Simulated Excitation Patterns in the Atria and Their Corresponding Electrograms

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Agenda

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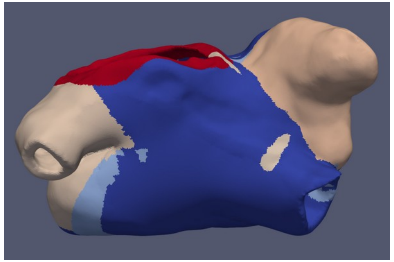
- **Introduction:** Our aim and what’s new, relation to MICROCARD
- **Methods:** Model, EGM calculation
- **Results:** Excitation patterns and their EGMs
- **Discussion:** What could be reproduced and what not?
- **Outlook:** What will future studies have to consider?

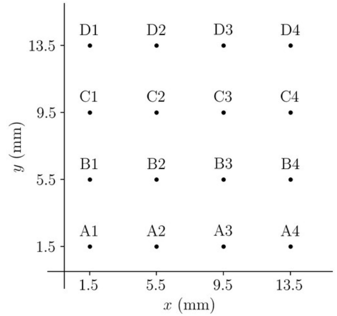
Introduction I: What is our aim and what's new?

- Electroanatomical mapping (**EAM**) is a crucial method to understand **rhythm disturbances** and to tackle them (e.g. for ablation therapy)
- Excitation dynamics may be characterised using electrograms (**EGMs**)
- In silico models provide a way to simulate different patterns and to study them **systematically**
- Such insights may help to **enhance clinical EAM systems** (set up and verification)

Introduction II: What is our aim and what's new?

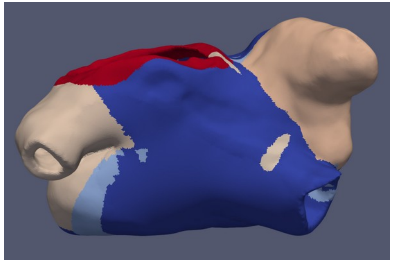
- So far, patterns observed only in simple 2- or 3D patches or geometries not considering e.g. differing wall thickness
- We consider **varying electrical properties** and a **realistic volumetric geometry**
- Characterisation: Place electrodes above abnormal excitation patterns and compare changes in EGM amplitude and morphology to the healthy case
- Baseline to MICROCARD project





Methods I

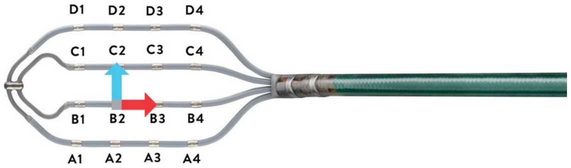
- Volumetric right atrial model from MRI patient data
- ~ 2.3 mio. tetrahedra with an avg. edge length of ~ 0.6 mm
- Applied different electric properties, depending on the atrial region
- Simulations: openCARP [1], visualisation: Meshalyzer [2]
- Ionic model: Courtemanche-Ramirez-Nattel [3]



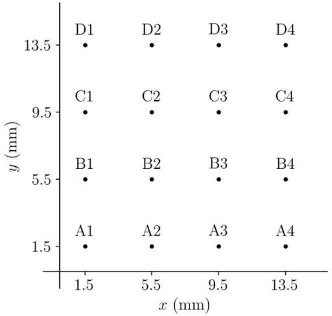
[1] Plank* et al., Comp. Meth. Prog. in Biomed. (2021)
[2] E. Vigmond et al., doi:10.35097/881 (2023)
[3] Courtemanche et al., Am. Journal of Phys. (1998)

Methods II

- Place 4 x 4 multielectrode array above excitation patterns to calculate uni- and bipolar EGMs



[4]



- uEGMs calculated via the **infinite volume conductor method**:

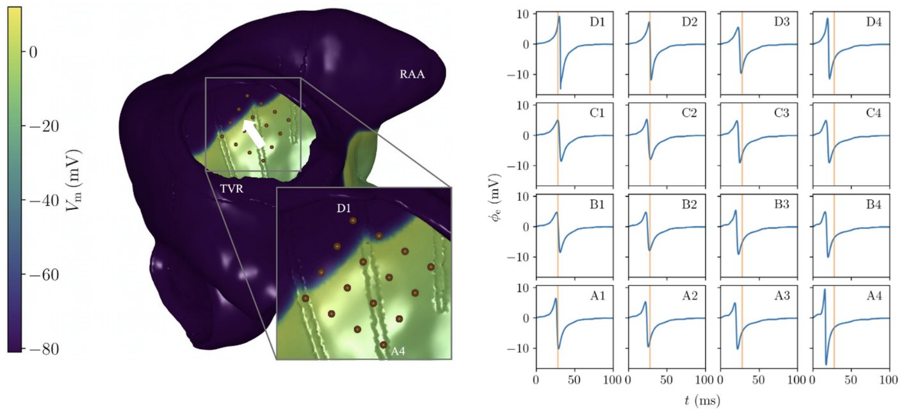
$$\phi_{\mathrm{e}} = \frac{1}{4\pi\sigma_{\mathrm{b}}} \int_V \frac{\sigma_{\mathrm{i}} \cdot \vec{\nabla} V_{\mathrm{m}}}{||\vec{x} - \vec{x}_{\mathrm{src}}||} \mathrm{d}V$$

$\sigma_{\mathrm{b}}, \sigma_{\mathrm{i}}$: bath & intracell. conductivity
V_{m}: transmembrane voltage
$||\vec{x} - \vec{x}_{\mathrm{src}}||$: electrode - source distance

- biEGMs calculated as the difference between two neighbouring uEGMs

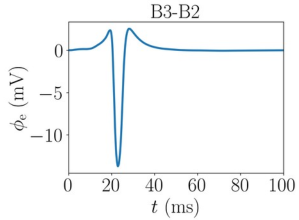
[4] Taken from https://www.cardiovascular.abbott/de/de/hcp/electrophysiology/advisor-hd-grid.html (last access 3rd July 2023)

Results: SIN Case

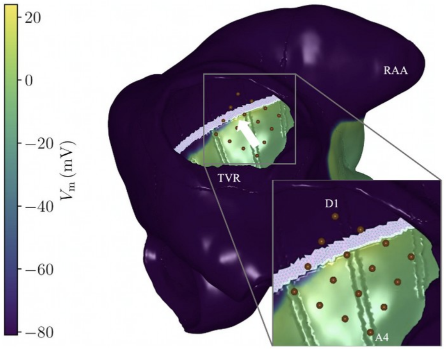


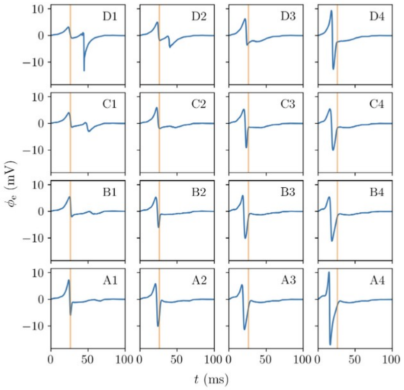
- Sinus rhythm: No abnormal excitation pattern
- EGMs: reference for the healthy case

- Fast activation along pectinate muscles, approx. plane wave propagation
- uEGMs (above): biphasic and almost symmetric
- biEGM (right): triphasic with pronounced minimum

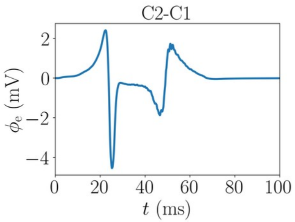


Results: Line of Block (LOB) Case

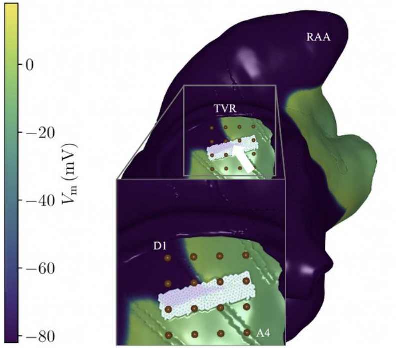


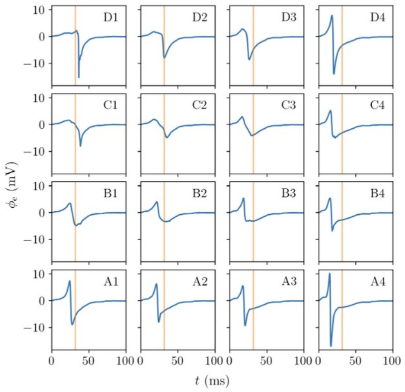


- Propagating wave collides with a non-conducting region ()
- uEGMs (above): Double potentials, lowered amplitude
- biEGM (right): Multiple deflections



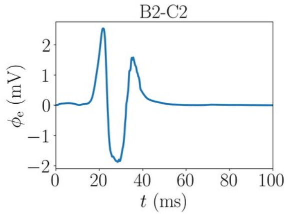
Results: Slow Conduction Zone (SCZ) Case



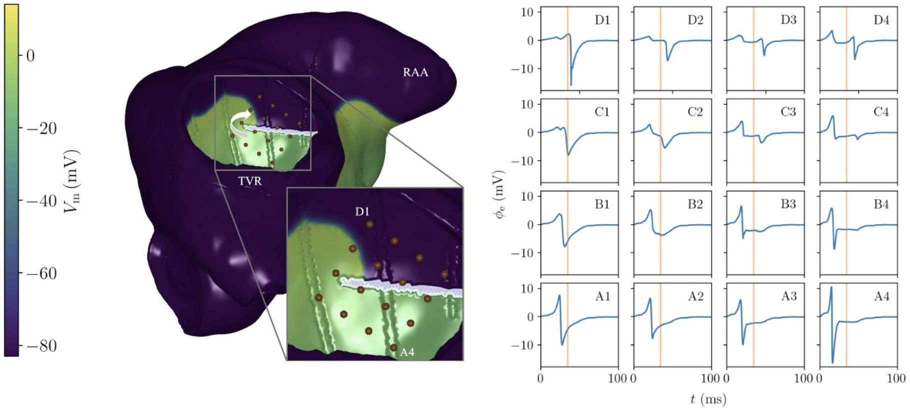


- Wave collides with a slowly-conducting region (), still allowing for excitation propagation

- uEGMs (above): Small deflections, severe reduction in amplitude
- biEGM (right): Triphasic, non-symmetric



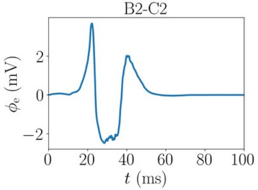
Results: Pivoting (PIV) Wave Case



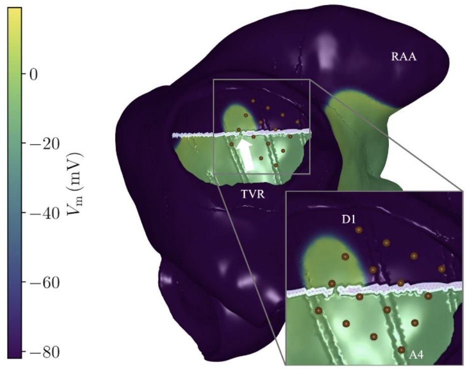
- Wave needs to circumvent a non-conducting block

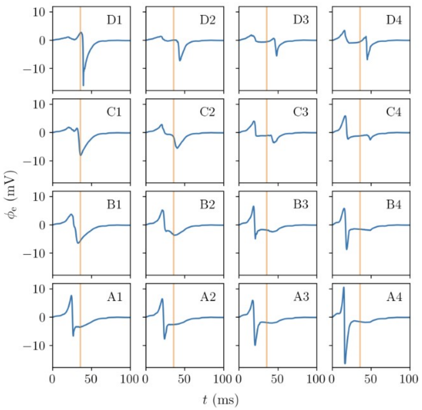
- uEGMs (above): Double potentials after the LOB

- biEGM (right): Triphasic, non-symmetric



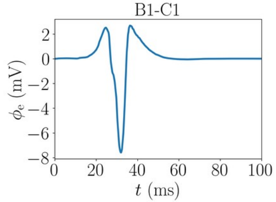
Results: Propagation Through GAP Case





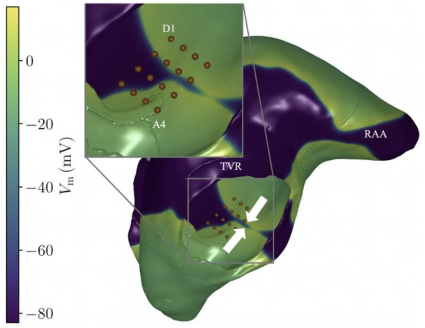
- Wave propagating through a conducting gap in a LOB

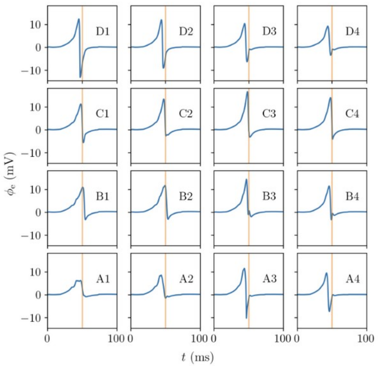
- uEGMs (above): Double potentials after the LOB, reduced amplitudes



- biEGM (right): Triphasic, almost symmetric

Results: Two Colliding (COL) Waves Case

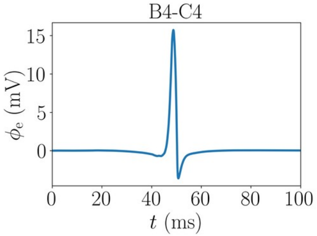




- Two wave fronts colliding (SIN wave with ectopic beat from right pulmonary vein)

- uEGMs (above): Almost single-phasic

- biEGM (right): biphasic with pronounced R-peak



Discussion and Conclusion

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- Could **reproduce important features** of clinical EGMs for all patterns (e.g. double potentials in uEGMs for the LOB or multiple deflections in the SCZ case found in EAM)
- However, **fractionation not properly reproduced** as well as e.g. narrowly spaced biEGMs for the PIV case
- In principle capable of correctly simulating EGM properties but not with all desired details requires follow-up studies

Outlook: Improvements in Further Studies

- **Finer (subcellular) mesh** resolution using the EMI model [5] contribution to MICROCARD

- More **properly reproduce characteristics** of e.g. non-conducting blocks (intermediate zones that decelerate the wave before it collides with the block)

- **More sophisticated EGM calculation approaches** [6]

- Considering spatial extension of the electrode [7]

[5] Tveito et al., Springer Briefs on Computing (2020)
[6] Bishop et al., IEEE Trans. on Biomed. Eng. (2011)
[7] Nairn et al., Comp. in Cardiol. (2020)

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