SHAPE, MOTION AND DEFORMATION ANALYSIS OF 2D ECHOCARDIOGRAPHIC SEQUENCES EXAMPLES OF APPLICATION TO THE CHARACTERIZATION OF MYOCARDIAL (DYS)FUNCTION

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1. INTRODUCTION

- Clinical applicability of myocardial motion and deformation comparison techniques remains limited → difficulty to comprehend how these features interrelate and how they can be interpreted to refine the clinical diagnosis.
- Classical measurements are extremely determined by the way they were carried out

  → difficulty to get a second medical opinion

  → interference with the personal health record (PHR) initiative.

2. OBJECTIVES

- Illustrate the use of 2D ultrasound (US) cardiac motion sequences on some typical cardiac pathologies.
- Create a computer program to obtain and visualize information about myocardial shape, motion (displacement and velocity) and deformation (strain)

3. METHODS

Data exportation and pre-processing

- Data from 2D ultrasound (US) sequences (4-chamber view) of *Hospital Clínic de Barcelona*: 2 healthy volunteers, 1 patient with left-ventricular dyssychrony and 1 patient with hypertrophic cardiomyopathy.
- Declaration of Helsinki was approved by the Local Ethics Committee, and informed consent was obtained from each participant.

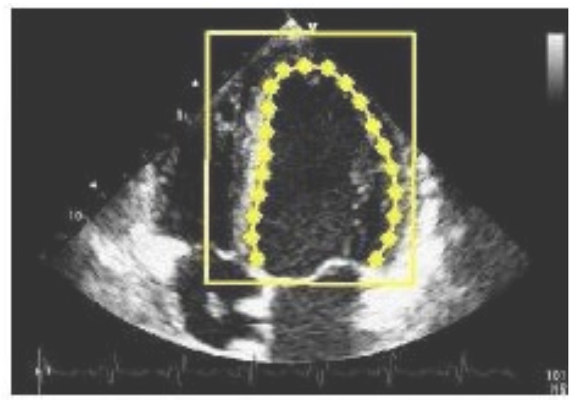


Figure 1: The myocardial wall has been automatically tracked along the 2D US-sequences using a speckle tracking algorithm from commercial software (Echopac software v.110.1.2, GE Healthcare, Milwaukee, WI, USA).

- The myocardial wall has been automatically tracked
- Drift correction was applied
- The data were temporally aligned

Data visualization

The different parameters for the characterization of myocardial (dys)function have been visualized in three different ways: imagesc MATLAB function, plotshaded function and surf function (**Figure 2**).

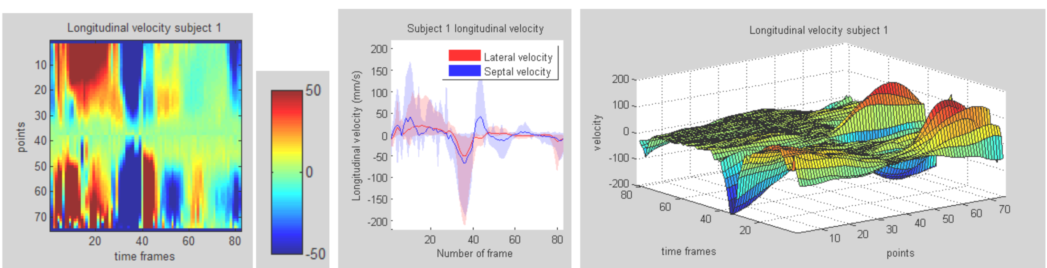


Figure 2: Example of the three methodologies of visualization used for longitudinal velocity of subject 1 (from left to right: *imagesc*, *plotshaded* and *surf* function).

Local system of coordinates: longitudinal and radial directions at each point of the myocardium

- 2 different coordinate systems:

  → radial-fiber-crossfiber coordinate system

  → radial-circumferential-longitudinal (RCL) coordinate system **(Figure 3)**

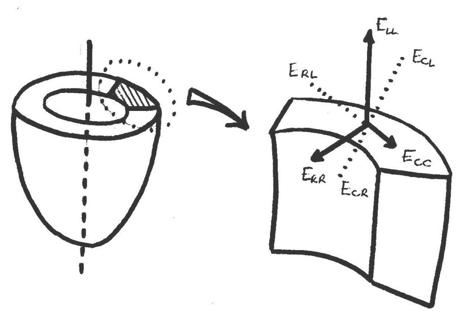


Figure 3: Schematic diagram demonstrating the RCL coordinate system.

- The longitudinal direction at each point of the myocardium and at each instant of the cycle is computed using a centered scheme:

$$\Delta_{long}(x_i,t_j)=\frac{\varphi(x_{i+1},t_j)-\varphi(x_{i-1},t_j)}{2}$$

$$e_{long}=\frac{\Delta_{long}}{|\Delta_{long}|}\ if\ i<\frac{number\ of\ points}{2}$$

$$e_{long}=-\frac{\Delta_{long}}{|\Delta_{long}|}\ if\ i\geq\frac{number\ of\ points}{2}$$

The radial direction e_{radial} corresponds to the longitudinal rotated by 90 degrees:

$$e_{radial}=\begin{bmatrix}0 & -1\\ 1 & 0\end{bmatrix}\times e_{long}$$

The output of these computations is illustrated on subject 1 at end-diastole **(Figure 4)**:

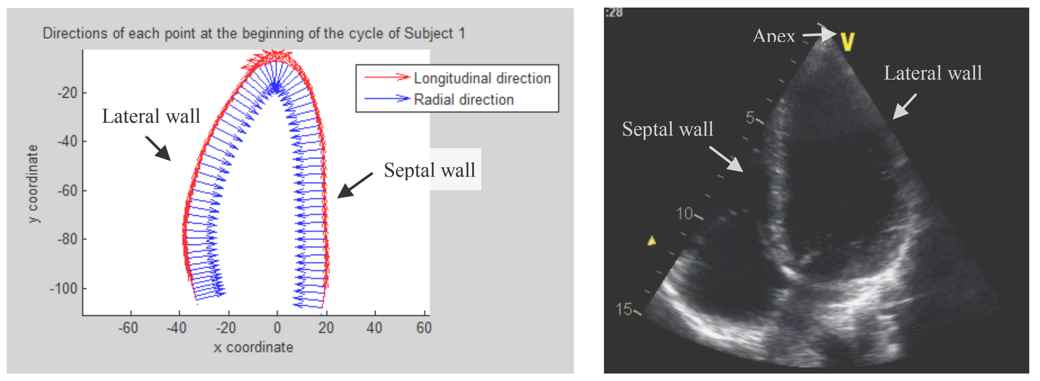


Figure 4: On the left, longitudinal and radial direction of subject 1 at each point of the myocardium. On the right, the real 2D ultrasound (US) sequences. Apex, septal and lateral walls are indicated in the figures.

4. RESULTS

4.1 Cardiac shape

Myocardial shape at the beginning of the cycle, at end-systole and end-diastole

Myocardial shape is used to compare the different subjects at concrete time frames of the cardiac cycle.

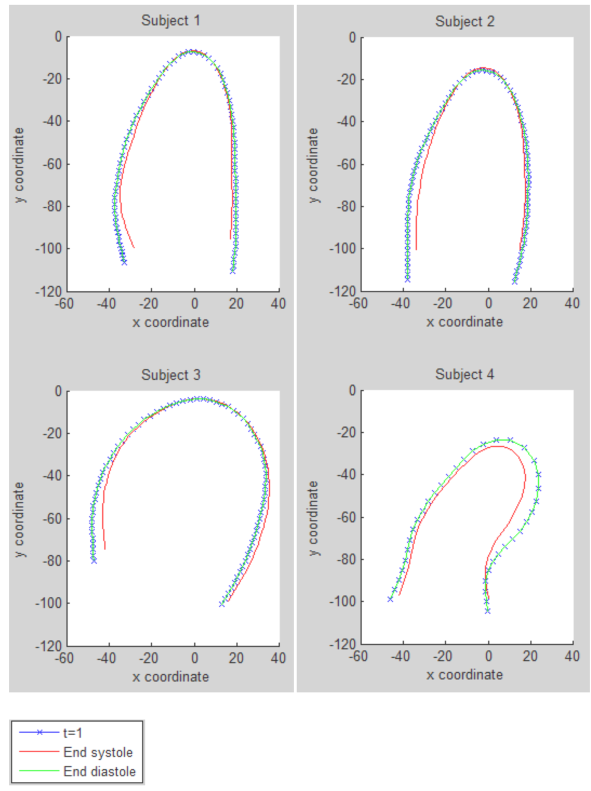


Figure 5: Myocardial shape at the beginning of the cycle, at end-systole and end-diastole for each of the subjects.

Length of the entire myocardial shape at end-systole (LES), end-diastole (LED) and ratio

In order to compute the total length of the entire myocardial shape at a concrete instant of time:

$$\Delta long_{x(j=83,i)}=\frac{\varphi_{x(j=83,i+1)}-\varphi_{x(j=83,i-1)}}{2}$$

$$\Delta long_{y(j=83,i)}=\frac{\varphi_{y(j=83,i+1)}-\varphi_{y(j=83,i-1)}}{2}$$

$$|\Delta long_{(j=83,i)}|=\sqrt{\Delta long_x^{\,2}+\Delta long_y^{\,2}}$$

$$L_{ED}=\sum_{i=1}^{No\ points}|\Delta long_{(j=83,i)}|$$

	L_{ED} (mm)	L_{ES} (mm)	Ratio (%)
Subject 1	221.441	198.368	0.104
Subject 2	218.212	188.193	0.138
Subject 3	216.531	208.605	0.037
Subject 4	189.043	167.113	0.116

Table 1: Length of the entire myocardial shape at end-systole (L_{ES}), end-diastole (L_{ED}) and ratio for each of the subjects.

4.2 Cardiac motion: displacement and velocities

Radial and longitudinal displacement

The displacement in Cartesian coordinates at each point x_i and time t_j is calculated as the difference in position between times t_j and t_0:

$$\begin{bmatrix}u_x(x_i,t_j)\\ u_y(x_i,t_j)\end{bmatrix}=\begin{bmatrix}\varphi_x(x_i,t_j)-\varphi_x(x_i,t_0)\\ \varphi_y(x_i,t_j)-\varphi_y(x_i,t_0)\end{bmatrix}$$

Then, its radial and longitudinal components are computed as follows:

$$\begin{bmatrix}u_r\\ u_l\end{bmatrix}=P^{-1}\begin{bmatrix}u_x\\ u_y\end{bmatrix}\ where\ P=\begin{bmatrix}e_{radial\ x} & e_{long\ x}\\ e_{radial\ y} & e_{long\ y}\end{bmatrix}$$

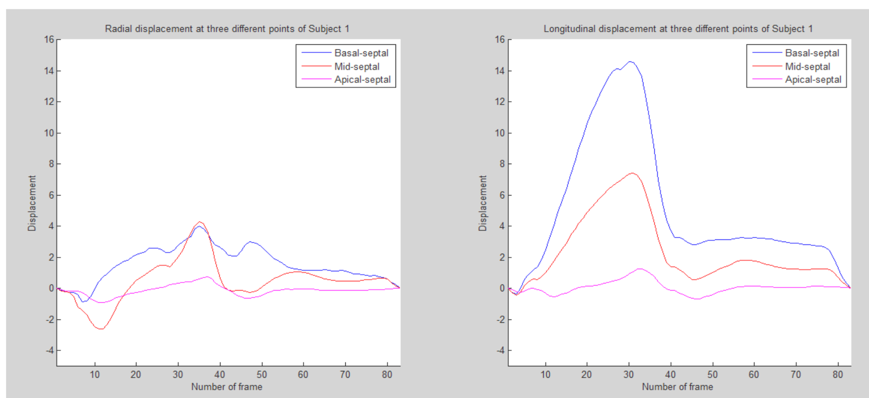


Figure 6: Radial and longitudinal displacement data (mm) along the whole cycle for subject 1 at basal-septal, mid-septal and apical-septal locations.

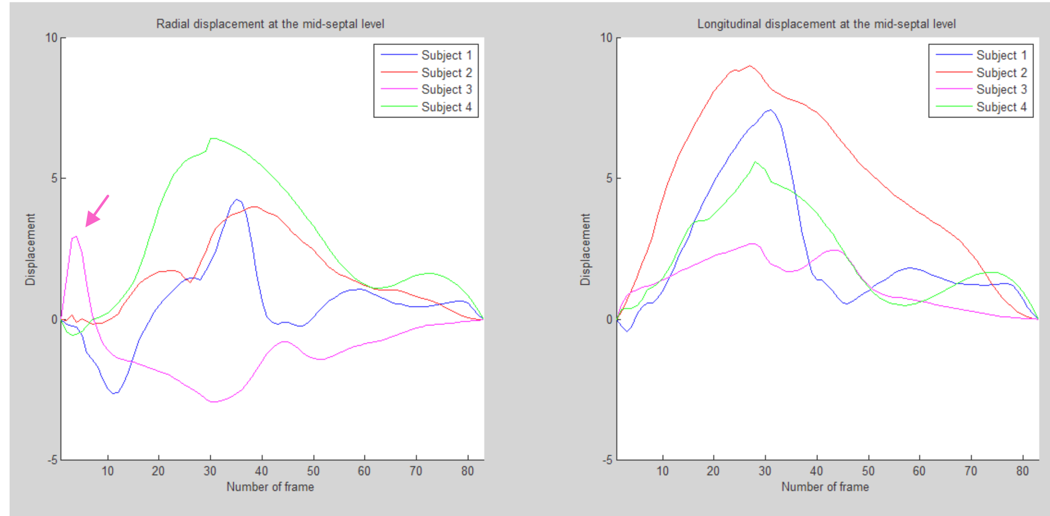


Figure 7: Radial and longitudinal displacement data (mm) along the whole cycle for each of the subjects at mid-septal level. Observe that subject 3 has little displacement, with an abnormal motion in the radial direction the beginning of the cycle: septal flash (arrow), as described in Parsai et al.

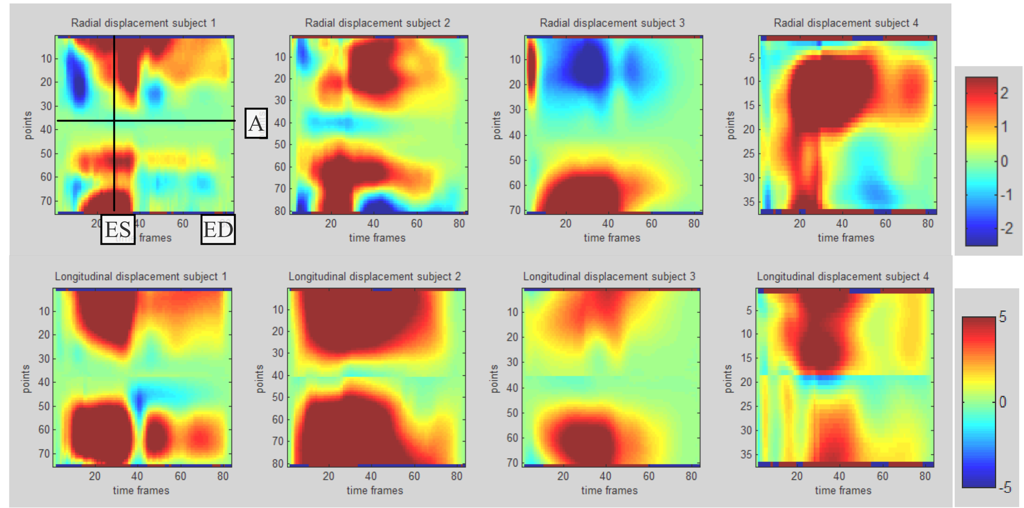


Figure 8: Spatiotemporal representation of radial and longitudinal displacement for each of the subjects using *imagesc* function. "ES" corresponds to "End-Systole" always at time frame 27, "ED" corresponds to "End-Diastole" at t = 83 and "A" corresponds to "apex" (lowest superficial part of the heart).

Radial and longitudinal velocity

Myocardial velocities are obtained from the temporal derivative of displacements:

$$\begin{bmatrix}v_r\\ v_l\end{bmatrix}=\begin{bmatrix}\frac{d(u_r)}{dt}\\ \frac{d(u_l)}{dt}\end{bmatrix}$$

which has been calculated as follows:

$$\begin{bmatrix}v_r(x_i,t_j)\\ v_l(x_i,t_j)\end{bmatrix}=\begin{bmatrix}\frac{u_r(x_i,t_j)-u_r(x_i,t_{j-1})}{time\_interval}\\ \frac{u_l(x_i,t_j)-u_l(x_i,t_{j-1})}{time\_interval}\end{bmatrix}$$

where *time_interval* corresponds to the period of framing (*time_interval* = 0.01 s).

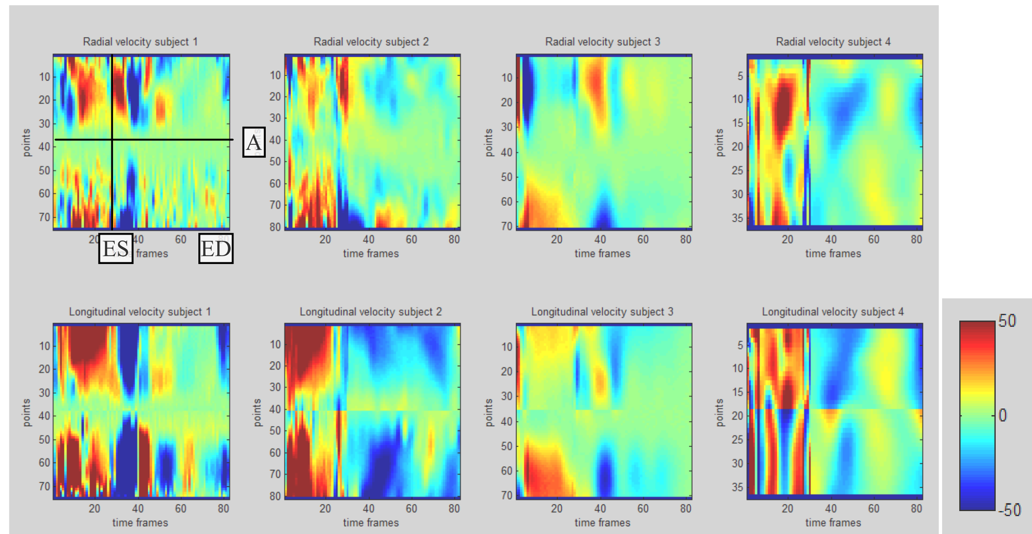
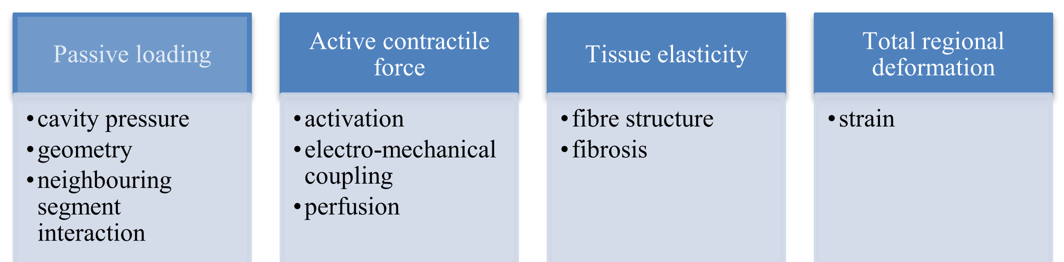


Figure 9: Spatiotemporal representation of radial and longitudinal velocity for each of the subjects using *imagesc* function. "ES" corresponds to "End-Systole" always at time frame 27, "ED" corresponds to "End-Diastole" at t = 83 and "A" corresponds to "apex" (lowest superficial part of the heart).

4.3 Cardiac deformation: longitudinal strain

- Deformation is caused by the pressure (exerted by the wall stress), the strength of the neighboring areas of the wall and, principally, the active contraction of the heart muscle (**Figure 10**).



$$WallStress_{passive}(t)-ContractileForce_{active}(t)=Elasticty\times Deformation(t)$$

Figure 10: Relationship between local forces and deformation.

- Lagrangian strain has been chosen and calculated as follows:

$$\frac{|\Delta_{long}(x_i,t_j)|-|\Delta_{long}(x_i,t_0)|}{|\Delta_{long}(x_i,t_0)|}\qquad E_{RCL}=\begin{bmatrix}E_{r,r} & E_{r,l}\\ E_{l,r} & E_{l,l}\end{bmatrix}$$

Observe that the formula corresponds to how an element defined by a longitudinal neighborhood elongates in the longitudinal direction. Therefore, it corresponds to the component $E_{l,l}$ of the strain tensor .

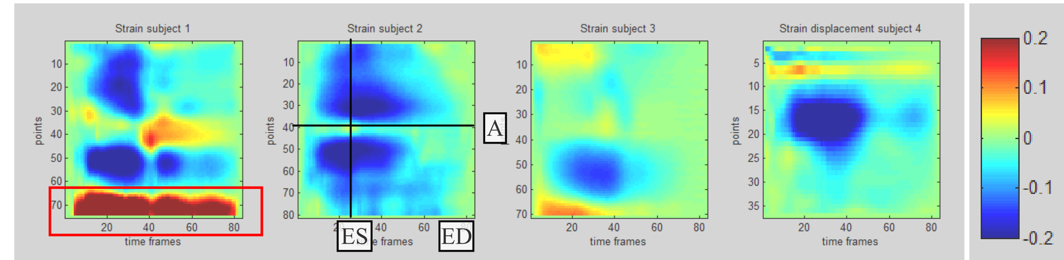


Figure 11: Spatiotemporal representation of strain for each of the subjects using *imagesc* function. Marked in red, a little artifact of the data (probably caused by the mitral valve influence on the speckle tracking accuracy).

4.6 Clinical experts US sequences interpretations

The interpretation based on the features (motion and deformation) was corroborated with other analysis techniques such as electrocardiogram (ECG) and visual interpretation by experienced clinical observers.

- Subjects 1 and 2 → images and the ECG seemed to be normal (no indications of thrombi or any other evident pathology)
- Subject 3 → ventricular low mobility and increased atria (not enough information for a proper clinical interpretation)
- Subject 4 → a case of hypertrophic cardiomyopathy (the thickness of the septum and auricles wall is increased)

5. CONCLUSIONS

- The computer program written in MATLAB proved its usefulness.
- The study performed was just an example of the potential of the computational analysis to the characterization of myocardial (dys) function. → the methodology proposed could be applied to any type of medical images.
- The computational analysis of 2D echocardiographic sequences is an approach of great interest that provides a vast quantity of information to the specialist, not only quantitative but also objective, which grants to this technique a promising future in the diagnostic field.

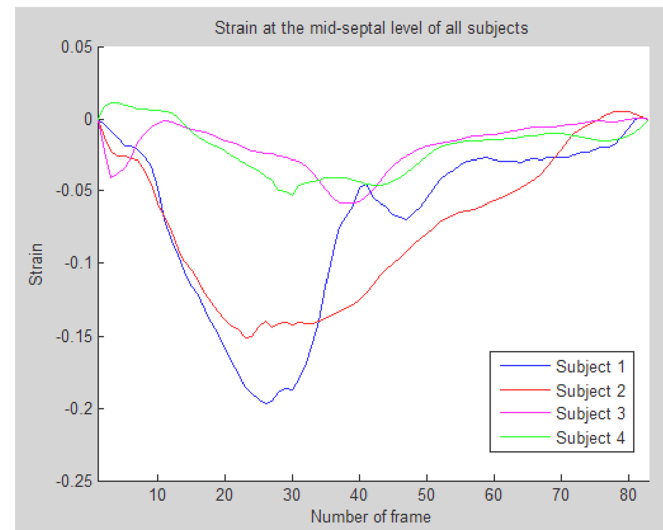


Figure 12: Strain for each of the subjects during the whole cardiac cycle at mid-septal level.

6. FURTHER WORKS

- Have a deeper understanding of the patterns, their variability within a healthy or unwell population and how they can evolve under treatment or due to certain pathology.
- Perform a detector of anomalies (advanced statistical tools for analyzing populations may be also useful to reach a statistical definition of "normal" ranges).

7. ACKNOWLEDGMENTS

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