THE MEASUREMENT OF THE GRADIENT ACROSS THE AORTIC VALVE*

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The ordinary clinical methods of diagnosis of aortic stenosis are not always reliable, and since surgical treatment has become available, a need has arisen for a more accurate assessment.[1-8] Radiographic evidence of calcification of the aortic valve obviously ensures a definite diagnosis, but many cases will escape recognition if an anacrotic pulse and a harsh basal systolic murmur with thrill are deemed necessary criteria.[9, 10] Similarly there are other conditions in which a harsh basal systolic murmur (and thrill) may occur, leading to problems in diagnosis even to the most experienced.[6, 11]

The characteristics of the peripheral pulse were first studied,[12] because of the importance of the quality of the pulse in the diagnosis of aortic stenosis.[11] It soon became clear, however, that although the pulse was of value in determining the diagnosis it provided no accurate quantitative information about the degree of stenosis present. The gradient

* A paper presented at the South African Medical Congress, Durban, September 1957.

across the aortic valve, which will indicate the exact degree of stenosis, can be measured by comparing the pressures in the left ventricle and the aorta. Several methods are available for measuring this gradient:

1. Retrograde arterial catheterization.[13]

2. Catheterization of the left auricle through the left bronchus.[14, 15]

3. Percutaneous catheterization of the left auricle.[16]

4. Percutaneous catheterization of the left ventricle.[17]

5. Direct catheterization of the left ventricle and aorta after the chest and pericardium have been opened.

The last three methods were used in this study.

Material and Methods

All the patients were carefully studied in the Cardiac Clinic, where electrocardiographic, phono-cardiographic and radiological examinations were obtained. Intra-arterial studies were carried out in many cases. The group under survey consisted of 7 cases of aortic valve disease, 24 cases of mitral stenosis, and 5 cases of constrictive pericarditis. The procedures for recording the cardiac pressures were all performed in the operating theatre, usually under general anaesthesia. The exploring needle was connected to a capacity-type electromanometer (N.E.P.) by a length of polythene tubing with Luer-Lock fittings. The pressure waves were monitored on a twin-beam oscilloscope before recording them photographically on a six-channel N.E.P. apparatus. An ECG lead was recorded synchronously with the pressures. In addition, a plastic catheter of polyvinyl tubing No. 442 T was inserted through the needle and manipulated in the heart chambers. This catheter was connected to the manometer by a specially adapted fitting. The catheters were flushed intermittently to prevent clotting and damping of the curves.

RESULTS

1. *Percutaneous Catheterization of the Left Auricle*

Percutaneous catheterization of the left auricle was only performed in the cases of mitral stenosis, just before the thoracotomy for the valvotomy. The posterior percutaneous route developed by Bjork *et al.*[16] was used. The patient was placed in the prone position, and a site about 2 fingers' breadth (4-4·5 cm.) to the right of the spinous processes in the right 7th or 8th intercostal space was selected. The point of an 18 T thin-walled styletted needle was then directed anteriorly and inclined at about 25° obliquely to the left, passing in front of the spine by a right paravertebral approach. The left auricle was usually entered at a needle-length of 10-14 cm., the emergence of bright-red blood being the indication that the needle was in the correct chamber.

Direct readings were taken of the pressures in the left auricle in 7 cases (Fig. 1). These readings were usually comparable with the pressures recorded from the left auricle at thoracotomy. Puncturing the left auricle was successfully accomplished in all cases, but not without considerable difficulty. Overt bleeding was slight. This minimal bleeding

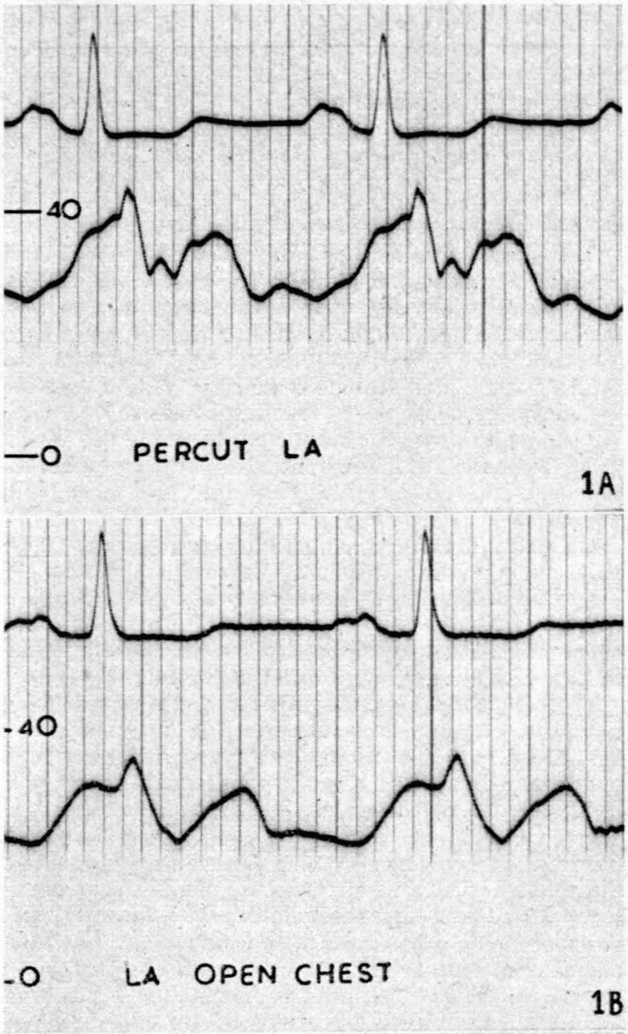


Fig. 1. Left auricular pressure records taken (A) percutaneously by the posterior route and (B) directly from the left auricle at open thoracotomy from a case of severe mitral stenosis. The curves show similar wave forms and pressures (taken at 80 mm. per second).

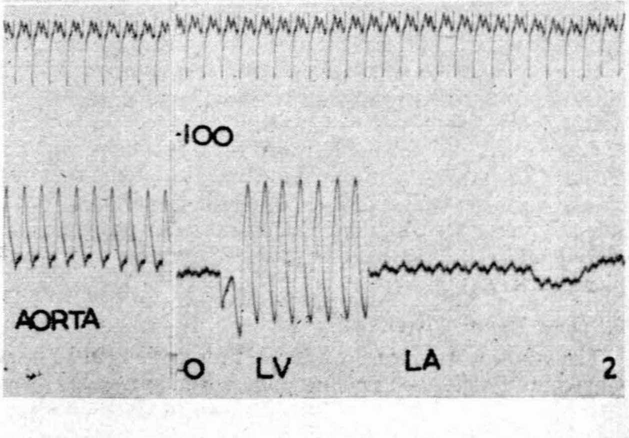


Fig. 2. Percutaneous catheterization of the left auricle, ventricle and aorta by the posterior route in a case of severe mitral stenosis. There is no gradient between the aortic and left ventricular systolic pressures (75/45 and 75/20 mm. Hg respectively). The left auricular pressure is very high (mean of 37 mm. Hg) and a considerable gradient (37-20 mm. Hg) exists between the left auricle and the left ventricle in diastole. The tracing is damped and taken at 8 mm. per second.

was confirmed when the pericardial sac was opened at subsequent operation. Bronchoscopy became necessary, however, in one case, before the thoracotomy, in order to remove blood clots. Difficulty was encountered in manipulating the plastic catheter after it had been passed through the needle into the auricle, because of coiling up in the chamber, particularly in the presence of grossly stenosed mitral valves. A typical pressure tracing is shown in Fig. 2. As damping of the pressure curves was a frequent occurrence, and the ventricle and aorta could not be catheterized with regularity, this method was abandoned. The passage of the needle into the left auricle was not observed under the fluoroscopic screen, as has been done by others.[18-23] Radner's method[24] of introducing a long needle behind the sternum down into the aorta, pulmonary artery and the left auricle was also not used.

2. *Percutaneous Catheterization of the Left Ventricle*

The anterior percutaneous route described by Brock *et al.*[17] was the first method employed. The patient was placed in the supine position, and a site was selected 2 cm. below and lateral to the apex of the heart. A No. 18 guage needle 12·5 cm. long was inserted at the apex and directed towards the 2nd right costo-chondral junction with a backward inclination of about 35°. The needle was advanced until the left ventricle was felt beating on the needle tip, at which stage the needle was inserted into the ventricle. Catheterization of the left ventricle was performed in 5 cases by this approach.

On several occasions the right ventricle was entered during the attempt to enter the left. Tracings taken through a catheter threaded through the needle and passed across the aortic valve were usually damped (Fig. 3). In order to overcome these difficulties the pressures in the left ventricle and in the brachial artery were recorded consecutively (Fig. 4).

The sub-xiphoid route provides a means of recording both right and left ventricular pressures (Fig. 5). The method has been described by Numy *et al.*[25] At first, prior to the puncture, a hard P.A. X-ray film was taken, to show the position of the xiphoid process and the heart border. A left lateral view was then taken with a series of metal markers placed down the mid-axillary line. The course to be taken by the needle was judged from these two films. The needle was then inserted near the xiphoid cartilage and directed towards the appropriate marker, which had been left *in situ* on the mid-axillary line. (With experience, markers were found to be unnecessary and their use was discontinued.) The needle was directed towards the centre of the right ventricle. Unoxygenated blood issued from the needle when the right ventricle was entered, and the pressure, which was monitored, was lower than the systemic pressure. Consecutive pressures were immediately recorded from the brachial or femoral arteries.

Catheterization of the left ventricle was performed in 7 cases. The systolic pressure in the brachial or femoral artery should normally be the same as, or a little higher, than that of the left ventricle. In aortic stenosis, however, there is a considerable gradient between the left ventricle and a peripheral artery (Fig. 6).

3. *Open Thoracotomy*

The gradient was measured during thoracotomy in 17 cases. Consecutive left ventricular and aortic pressures were recorded. This procedure is necessary for cases known to require a mitral valvotomy but with suspected superadded aortic stenosis, for it may be necessary to perform an aortic valvotomy at the same operation. In two early cases, a polythene tube was passed into the aorta through an incision in the left ventricle, and the gradient was measured as the tube was withdrawn back into the ventricle (Fig. 7). Aortic stenosis had been suspected in both these patients. In one, no aortic valve disease was detected and in the other, surgery was contra-indicated because of an insufficient gradient and too much incompetence.

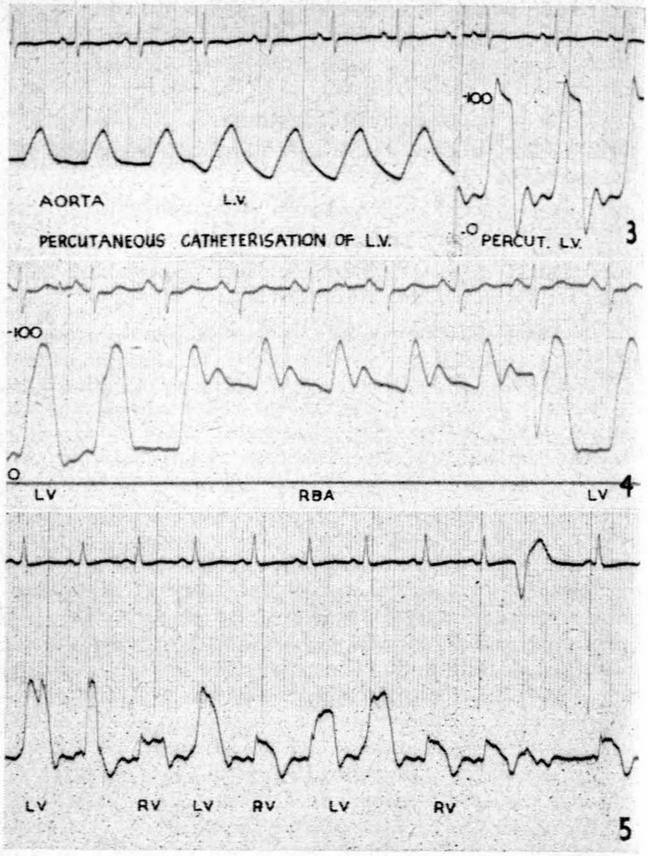
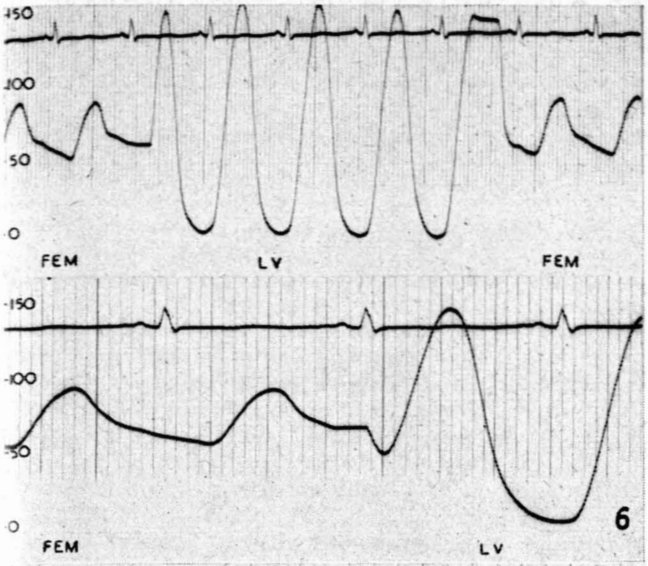


Fig. 3. Percutaneous catheterization of the left ventricle and aorta via the anterior percutaneous route in a case of constrictive pericarditis. There is no systolic gradient between aorta and left ventricle during the passage of a polythene catheter across the valve, but the tracing is considerably damped. The percutaneous undamped left ventricular pressure taken directly from the needle (112/0-25 mm. Hg) shows the diastolic dip encountered in constrictive pericarditis.

Fig. 4. Immediately consecutive pressures from the left ventricle *via* the anterior percutaneous route and the right brachial artery in a case of severe mitral stenosis showing no gradient between the systolic pressures (94/12 and 95/60 mm. Hg respectively). The pressures are recorded through a two-way tap with one needle in the left ventricle and one in the right brachial artery.

Fig. 5. Right and left ventricular pressure taken *via* the percutaneous sub-xiphoid route in a case of constrictive pericarditis. The needle is inserted through the ventricular septum into the left ventricle and then withdrawn into the right ventricle. The right ventricular trace shows the diastolic dip associated with constrictive pericarditis.



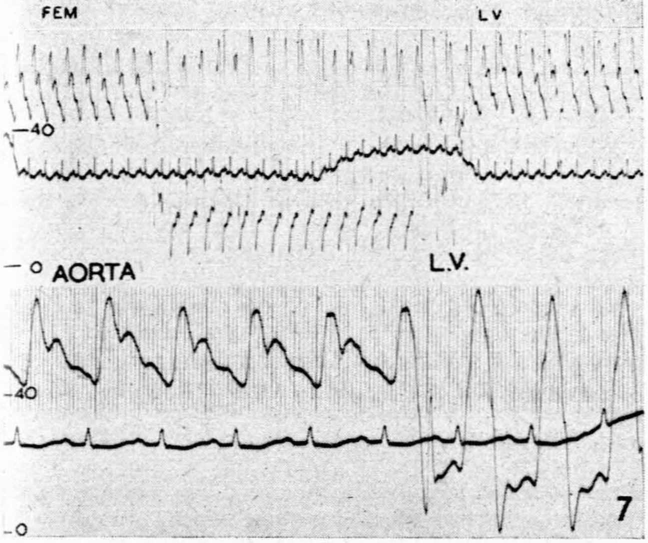


Fig. 6. Immediately consecutive pressures from the left ventricle via the percutaneous sub-xiphoid route and the femoral artery in a case of severe aortic stenosis. The aortic systolic gradient is 64 mm. Hg (aortic pressure 90/50, left ventricular 154/5). The anacrotic pulse is well shown in the fast record taken at 80 mm. per second, as is the symmetrical type of left ventricular pressure recording.

Fig. 7. Catheterization of the left ventricle and aorta during open cardiotomy in a case of heart failure of unknown origin simulating aortic stenosis. There is no significant gradient between the systolic pressure in the left ventricle and the aorta. There is no prolongation of the upstroke in the aortic trace and the left ventricular record does not show the symmetrical limbs of aortic stenosis. The top tracing is taken at 8 mm. per second, the bottom at 25 mm. per second.

DISCUSSION

Catheterization of the right side of the heart is a routine procedure in all cardiovascular centres, but unfortunately it provides no information of the state of the left ventricle and the aorta. The successful development of aortic-valve surgery has rendered it imperative to determine the simultaneous or consecutive pressures in the left ventricle and the aorta or its branches. A simultaneous measurement of the cardiac output is required to understand the significance of the aortic gradient.[26, 19] This is particularly important where aortic stenosis alone is present. The calculation of the flow across the aortic valve is inaccurate when the stenosis is accompanied by aortic incompetence. Thus, a pressure gradient of 60-100 mm. of mercury may be found with dominant aortic regurgitation.[27, 11]

The gradient across the aortic valve alone, was measured in this preliminary study. This procedure proved valuable in assessing the severity of the stenosis as an indication for surgical treatment. Needling of the left ventricle through the sub-xiphoid route was the simplest method, and pressures could be obtained which could be recorded consecutively with the brachial or femoral artery. Percutaneous puncture of the ventricles is not without danger, as we have seen. The pericardial sac usually contained some slight amount of blood after the procedure. An acute tamponade developed in one patient, and an immediate thoracotomy was required to relieve the haemopericardium. This investigation should therefore only be undertaken where adequate facilities exist for immediate thoracotomy and aortic valvotomy.

One other patient died suddenly a week after puncture, and although he had significant valve disease with severe symptoms, it was considered that the investigation may have contributed to his death.

Asystole and ventricular fibrillation have been described as a result of these investigations. One of our cases developed ventricular fibrillation and died as the local anaesthetic was being injected into the chest wall. This was a particularly severe and pre-terminal case, however.

Air embolism is a potential and avoidable hazard. Precautions must be taken to keep syringes and catheters completely filled with saline throughout the investigation. Chest radiographs were always taken after the procedures to exclude pneumothorax, haemothorax or haemopericardium.

CONCLUSIONS

1. Measurement of the gradient across the aortic valve is indicated in the assessment of the severity of aortic stenosis.
2. The method of choice is simultaneous or immediately consecutive measurement of the pressures in a peripheral artery such as the brachial or femoral artery, and the left ventricle.
3. The sub-xiphoid route is the method of choice for percutaneous needling of the left ventricle.
4. Simultaneous or immediate consecutive measurement of the aortic and left ventricular pressures is indicated during mitral valvotomy when co-existent aortic stenosis is suspected. This is best performed during thoracotomy.

We wish to thank the various members of the hospital staff for referring cases to the Cardiac Clinic. Our special thanks are due to the *Cape Times*, the Cape Town City Council and the people of Cape Town, without whose generous contributions the equipment used for this study could not have been acquired. We also wish to thank Mr. L. W. Piller for his technical assistance throughout the investigation. Part of the expenses for this work have been defrayed by grants received from the Council for Scientific and Industrial Research.

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