Tracking of myocardial walls and study of contractility and thickening

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Abstract. The study of cardiac muscle contractility is fundamental in the evaluation of cardiac function. We propose a continuous measure of contractility based on segment thickening in echocardiographic contrast B-mode time series. Thickness is computed with the symmetric nearest neighbour distance method from the inner to the outer myocardial walls. Preliminary results from 2 studies are compared to nominal scoring by an expert and illustrate how this measure can be useful in the detection of hypokinetic segments.

1 Introduction

Contractility is a term that in cardiology refers to the ability of the cardiac muscle (myocardium) to shrink and stretch to pump blood with the right preassure and timing. Multiple cardiac pathologies produce abnormal regional contractility that, if detected, is of critical importance for diagnosis and may enable preemptive treatment. Of special interest are non-invasive methods, amongst which transthoracic echocardiography (or standard echo) is one of the most widely used because of its safety, speed, low cost and lack of magnetic radiation. Transthoracic echocardiography is a medical data acquisition technique based on ultrasound waves that are sent from a transducer placed on the chest so that they intersect the heart. By processing the sound wave echoes caused by acoustic impedance mismatches it is possible to obtain structural, motion or velocity information of heart tissues and fluids. In the case of standard echo, the left ventricle (LV) is favoured over other cavities in research, not only because the oxygen-rich blood is pumped out from it at high pressure into the arteries and is the part of the heart most likely to have a problem, but also because it is most conveniently positioned near the probe. There is not a unique quantitative measure for contractility, so several indirect parameters are targeted for its assessment, for example the Ejection Fraction (EF, the fraction of end-diastolic volume ejected in systole by the LV), inner wall (endocardial) wall motion i.e. excursion or velocity, myocardium thickening and strain. See e.g. García-Fernández et al. [1] for a review. Other authors work with intraventricular preassure gradients [2] or tissue texture classification [3], although the latter requires invasive catheterization for the probe.

Contractility problems appear generally in local neighbourhoods of the myocardium. Global parameters such as the EF are unsuitable for detecting myocardial defects, as the heart can compensate for a local damaged region by making the rest work harder so that the global function is not affected. Such a measure can also not locate where the problem is. Other parameters such as wall motion, thickening and strain are implicitily local, but they are generally averaged for a given myocardial segment, rather than evaluated in the muscle as a continuous function. There are segment models with 9 to 20 segments, although the commonest in echocardiography is the 16-segment model [4]. In clinical practice, assessment of segment contractility is performed with the nominal method of scoring, where each segment is classified into one of the following categories: normokinetic (healthy), hypokinetic (reduced contractility), akinetic (dead) and dyskinetic (when there is a paradoxic outward bulging during systole). Thus clinicians use an evaluation function f, such that $f : \Omega \mapsto \Phi$ where Ω is the discrete domain of segments and Φ is the discrete range of scoring. Jacob et al. [5] proposed functions f for the evaluation of endocardial excursion and myocardial thickening as $f : Q \mapsto \mathbb{R}$, i.e. the parameters are real variables evaluated over the discrete domain of B-spline control points Q. Contours are represented as uniform parametric B-splines with N control points for both the endocardium $\{Q_{\text{en},i}\}_{i=1}^{N}$ and epicardium $\{Q_{\text{ep},i}\}_{i=1}^{N}$, where Q_i are the cartesian coordinates of the i-th control point. Thickening for the two i-th corresponding control points $Q_{\text{Diff},i}$ is computed as the difference

$Q_{\text{Diff},i} = Q_{\text{ep},i} - Q_{\text{en},i}$. Thickening $Q_{\text{Diff},\omega}$ for a given segment $\omega \in \Omega$ is computed as $Q_{\text{Diff},\omega} = 1/J \sum_j Q_{\text{Diff},j}$, such that there are J control points $Q_{\text{Diff},j} \in \omega$. This approach has however some drawbacks: (1) Thickening for a segment would be better defined as $Q_{\text{Diff},\omega} = 1/J \sum_j \|Q_{\text{Diff},j}\|_2$. (2) We are limited to interpolating splines, i.e. control points are points of the curve, because only in this case is $Q_{\text{Diff},i}$ meaningful. (3) To increase the number of points for which thickening is measured, one has to increase the number of control points, and recompute the training set and the Principal Component Analysis for the new control points.

In this paper we propose a thickening measure to evaluate contractility based on the symmetric nearest neighbour method [6]. The details are provided below in section 2. We have tested this measure with 2 B-mode contrast echo studies, where each study represents a complete cardiac cycle. B-mode is an echocardiograpy modality where grey-scale time series of a two-dimensional plane across the heart are displayed on a screen. It is possible to enhance the signal-to-noise ratio of the B-mode image injecting a gas-filled microbubble suspension (called contrast agent) into the patient's blood stream. Contrast echo's safety and tolerance are extremely favourable and the technique is considered to be cost effective [7]. The inner and outer wall of the myocardium were segmented automatically with a prototype commercial tracker called Quamus®. This paper reports for the first time how this system can be used for epicardial as well as endocardial automatic tracking.

2 Contractility measure based on thickening

The tracker represents contours as interpolating uniform B-splines. These contours are sampled uniformly to obtain a vector of coordinates $p = (p_1 p_2 \dots p_N)$ for the the inner contour (endocardium) and a vector $r = (r_1 r_2 \dots r_M)$ for the outer contour (commonly called epicardium, although e.g. in 4C the outer wall is part LV epicardium and part right ventricle endocardium). We propose to use the distance measure obtained from applying the symmetric nearest neighbour (SNN) method [6] to the myocardial inner and outer wall contours to compute myocardial thickening as $T = T(p)$ such that

$$T(p_i) = \|p_i - r_j\|_2 \tag{1}$$

where p_i and r_j are correspondent points. The reason to use p rather than r is that in B-mode time series the uncertainty in the segmentation of the inner wall is lower than in the outer wall. Thus clinicians work with a domain of segments Ω (typical dimension for the 4C plane is 6 elements), Jacob et al. [5] work with a domain of control points Q (typical dimension is 24), and our approach works with a domain of any sampling p of the endocardial contour (typical dimension is 300). The SNN method finds a correspondence between p and r. First, for each point p_i in the endocardium, the nearest neighbour r_j in the epicardium is obtained. Then, if $p_l = p_i$, where p_l is the nearest neighbour of r_j in the endocardium, we say that p_i and r_j are symmetric nearest neighbours and the match is kept. In a second run, a correspondence is computed for the sets of K consecutive unmatched points $p_{i+1}, \dots, p_{i+K}$, drawing equally spaced points in the epicardium, between the points r_j and r_{j+K+1}. In the two test studies, we have got between 20% and 30% of symmetric nearest neighbour points from a total of $N = M = 300$ points for each contour in every frame. Figure 1 shows an example of the distance measure between the inner and outer walls of the myocardium as seen in a 4C view. In this figure we can see a line that links every $p_i \in p$ to its correspondent point $r_j \in r$. $T(p_i)$ is the length of that line. Finally, we propose to evaluate contractility C as the ratio between maximum thickening $T_{\max}$ and thickening in end-diastole T_{ED}.

$$C(p) = \frac{T_{\max}(p)}{T_{\text{ED}}(p)} \tag{2}$$

3 Experimentation and Results

Quamus® has previously been validated against expert hand tracing and cine-MRI [8] for endocardial tracking. We have used it to track the epicardium in the 2 test studies too, and to assess its performance we have compared automatic tracking to a single expert hand tracing in 3 planes: 2 chamber (2C), 3 chamber (3C) and 4C. The SNN method described in the previous section was used to find the distances between contours. The results are

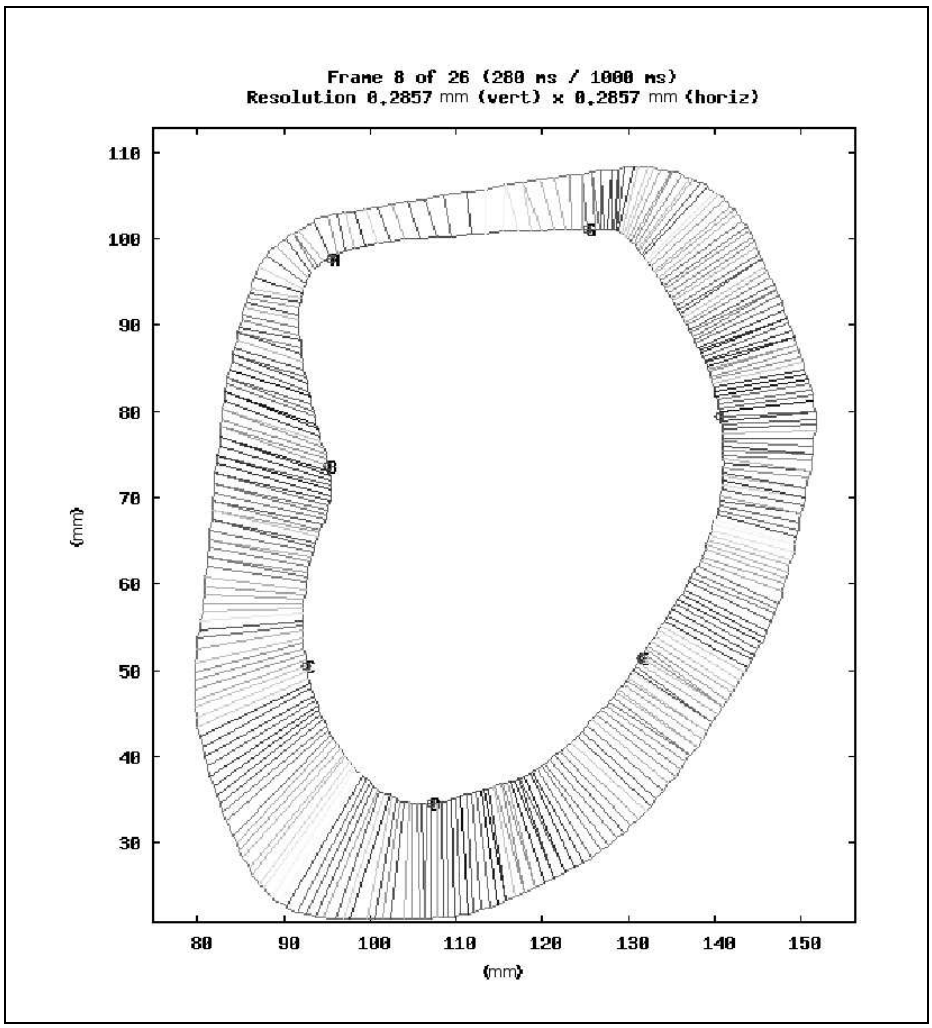

Figure 1. Distance between two contours computed with the symmetric nearest neighbour method for a frame of a 4C view. Lateral wall is on the right, septum is on the left, apex is at the bottom and the base is on top.

summarized in Table 1. The variability for automatic tracking with 2 different initializations of the tracker was found to be between 0.79 mm and 1.05 mm. The variability for a human expert drawing the same epicardial contours 2 weeks later (intraobserver variability) is between 0.94 mm and 1.32 mm. Thus the automatic tracker is more consistent in its results than the human expert. The variability between hand traced contours, that we use as our pseudo-gold standard, and automatic tracked contours, is between 1.18 mm and 1.46 mm, a result that in the worst case is only a 10.6% bigger than intraobserver variability. There is, to our best knowledge, no continuous real measure of contractility based on thickening against which we can validate the one that we propose in Equation 2. To illustrate how the proposed measure can be used for diagnosis, we divided the myocardium in the 4C plane into 6 segments following the 16-segment model [4]. For each segment ω we average the thickening of all the endocardial points $p_i \in \omega$ such that $\bar{T}(\omega) = 1/L_\omega \sum_{L_\omega} T(p_i)$ where L_ω is the number of endocardial points that belong in segment ω. Then contractility $C(\omega)$ was computed for each segment as in Equation 2. This value is compared to the scoring value assigned to that segment by an expert observer in Table 2. The ratio (study 1)/(study 2) between $C(\omega)$ values for segments BS, MS and AS in the two studies is between 0.8 and 0.9, which shows good correlation, whereas for segments AL, ML and BL, that in the first study are normokinetic but in the second are hypokinetic, is between 0.4 and 0.5.

4 Conclusions

A quantitative measure for contractility based on myocardial thickening over a domain of any sampling of the endocardial contour has been proposed. Automatic tracking of the epicardium is only 10.6% worse and has better

Plane	A-A (mm)	H-H (mm)	A-H (mm)
2C	1.05	1.32	1.46
3C	0.79	1.13	1.28
4C	0.87	0.94	1.18

Table 1. Automatic epicardial tracking compared to expert hand tracing. A-A: Variability between automatically traced contours. H-H: Intraobserver variability. A-H: Variability between automatic and hand traced contours.

	BS	MS	AS	AL	ML	BL
study 1, Equation 2 (%)	108	157	171	117	110	131
study 1, scoring	N	N	N	H	H	H
study 2, Equation 2 (%)	136	175	186	225	272	265
study 2, scoring	N	N	N	N	N	N

Table 2. Comparision of contractility measure of Equation 2 to expert scoring in 4C plane. N: normokinetic. H: hypokinetic. The segments are: BS, MS, AS (basal, mid and apical septum) and AL, ML, BL (apical, mid and basal lateral).

reproducibility than expert hand tracing, according to some preliminary results, although it remains to perform an extensive validation. Finally, it has been illustrated how the proposed measure is consistent with evaluation by scoring in normokinetic and hypokinetic segments. The obvious next steps are to define the contractility function $C : [0, 1] \mapsto \mathbb{R}$, i.e. to define contractility over a normalized continuous parametrization of the endocardium rather than over a sampling, and to perform extensive validation in a larger clinical study with comparision with a gold standard.

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