Upsala J Med Sci 79: 148–154, 1974

The Videovolumeter

A New Desk-top Instrument for Real Time Videodensitometric Analysis of Dynamic Contrast Agent Changes in Roentgen Images

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ABSTRACT

An instrument for measuring volumes and areas of contrast agents is described. Time relationships can be recorded. Preliminary results from patients indicate that the ejection fraction of the left ventricle and the degree of aortic incompetence can be calculated with reasonably high accuracy.

INTRODUCTION

The determination of the heart pump function, i.e. the ejection fraction, is based on measurements of cardiac volumes, particularly the volume of the left ventricle. This has become an important and in many places a routine method for assessment of patients with cardiac disease.

The existing methods are generally based on the detection of ventricular boundaries on bi-plane cineangiography (1, 2, 3).

In general the volume calculation methods necessitate the use of a fairly high concentration of contrast medium to increase the boundary detection probability.

The volume is determined by the area-length method or by iterative Simpsons rule calculations on bodies with shapes approximating a stack of elliptical cylinders lying within the boundaries. The boundary detection is made either by visual frame to frame inspection on a monitor followed by writing of two borders, frontal and lateral, into a computer memory for each frame, or by full computerization of the process with digitizing of the video signal and subsequent maximum likelihood computation of the boundary position.

This means either time-consuming tedious manual work or heavy reliance on expensive large computer time. Furthermore due to necessary approximations, the computation accuracy is acceptable in diastole but sometimes very doubtful in systole because of the larger irregularities of the shape (4).

The videovolumeter provides a new method for quick, real-time analysis of temporal changes of contrast agent in roentgen images such as videoangiograms and therefore opens up new possibilities for dynamic analysis of, for instance, the cardiovascular system or the renal blood flow. The principles of the method were first outlined in 1968 (5, 8). Later, two other studies following the same principle have been published (6, 7).

The instrument, which is of desk-top format, performs a videodensitometric analysis of the videosignal from a tape recorder and integrates the signal to a measure of contrast changes in the image. The information rate is 50 completely evaluated video frames per second. This can be split into two measuring channels to facilitate simultaneous dynamic analysis of two image areas.

THEORETICAL BACKGROUND

The video signal from a small area element of a roentgen image as recorded on the video tape recorder can be written as

$$v = R_0 \cdot e^{-\lambda_b x_b} \cdot e^{-\lambda_c x_c} \cdot K_s + I_d$$

where

v = vidicon signal

R_0 = intensity of roentgen source

λ_b, λ_c = mean damping coefficient per unit length of roentgen ray in background image and contrast, respectively.

x_b, x_c = length of roentgen ray in background image and contrast, respectively.

K_s = system gain factor.

I_d = dark current level.

After subtraction of dark current level I_d and passing the signal through a logarithmic corrector we obtain a new signal S:

$$S=\log (v-I_d)=\log R_0-\lambda_b x_b-\lambda_c x_c+\log K_s$$

If no contrast medium is present in the image we have $\lambda_c=0$, thus

$$S_0=\log R_0-\lambda_b x_b+\log K_s$$

Now the increase in image damping due to injection of contrast is

$$S_0-S_1=\log R_0-\lambda_b x_b+\log K_s$$
$$-(\log R_0-\lambda_b x_b-\lambda_c x_c+\log K_s)=\lambda_c x_c$$

where the influence of background image, roentgen source intensity and system gain is roughly eliminated, provided they are stable during the recording and no saturation effects occur in the recording chain.

Now the signal S originates from a thin roentgen pencil beam forming a grey area element dA on the monitor screen. By summing (integrating) all signal elements from an urea A of interest, e.g. the left ventricle, we obtain an integrated signal I

$$I=\int_A S dA=\int_A (\log R_0-{}_b x_b-\lambda_c x_c+\log K_s) dA$$

with no contrast medium present we obtain likewise

$$I_0=\int_A S_0 dA=\int_A (\log R_0-\lambda_b x_b+\log K_s) dA$$

By subtracting the integrals we obtain the net content of contrast medium in the image area

$$I_0-I=\int_A \lambda_c x_c \, dA \quad \text{(contrast volume)}$$

If the signal I is plotted with a pen recorder the integral I_0 represents the equivalent background or reference value before the dye injection and the difference I_0-I is simply the curve height with respect to I_0.

Therefore no image subtraction is needed to eliminate the background image.

As the level of I_0 can vary between different recordings the output signal must have provisions for offset balance.

The integration area A is gated out on the TV-monitor with the aid of a light pen. As both integrals are gated with the same area there is no strong demand on sharp boundary identification as in elliptic stack calculations. A fairly coarse gating memory grid is sufficient.

Further, due to the elimination of background effects in the recording it is sufficient to gate out the integrating area once for the whole registration in the maximum diastole image following the injection.

PREPARATION OF THE VIDEO RECORDING

It is important to preserve the transparency in the image measuring area so that the maximum blackening introduced by the dye injection is easily discernible from the dark current level which corresponds to the shade of grey in the circular disc on the TV monitor when the roentgen source is switched off. Therefore lower contrast medium concentrations are used here than in ordinary videoangiography where the primary interest lies in identifying the contrast borders of injected vessels or heart chambers.

The settings of kV and mA on the roentgen source and the manual sensitivity setting on the TV camera should be adjusted so that the image grey scale in the measuring area with contrast medium present or not lies well within the amplitude range of the video signal. In practice this is done by moving a small aluminium step wedge about in the measuring area: all steps in the wedge should be clearly visible in the monitor. The thickness of the wedge should exceed the equivalent "thickness" of the contrast medium.

It is important, further, to record the dark current level just prior to the angiography simply by running the tape recorder for some 20 seconds with the roentgen source switched off. The reason for doing this is that the dark current level should later be corrected for in order to establish a proper reference level for the logarithmic corrector.

BLOCK DIAGRAM

The block diagram (Fig. 1) of the videovolumeter can be partitioned in two main sections:

(i) the analogue signal processing chain, containing dark current subtraction, logarithmic video

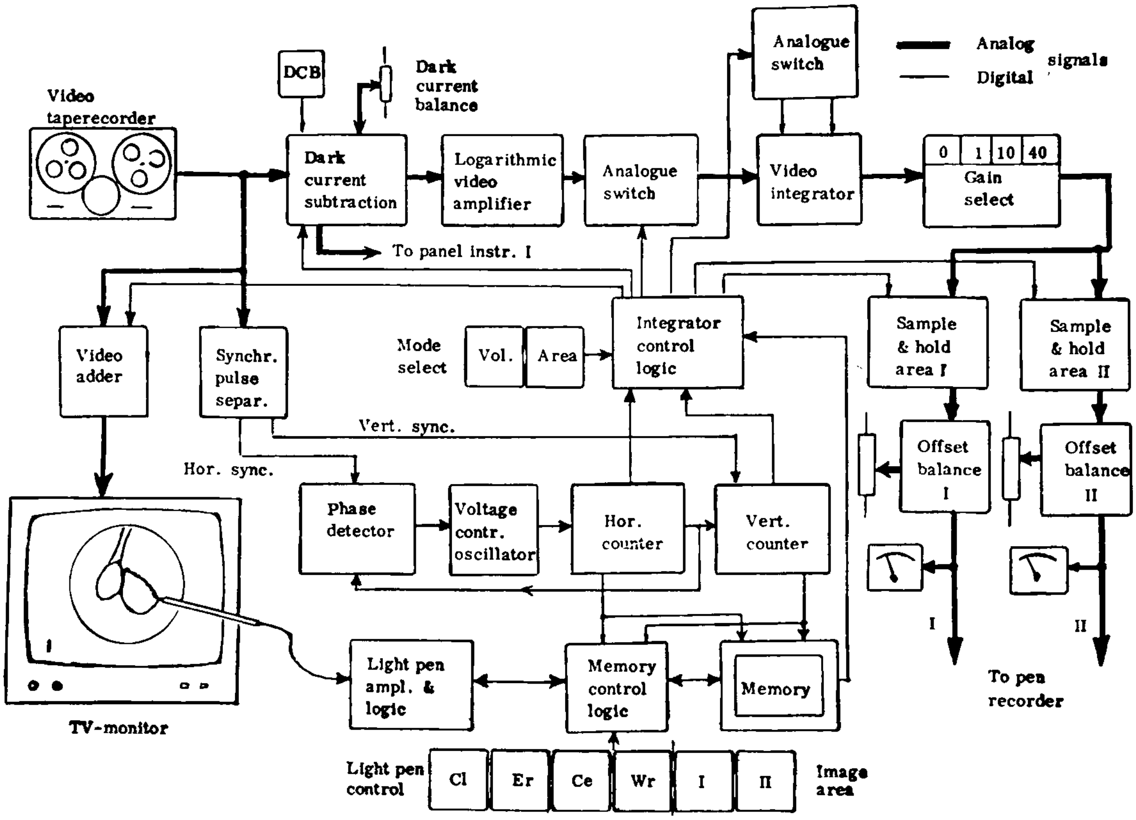


Fig. 1. Block diagram of the videovolumeter.

amplifier, video integrator, block with analogue switches, gain selector etc.

(ii) the digital control circuitry containing phase lock loop with counter chain, light pen, memory, integrator, control logic etc.

When operating the videovolumeter (Fig. 2) the light pen is used for gating out one or two areas in the image. The light pen controls are used to store the gating area in the memory. The controls are clear, erase, write and cells for showing the memory cell pattern on the monitor screen.

The phase lock loop with horizontal and vertical counters is used to establish a logical coordinate system over the monitor screen. The integrator control logic is driven by the stored memory pattern to administrate fairly complex timing functions in the video integrator block and the analogue sample and hold memories for gating areas I and II.

The dark current balance in the analogue signal chain is set by the operator by pressing the DCB button and adjusting the potentiometer until the panel instrument I is balanced. This is done with the recorded dark current signal.

The gain select and offset balance adjustment serve to facilitate signal conditioning to the pen recorder.

In a 50Hz 625 lines interlace TV system the half frame frequency is 50 Hz. If two measuring areas are used the sample and hold memories are driven so that information frequency is 25 Hz in each channel. Each image frame leads to a complete evaluation of the integral I.

RESULTS

Model experiments

To test the accuracy of this apparatus, thin-walled plastic bags of various sizes have been used containing varying amounts of roentgen contrast medium to represent the left ventricle. The bags have been submerged in 20 cm of water to simulate the absorption and scatter generated by a heavy cardiac patient. Video tape recordings of

Fig. 2. Videovolumeter with areas of interest marked on the monitor. The indications should be compared with Fig. 1.

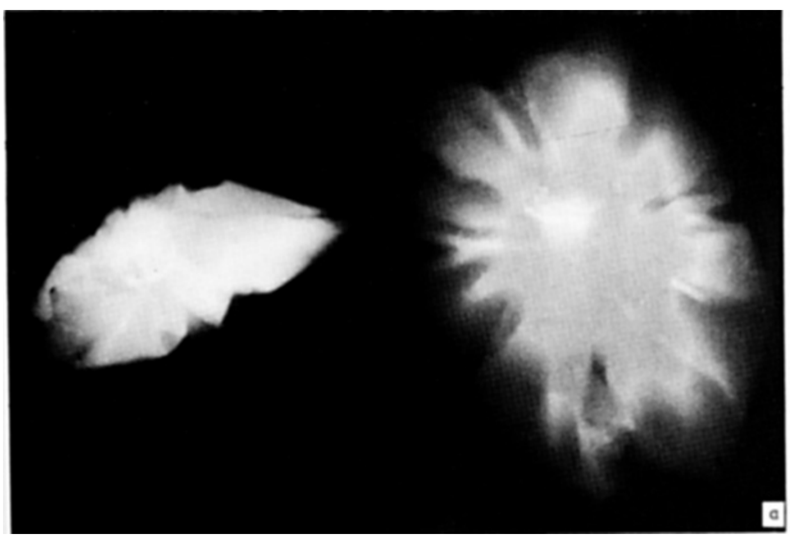
the image of the plastic bags have been obtained. The integrated video signal in the areas comprising the plastic bags has been recorded. In one experiment four bags with a volume of 150 ml were used. In the bags were varying amounts of roentgen contrast medium containing 350 mg iodine/ml. A practically linear relationship between the integrated signal and the amount of roentgen contrast medium in these four models was observed (Fig. 3*a*, *b*).

In another experiment the same amout of roentgen contrast medium was put into four plastic bags containing different volumes of water. Deviation of less than a few percent was observed, showing that accurate measurements of the amount of iodine present in an organ can be made within a large variation of volumes and concentrations.

Investigations on patients

The two channels for measurements produced recordings which were practically identical, indicating good reproducibility. An injection of 15 ml of Isopaque 60 (15 ml/sec) in the left ventricle increased the signal from the pre-injection level, I_0 (Fig. 4), to a level proportional to the amount of contrast in the left ventricle.

The variations in I_0 are mostly due to variations in size of the superimposed left and the right ventricles. It may be speculated whether this could be used as a method for "non-invasive" determina-



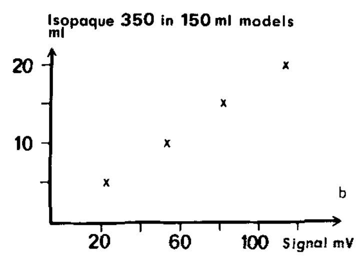


Fig. 3. Bags of different sizes (*a*) were studies when the amount of contrast agent varied. There was a linear relationship between the signal (mV) and the amount of contrast medium (ml), (*b*).

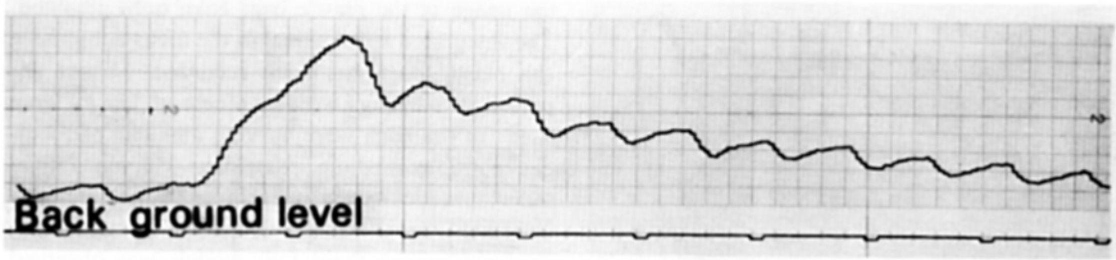


Fig. 4. One registration of temporal contrast variations of the left ventricle in a patient. 15 ml of 60% Isopaque was injected in 1 sec into the left ventricle. Time in seconds is registered on the lower line.

tion of the combined ejection fraction of the left and right ventricles.

The ejection fraction can be calculated. After one heart beat the contrast residue is C_1 in systole, the difference from the foregoing diastolic contrast level C_0 is the amount of contrast ejected from the ventricle. The ratio $(C_0-C_1)/C_0$ is a measure of the pump efficiency. In the end we can observe a small contrast level change due to recirculation effects.

To arrive at the true volume of the left ventricle a calibration is necessary. This can be achieved in the following way.

The projected area of the left ventricle can be easily and rapidly measured on one single frame in end-diastole, using the area measuring device incorporated in the instrument (Figs. 1 and 2). The long axis of the ventricle can also be measured on the same frame. A known area is used for comparison.

Using the area-length method the volume of the ventricle on this single frame in end-diastole can be calculated with good accuracy. On the same frame the integrated and amplified density is measured and the density value can then be related to the volume in ml.

Adequate mixing of the contrast agent with the blood in the left ventricle may be of importance for the accuracy of the volume determinations.

Injection in the left atrium thus would be preferable, since the mixing would then always be more complete, as shown in animal experiments. However, biplane cinéangiocardiography seems to indicate that good mixing is achieved by left ventricular injection in most cases. In a few patients we have had the opportunity to compare left atrial and left ventricular injections and the density curves for the left ventricle have been very similar (Fig. 5).

Simultaneous recordings from the left ventricle

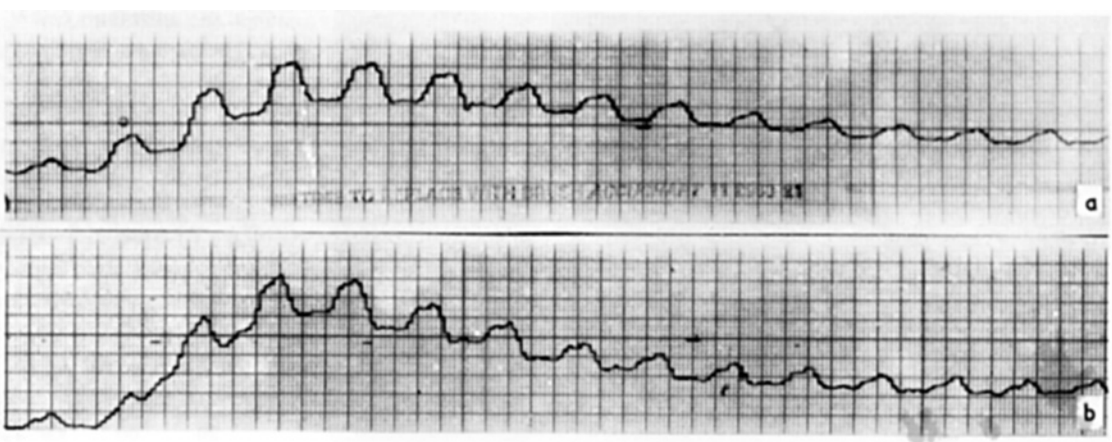


Fig. 5. Left atrial (*a*) and left ventricular (*b*) Injections of contrast agent and recording over the left ventricle. The curves are very similar, indicating good reproducibility and adequate mixing of contrast agent with blood at both injections.

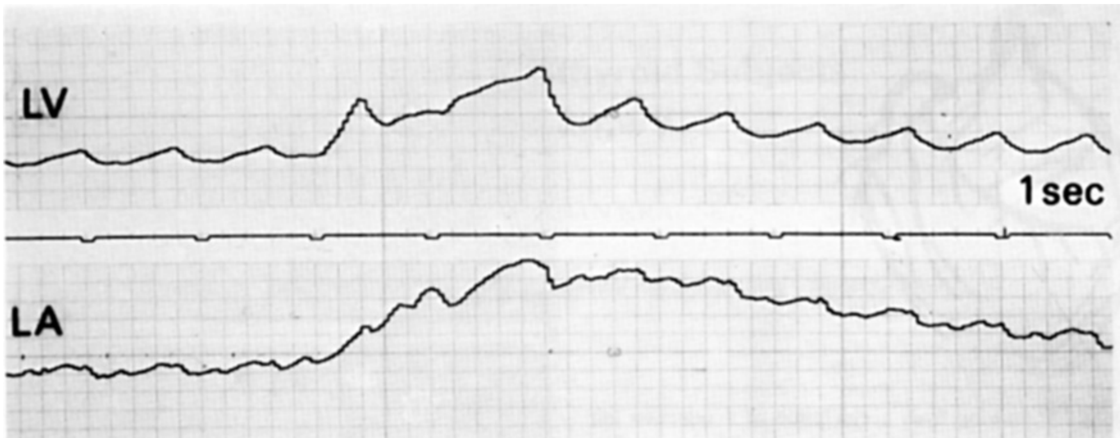


Fig. 6. Simultaneous recording of left ventricle and left atrium in a patient with mitral incompetence. 15 ml of 60% Isopaque was injected in 1 sec in the left ventricle. The increase of iodine in the left atrium indicates mitral insufficiency.

and the left atrium in a patient with mitral insufficiency can be performed (Fig. 6). As expected, there is a build-up of contrast agent in the left atrium followed by a relatively slow elimination. A recording of the left ventricle following aortic injection in a patient with aortic incompetence (Fig. 7) again shows a build-up in the left ventricle and permits calculation of the degree of aortic incompetence.

The amount of contrast medium present in a segment of the myocardium and its variation with time following injection into the aorta or a coronary artery can be measured with the instrument described here. A left coronary arteriogram in LAO projection with a stenosis in the circumflex branch is shown as an example (Fig. 8). The temporal variation in the contrast medium content of the two similar-sized segments of the left ventricular wall myocardium were studied (Fig. 9). The upper curve is from a segment supplied by the stenosed circumflex artery and the lower curve is from a segment supplied by the unobstructed left anterior descending coronary artery. This indicates that the videovolumeter may be useful for detection of relative differences in blood supply to various parts of the myocardium. Advantages over isotope studies would include more accurate anatomic definition of various segments of the myocardium, a faster sampling rate and easily repeated studies, e.g. under resting.

Simple measurements of volumes and flow (or distribution) of contrast agent in the heart and other organs take only a few minutes with the present instrument. Automatic calculation of left ventricular volumes during the cardiac cycle, construction of pressure-volume loops, etc., would require simultaneous digital recording of aortic and left ventricular pressures on the videotape for synchronization purposes and the off-line use of a large computer or the use of a mini computer adopted to the videovolumeter. The videodensitometric procedure is easily incorporated in the

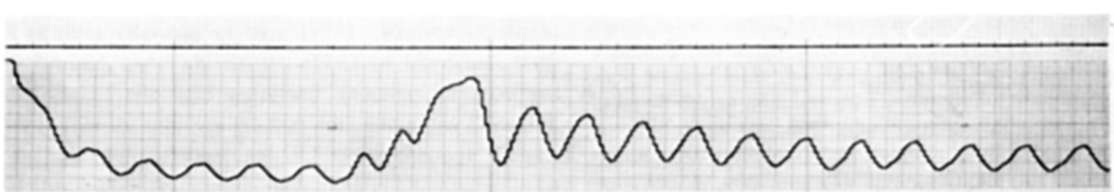


Fig. 7. Recording of left ventricle in a patient with aortic incompetence when 20 ml of 60% Isopaque was injected in the aorta. A large proportion of the stroke volume regurgitates, as indicated by the increase in iodine amount in diastole as compared with the foregoing systolic amount of iodine. /—/=injection time.

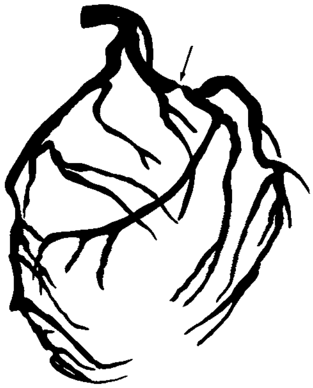


Fig. 8. A drawing from a cinéframe of a selective left coronary arteriography. Stenosis of left circumflex branch (*arrow*).

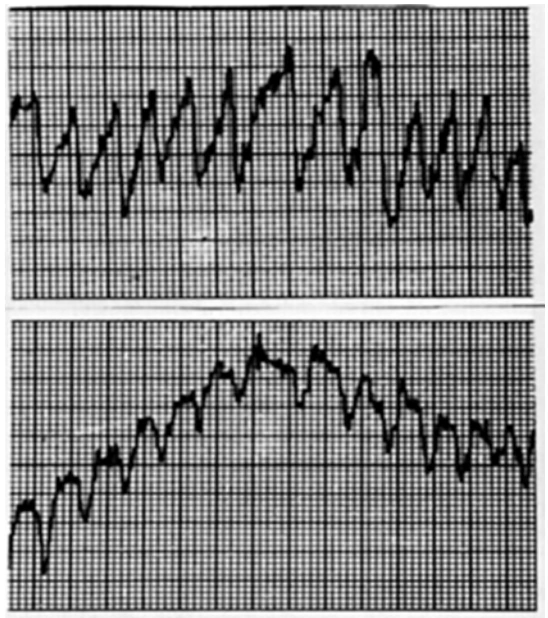


Fig. 9. Variations in time of contrast agent in two segments of left ventricular wall. The upper curve from a segment supplied by stenosed LCA may indicate a reduced blood flow to that part.

standard catheterization and angiographic procedures with little or no additional risk or discomfort for the patient. Since small amounts of roentgen contrast agent are used the effect of such agents on the circulation is largely eliminated.

Studies where results from the videovolumeter is compared with measuring of stroke volumes and regurgitations by clinical physiological methods will later be reported.

ACKNOWLEDGEMENT

This research was supported by a grant from the Swedish Medical Research Council.

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Received March 29, 1974

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