Assessment of Left Ventricular Function Using a Conductance Catheter in the Human Heart

MOTOSHI TAKEUCHI, M.D., HIDEYUKI TAKAOKA, M.D., MICHIKO ODAKE, M.D.
YOSHIHIKO HAYASHI, M.D., KATSUYA HATA, M.D.
AND MITSUH lRO YOKOYAMA, M.D.

To validate the usefulness of the conductance catheter in the clinical setting, we first studied the accuracy of human left ventricular (LV) volume measured by conductance catheter in comparison with LV volume measured by biplane angiography in 19 patients with heart disease. Secondly, we made a comparison of end-systolic pressure volume relation (ESPVR) and preload recruitable stroke work (PRSW) relation in 60 patients with heart disease. Thirdly, we studied the myocardial oxygen consumption (VO₂)-pressure volume area (PVA) relation to assess contractile efficiency in 22 patients with heart disease. There was a good correlation between the corrected conductance volume (Vcc) and the angiographic volume (V angio) (Vcc = 0.94 Vangio + 5.4, r = 0.94, P < 0.001). Two relations, ESPVR and PRSW, were well described by straight lines with high correlation coefficients. However, PRSW was a more linear contractile index than ESPVR. The reciprocal of the slope of the VO₂-PVA relation was approximately 40% in the control contractile state. We conclude that the conductance catheter accurately measures LV volumes and facilitates the assessment of ESPVR, PRSW and contractile efficiency in human LV.

(Ipn Circ J 1992; 56: 730–734)

Assessment of left ventricular (LV) contractility is important in both clinical practice and physiological investigation. The end-systolic pressure volume relation (ESPVR) has been shown to be almost independent of preload, afterload and heart rate in a given constant contractile state in the isolated LV. ESPVR has been proposed as an index of ventricular contractility. Recently, another index of LV performance derived from variably loaded pressure and volume (P-V) loops have been proposed as a new measure of LV contractile state: linear relations between left ventricular stroke work and end-diastolic volume, namely, preload recruitable stroke work (PRSW). More recently, it has been reported that the systolic pressure volume area (PVA) circumscribed by end-systolic and end-diastolic P-V relations and the systolic P-V trajectory linearly correlates with LV oxygen consumption per beat (VO₂) in excised, cross circulated dog hearts and intact dog hearts. The reciprocal of the slope of the linear VO₂-PVA relation has been considered to reflect the chemomechanical energy transduction efficiency (contractile efficiency) from VO₂ to PVA.

Measurement of LV volume is essential for understanding and assessing these concepts, i.e., ESPVR, PRSW and VO₂-PVA relations. A new method that combines the measurement of LV pressure and volume by

Key words:
Conductance catheter
End-systolic pressure-volume relation
Preload recruitable stroke work
Contractile efficiency

First Department of Internal Medicine, Kobe University School of Medicine
Mailing address: Motoshi Takeuchi, M.D. First Department of Internal Medicine, 7-5-1, Kusunoki-cho, Chuo-ku, Kobe 650, Japan

730 Japanese Circulation Journal Vol. 56, July 1992
means of a conductance catheter has been introduced by Baan and co-workers. The purpose of this study was to investigate the accuracy of LV volume measurement by the conductance catheter and to assess the ESPVR, PRSW and V₀₂-PVA relation in the human diseased heart.

METHODS

Patients
This study consisted of three parts. In the first part, 19 patients with suspected coronary artery disease were studied during diagnostic cardiac catheterization. In the second part of our study, 60 patients were included. We subjects were divided into two groups according to the LV ejection function (LVEF). Group 1 consisted of 39 patients whose LVEF was higher than 50%. Group 2 consisted of 21 patients whose LVEF was lower than 50%. In the third part of our study, 22 patients were included. Complete, informed and written consent was obtained from each patient before the study, and no unfavorable complications occurred as a result of this study.

Catheterization procedure

Cardiac catheterization including coronary arteriography and ventriculography was performed, as described in detail previously. The conductance catheter with micromanometer tip (Leycom, The Netherlands) was inserted to the LV through the right femoral arterial sheath. A right atrial pacing catheter was placed to maintain a constant heart rate throughout the protocol.

Conductance measurement

The conductance method to determine LV volume is based on measuring the conductivity of the blood inside the LV cavity. This catheter has 10 electrodes which are equidistantly placed distal from the tip with an inter-electrode distance of 0.9 cm. This catheter is connected to the conditioning amplifier (Leycom Sigma-5), which apply a 20 kHz and 30 mA current between the most distal and the proximal electrode just above the aortic volume and measures conductances between electrodes pairs, and then sums them up to obtain the total time-varying conductance, G(t). Vuc is computed as:

\[ Vuc(t) = L^2 \rho G(t) \]  

where L is the distance between two adja-
cent electrodes; $\rho$ is a blood resistivity in the LV and $G(t)$ is the instantaneous sum of the conductances. Absolute LV volume, $V_{cc}$, is computed as:

$$V_{cc} = (l/\alpha)[L^2 \rho G(t) - \alpha Vc] \cdots (2)$$

where $l/\alpha$ is a gain constant; and $\alpha Vc$ is the correcting volume for the conductance of the surrounding tissues. Blood resistivity of the LV was measured in a calibrated cuvette. In this study, $l/\alpha$ was determined individually by obtaining the ratio of stroke volume (SV), determined by thermodilution method, to that measured by the conductance catheter. Thus, $l/\alpha$ can be expressed as:

$$l/\alpha = SV_{thermo}/SV_{Vc} \cdots (3)$$

where $SV_{thermo}$ is the SV determined by the thermodilution catheter and $SV_{Vc}$ is the SV determined by the uncorrected conductance volume. $\alpha Vc$ can be estimated by bolus injection of 10 ml of hypertonic saline (5%) into the pulmonary artery. This value represents the contribution of the heart muscle and surrounding structures to the total signal of conductivity.

**Assessment of LV contractility**

After completion of calibration, a large balloon occlusion catheter was advanced to the right atrium (RA)-inferior vena cava (IVC) junction, and pulled back to occlude venous return. P-V loops for the sequence of the beats following the reduction in LV preload resulting in 30—40 mmHg drop in LV systolic pressure were recorded. The slope of an ESPVR, $E_{max}$, and the volume intercept of an ESPVR, $V_0$, were obtained by using the least-squares technique as shown in Fig. 1. PRSW relation was also quantified by fitting the data from the same beats from each caval occlusion used to evaluated the ESPVR to:

$$SW = M_w (EDV-V_w)$$

where $M_w$ is the slope of the linear PRSW relation and $V_w$ is the intercept with volume axis.

**Calculation of pressure-volume area (PVA)**

PVA was calculated as an area that is bounded by the end-systolic and end-diastolic P-V relations and the systolic P-V trajectory of each beat.

**Measurement of myocardial oxygen consumption ($V_{O_2}$)**

Using the Webster catheter, coronary sinus blood flow (CSF) was measured. In all patients coronary venous blood was sampled from the distal lumen of the Webster catheter for oximetry and the determination of myocardial oxygen consumption. Myocardial oxygen consumption per minute was calculated as the product of CSF (ml/min)
and coronary arteriovenous oxygen content difference (vol%), divided by heart rate to yield myocardial oxygen consumption per beat (VO₂).

STATISTICS

Data values are given as means±SD. The correlation between conductance and angiographic volume was obtained by least-squares regression analysis. Comparison of the mean of matched pairs was made by paired t test, and the difference was considered significant if p<0.05. The mean value of correlation coefficients was compared after the Z transformation method.

RESULTS

Correlation between conductance and angiographic volume

Regression lines between the corrected conductance volume and the angiographic volume throughout one cardiac cycle in all subjects were shown in Fig. 2. Note that the slopes were very close to unity and the intercepts were very small. The correlation coefficients were very high (r=0.95, SEE=9.9 ml). Fig. 2 shows a representative volume-time plot constructed from conductance method and angiography. The shape of volume-time plots of the conductance method was quite similar to that of the angiography.

Comparison of PRSW with ESPVR

Eₘₐₓ in Group 2 (2.8±0.8 mmHg/ml/m²) was significantly lower than that of Group 1 (4.6±2.3 mmHg/ml/m²) and VO in the Group 2 (19±25 ml/m²) was significantly higher than that of Group 1 (−14±27 ml/m²). Mw in Group 2 (86±28×10³ erg/ml) was significantly lower than that of Group 1 (109±31×10³ erg/ml) and VW in the Group 2 (59±21 ml/m²) was significantly larger than that of Group 1 (19±18 ml/m²). The correlation coefficients of ESPVR and PRSW were high. The Z value of 2.29±0.58 for ESPVR was significantly lower than those of 2.54±0.64 for PRSW.

Assessment of VO₂-PVA relation

Highly linear regression lines were obtained from each VO₂-PVA relation of 22 patients in control run. The correlation coefficient was 0.922±0.092. The slope of the VO₂-PVA relation and the contractile efficiency were (1.75±0.62)×10⁻⁵ ml O₂/mmHg/ml, and 41±9.5%.

DISCUSSION

In the first part of this study, we compared LV volume obtained from the conductance catheter method with LV volume obtained from angiography in 19 patients with ischemic heart disease. The major finding of this study was that, after correction using l/α and αVe, conductance volume could estimate angiographic volume accurately. There was a high correlation between LV volume obtained from the conductance method and those calculated from the angiography. These results suggest that the conductance catheter method is suitable for the measurement of LV volume in human hearts.

In the second part of this study, we assessed the indices of contractility and compared the linearity between ESPVR and PRSW in the clinical setting. ESPVR and PRSW were well described by a straight line. However, PRSW was a more linear contractile index than ESPVR.

In the last part of this study, we focused on the relationship between mechanical performance and myocardial oxygen consumption. PVA is an expression of the total mechanical energy. The dimensionless ratio of PVA (in J/best) to excess VO₂ above unloaded VO₂ (in J/best) has been considered the ratio of the total mechanical energy output to energy input that is used for mechanical contraction, i.e., contractile efficiency. Contractile efficiency derived from VO₂-PVA relation, efficiency from VO₂ to the total mechanical energy, could be assessed and was approximately 40% in control contractile state. Contractile efficiency assessed in the present study was consistent with the previous reports⁹,¹⁰

Clinical Implications and conclusion

The most important advantage of the conductance catheter method is the continuous and real-time measurement of absolute LV volume without contrast mediums or isotopes. Our results suggested that the con-
ductance catheter accurately measures LV volumes and facilitates the assessment of ESPVR, PRSW and contractile efficiency in human LV.

Acknowledgment

The authors gratefully acknowledge Kaoru Yoshizawa and Teruo Nakatsuka for their technical assistance with the catheterization laboratory studies.

REFERENCES

4. SUGA H: Ventricular energetics. Physiol Rev 1990; 70: 247—277
5. BANN J, VERDE VET, BRUIN DH, SMEENK GJ, KOOPS JAD, DIJK AD, TEMMERMAN D, SENDER J, BUIS B: Continuous measurement of left ventricular volume in animals and humans by conductance catheter. Circulation 1984; 70: 819—823

Japanese Circulation Journal  Vol.56, July 1992