Heart failure patient stratification via estimation of myocardial tissue properties

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Background

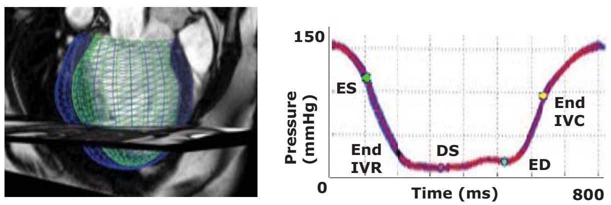
Heart failure (HF) is clinically categorised according to reduced or preserved ejection fractions (EF) of the left ventricle (LV) as a measure of pumping performance. However there is large heterogeneity in the underlying tissue level causes of HF. [1]

Aims

- Integrate magnetic resonance (MR) image and pressure measurement from catheterisation.
- Estimate subject-specific myocardial tissue passive and contractile parameters.
- Compare parameters estimated for normal and diseased subject groups.

Methods

- Nine patient cases with dilated cardiomyopathy (DCM) and four normal cases were analysed.
- MR images were segmented to extract LV geometries throughout cardiac cycle and derive LV finite element model of geometry at diastasis. (Fig. 1A)
- LV pressures were extract from catheter measurements. Temporally aligned pressure traces with MR frames using valve timing. (Fig. 1B)
- LV mechanics was simulated using the aligned pressure traces as loading constraints, and the constitutive models given in Fig. 1C.
- Passive tissue properties and contractile tension transients were estimated to best match the simulated LV geometries with those tracked from the MR images throughout the cardiac cycle.



Passive:

$$W = C_1 e^Q$$

where $Q = C_2 E_{ff}^2 + C_3(E_{cc}^2 + E_{rr}^2 + 2E_{cr}) + 2C_3(E_{fc}E_{cf} + E_{fr}E_{rf})$

Contractile:

$$T_a = T_{Ca}(1 + \beta(\lambda - 1))$$

C

Figure 1: (A):Finite element model of LV geometry extracted from MR images (using Cardiac Image Modeller). (B): Beat-averaged pressure temporally aligned with MR images. (C): Constitutive equations used in modelling: transversely isotropic equation [2], and active tension equation [3].

Results

- DCM cases had elevated myocardial tissue passive stiffness (C_1) in comparison with normal cases.
- There was no statistical difference in the maximum tissue contractile stress (T_{Ca}) between normal and DCM cases.
- The temporal profile of the contractile stress is similar to that of the LV pressure .

	Normal	DCM	T-test p-value
Preload (kPa)	0.5±0.2	1.4±0.6	0.0068
C1 (kPa)	1.1±0.1	6.6±3.6	0.013
Afterload (kPa)	14±1.9	14±3.2	0.90
Max. T_{Ca} (kPa)	71±15	83±15	0.21

Table 1: Averaged estimated passive and contractile parameters for the two subject groups with pressure at end diastole (preload) and end systole (afterload).

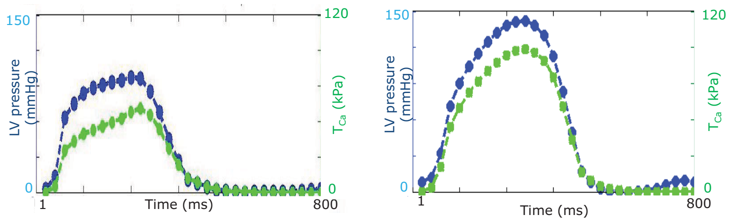


Figure 4: T_{Ca} transients (green) overlaid with LV pressure (blue). One case from each of normal (left) and DCM (right) shown.

Conclusions

- DCM and normal subjects could be stratified using myocardial tissue passive stiffness parameters.
- Novel method using subject-specific pressure measurements allowed per-frame estimation of contractile stress transients and gives insight for myocardial contractile stress development.

Future work

- Analyse larger sample sizes for more conclusive statistical analyses for stratification.
- Estimation of patient-specific passive and contractile tissue properties has potential for assisting in making clinical decision for the treatment of HF.

References

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[2] Guccione J. et al. J. Biomech. Eng. 113(1) (1991)

[3] Hunter P.J. et al. Prog. Biophys. Mol. Biol. 69(2-3) (1998)

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