An In-Silico Coupled Electromechanical Model to Identify Arrhythmogenic Patterns in Mitral Valve Prolapse

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Introduction

- **Background.** A subset of MVP (A-MVP) develops ventricular arrhythmias and SCD risk despite minimal MR.
- **Signatures.** Inferior-lead T-wave inversion; modest QTc/Tp–Te prolongation; increased mechanical dispersion (MD); focal fibrosis on LGE in papillary/inferobasal LV.
- **Objective.** Build a patient-specific, coupled EP–EM model that *reproduces and identifies* arrhythmogenic patterns and enables an inverse retrieval of segmental substrate from ECG + CMR/LGE.

Methods

Overall patient-to-model pipeline.

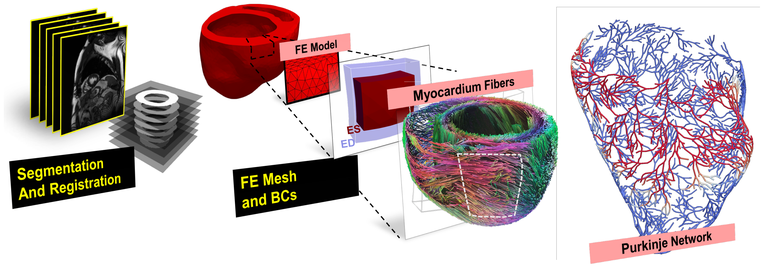

Figure 1. Cine CMR → segmentation/registration → FE mesh/BCs → rule-based fibers → endocardial Purkinje network.

Cohort & input data.

Imaging & preprocessing.

Minimal model equations (short form).

$$C_m \dot{V}_m = \nabla \cdot (\mathbf{D} \nabla V_m) - I_{\text{ion}} + I_{\text{stim}},$$
$$T_{\text{active}} = f(v, \lambda), \ \lambda = \sqrt{\mathbf{f}_0 \cdot \mathbf{C}\, \mathbf{f}_0},$$
$$\nabla_x \cdot (\mathbf{FS}) + \mathbf{b}_0 = \rho_0 \ddot{\mathbf{u}}.$$

Methods *(contd.)*

Pseudo-ECG.

Mechanical dispersion (cine FT).

Inverse identification (segment-level).

$$\min_{\boldsymbol{\theta}} \sum_{\ell} \left\| E_{\text{sim}}^{(\ell)}(\boldsymbol{\theta}) - E_{\text{obs}}^{(\ell)} \right\|^2 + \alpha \left\| \mathbf{TTP}_{\text{sim}}(\boldsymbol{\theta}) - \mathbf{TTP}_{\text{CMR}} \right\|^2 + \beta\, \mathrm{TV}\big(\mathrm{APD}(\boldsymbol{\theta})\big) + \gamma\, \Phi\big(\mathrm{APD}; S(\mathbf{x})\big),$$

where Φ is an LGE-weighted smoothness prior and ℓ emphasizes II/III/aVF.

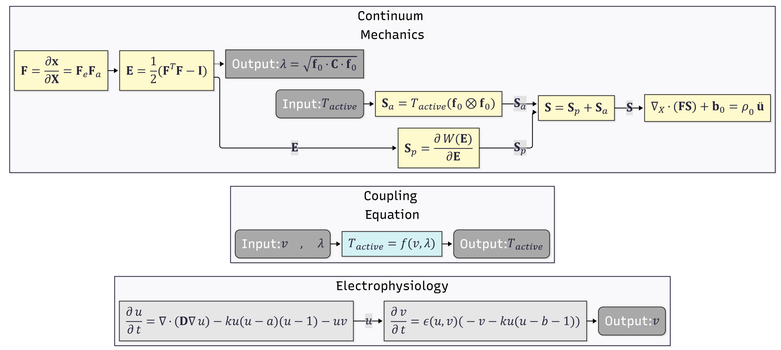

Figure 2. Coupling of the electromechanical problem

Results

Patient-specific LV model, fibers, and Purkinje (visual).

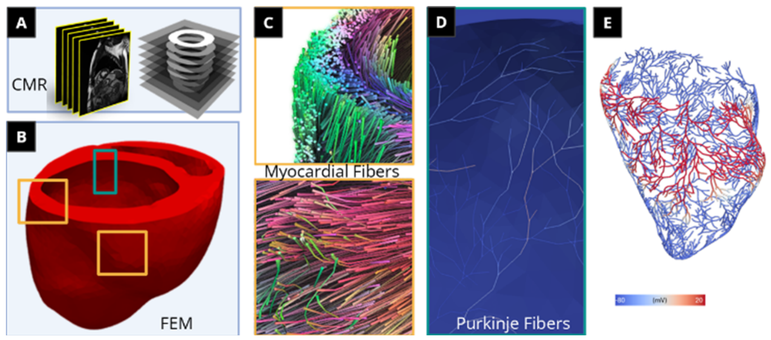

Figure 3. CMR→mesh, rule-based helix-angle fibers, and simplified endocardial His–Purkinje network.

Results *(contd.)*

Electrical remodeling comparison (placeholder).

Discussion

LGE→fibrosis→electrical & mechanical impact.

Conclusion

A coupled, patient-specific EP–EM framework calibrated to ECG and cine/LGE reproduces hallmark A-MVP findings and supports an LGE-regularized inverse workflow to *identify* arrhythmogenic patterns for risk stratification and post-repair tracking.

References

1) Essayagh B, et al. *J Am Coll Cardiol* (2020) — Arrhythmic MVP phenotype and risk.
2) Haugaa KH, et al. *JACC Imaging* (2010) — Mechanical dispersion and arrhythmic risk.
3) Holzapfel & Ogden (2009) — Myocardial constitutive modeling; monodomain/forward ECG basics.

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