiers in Physiology*, 2019)**

Modelado Electrofisiológico Multiescala



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