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Contribution to the Problems of Volume Parameters of the Left Heart Ventricle of Patients with Ischaemic Heart Disease

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Summary
The authors studied some methodological questions associated with evaluation of the X-ray of the left ventriculogram (VTG). On the basis of their results they suggest that, in addition to the usual comprehensive volume parameters of the left ventricle (EDVI, ESVI, the EF), further indices, obtained either by drawing the cardiac contour frame-by-frame (norm dV/dt_{min}), or by dividing the diastole into halves or thirds (the indicies norm FF 1/2 or norm FF 1/3), should be used. These indices allow more sensitive differentiation of patients with impaired left ventricular function.

Key words
Cardiac ischaemia – Ejection fraction – Left ventricular volume – Peak systolic ejection rate – Peak diastolic filling rate

Introduction

Reduced functional effectiveness of the left ventricle (LV) of the heart has a marked influence on the prognosis for patients with myocardial ischaemia (MI). It is one of the basic criteria determining whether surgery is called for (Beránek *et al.* 1975, Fabián 1973, Fabián *et al.* 1973, 1979, Krayenbühl *et al.* 1968). In patients in whom the coronary bed is to be surgically reconstructed it increases the hazards of the operation and worsens the postoperative prognosis (Beránek *et al.*1973, Kelly *et al.* 1985, Kennedy *et al.* 1980). In conservatively treated patients it shortens the survival time (Pujadas 1980). A whole series of methods and indicators has been evolved for evaluating left ventricular function of the heart. These indicators can be obtained in many different ways – by left X-ray ventriculography (VTG), by echocardiography, by radionuclide VTG and by magnetic resonance visualization, etc. Left X-ray VTG is considered to be the "gold standard" with which the values obtained by other methods are compared.

The evaluation of left ventricular function and the left X-ray VTG is concentrated to the systolic part of the cardiac cycle, i.e. on comparison of the state of the LV at the beginning and end of a systole (end-diastolic volume – EDV – and end-systolic volume – ESV). In routine practice these parameters are usually sufficient. Some published studies show, however, that kinetic disturbances are to be found during the systole in patients with myocardial ischaemia (Dodge *et al.* 1966, Hammermeister *et al.* 1974, Peregrin *et al.* 1982) and some authors also describe significant changes in the diastolic phase of the cycle (Austin *et al.* 1982, Gibson *et al.* 1976, Hammermeister *et al.* 1974, Miller *et al.* 1987).

Our aim in this study was to make a detailed analysis of the basic LV volume parameters of the heart commonly used in routine clinical practice (EDV and ESV) and to determine the potential usefulness of the indices obtained by drawing the cardiac cycle in detail, frame-by-frame.

Methods

The series chosen for analysis consisted of 52 patients (40 males, 12 females, mean age 48 ± 2 years). The patients, who were all given a detailed cardiological examination, including coronarography and VTG, were divided into three groups, according to the clinical findings:

1. a control group (25 patients),
2. a group with effort angina pectoris (AP),

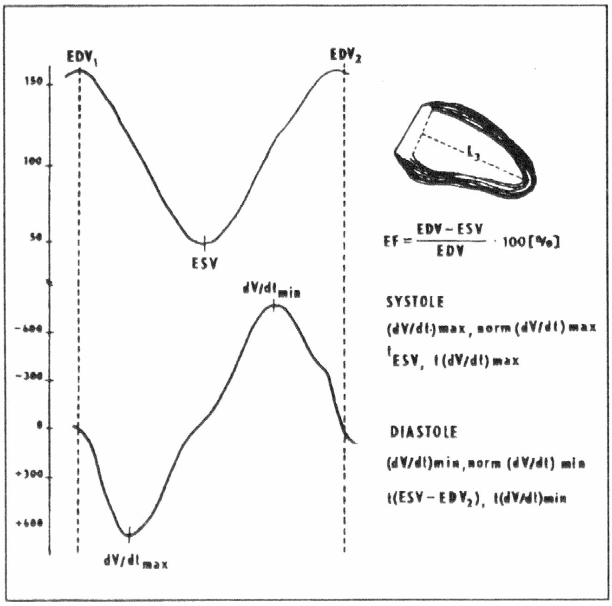

Fig. 1

Scheme of volume changes in the left ventricle of the heart during the cardiac cycle (upper curve). The bottom curve was derived from the LV volume values throughout the whole of the cardiac cycle. Some of the indices obtained by this evaluation method are shown on the right-hand side of the scheme. EF – ejection fraction, EDV – end-diastolic volume, $(dV/dt)_{max}$ – maximum ejection rate, norm$(dV/dt)_{max}$ – maximum ejection rate related to EDV, tESV – ejection time (between EDV and ESV), $t(dV/dt)_{max}$ – time needed to reach the peak ejection rate, $(dV/dt)_{min}$ – maximum filling rate, norm$(dV/dt)_{min}$ – maximum filling rate related to EDV, $t(ESV\text{-}EDV_2)$ – filling time (between ESV and EDV_2), $t(dV/dt)_{min}$ – time needed to reach the peak filling rate.

3. a group of patients recovering from transmural infarction of the myocardium (10 patients).

For left X-ray VTG, the contrast substance was injected into the pulmonary artery. A cinematographic recording of pulsation of the LV was made in the right anterior oblique (RAO) projection, at a frequency of 50 frames per second. Silhouettes of the LV were drawn, frame-by-frame,from the recordings during 2.5 cardiac cycles. The volume curves obtained from the mean values (Fig. 1) were used to determine EDV and ESV, i.e. the highest and lowest LV volume. Further parameters derived from the volume curve included the maximum ejection rate, $(dV/dt)_{max}$, and the maximum filling rate, $(dV/dt)_{min}$, and after dividing by the maximum volume their normalized values, norm$(dV/dt)_{max}$ and norm$(dV/dt)_{min}$, were obtained. Since frame-by-frame evaluation of the cardiac cycle is laborious and time-consuming, this method can be employed in clinical practice only when computer systems allowing automatic analysis of the cineventriculogram have been introduced. We therefore replaced this method by a simpler method, in which the systole and diastole contours were divided into thirds and halves. In this way we obtained the ejection fraction (EF) and filling fraction (FF) of one third and one half of the diastole and systole (EF 1/3, EF 1/2, FF 1/3, FF 1/2, normFF 1/3, normFF 1/2).

In this context we must emphasize the limitation of our method, which does not allow detailed differentiation of the individual parts of the systole and diastole (isovolumic contraction or relaxation), so that it likewise does not show exactly when the individual valves close or open (concealed by the contrast filling). For obtaining data about the duration of the systole and diastole we therefore confined ourselves to determination of the smallest and largest silhouette of the LV during the cardiac cycle. The number of images between the largest and smallest silhouette of the LV, multiplied by the period between two images (0.02 s), provided information about the duration of the systole and diastole.

Results

The mean values of total volume parameters obtained in the control group and related to body surface area – i.e. EDVI = 81.6 ± 2.1 ml, ESVI = 23.7 ± 1.2 ml, SVI = 60.0 ± 2.1 ml, EF = 71.4 ± 1.2 ml – correspond to the data in the literature (Dodge *et al.* 1966, Kennedy 1970, Vančura 1983) and allow our results to be compared with those of other authors.

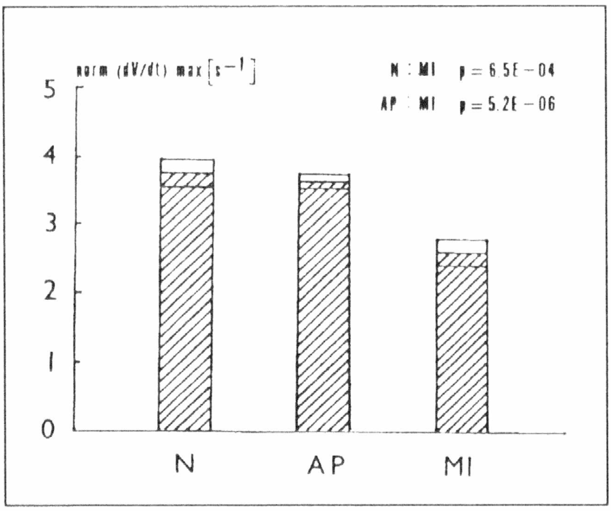

Fig. 2

Mean values and standard deviation of normalized $(dV/dt)_{max}$. The maximum ejection rate related to EDV. The significance levels at which the null hypothesis of agreement of the means can be rejected are also given.

When comparing the results in the various groups of test subjects, we found a statistically significant difference between the group of patients with MI and the control group (or the group with AP)

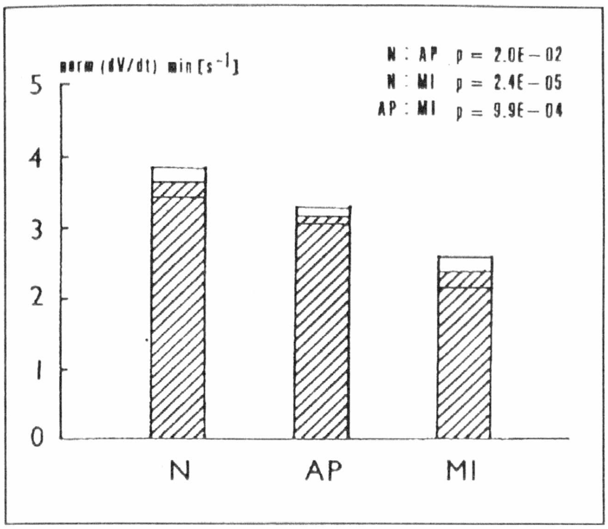

Fig. 3
Normalized $(dV/dt)_{min}$ values and standard deviation of the mean (the maximum filling rate normalized by relating it to EDV).

as regards the EDVI, ESVI and EF values. The group of patients with MI showed greater variability of all the parameters calculated. No statistically significant differences between the control group and the group with AP were found.

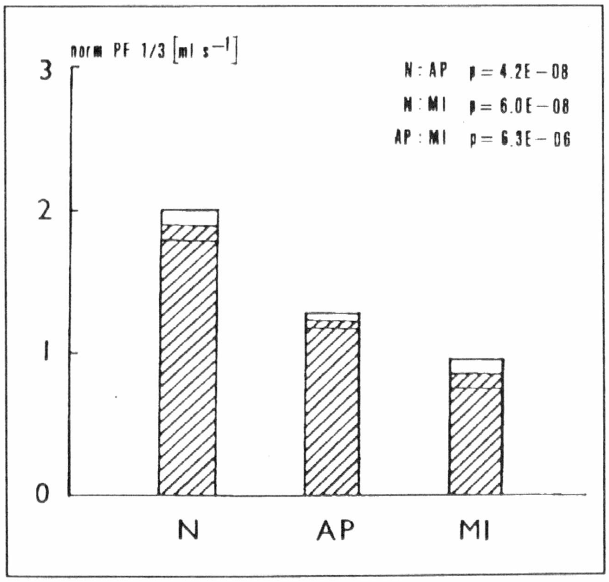

Fig. 4
Normalized FF 1/3 values ± the standard deviation of the mean (the filling fraction in the first third of the diastole, related to the time parameter, i.e. the duration of diastole).

In the frame-by-frame evaluation of the systole (or by dividing the systole and diastole into thirds and halves), statistically significant differences were found only between the N and MI groups (i.e. not the AP group). That means that the parameters $(dV/dt)_{max}$, $norm(dV/dt)_{max}$, EF 1/3 and EF 1/2 have the same differentiating value as the EF (Fig. 2). A comparison of the utilizability of the individual indices is naturally in favour of the EF, however, which has the advantage that it can be determined more easily and more rapidly than the other indices.

When evaluating the diastolic parameters obtained in the same way, we found statistically significant differences between groups N and AP (and, of course, MI) (Figs. 3, 4 and 5). The control group did not differ statistically significantly from the AP group as regards either age or the heart rate. A decrease in the values of those parameters cannot therefore be due to these factors. That means that the indices $norm(dV/dt)_{min}$, norm. EF 1/3 and normFF 1/2 allow patients with reduced myocardial function to be distinguished at much earlier stages of the disorder than on using parameters of systolic left ventricular function (EF, EF 1/2, $norm(dV/dt)_{max}$). As far as the accuracy of the given indices is concerned, we regard the index normFF 1/2 as the most convenient and practicable in clinical practice. Basically, it only means drawing and computing the volume of the LV in the image obtained in half the filling phase of the LV.

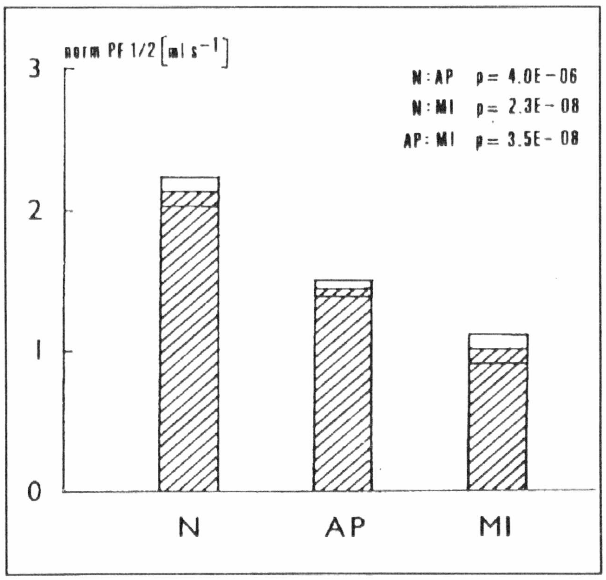

Fig. 5
Normalized FF 1/2 values ± the standard deviation of the mean (the filling fraction in the first half of the diastole, related to the duration of diastole).

Discussion

In clinical pathophysiology of the myocardium, the finding of a disturbance of diastolic function of the myocardium of patients with AP while ejection parameters are still within normal limits, seems definitely to be of interest.

A similar finding (but made on an isolated strip of LV muscle) was already described by Trautwein and Dudel (1936), who found slower relaxation of the muscle at a time when the contractility of the myocardium was not yet impaired. What is the cause of these changes? No exhaustive explanation has been put forward to date. It is assumed that hypoxia of the myocardium plays a role, by inhibiting or arresting aerobic and dependent processes. Hypoxia-induced slowing down of relaxation evidently has complex causes. Energy consumption by the myocardium is highest in the actual contraction phase. Since the contractile apparatus uses up the greatest amount of energy when the cross-bridges between actin and myosin are being disrupted (Bravený and Šumbera 1974, Fejfar 1987), it would only be natural for energy deficiency to become manifested first of all in slower relaxation.

The removal of calcium ions from the region of the myofibrils is another energy-consuming mechanism, which involves active reabsorption of these ions into the sarcoplasmic reticulum through the activity of the "calcium pump". The quantitative data indicate that the activity of the calcium pump is metabolically very exacting (the transport of 1 mol calcium requires 1 mol ATP – Bravený and Šumbera 1974). If the uptake of calcium ions by the sarcoplasmic reticulum is inhibited, the calcium remains bound to troponin, the actin-myosin complexes are not disrupted and relaxation of the myocardium slows down or stops.

The anomalous course of the systolic and diastolic part of the cardiac cycle in patients with IM – a decrease in $(dV/dt)_{max}$, $(dV/dt)_{min}$ and norm $(dV/dt)_{min}$ – can be attributed to the presence of a fibrotically altered region of the myocardium following IM. This hypothesis is also supported by the incidence of local abnormalities in LV mural kinetics in this group of patients (Herman *et al.* 1909, Tennant and Wiggers 1935).

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