Study of high-resolution voltage maps of the left atrium

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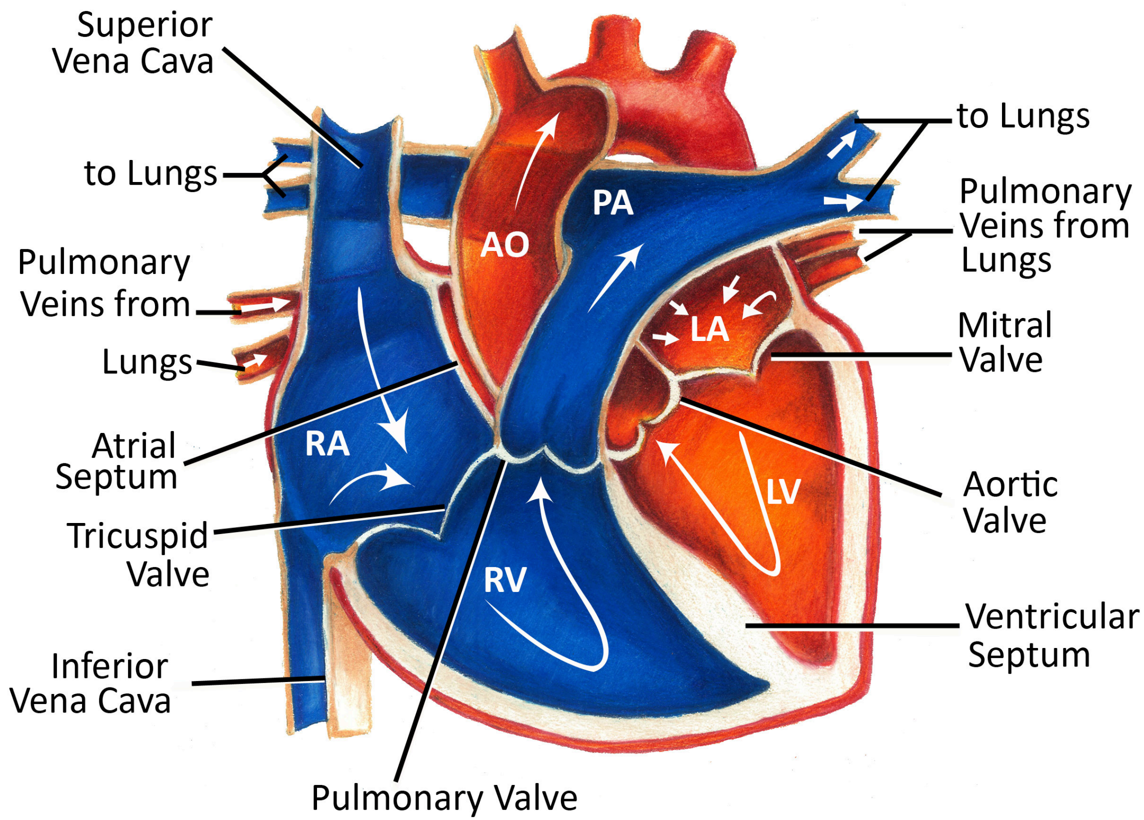
Why are we interested in studying cardiac dynamics ?

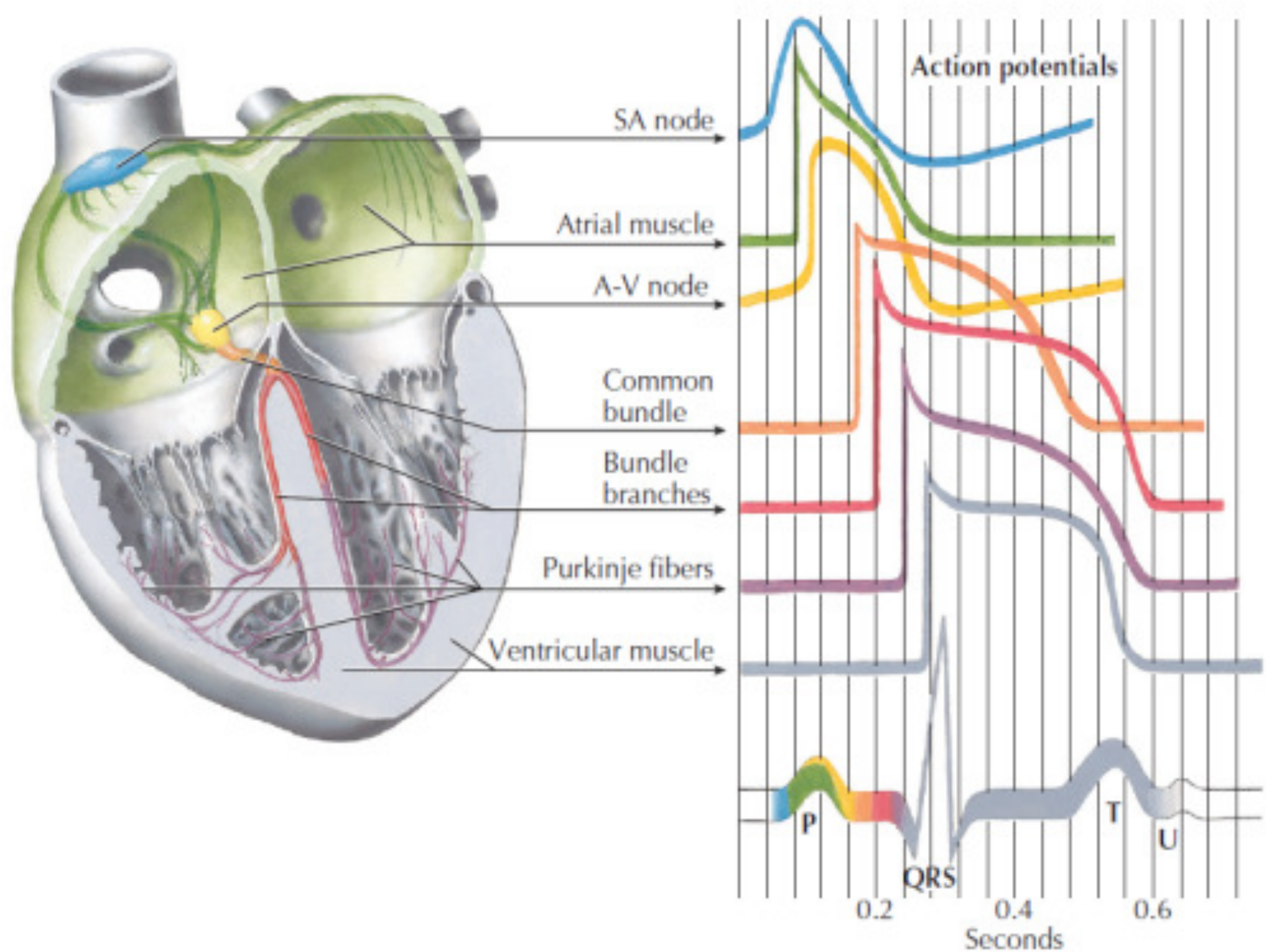
Rank[1]	Cause of death (based on ICD–10, 1992)	Number	Percent of total deaths	2005 crude death rate
...	All causes	2,448,017	100.0	825.9
1	Diseases of heart . . . . (I00–I09,I11,I13,I20–I51)	652,091	26.6	220.0
2	Malignant neoplasms . . . . (C00–C97)	559,312	22.8	188.7
3	Cerebrovascular diseases . . . . (I60–I69)	143,579	5.9	48.4
4	Chronic lower respiratory diseases . . . . (J40–J47)	130,933	5.3	44.2
5	Accidents (unintentional injuries) . . . . (V01–X59, Y85–Y86)	117,809	4.8	39.7
6	Diabetes mellitus . . . . (E10–E14)	75,119	3.1	25.3
7	Alzheimer's disease . . . . (G30)	71,599	2.9	24.2
8	Influenza and pneumonia . . . . (J10–J18)	63,001	2.6	21.3
9	Nephritis, nephrotic syndrome and nephrosis . . . . (N00–N07,N17–N19,N25–N27)	43,901	1.8	14.8
10	Septicemia . . . . (A40–A41)	34,136	1.4	11.5
11	Intentional self-harm (suicide) . . . . (*U03, X60–X84, Y87.0)	32,637	1.3	11.0
12	Chronic liver disease and cirrhosis . . . . (K70, K73–K74)	27,530	1.1	9.3
13	Essential (primary) hypertension and hypertensive renal disease . . . . (I10,I12)	24,902	1.0	8.4
14	Parkinson's disease . . . . (G20–G21)	19,544	0.8	6.6
15	Assault (homicide) . . . . (*U01–*U02, X85–Y09, Y87.1)	18,124	0.7	6.1
...	All other causes (residual)	433,800	17.7	146.4

Cardiac diseases are among the leading causes of death and
we should understand better all the mechanisms associated with them.

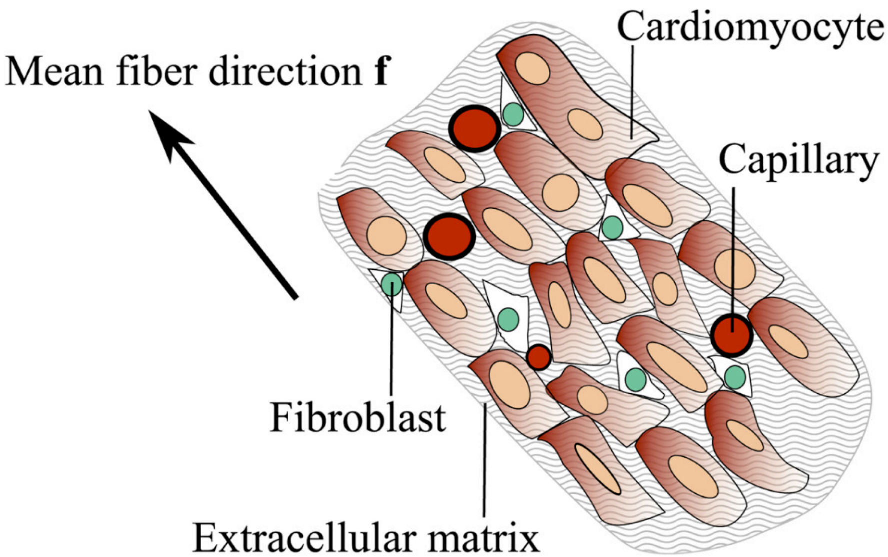
The heart is a double muscular pump

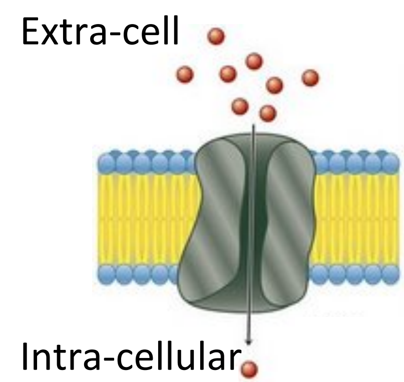


Cardiac conduction system and its relation with the ECG



Composition of the heart at the cellular level



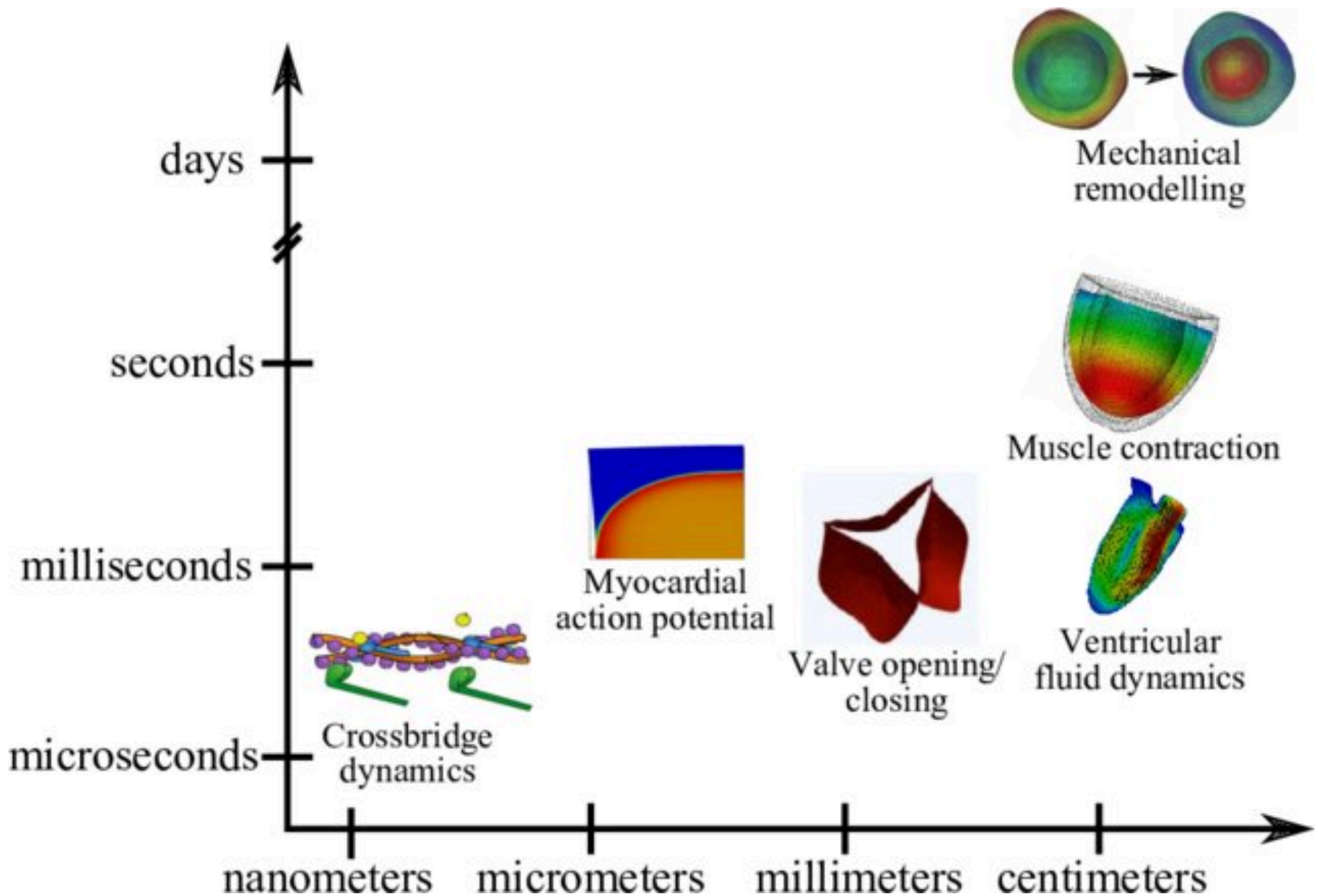


$$V_{myo} = \phi_{myo} - \phi_e$$

The electrical activity is due to the ion transport across the cell membrane

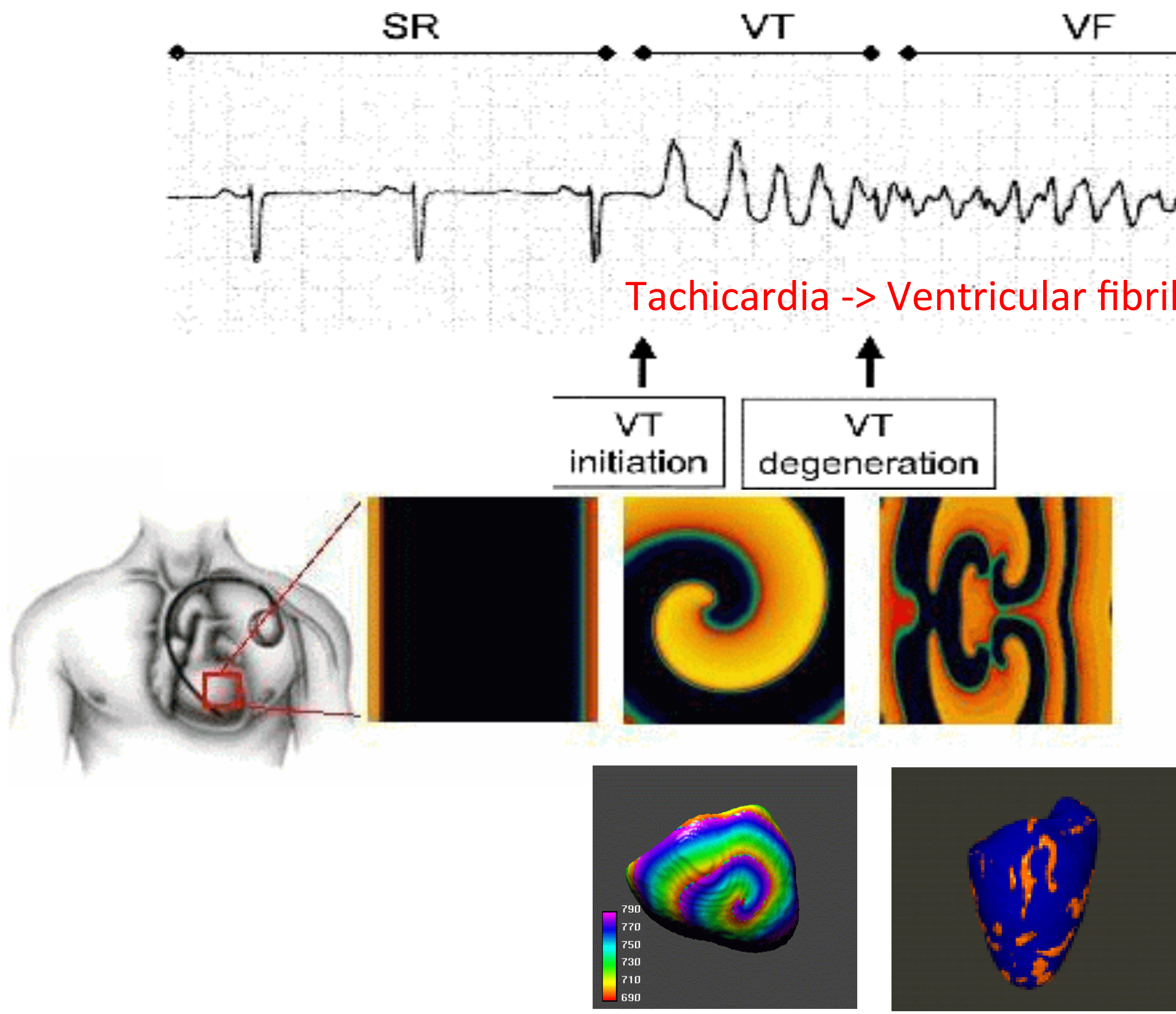
"Integrated Heart - Coupling multiscale and multiphysics models for the simulation of the cardiac function"
A. Quarteroni, et al. , May 2016. Computer Methods in Applied Mechanics and Engineering 314

The heart is a multiphysics and multiscale system



"Integrated Heart - Coupling multiscale and multiphysics models for the simulation of the cardiac function" A. Quarteroni, et al. , May 2016. Computer Methods in Applied Mechanics and Engineering 314

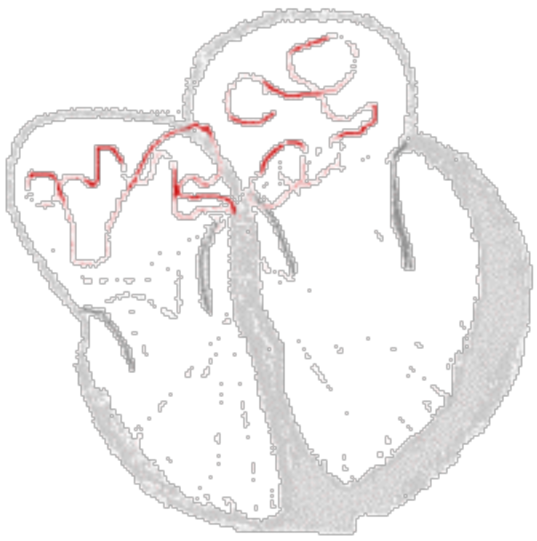
Normal electric activity may be disrupted by failures in the propagation of the action potentials



(Keener y Panfilov (1995))

One common type of arrhythmia is atrial fibrillation (Afib)

Healthy



Afib

"Integrated Heart - Coupling multiscale and multiphysics models for the simulation of the cardiac function"
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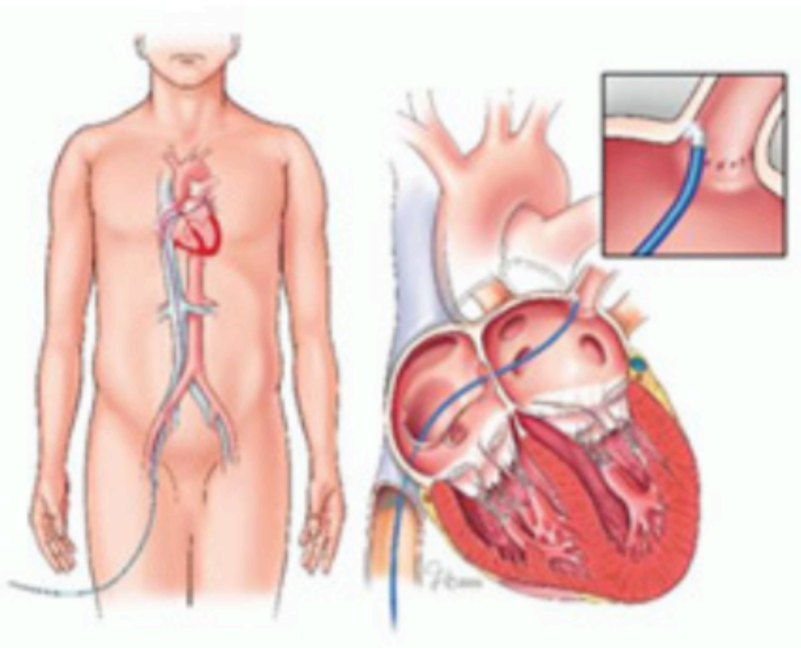
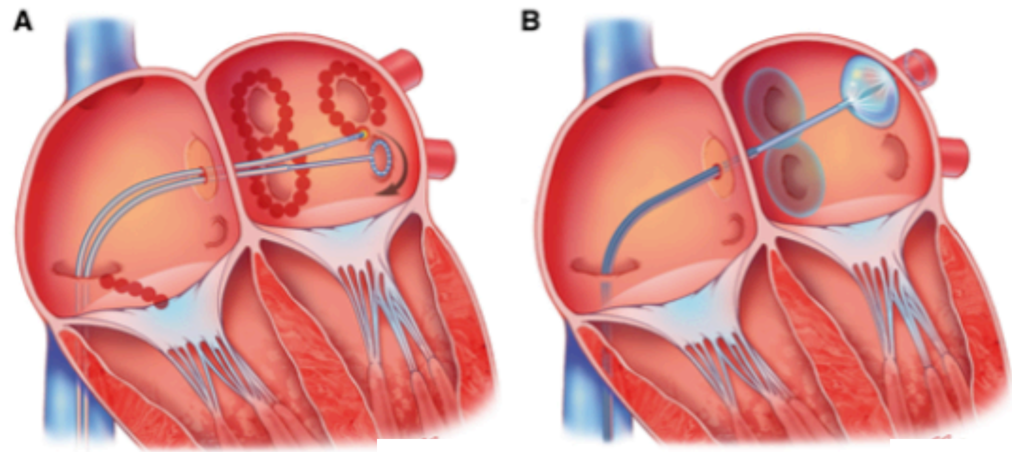
One of the clinical solution to Afib is to ablate the re-entry circuit and essentially the PVs

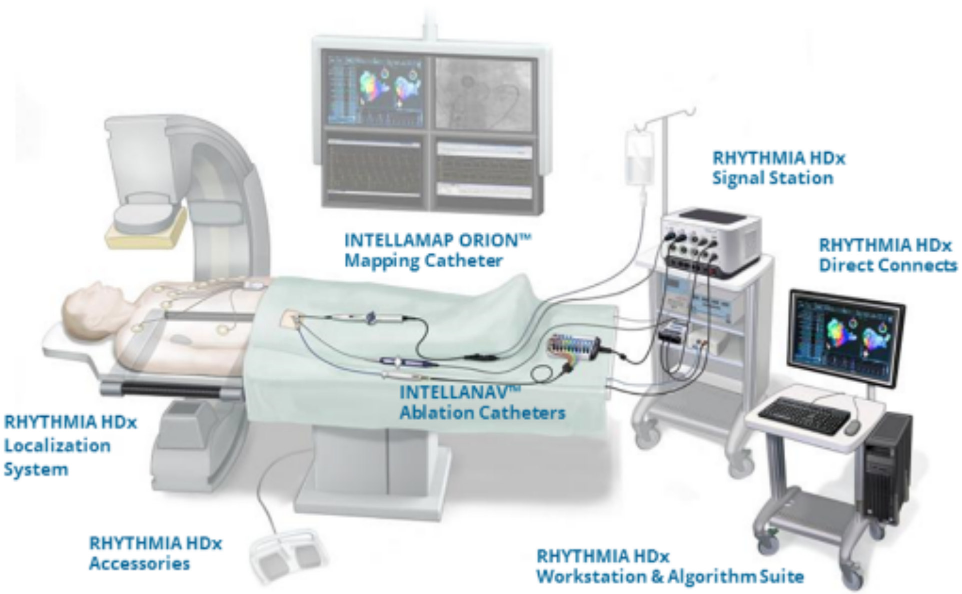


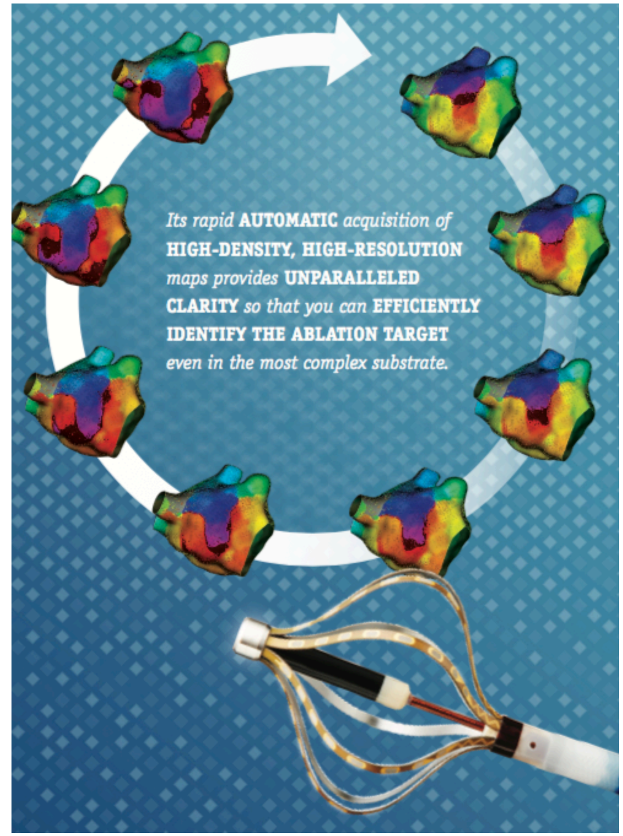


~30% of the ablation procedures will fail (Afib presents after 1 year follow-up)

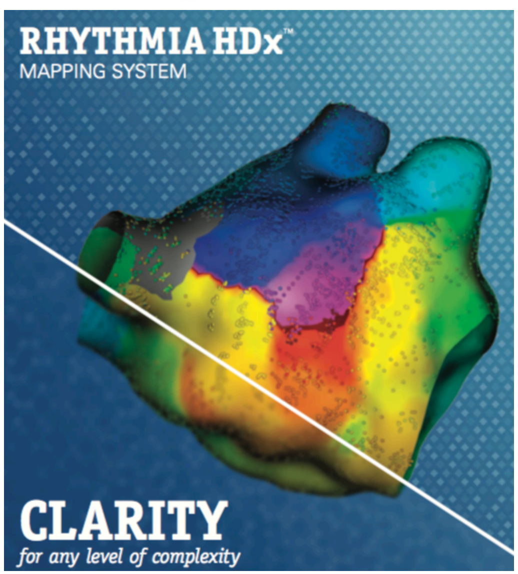
"M. Nuñez Garcia, Ph.D. thesis, UPF, 2018"

System used prior to ablation to map the patient left atrium Rhythmia system (Boston scientific)





64 electrodes



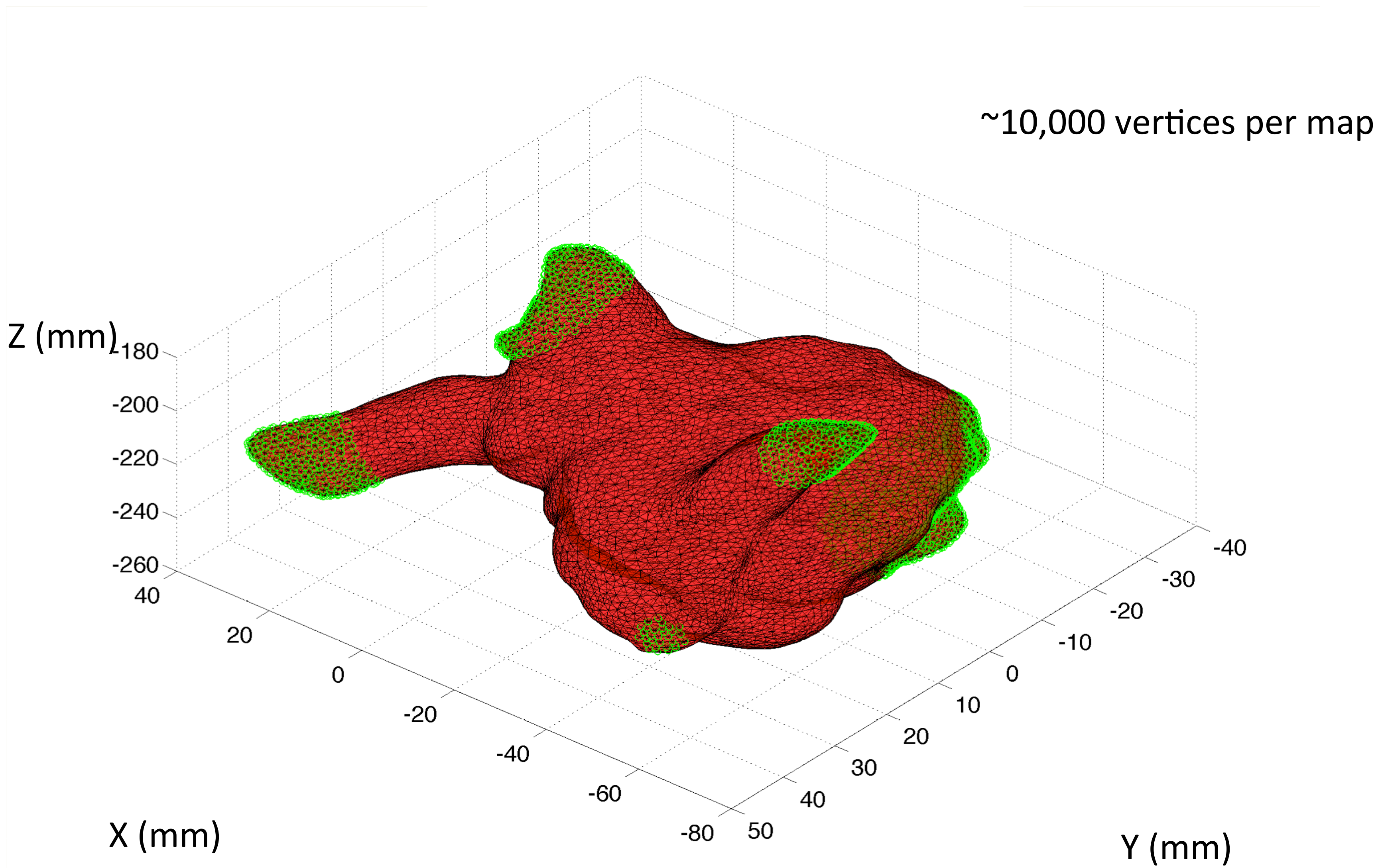
Activation time mapping,

and bipolar/unipolar voltage mapping are acquired

(~20 min/patient)

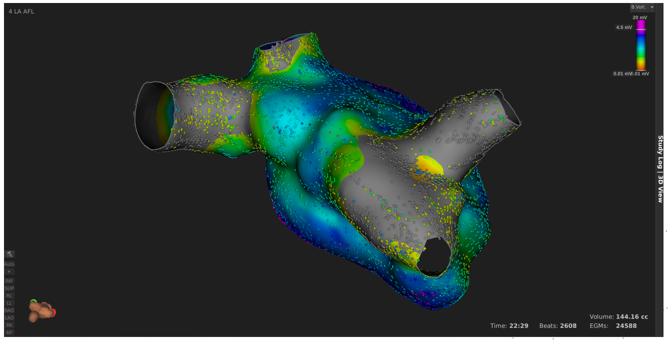
The data are saved in a readable Matlab format for analysis

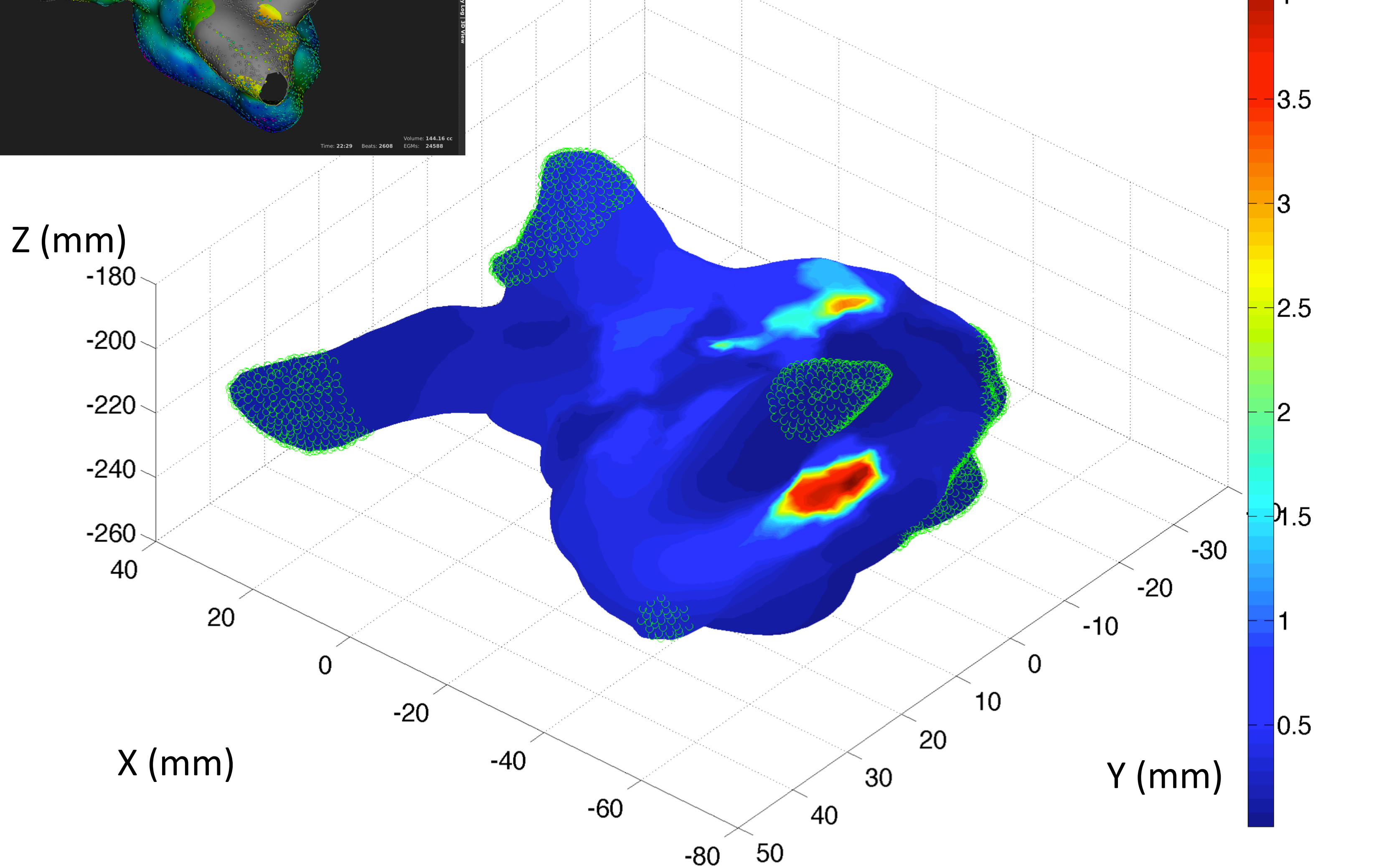
Anatomical mesh of the Left Atrium



Note: Green dots indicate the “Mask” that is the location of the Pulmonary veins (PV).

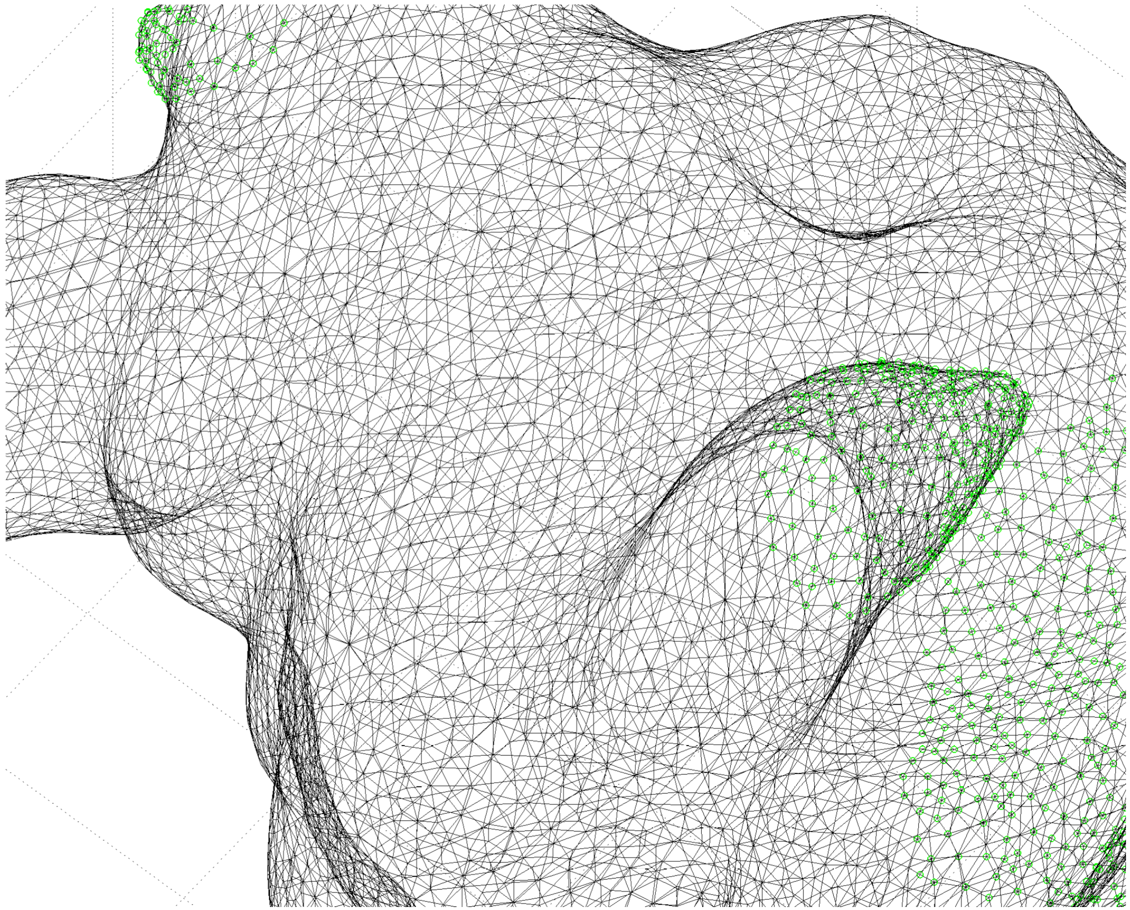
Bipolar Voltage Maps (Matlab)





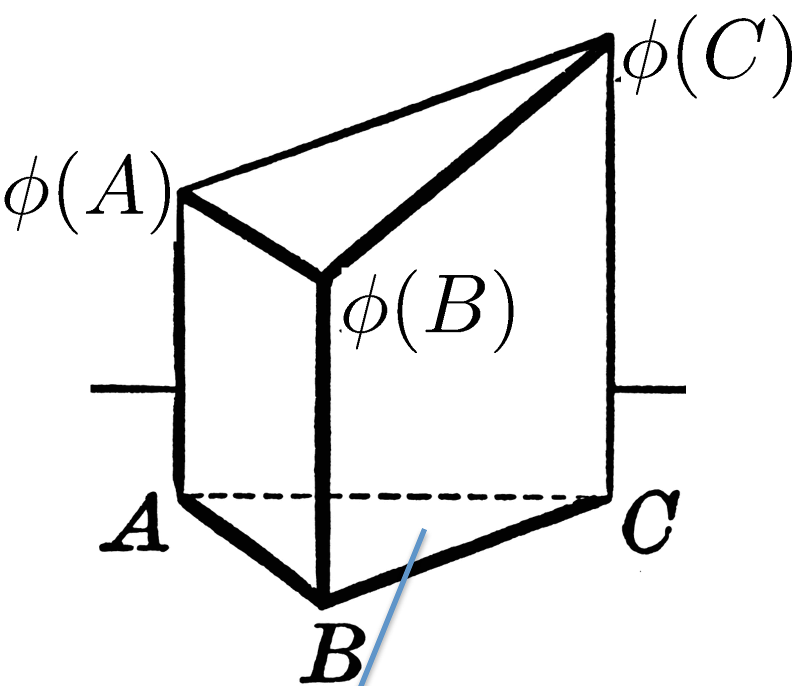
Bipolar measurements reduce SNR with respect to unipolar measurements !

‘close-up’ of the geometry of the LA



In this case, e.g., the total surface consists of 18,546 triangles (faces) and 9,275 vertices.
Note: Not all triangles have the same area !!

Remainder of basic geometry



Vertices A, B and C define the triangle area. At each vertices we have the corresponding voltage ϕ. So we can compute easily the average voltage on each triangle. The average voltage on the entire surface is the weighted average of the local voltage.

$$\text{Area} = \frac{1}{2}|\vec{AB} \wedge \vec{AC}|$$

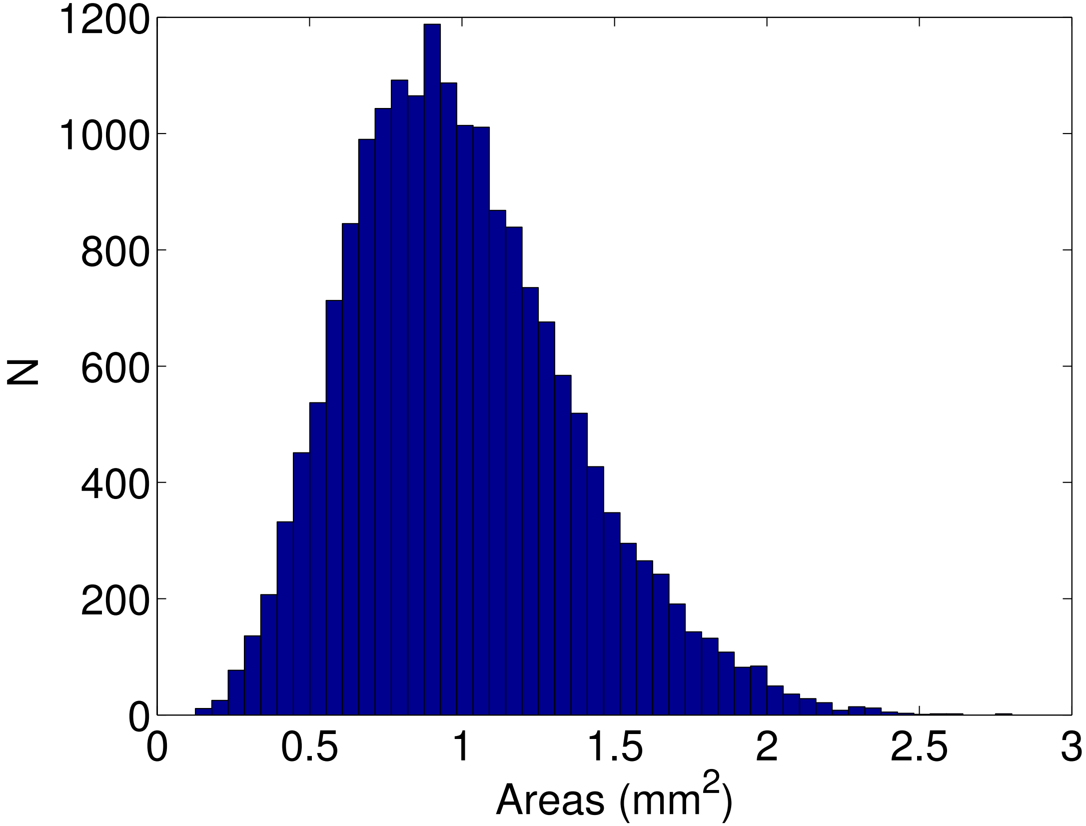
$$\text{Volumen} = \text{Area}\ \frac{\phi(A) + \phi(B) + \phi(C)}{3}$$

Compute the total Area of the LA

of triangles forming the total surface

$$\text{Area total} = \sum_{i=1}^{18546} \text{Area}_i = 185.2575\,\text{cm}^2$$

Triangle area histogram



$$< \text{Area}_i > \approx 1\,\text{mm}^2$$

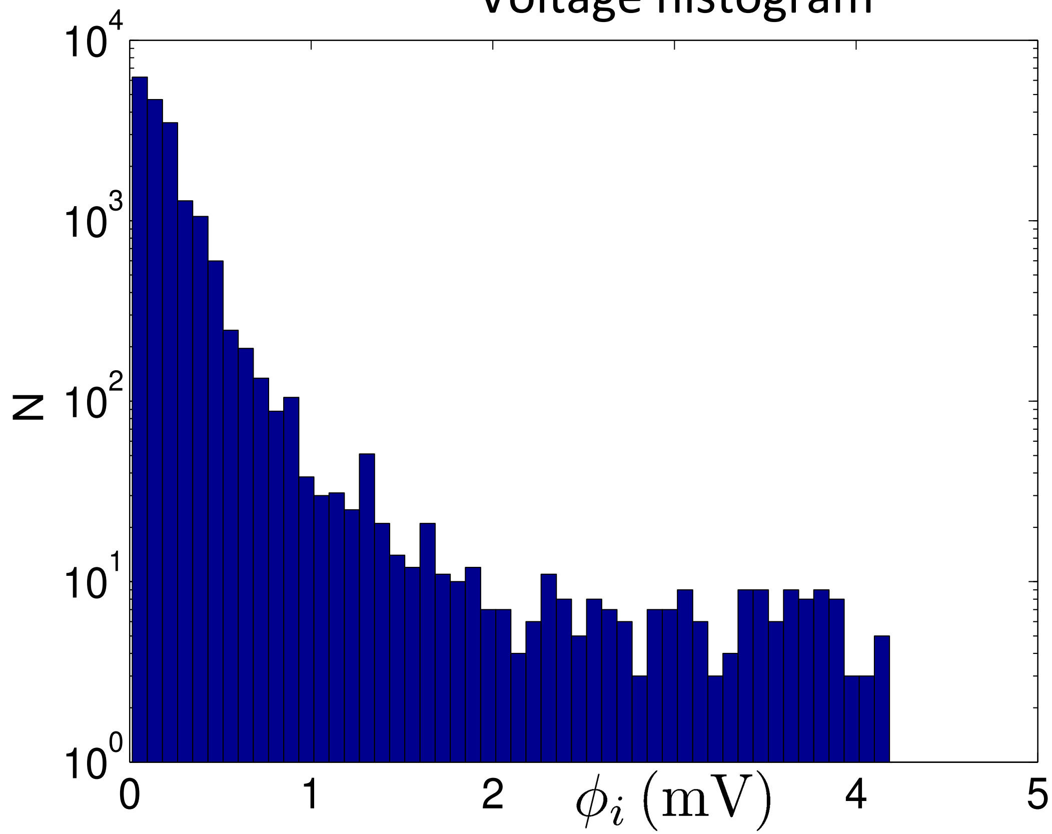
$$\sigma_{\text{Area}_i} \approx 0.37\,\text{mm}^2$$

Average potential on the LA

$$\phi_i = \frac{\phi(A) + \phi(B) + \phi(c)}{3}$$ Average voltage on each triangle

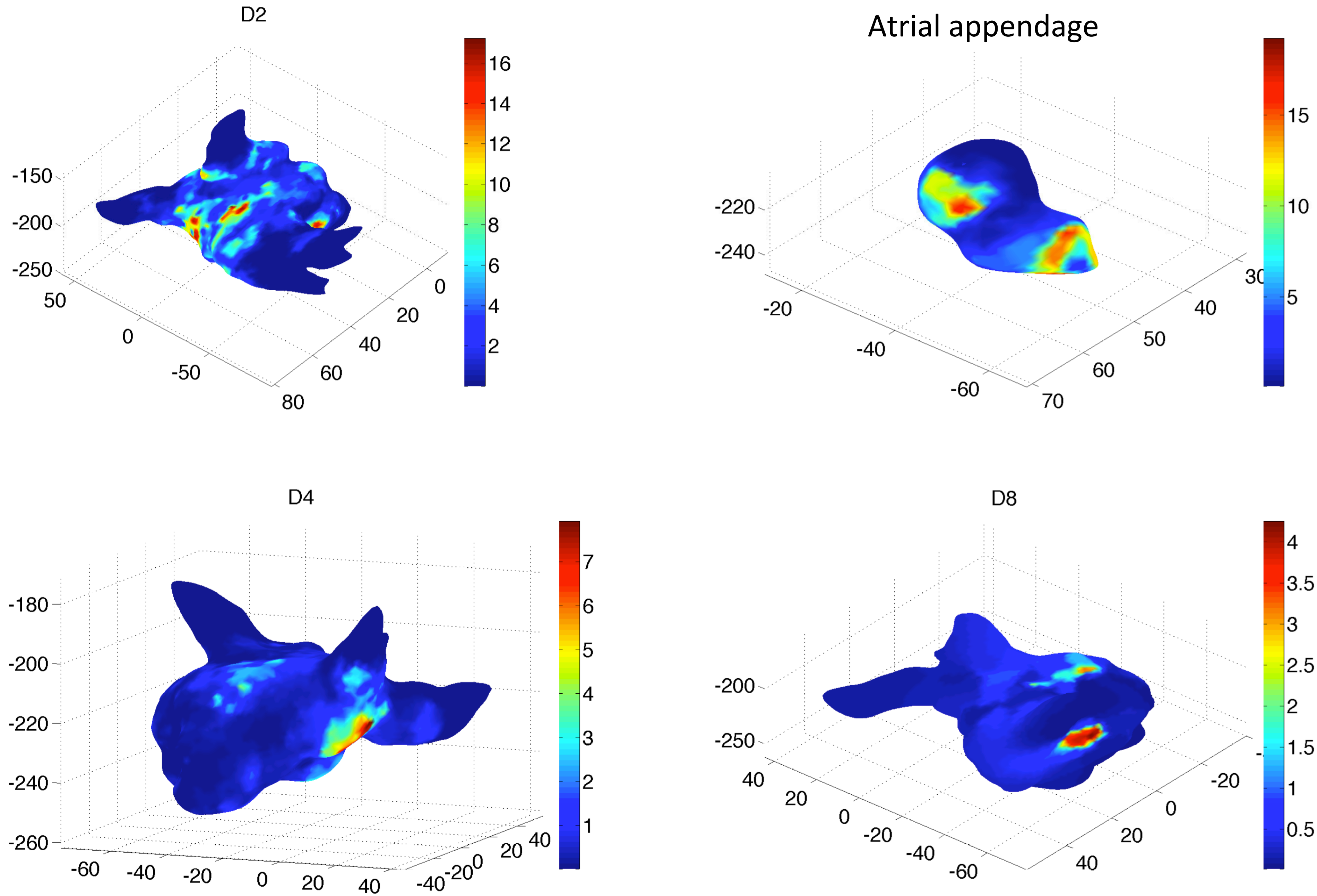
$$< \phi >= \frac{1}{\text{Area tot.}} \sum_{i=1}^{18546} \text{Area}_i \ \phi_i = 0.2244\,\text{mV}$$

Voltage histogram

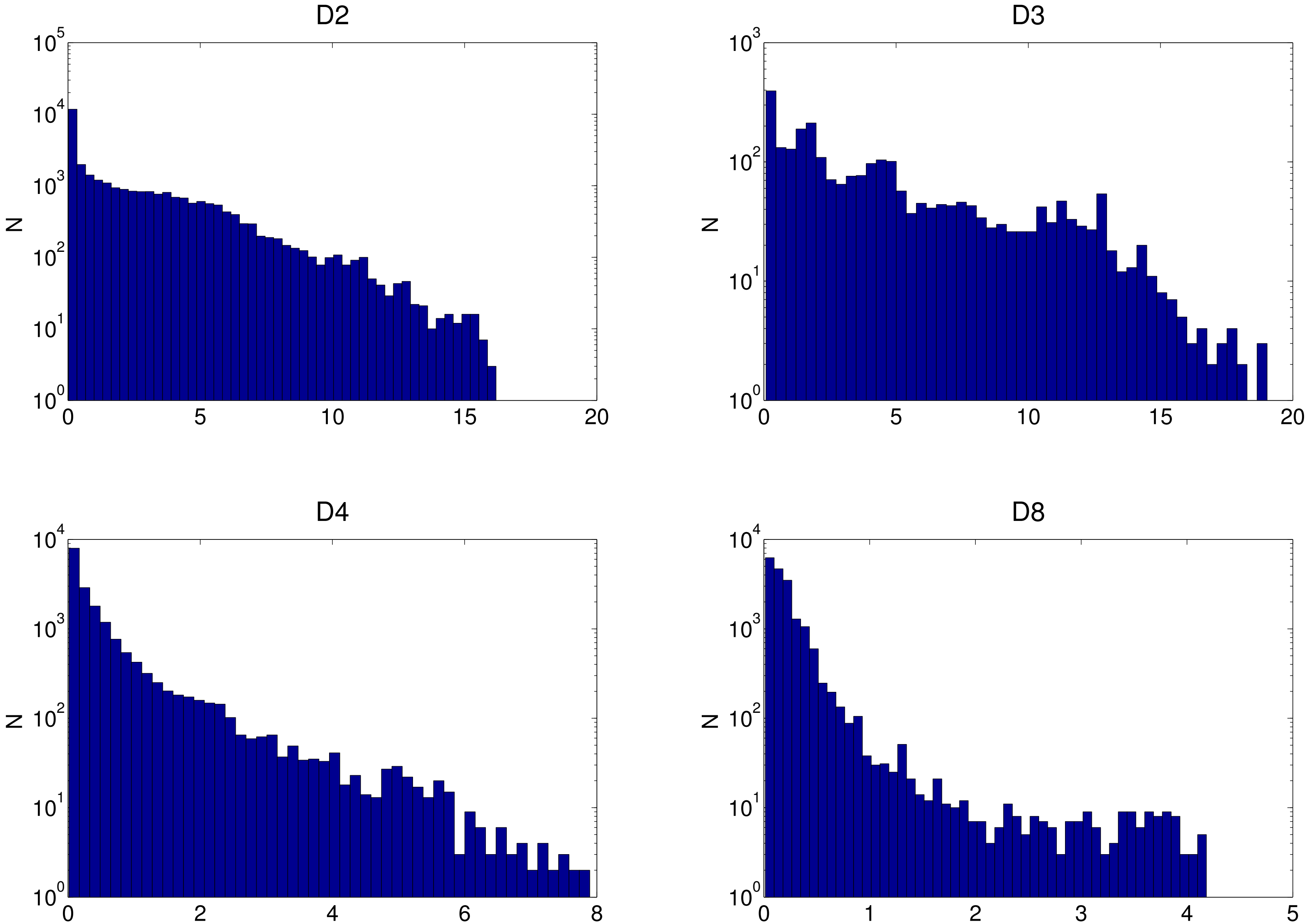


$$< \phi_i >= 0.2216\,\text{mV}$$

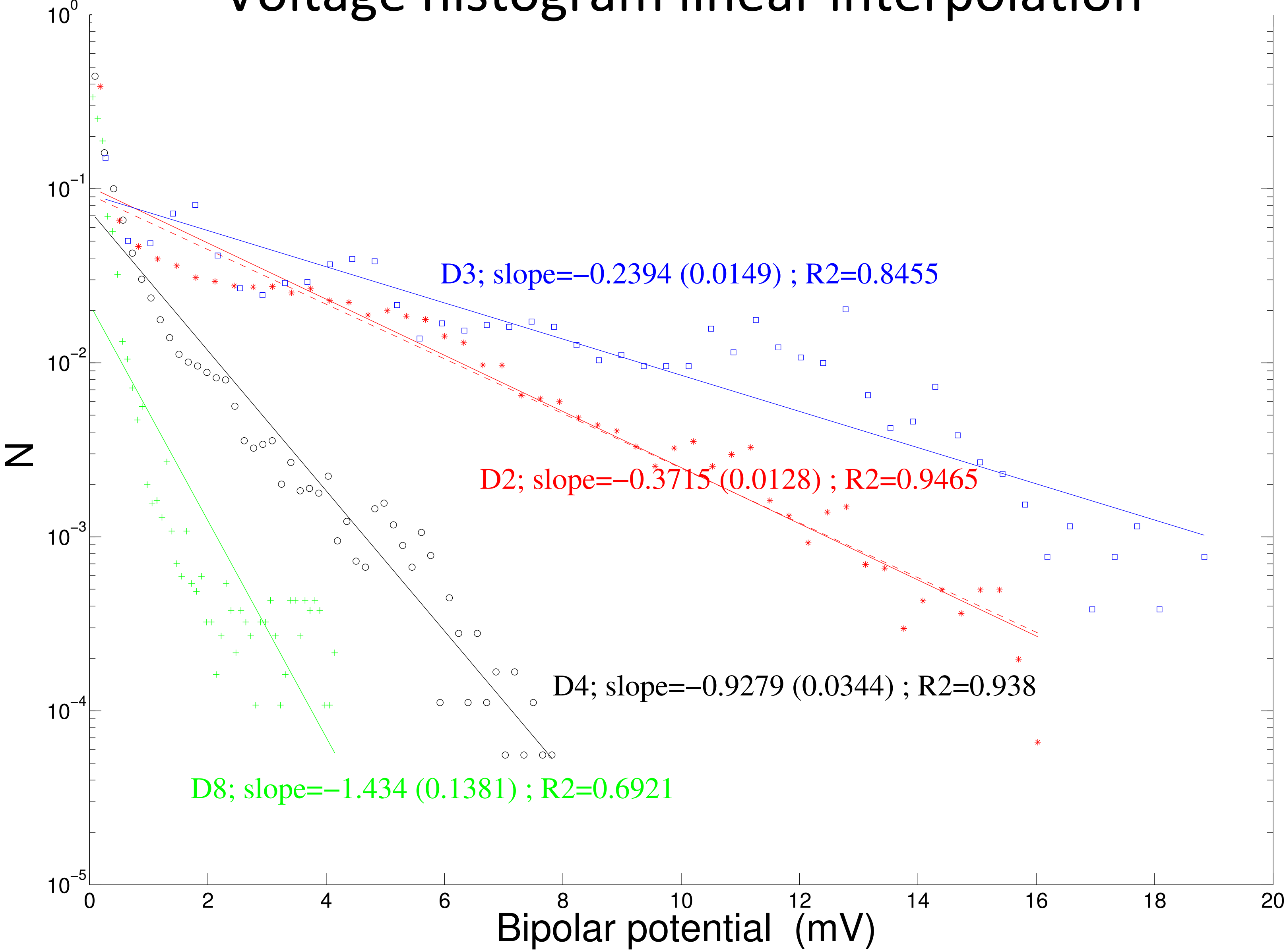
$$\sigma_{\phi_i} = 0.3331\,\text{mV}$$


D2
Atrial appendage
D4
D8

Voltage histograms (bipolar recordings)



Voltage histogram linear interpolation



Quantitative values for the 4 examples

File	NV	NF	Area (cm^2)	$< \phi >$ (mV)	Slope (mV^-1)	R^2	$< \phi_i >$ (mV)	$< A_i >$ (mm^2)
D2	15148	30292	215.15	2.2293	**-0.3715** (0.0128)	0.9465	2.2331 (2.7616)	0.7103 (0.2051)
D3	1307	2610	20.18	4.4067	**-0.2394** (0.0149)	0.8455	4.442 (4.1126)	0.7734 (0.2426)
D4	8971	17938	182.82	0.5557	**-0.9279** (0.0344)	0.938	0.537 (0.8706)	1 (0.38)
D8	9275	18546	185.26	0.2244	**-1.434** (0.1381)	0.6921	0.2216 (0.3331)	1 (0.37)

Numbers in parentheses in the table indicate standard errors or std.

We studied 98 patient maps (prior to ablation)

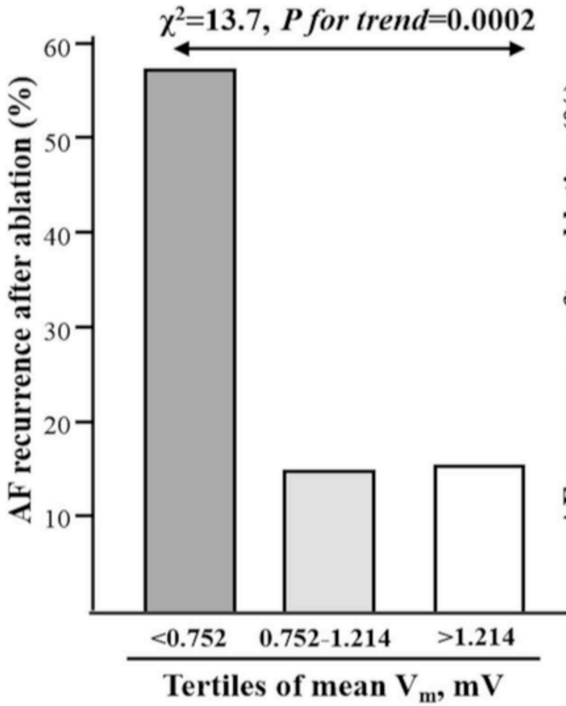
	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	R	S	T
1	name	NVERT	NFACES	AREA	MEDIA POT	Slope	R2	False media	dispersion	Q1	Q2	Q3								
2	pot<0,1	P<0,2	P<0,3	P<0,4	P<0,5	P<0,6	P<0,7	P<0,8	P<0,9	P<1	P<1,1	P<1,2	P<1,3	P<1,4	P<1,5	P<1,6	P<1,7	P<1,8	P<1,9	P<2
3																				
4	F01_12_2015T09h08	7357	14513	137.3	0.7143	-0.9682 (0.0302)	0.956	0.7155 (0.912)	0.9460 (0.349)	0.1416	0.3492	0.9248								
5	0.1654	0.3522	0.4587	0.5387	0.6017	0.6494	0.6863	0.7168	0.7434	0.7668	0.7869	0.8059	0.8218	0.8375	0.8534	0.8661	0.8805	0.8914	0.9006	0.9103
6																				
7	F03_11_2015T09h58	7828	15470	145.31	1.0769	-0.4961 (0.0203)	0.926	1.0618 (1.587)	0.9393 (0.357)	0.1312	0.3573	1.4863								
8	0.1925	0.3767	0.4603	0.5219	0.566	0.5972	0.6222	0.6418	0.6607	0.6807	0.6979	0.7136	0.728	0.7406	0.7513	0.7634	0.7773	0.7869	0.7997	0.8109
9																				
10	F04_08_2015T13h08	7795	15440	147.52	0.1869	-1.8882 (0.1251)	0.847	0.1809 (0.290)	0.9554 (0.363)	0.0428	0.0801	0.1922								
11	0.5809	0.7589	0.8346	0.879	0.9091	0.9306	0.945	0.9562	0.9659	0.9727	0.9778	0.9815	0.9842	0.9873	0.9902	0.9926	0.994	0.9948	0.9965	0.9979
12																				
13	F05_11_2015T09h20	5068	9955	97.15	1.1941	-0.4625 (0.0208)	0.92	1.1807 (1.669)	0.9759 (0.361)	0.176	0.5399	1.5004								
14	0.1339	0.2749	0.3693	0.4337	0.484	0.5231	0.5619	0.5929	0.6297	0.6543	0.6787	0.7002	0.7175	0.7323	0.7499	0.7612	0.7743	0.7877	0.7999	0.8112
15																				
16	F09_09_T08h49	6989	13832	137.41	0.8219	-0.7329 (0.0289)	0.933	0.8191 (1.198)	0.9934 (0.375)	0.1176	0.2619	1.1075								
17	0.1674	0.4429	0.5233	0.5807	0.6235	0.6552	0.6803	0.702	0.7188	0.7336	0.7493	0.765	0.7784	0.7923	0.807	0.8199	0.8308	0.8419	0.8539	0.8652
18																				
19	F17_11_T14h51	7539	14836	143.93	2.0659	-0.4578 (0.0134)	0.96	2.0679 (2.401)	0.9701 (0.351)	0.1938	1.2555	3.033								
20	0.185	0.2531	0.3003	0.3326	0.357	0.3786	0.3998	0.419	0.4358	0.4559	0.4726	0.4896	0.5073	0.5252	0.5419	0.5584	0.5745	0.5904	0.6096	0.6245
21																				

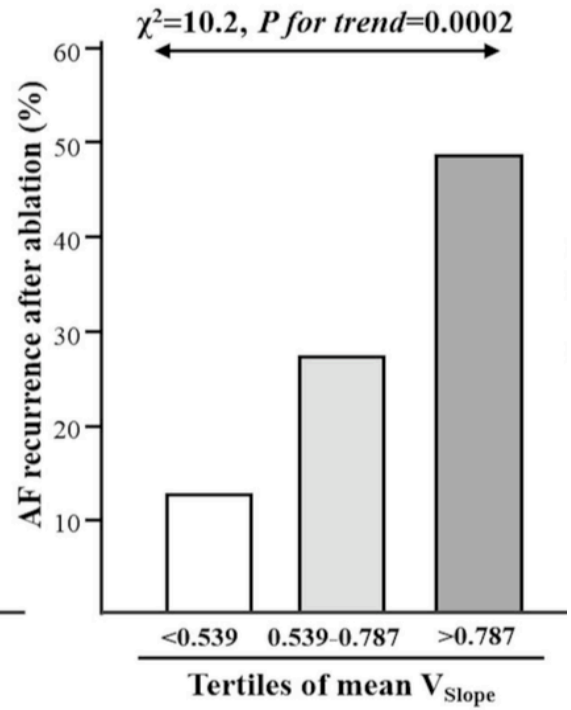
Working hypotheses:

1) Low voltage areas correlate with scar tissue areas (see LGE-MRI studies)
2) Scar tissue (fibrosis) is prone to generate re-entry (arrhythmogenic substrate)
3) Heavily damaged LA is more susceptible to lead to “redo procedure” (probability)

→ Average potential and slope are two “electrical” biomarkers of the LA !

Main results of the map analysis





Results:

Both mean voltage (V_m) and V_{slope} are predictors of AF recurrence after ablation !

29/98 patients showed AF recurrence

	Recurrence of AF: No	Recurrence of AF: Yes(29/98)
Type of AF, n (%)		
Paroxysmal	46 (66.7)	12 (41.4)
Persistent	23 (33.3)	17 (58.6)

Journal of Cardiovascular Electrophysiology

ORIGNAL ARTICLE

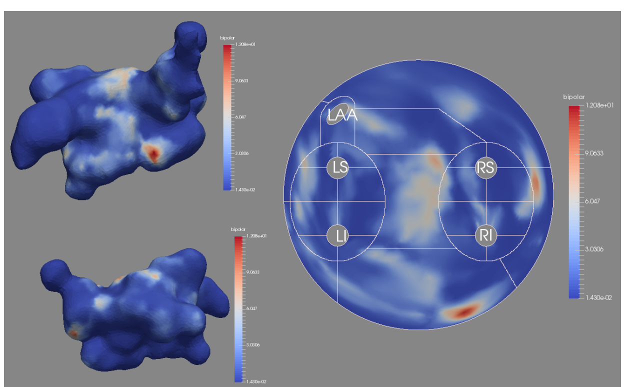
Association of left atrium voltage amplitude and distribution with the risk of atrial fibrillation recurrence and evolution after pulmonary vein isolation: An ultrahigh-density mapping study

Gabriel Ballesteros MD, Susana Ravassa PhD, Jean Bragard PhD, Pablo Ramos MD, Begoña López PhD, Enrique Vives MD, Renzo Neglia MD, Bernardo Wise MD, Arantxa González PhD ... See all authors

First published: 11 May 2019 | https://doi.org/10.1111/jce.13972

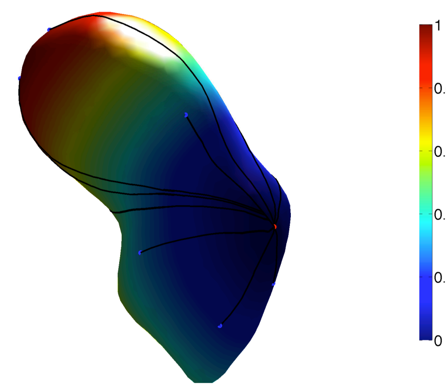
Conclusion and Perspectives:

The average potential and the slope are good predictors for a repeat procedure at one year (persistent Afib.). More complicated statistics are currently being tested.



← Regional statistics UPF

Geodesic distance in the activation time map →



Main collaborators

New study identifies biomarkers to predict the risk of atrial fibrillation

CUN – CIMA – Sciences UNAV

From left: Gabriel Ballesteros, Susana Ravassa, Ignacio García-Bolao, Begoña López, Javier Díez, Arantxa González, Pablo Ramos, Jean Bragard y Ujué Moreno. FOTO: Manuel Castells

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Collaborators:

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