INITIAL EXPERIENCE WITH A THIN SINGLE SEGMENT PRESSURE AND CONDUCTANCE CATHETER FOR MEASUREMENT OF LEFT VENTRICULAR VOLUME

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***Abstract*- Aims: To evaluate a thin and soft multifunctional catheter for the simultaneous real time monitoring of left ventricular volume and pressure with special consideration to side effects such as interference with normal cardiac electrophysiology.**

Methods and results: In four pigs, pressure and volume were simultaneously recorded by using the thin single segment pressure and conductance catheter. Measurements were done under varied cardiac conditions: at baseline, during preload reduction and afterload increase. Volumes were calibrated with intracardiac ultrasound measurements. During preload reduction the pressure and volume decreased as expected. A cautious afterload increase resulted in a corresponding pressure and volume increase, the maximum of the pressure curve changed from early to late. Both SV and EDV increased. The very few arrhythmias were mainly caused by surgical interference.

Conclusion: The present study demonstrates that our thin single segment conductance catheter for the simultaneous measurement of LV volume and pressure has a performance that warrants further development with the goal to make the method available for human use. In particular, the catheter did not cause any arrhythmias.

***Keywords*- Left ventricular volume, conductance catheter, segment volume**

I. Introduction

Instantaneous ventricular pressure and volume are fundamental variables essential for understanding and assessing ventricular function [1]. Thus, a clinically acceptable method for real time monitoring of left ventricular (LV) volume and pressure is desirable. Unfortunately, today's methods of volume measurements will not meet the requirements of time resolution, endurance and accessibility (MR, CT, MUGA).

With the conductance catheter technique, originally developed by Baan [2-4] a continuous on-line registration and quantification of LV volume is, however, possible. This method is based on the fact that the conductivity of blood is much higher than that of the myocardium and the tissues surrounding the heart. The conductance catheter is an insulated catheter with several electrodes evenly spaced along the part placed inside the LV. From the most distal and the most proximal electrode runs a weak, alternating current. The electrodes in between are sensing electrodes, measuring the potential differences from which conductances are derived. The number of electrodes is typically 10 or 12. Through the summation of the conductance from each electrode segment we get a total conductance, which is used to derive the volume according to the formula [3]:

$$V(t) = \frac{1}{\alpha}\left(L^2 \cdot \rho \cdot \sum_{i=1}^{5} G_i(t) - V_c \right)$$

where α is a dimensionless slope factor; L is the length between the measuring electrodes; ρ is the blood resistivity; G is the measured conductance and V_c is the parallel conductance from structures surrounding the left ventricle.

State of the art conductance catheters are, however, unsuitable for clinical use since they, among other things, are too thick and too stiff. When placed into the heart the conductance catheter easily causes arrhythmias, due to mechanical stimuli of the cardiac walls.

Thus, if the catheter dimensions could be made smaller, and a different material be used, the disadvantage of arrhythmias would supposedly disappear, and a first step towards clinical use be taken. In order to minimise the catheter dimensions the number of electrodes has to be reduced. Our group has shown that with strategically placed electrodes the same performance can be expected from a catheter with just one segment as from one with 10 or 12 evenly spaced electrodes [5,6], at least in the porcine model.

In collaboration with Radi Medical Systems, Uppsala Sweden, we designed a thin and soft conductance catheter. The diameter is only 0.36 mm, the same as that of an ordinary guide wire. The catheter has four electrodes placed accordingly to [6]. It is also equipped with a high bandwidth pressure sensor manufactured with Radi Medical's Pressure Wire technology. The system incorporates computerised data collection. The measurement frequency is 32 kHz with an applied current of 100 µA. The voltage measurement is based on coherent detection of real and imaginary parts that are integrated during a sample interval of 2 ms. AD-conversion has a resolution of 12 bits.

In this study we report initial experience of this conductance catheter in a porcine model under different cardiac loading conditions.

II. Methodology

All animals received human care in compliance with the European Convention on Animal Care. The study was approved by the local Ethics Committee for Animal Research.

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Abstract

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A. Animal preparation

Farm pigs (30-33 kg, n=4) of either sex were obtained from a local breeder. After an overnight fast, the pigs were premedicated with intramuscular azaperon 2-4 mg/kg. Anaesthesia was induced by intramuscular bolus of tiletamin/zolazepam 6 mg/kg, xylazin 2.2 mg/kg and atropine 0.04 mg/kg, and was maintained by a continuous infusion of clomethiazol 16 mg/kg/h, fentanyl 4μg/kg/h and pancuronium bromide 0.08 mg/kg/h. The animals were intubated and automatically ventilated with air and oxygen. Respiratory rate and tidal volume were adjusted to keep arterial blood pH, PO2 and PCO2 within the physiological range. Body temperature was kept at 38.0-39.0°C by means of a heating pad.

A 1.45 mm arterial catheter (Ohmeda AB, Helsingborg, Sweden) was inserted in the right femoral artery and connected via a DPT-4003 pressure transducer (Peter von Berg Medizintechnik GmbH, Eglharting, Germany) to a Sirecust 630 module and Datex-Engström monitor AS3 for arterial pressure monitoring throughout the procedure. The neck was dissected for bilateral access to the external and internal jugular veins and the carotid arteries. A median sternotomy was done, and care was taken to keep the pericardium intact. A silicone tape was placed extrapericardially around the inferior vena cava (IVC) and pulled through a tourniquet for controlled intermittent reduction of preload. After meticulous hemostasis, 10000 IU of heparin sodium was given. Heparin was repeated with 5000 IU every hour. A pulmonary artery (PA) catheter (CritiCath SP5107-H) was advanced into the PA from a jugular vein and used for cardiac output (CO) measurements by the thermodilution technique. An 8.5 F vascular introducer was advanced from the right carotid artery into the LV over a J-tipped guide wire. Passage into the LV was verified with pressure measurement in the vascular introducer. The 0.36 mm pressure-conductance catheter was placed through the introducer in the LV. The introducer was then withdrawn to the ascending aorta. An intravascular ultrasonic probe (Acuson AcuNav), linked to Acuson Sequoia 512, was advanced through the right external jugular vein into the right ventricle for measurement of ejection fraction.

LV conductance and pressure data were displayed and stored on a personal computer.

B. Manipulation of cardiac loading conditions and data acquisition

After finishing the preparation procedure the animals were allowed to stabilize for approximately 20 minutes followed by calibration of the pressure transducer according to Pressure Wire standard recommendations. Throughout all recordings measurements with intracardiac ultrasound were made. From these measurements ejection fractions (EF) were estimated.

Before every measurement, a series of calibration signals (of 0, 20, 40, 100, 200, -20 mm Hg) were recorded. The measurements began with a determination of CO through at least 3 thermodilutions, and after that at least 17 basal recordings were made to determine base-line data.

In order to rapidly decrease preload, the inferior vena cava was occluded (VCO). The procedure was recorded twice. The VCO was performed with caution, to avoid ventricular extra-systoles. Each preload reduction was followed by a recovery interval for return to base-line status. A basal recording was made less than a minute before the next VCO.

Afterload was increased using phenylephrine (0.05 mg to 0.2 mg). This was made twice. After each recording of increased afterload, the pig stabilised for approximately 10 minutes during which it returned to baseline conditions. A basal recording was then made.

During all measurements ECG was recorded. Pressure, volume and ECG measurements were recorded for a period of at least 8 heartbeats.

Sampling frequency was 500Hz for the volume signal and 1 kHz for pressure and ECG.

C. Data analysis and calculations

All data were analysed off-line, and each measurement was inspected visually. The data were analysed and plots were made using Matlab software. The conductance signals were upsampled with Lagrangian interpolation to 1 kHz and synchronised with the pressure and ECG signals. All signals were low pass filtered with a digital IIR 3-pole Butterworth low pass filter having a cut off frequency of 33 Hz.

Ejection fraction was derived from the ultrasound according to [7]. Stroke volume (SV) was calculated as cardiac output divided by heart rate for which the volume signal was calibrated. The maximum of the volume curve was given by end-diastolic volume, calculated as stroke volume divided by ejection fraction.

III. RESULTS

A. Hemodynamic data and baseline measurements

Hemodynamic data are presented in table 1. An example of simultaneous recording of LV volume computed from electrical conductance, LV pressure and ECG are seen in Fig. 1a. Fig 1b shows a volume curve in more detail.

TABLE I
HEMODYNAMIC DATA

	Baseline			
	Pig 1	Pig 2	Pig 3	Pig 4
HR	98 beats/min	111 beats/min	83 beats/min	113 beats/min
CO	3.0 l/min	4.4 l/min	3.2 l/min	3.1 l/min
EF	29.3%	51.3%	60.4%	25.6%
SV	30 ml	39 ml	38 ml	27 ml
EDV	103 ml	76,5 ml	64 ml	107 ml

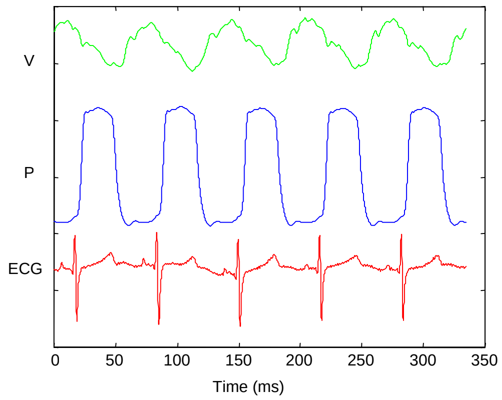

Fig. 1a. Simultaneous recording of left ventricular intracardiac electrical conductance (V), pressure (P) and electrocardiogram (ECG) as functions of time.

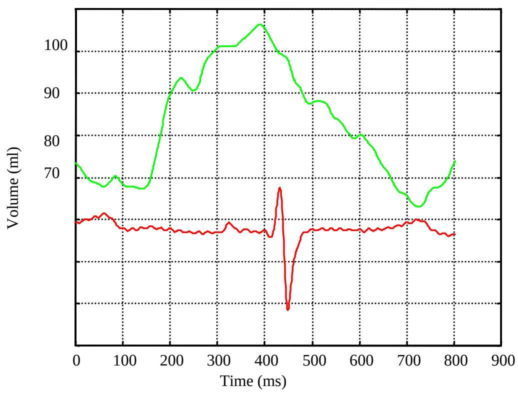

Fig. 1b. Intracardiac electrical conductance (V) and ECG as functions of time.

B. Preload reduction

During preload reduction pressure(-35 %), SV (-46 %), end diastolic volume (EDV) and end systolic volume decreased during 15 to 19 heart beats. Values within brackets are typical deviations from baseline values.

C. Afterload increased

A cautious afterload increase resulted in a pressure (33 %) and SV (38 %) increase during 15 to 19 heartbeats. The maximum of the pressure curve changed from early to late.

A recording made during afterload increase is shown in Fig. 2.

D. General observations

In our recordings covering some 20 000 heartbeats from the 4 animals we observed only 18 brief episodes of arrhythmia. Most of these can be attributed to the manipulations, 9 during thermodilution, 2 during vena cava occlusion and 3 during administration of phenylephrine. Four are of unknown origin but were most likely caused by the ultrasonic transducer.

IV. Discussion

The volume curve obtained from the thin catheter (Fig. 1b) shows a number of small notches not visible in the otherwise similar recordings obtained with the Baan catheter [5]. The ultrasound images (Fig. 3) showed that the catheter had a relatively constant position, along and close to the cardiac wall, replicating the movements of the LV endocardium. These movements may contribute to the notches but we are convinced that the notches are the result of the heart reshaping and the movements of the valves. The bandwidth and temporal resolution is higher in our system than that in the system normally used together with the Baan catheter enabling finer details in the recordings.

A problem with the evaluation of continuous measurements of the LV volume is that there exists no adequate reference method. We had hoped to use 3D echocardiography for this purpose but in our experience accuracy and reproducibility still is inadequate. Therefore we cannot today say how well our measurements reflect true LV volumes. Our data, however, indicates that the method is reproducible; when the animals returned to baseline status

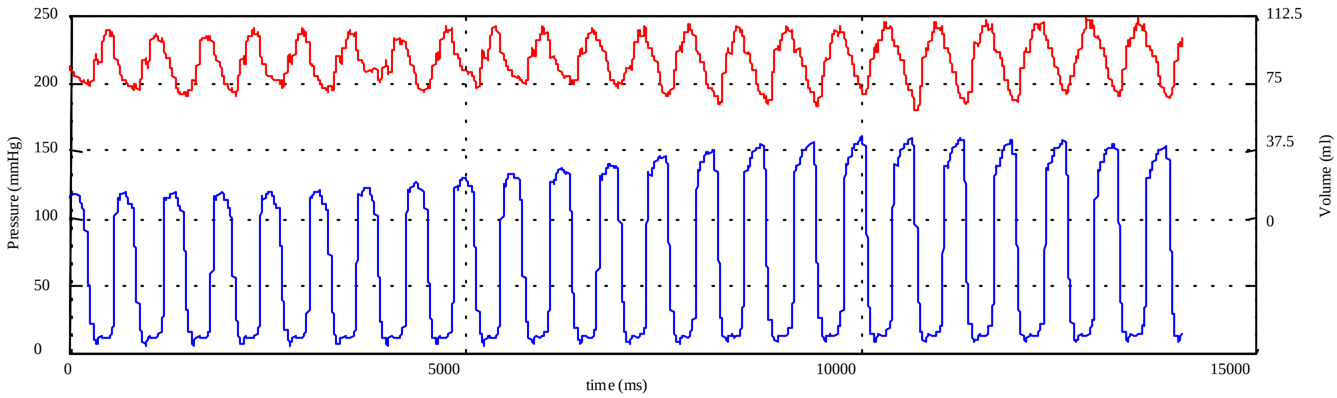

Fig. 2. Acquisition at afterload increase. Lower curve shows pressure and upper curve volume.

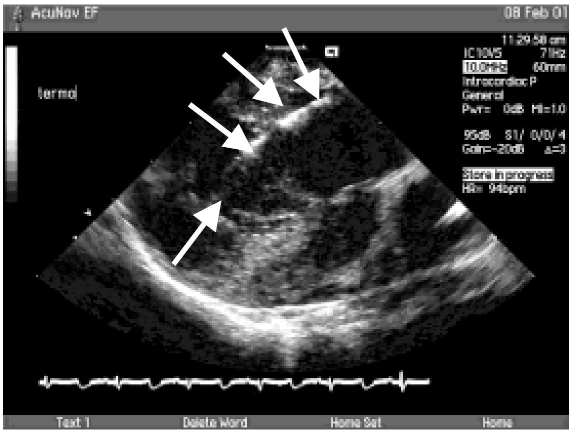

Fig. 3 Ultrasound image of the thin catheter. The electrodes are marked.

after a manipulation volume estimates returned to baseline values.

One important task in this project was to determine that the catheter didn't cause any arrhythmias. We experienced few arrhythmias and these were mainly caused by surgical interference. In all four animals we observed less than 7 ventricular extra systoles that could not be attributed to surgery or cardiac manipulation. We have no indications that the combined pressure and conductance catheter is disturbing the heart's electrophysiology, neither by the catheter current nor by any mechanical stimuli.

The current catheter is not suitable for exact measurements of absolute LV volumes. It is, however, stable and delivers consistent and reproducible volume and pressure data from the individual animal. We believe that the method has potential applications in human intensive care. For the clinician continuous real time monitoring of volume trends together with pressure offers new opportunities to monitor LV work.

V. Conclusion

In conclusion, the present study demonstrates that our thin single segment conductance catheter for the simultaneous measurement of LV volume and pressure has a performance that warrants further development with the goal to make the method available for human use. In particular, the catheter did not cause any arrhythmias.

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