Regional Myocardial Work: A New Method to Assess Local Myocardial Function

C Mekkaoui[1], F Thuny[1,2], Y Seree[1,3], A Riberi[1,3], TG Mesana[4]

[1]Laboratoire d'Hémodynamique et de Mécanique Cardiovasculaire, Marseille, France
[2]Service de Chirurgie Cardiaque, Hôpital de la Timone, Marseille, France
[3]Service de Cardiologie B, Hôpital de la Timone, Marseille, France
[4]Ottawa Heart Institute, Ottawa, Canada

Abstract

The aim of this study was the assessment of the Regional Myocardial Work (RMW) by measuring the stress-strain relationships in the left myocardium, under basic and ischemic conditions.

In 11 swines, 4 Sonometrics crystals were placed in the region perfused by the left anterior descending artery (LAD) circumscribing a tetrahedral myocardial volume (TMV). The 1st crystal was situated 45mm below the pulmonary artery, beside the LAD. Under control of the acquisition device, the 2nd was placed 10mm below the 1st following the LAD, the 3rd 10mm at the left side of the 1st and the 4th in equidistant point between the 1st and the 2nd, 5mm deep within the myocardium. A Millar, omnidirectional pressure catheter was placed within the TMV. The 6 distances and intramyocardial pressure measured were digitized and mathematically synthesized. The variation in TMV strain (µv) and stress (µp) was calculated throughout the cardiac cycle, resulting in 2 equations. The relationships between µp and µv result in a stress-strain loop, from which RMW was calculated. Simultaneously, Pulsed Doppler Tissue Imaging (DTI) assessed systolic (VS), early-diastolic (VE) and late-diastolic (VA) myocardial velocities. Measurements were performed under basic (B), during ischemia by occlusion LDA for 40 seconds, after 1 and 15 minutes of reperfusion (Occlusion (O), Reperfusion1 (R1) and 2 (R2) periods).

*The average of RMW, under basic conditions, was 0.679±0.025mJ. While DTI,VS :0.09±0.03ms-1;VE:-0.10±0.03ms-1;VA:-0.08± 0. 04ms-1;VE/VA :1.4±0.6ms-1.RMWsignificantly decreased during Occlusion: 0.042±0.005*mJ,and recovered partially in Reperfusion1 :0.212±0.015*mJ,and was increased in Reperfusion2 :0.928±0.029*mJ. In contrast, DTI shows a decrease of velocities in occlusion, VS: 0.06±0.01*ms-1;VE:-0.06±0.03*ms-1;VA:-0.08±0.02ms-1;VE/VA:1.04 ±0.3 ms-1 and did not significantly vary in reperfusion periods.*

The RMW quantifies the regional myocardial function, showing a decrease under ischemic condition and complete recovery in reperfusion. While DTI failed to demonstrate recovery in reperfusion, RMW appears more accurate than DTI in the assessment of the regional myocardial function and may be used in the evaluation of heart function under basic and pathological conditions. {: P<0.05}*

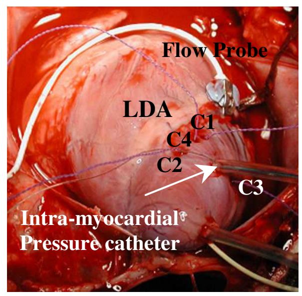
1. Introduction

In clinical practice, the assessment of the regional myocardial motion, which traduces the regional myocardial function, is assessed by echocardiography and DTI [1]. This method evaluates only the strain parameters, deformation, of the myocardial wall. In our study, we have assessed the regional myocardial function by the measurements of the strain and stress parameters, which allow us to define the regional myocardial work (RMW). This method permit to differentiate the active to the passive movement of the myocardial wall under some pathological conditions characterized by a regional dysfunction of the myocardial wall and result in a more accurate way to evaluate the regional myocardial function.

2. Methods

In 14 swines, 12 months olds Pietrain pigs regardless of sex had a sternotomy to assess the regional myocardial motion and intramyocardial pressure, under physiological and post ischemic condition. The pigs were raised at a farm and 10 days before the surgical procedure transferred to the laboratory where the rate body weight was 86 ± 3kg. Twenty four hours before the procedure, the animals were starved of food but allowed free access to water until 12 hours before the operation, at the end of the procedure the pigs were euthanasied by administration of ClK under continuous anesthesia. The LDA was perfused with "Bleu de Cresyl" in 3 shames, in order to define the region of the left ventricular wall perfused by this vessel. With the agreement of the ethic council of the Medical School and taking great care in order to avoid suffering, 900 mg of ketamine (ketalar were injected in the back of the neck. An intravenous catheter was introduced in an ear vein. Then the pig was transferred to the operating room, where after the administration of 50 mg of Pancourominium (Pavulon) and 500 ug of Fentanyl, the animal was placed in the supine position and endotracheal intubation was carried out with a 9 mm tube. The anesthesia was maintained by perfusion of Pavulon 15 mg and additional administration of Fentanyl 900 ug every 30 minutes. A catheter was placed in the right atrium through the internal jugular vein. The arterial blood pressure was measured via a catheter inserted in the ascending aorta, 4 Sonometrics® crystals were placed in the region perfused by the left anterior descending artery (LDA) circumscribing a tetrahedral myocardial volume (TMV). The 1st crystal was situated 45mm below the pulmonary artery, beside the LDA. Under control of the acquisition device, the 2nd was placed 10mm below the 1st following the LDA, the 3rd 10mm at the left side of the 1st and the 4th in an equidistant point between the 1st and the 2nd, 5mm deep within the myocardium. A Millar®, omnidirectional pressure catheter was placed within the TMV. The LDA was dissected and taped and a Transonic® transducer was placed in order to measure continuously the instantaneous blood flow. A caudal infrared plethysmograph was used to measure the percutaneous arterial saturation and a surface EKG was monitored during the overall duration of the procedure.

Through a median sternotomy the heart was approached and 4 crystals were placed in order to obtain a TMV (see below). A Millar, omnidirectional pressure catheter was placed within the TMV. The 6 distances and intramyocardial pressure measured were recorded, digitized and mathematically synthesized (ATMIO-16X, 16bitsADC, 500Hz sampling-frequency, National Instruments®, Austin,Tx). Data were recorded for 50 cardiac cycles, and treated by using custom-designed data-capturing window in Labview software (National Instruments). The measurement of distances between crystals was done with a "Sonometrics device" which is composed by a transmitter-receiver. The transit-time is proportional to the distance between crystals. For the intramyocardial pressure measurements, a 3F-sized omnidirectional microcatheter (Millar microtip SPC-340) was placed within the TMV, in an intramyocardial position. The distal extremity of this catheter is provided of a diaphragm where the pressure exerted generates a proportional analogical signal, which is digitalized and recorded in a computer. For each numerical signal, after calibration, we obtain a physical values resulting in a pressure wave. Basal measurements of flow were done in the LDA. The flow was measured with a Transonic® flowmeter for animal research T206. This system had 2 ultrasonic transducers and an acoustic reflector. The ultrasonic wave passes through the blood flow via the acoustic reflector and an electrical signal is sent each time that the sound wave is wined. In this way, the time separating 2 sound waves determines the flow. This time is independent of the vessel size. Six distances were obtained from measurements done with the 4 crystals. These distances were used to calculate the TMV with the following equation: $V = \sqrt{2}\ \left[\left(a^2.d^2.f^2\right)+\left(b^2.e^2.c^2\right)\right]^{1/2}$. In which ***a*** is the distance between the 1st (C1) and the 2nd (C2) crystals, ***b*** is the distance between the 2nd and the 3rd (C3) crystals, ***c*** is the distance between the 1st and the 3rd crystals, ***d*** is the distance between the 1st and the 4th (C4) crystals, ***e*** is the distance between the 2nd and the 4th crystals and f is the distance between the 3rd and the 4th crystals.



Operative view of the heart during occlusion of the LDA

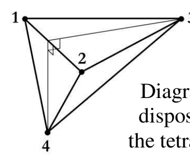


Diagram of crystals disposition defining the tetrahedral volume

The intra-myocardial pressure measures the intra-parietal stress. The RMW is calculated from the surface of the hysteresis loop obtained from the variation of the TMV and intra-myocardial stress. The variation in TMV strain (V) and stress (P) are calculated throughout the cardiac cycle and result in two equations. The relationships between P and V result in a stress-strain loop, from which RMW was calculated: $\mathrm{TMV} = \frac{1}{2}\int_0^T \left(PdV - VdP\right)$. Simultaneously, Pulsed Doppler Tissue Imaging (DTI) assessed systolic (VS), early-diastolic (VE) and late-diastolic (VA) myocardial velocities. Measurements were performed with Acusson® under basic, during ischemia by occlusion LDA for 40 seconds, after 1 and 15 minutes of reperfusion (Occlusion, Reperfusion1 and 2 periods). Moreover, the systemic arterial pressure and a caudal infrared-plethysmography were continuously monitored.

Statistical Analysis:

Statistical analysis was performed using Systat 9.0 software. Results are given as mean ± SD. Analysis was performed with the Kruskal-Wallis test (ie, nonparametric analog of 1-way analysis of variance), which was reduced to the Mann-Whitney test (ie, nonparametric analog of 2-sample t test) when there were 2 groups.

3. Results

Among 14 pigs undergoing a surgical procedure, 3 dies during the surgical procedure due to ventricular fibrillation, secondary to the manipulation of the LDA. In all others swines, the measurements of TMV and DTI were completely done, once the experimentation ended the animals were euthanasied by perfusion of ClK.

The average of RMW, under basic conditions, was 0.679±0.025mJ. While DTI, VS:0.09±0.03ms-1; VE:-0.10±0.03ms-1; VA:-0.08±0.04ms-1; VE/VA:1.4±0.6ms-1. RMW significantly decreased during Occlusion:0.042±0.005* mJ, and recovered partially in Reperfusion1:0.212±0.015*mJ, and was increased in Reperfusion2:0.928±0.029*mJ. In contrast, DTI shows a decrease of velocities in occlusion, VS:0.06±0.01*ms-1; VE:-0.06±0.03*ms-1;VA:-0.08±0.02ms-1;VE/VA: 1.04±0.3 ms-1 and did not significantly vary in reperfusion periods. The RMW analyzed under basically conditions results in 4 well-individualized periods: the isovolumic systolic period (***1***), the stress-volumic period (***2***), the isovolumic diastolic period (***3***), and diastolic period (***4***). In the first the parietal stress and the intramyocardial pressure dramatically increase without variation of the strain. In the second, the tetra-myocardial volume decrease while the stress remain high, in the third the TMV decrease dramatically as well as the stress, finally in the diastolic period the strain increase and the stress remain low. In the ejection period, the intraparietal pressure doesn't varies while the parietal strain increase resulting in an increased TMV, and following this period the stress and strain decrease corresponding at the diastolic period.

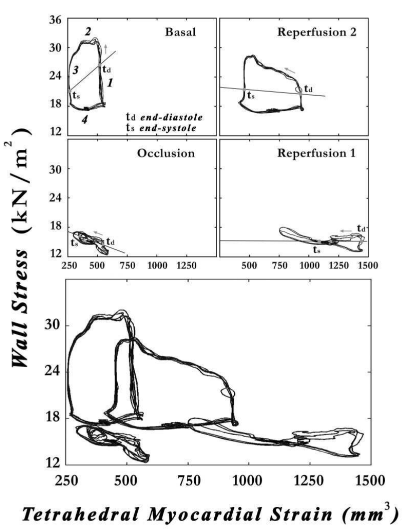
Cardiac cycle and variation of the strain-stress parameters :

Basal,

Occlusion,

Repefusion1,

Reperfusion2.



The rate flow in the LDA was under basic conditions: 50 ± 5 mL/min, during Occlusion we were unable to measure the flow in this vessel, once the tape released the flow in the LDA increased dramatically, 71 ± 8 mL/min (P<0.05) above the basic flow and 15 minutes after the tape released this flow decrease to 37 ± 3 mL/min (P<0.05). The rate of systemic arterial pressure was 148±23 / 83±11 mmHg under basic conditions, and doesn't varies significantly under ischemic conditions.

The rate of arterial blood oxygenation measured by plethysmography was of 100, while the overall procedure.

Table 1: Data from RMW and DTI

		B	O	R1	R2
Mechanics	P*max* (kN.m^{-2})	18.5 ± 0.7	8.5 ± 1.6*	9.9 ± 1.6*	18.4 ± 0.9
	P*min* (kN.m^{-2})	6.1 ± 0.2	4.6 ± 0.4*	4.4 ± 0.1*	6.5 ± 0.4
	ΔP (kN.m^{-2})	12.3 ± 0.3	3.8 ± 0.2*	4.0 ± 0.2*	10.4 ± 0.3*
	P*mean* (kN.m^{-2})	12.3 ± 0.4	6.5 ± 1.2*	7.9 ± 1.3*	13.2 ± 0.7
	V*max* (mm^3)	428 ± 16	454.3 ± 19.5	1222 ± 30.4*	863.8 ± 11.6*
	V*min* (mm^3)	233 ± 30	267 ± 5	747 ± 26*	448 ± 14*
	ΔV(mm^3)	194 ± 7	187 ± 13	474 ± 37*	415 ± 10*
	V*mean* (mm^3)	330 ± 11	360 ± 12*	984 ± 18*	655 ± 12*
	RMW (mJ)	0.679 ± 0.025	0.042 ± 0.005*	0.212 ± 0.015*	0.928 ± 0.029*
DTI	VE (ms)	-0.10 ± 0.03	-0.06 ± 0.03*	-0.06 ± 0.02	-0.08 ± 0.009
	VA(ms)	-0.08 ± 0.04	-0.08 ± 0.02	-0.09 ± 0.02	-0.09 ± 0.03
	VE/VA	1.4 ± 0.6	1.04 ± 0.3	0.87 ± 0.3	1.13 ± 0.2
	VS(ms)	0.09 ± 0.03	0.06 ± 0.01*	0.09 ± 0.02	0.07 ± 0.004
Hemodynamics	Qc*diast* (mL/min)	133 ± 15	None	118 ± 18	83 ± 8 *
	Qc*syst* (mL/min)	-42 ± 6	None	-17 ± 3 *	-20 ± 4 *
	ΔQc (mL/min)	175 ± 13	None	127 ± 15 *	99 ± 17 *
	Qc*mean* (mL/min)	50 ± 5	None	71 ± 8 *	37 ± 3 *

RMW and DTI:
P: Intra-Tetrahedral Myocardial Pressure
V: Tetrahedral Myocardial Volume
RMW: Regional Myocardial Work
Doppler Tissue Imaging:
VE: Proto-Diastolic Velocity
VA: End-Diastolic Velocity
VS: Systolic Velocity

LDA Flow:
Qc*diast*: LDA diastolic Flow
Qc*syst*: LDA systolic Flow
ΔQc: LDA differential Flow
Qcmean: LDA mean Flow

***: Statistical Significant (P<0.05), when compared to Basal**

4. Discussion and conclusions

The myocardial function is usually assessed by echocardiography. This method can evaluate the movement and variation in thickness of the ventricular wall. More recently, with the DTI physicians were able to evaluate the regional function of the myocardium [1]. In an attempt to render more accurately the assessment of the myocardial function, several studies have measure the variation in length of myocardial fibers, which is thought to be a parameter of myocardial dysfunction. In some studies [2,3], the intra-ventricular pressure-length loop area were analyzed under basic and ischemic conditions, and the strain parameters decrease in relation with the degree of the myocardial ischemia as well as after-loading, the period of ischemia was 15 minutes.

In our study, the ischemia was 1 minute and in our series there was not variations of strain parameters under ischemic condition. The intra-ventricular pressure may vary under several conditions independently of the myocardial function. In our study, the intra-myocardial pressure is dependent of the myocardial stress itself. Moreover, the measurement of 6 distances allows us to evaluate the more basic volume, which is more accurate in matters of variation than a single distance. In an experimental model in dogs [4], the measurements of 3D systolic strain was analyzed under basic and ischemic conditions and the authors assume that the length of the myocardial fibers significantly decrease in ischemic periods in the whole myocardial wall.

In our series, the variation in TMV, which reflect the strain parameters, were not significantly different under basically and ischemic conditions. In contrast, the stress parameters decrease dramatically under ischemic conditions resulting in a decreased RMW. Moreover, the shortening of the myocardial fibers may be a passive movement [5], and due to the active shortening of the adjacent segments of myocardium [6].

In our study, TMV and the ΔV were significantly increased in the reperfusion periods as a result of a hyperaemic reaction to the ischemia. In our experience, the RMW varies under ischemic conditions. Ischemia by occlusion of the LDA show a dramatically decrease of the RMW with a partially recover after reperfusion. Thus, in ischemic period the RMW passes from 0.679 ± 0.025 to 0.042 ± 0.005, as a result of the decreasing in stress parameters. The RMW recover after reperfusion to reach values of 31 % of basic measurement (0.212 ± 0.015) and after 15 minutes of reperfusion the RMW is 0.928 ± 0.029 which represent an increase of 36 % when compared with the basic measurement. The DTI measurements show under basic conditions, VS:0.09±0.03ms-1; VE:-0.10±0.03ms-1; VA:-0.08±0.04ms-1; VE/VA:1.4±0.6ms-1. In occlusion period DTI velocities were VS:0.06±0.01*ms-1; VE:-0.06±0.03* ms-1; VA:-0.08±0.02ms-1; VE/VA:1.04±0.3ms-1 and did not significantly vary in reperfusion periods, which represent an abolition of the activity of the myocardial segment in occlusion. In contrast, DTI doesn't detect the recover activity in the reperfusions periods.

In a study [7], in which DTI was correlated to fibers shortening measured by crystals, under basic conditions and after perfusion of dobutamine, there was a tight correlation between the two methods.

In our study, the DTI shows the same events than the RMW under basic conditions and in occlusion of the LDA.

Conclusion:

The RMW quantifies the regional myocardial function, showing a decrease under ischemic condition and complete recovery in reperfusion. These data is correlated with DTI under basic and ischemic condition. Our study doesn't show strain alteration under ischemic conditions probably due to the short ischemia period.

This method was used under experimentation conditions in a little number of subjects and further studies should be necessary in order to confirm our results.

References

[1] Derumeaux G, Ovize M, Loufoua G, et al. Doppler tissue imaging quantitates regional wall motion during myocardial ischemia and reperfusion. Circulation 1998; 97:1970-1977.

[2] Forrester JS, Tyberg JV, Wyatt HL, et al. Pressure-length loop: a new method for simultaneous measurement of segmental and total cardiac function. J Appl Physiol 1974; 37:771-5.

[3] Safwat A, Leone BJ, Norris RM, et al. Pressure-length loop area: its components analyzed during graded myocardial ischemia. J Am Coll Cardiol 1991; 17:790-6.

[4] Skulstad H, Edvardsen T, Urheim S, et al. Postsystolic shortening in ischemic myocardium: active contraction or passive recoil? Circulation 2002; 106:718-724.

[5] Yin FCP, Chan CCH, Judd RM. Compressibility of perfused passive myocardium. J Am Physiol 1996; H1864-H1870.

[6] Mazhari R, Omens JH, Pavelec RS, et al. Transmural distribution of three-dimensional systolic strain in stunned myocardium. Circulation 2001; 336-341.

[7] Gorcsan J, Strum DP, Mandarino WA, et al. Quantitative assessment of alterations in regional left ventricular contractility with color-coded tissue Doppler echocardiography. Circulation 1997; 95:2423-2433.

Address for correspondence

Choukri Mekkaoui.

Animal Research Laboratories, Cardiovascular Medicine.
Yale University - School of Medicine.

333 Cedar Street, PO Box 208017
New Haven, CT 06510, USA

mekkaoui@medecine.univ-mrs.fr