Assessment of Cardiac Rotation by Means of Gyroscopic Sensors

E Marcelli[1], L Cercenelli[1], M Musaico[1], P Bagnoli[2], ML Costantino[2], R Fumero[2], G Plicchi[1]

[1]Università di Bologna, Bologna, Italy
[2]Politecnico di Milano, Milano, Italy

Abstract

During the cardiac cycle, contraction of the helically oriented myocardial fibers results in torsion, a wringing motion as the cardiac apex rotates with respect to the base about the Left Ventricle (LV) long axis. We evaluated in animals the use of gyroscopic sensors to quantify cardiac rotation, which was demonstrated to be a sensitive index of cardiac function. Three gyroscopes were epicardially glued at different levels along the LV long axis (apex, middle, base) to assess LV twist dynamics: Angular Velocity (Ang V) and Angle of cardiac rotation (Angle) were measured and evaluated against hemodynamic measurements of LV pressure (LVP, LVdP/dt), at baseline and after acute ischemia induced by coronary ligation. Results demonstrated the feasibility of assessing cardiac rotation and LV twist alterations by means of gyroscopic sensors, especially at apical level: compared with baseline, acute ischemia caused a significant decrease of both Angle and the maximum value of Ang V (mean variation of -37±6% and -21±4%, respectively); a concomitant reduction of $LVdP/dt_{MAX}$ (-43±4%) was observed.

1. Introduction

The myocardial structure of the Left Ventricle (LV) consists of obliquely oriented muscle fibers, which vary from a right-handed helix at the subendocardium to a left-handed helix at the subepicardium. During the cardiac cycle, contraction of these helically oriented fibers results in torsion, a wringing motion as the apex rotates with respect to the base about the LV long axis. The systolic rotation winds the heart muscle up like a spring, setting up recoil for early diastole. Apical rotation is the main cause of global LV systolic twist. Apical back-rotation also plays a dominant role in the subsequent diastole [1-3]. LV twist has been shown to provide a sensitive index of both systolic and diastolic ventricular function as well as of cardiac dysfunction [4-6]. Over the years, cardiac torsion has been quantified by several methods, including the use of multiple implanted markers and biplane cine angiography in transplanted hearts [7], optical devices [8] and, more recently, non-invasive techniques such as tagged Magnetic Resonance Imaging (MRI), Doppler Tissue Imaging (DTI) and Speckle Tracking Imaging [9-11]. As an alternative to these techniques, which are not suitable for chronic monitoring of LV dynamics, we recently proposed the use of a Coriolis force based gyroscopic sensor (gyro) to quantify LV twist [12-13].

In this study we report results from in vivo animal experiments performed to evaluate LV twist dynamics by the use of gyros.

2. Methods

Four adult sheep (58±4 Kg) were used for the study. All surgical procedures were performed in aseptic conditions and under general anaesthesia following a standardized protocol approved by the institutional animal care and use committee. The animal was placed in a right lateral decubitus position and surgically treated in order to gain proper access to the heart by performing a thoracotomy in the fifth intercostal space and incising the pericardium. A pressure catheter (Millar Instruments, Houston, Texas) was placed in the LV through the carotid artery to carry out hemodynamic measurements (LV pressure: LVP) which were used to derive the known index of cardiac function, LVdP/dt (the first derivative of LVP). In order to assess LV twist dynamics, three piezoelectric vibrating gyros (XV-3500CB, Epson Toyocom, Japan) were epicardially glued at different levels along the LV long axis: a) apical level (Gyro Apex); b) basal level (Gyro Base); c) middle level (Gyro Mid) [Fig.1].

Starting from a condition of normal myocardial function (baseline), a progressive impairment of cardiac function was obtained by ligation of the left anterior descending coronary artery. The ligation was maintained for 2 minutes and then released. A sequence of two consecutive 'ligation-release of ligation' was performed. For all experimental conditions Angular Velocity (Ang

V) signals, directly provided by the three gyros, and Angle of cardiac rotation (Angle) obtained integrating Ang V, were acquired and evaluated against hemodynamic measurements (LVP, LVdP/dt).

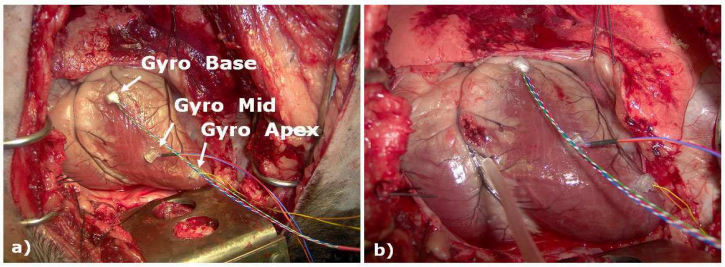

Figure 1. Epicardial positioning of gyro sensors at different levels along LV long axis: apical (Gyro Apex), middle (Gyro Mid), basal (Gyro Base) during in vivo animal trials; a) baseline cardiac condition; b) induction of acute ischemia by coronary ligation.

3. Results

The experimental results confirmed findings and observations about cardiac rotation reported in the literature for both normal and failing hearts. An example of Ang V and Angle waveforms resulting from the three gyros positioned epicardially along the LV long axis is reported in Figure 2. In all animals, a marked Angle reduction occurred during coronary ligation for both apical and middle level myocardial fibres; the gyro positioned at the base of the heart showed scarce rotational movement both at baseline and after coronary ligation [Fig. 3]. LV twist dynamics at apical level showed the most significant results [Fig.4].

Ang V and Angle measured with the gyro positioned at the cardiac apex were particularly sensitive to cardiac alterations and reflected variations in $LVdP/dt_{MAX}$. Attenuation of apex twist dynamics was observed after acute impairment of cardiac function caused by ligation of the coronary artery: both Angle and the maximum value of Ang V during systole – defined as Ang V_{MAX} – decreased from baseline (mean variation of -37±6% and -21±4%, respectively). The acute impairment of cardiac function induced by coronary ligation was demonstrated by a concomitant reduction of $LVdP/dt_{MAX}$ (mean variation of -43±4%) from baseline.

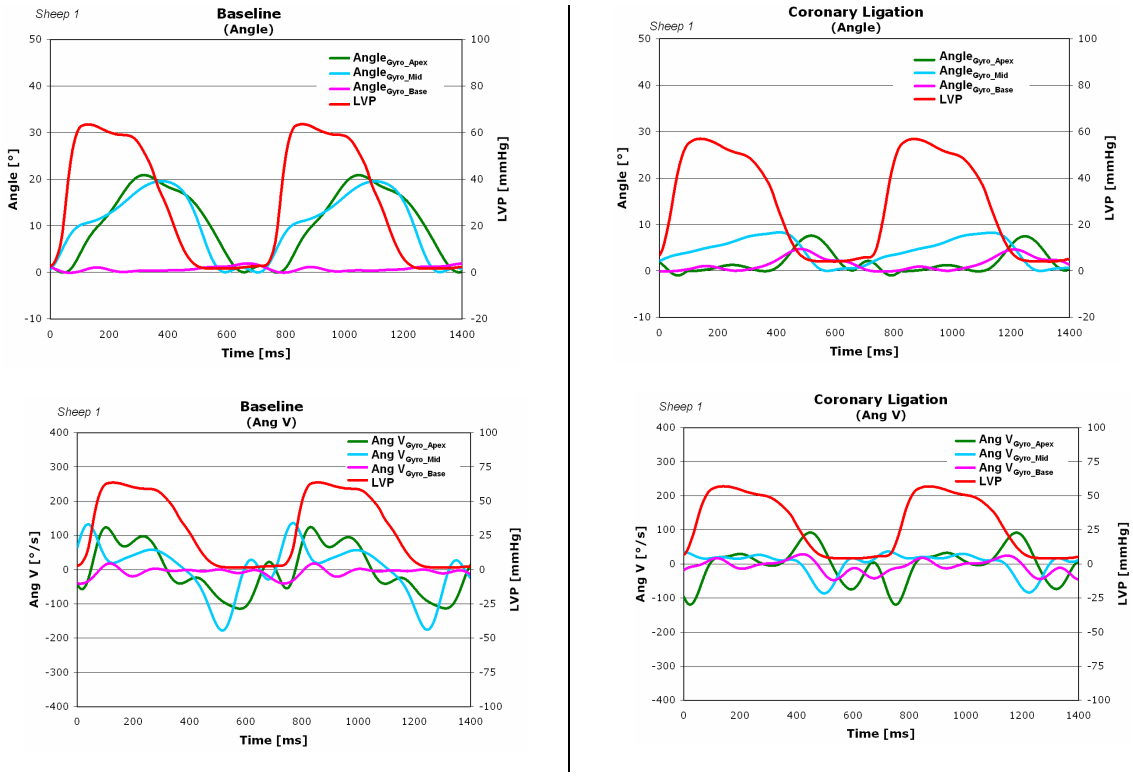

Figure 2. Waveforms of cardiac rotation (Angle, Ang V) assessed with gyros at different epicardial levels of LV long axis (Apex, Mid, Base), for two consecutive cardiac cycles, at baseline (*left*) and after coronary ligation (*right*).

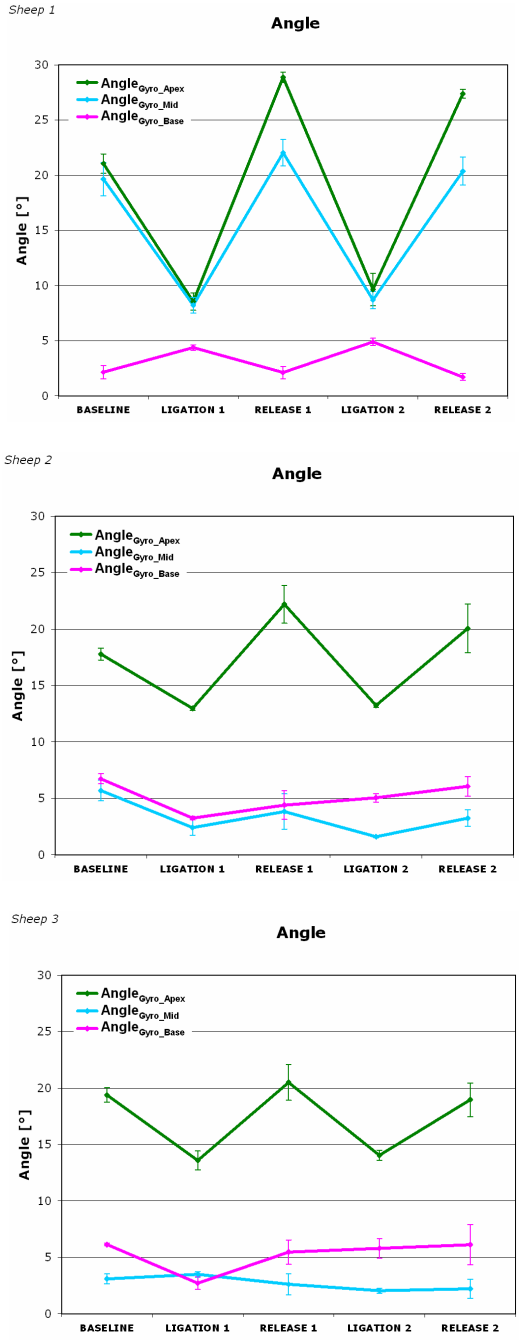

Figure 3. Trends of Angle of cardiac rotation assessed for the three different epicardial levels (Apex, Mid, Base), reported for the two consecutive sequences of coronary ligation-release of ligation.

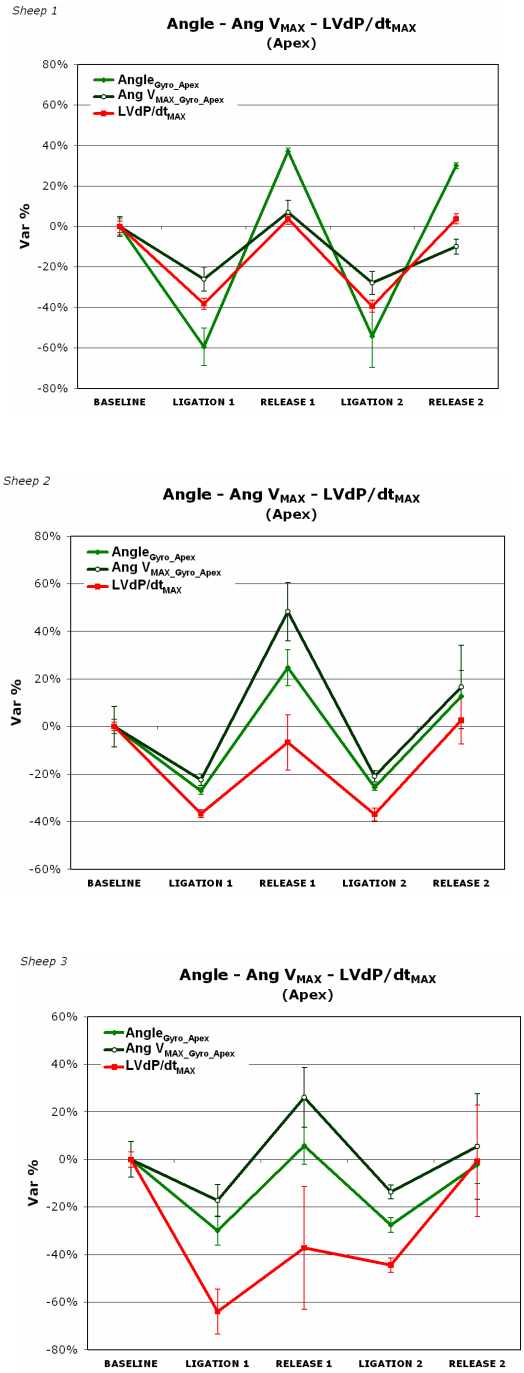

Figure 4. Trends of % variation of rotational parameters (Angle, Ang V_{MAX}) assessed with gyro at apical level against variation of hemodynamic measurements ($LVdP/dt_{MAX}$), relative to baseline.

4. Discussion and conclusions

The results of this study demonstrated the feasibility of assessing cardiac rotation by means of gyroscopic sensors. Monitoring of cardiac rotation, particularly of apex, allows the assessment of mechanical changes in cardiac function: when alteration of baseline cardiac performance was induced in animals the gyroscopic sensors were able to reveal significant changes in LV twist dynamics, which were also reflected by $LVdP/dt_{MAX}$ variations. Recently, non-invasive echocardiographic and magnetic resonance imaging techniques have been proposed to quantify cardiac rotation; however, they are not suitable for chronic monitoring of LV twist dynamics. Compared with these existing techniques for the measurement of LV twist dynamics, a miniaturized gyroscopic sensor could potentially be utilized for the chronic monitoring of cardiac function, if adequately implanted in the heart. Mechanical signals, such as the one related to apex rotation, are not subjected to interference from electrical pacing signals generated by implantable stimulating device (pacemakers, defibrillators), thus a rotation sensor can be thought integrated into such implantable devices. Alternatively, an implantable rotation sensor could be developed as a stand-alone gyroscopic sensor placed at the appropriate cardiac location and equipped with an on-board processing unit able to provide effective clinical information for detection and monitoring of cardiac function.

In our study the gyroscopic sensors were acutely glued on the epicardial surface of the heart, at open chest, thus resulting in a highly invasive measurement. Additional studies are required to succeed in the effective implantation of the cardiac rotation sensor for providing assessment of cardiac function over the time and to investigate the potentiality of the gyroscopic signal to characterize cardiac alterations.

References

[1] Taber LA et al.. Mechanics of ventricular torsion. J Biomech 1996; 29(6): 745-52.

[2] Arts T et al.. Torsion of the left ventricle during the ejection phase in the intact dog. Cardiovasc Res 1984; 18(3): 183-93.

[3] Rademakers FE et al.. Dissociation between left ventricular untwisting and filling. Accentuation by catecholamines. Circulation 1992; 85(4): 1572-81.

[4] Fuchs E et al.. Cardiac rotation and relaxation in patients with chronic heart failure. Eur J Heart Fail 2004; 6(6): 715-22.

[5] Hansen DE et al.. Effect of volume loading, pressure loading, and inotropic stimulation on left ventricular torsion in humans. Circulation 1991; 83(4): 1315-26.

[6] Nagel E et al.. Cardiac rotation and relaxation after anterolateral myocardial infarction. Coron Artery Dis 2000; 11(3): 261-7.

[7] Ingels NB et al.. Measurement of midwall myocardial dynamics in intact man by radiography of surgically implanted markers. Circulation 1975; 52(5): 859-67.

[8] Gibbons Kroeker CA et al.. An optical device to measure the dynamics of apex rotation of the left ventricle. Am J Physiol 1993; 265(4 Pt 2): H1444-9.

[9] Gotte MJ et al.. Myocardial strain and torsion quantified by cardiovascular magnetic resonance tissue tagging: studies in normal and impaired left ventricular function. J Am Coll Cardiol 2006; 48(10):2002-11.

[10] Notomi Y et al.. Assessment of left ventricular torsional deformation by Doppler tissue imaging: validation study with tagged magnetic resonance imaging. Circulation 2005; 111(9): 1141-7.

[11] Amundsen BH et al.. Noninvasive myocardial strain measurement by speckle tracking echocardiography: validation against sonomicrometry and tagged magnetic resonance imaging. J Am Coll Cardio 2006; 47(4):789-93.

[12] Marcelli E et al.. First experimental evaluation of cardiac apex rotation with an epicardial coriolis force sensor. Asaio J 2005; 51(6):696-701.

[13] Marcelli E et al.. Effect of right ventricular pacing on cardiac apex rotation assessed by a gyroscopic sensor. Asaio J 2007; 53(3):304-9.

Address for correspondence

Emanuela Marcelli
Università di Bologna
Dipartimento Clinico di Scienze Radiologiche e
Istocitopatologiche - Sezione Tecnologie Biomediche
Policlinico S. Orsola Malpighi
Via Massarenti, 9 (Palazzina 17)
40138 Bologna, Italy
emanuela.marcelli@unibo.it