Echocardiography of the intra-aortic balloon

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Echocardiography was performed on 9 patients being treated for cardiogenic shock with an intra-aortic balloon. The value of simultaneous recording of the electrocardiogram, cardiac movements, and arterial pressure, with the echocardiogram of the intra-aortic balloon is discussed. The results indicate that echocardiography provides a method of studying intra-aortic balloon function.

The clinical importance of counterpulsation using an intra-aortic balloon has been established over the past few years (Kantrowitz and Kantrowitz, 1953; Moulopoulos, Topaz, and Kolff, 1962; Kantrowitz *et al.*, 1968a; Dunkman *et al.*, 1972). The effectiveness of counterpulsation depends on accurate timing of inflation and deflation of the balloon, and on an optimal relation between the size of the balloon and the descending aorta. Ultrasound techniques provide an accurate non-invasive method of visualizing balloon movement within the descending thoracic aorta. The purpose, therefore, of this paper is to describe the echocardiographic features of intra-aortic balloon counterpulsation, to attempt to correlate these findings with other clinical data, and to explore the potential value of ultrasound in evaluating intra-aortic balloon function.

Patients and methods

Nine patients with an intra-aortic balloon were studied by echocardiography: 8 men and 1 woman, with ages ranging from 42 years to 64 years. Sixteen separate recordings were obtained. The indication for counterpulsation in all patients was severe cardiogenic shock, caused by myocardial infarction alone in 3 patients, associated with ruptured interventricular septum in a further 5 patients (2 patients also had left ventricular aneurysms), and with infarction accompanied by acute mitral regurgitation caused by papillary muscle dysfunction in the last patient. The counterpulsation in 8 patients was achieved with Datascope System 80, the remaining one patient being on the Avco machine.

The echogram traces were all obtained using a Smith Kline Eskoline 20 Diagnostic Ultrasonoscope with a Cambridge Multichannel Recorder. Simultaneous electrocardiogram and radial arterial pressure traces were recorded routinely.

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The normal transducer position for mitral valve recordings has to be slightly modified in order to obtain echoes from the descending aorta. The transducer is placed as near to the sternum as possible and angled towards the left side of the vertebral column, where the descending aorta lies adjacent to the left side of the vertebral bodies. The descending aorta is situated approximately 15 cm from the anterior chest wall. In obese patients, this distance can be up to 20 cm. One of the problems of recording echoes at such a depth is the numerous artefact echoes due to scatter from surrounding mediastinal structures. Elimination of these artefacts by the 'gain' and 'reject' controls results in loss of echoes from the anterior cardiac structures. This makes clear satisfactory recording of anterior aortic valve with posterior intra-aortic balloon difficult.

The echographic recording was considered satisfactory when it showed the walls of the descending thoracic aorta, the movement of the balloon on inflation and deflation, and the electrocardiogram. The aortic valve, the mitral valve, the interventricular septum, or the posterior left ventricular wall were recorded on the same time trace to provide accurate synchronization of intra-aortic balloon function with events during the cardiac cycle.

It is not always possible to record anterior and posterior aortic surfaces to the best advantage simultaneously. When the posterior wall of the descending aorta is being recorded, it is frequently necessary to turn the gain so high that a large number of artefacts are seen anteriorly. In Fig. 1, the posterior wall of the descending aorta is not seen but careful adjustment of the near and coarse gains allows the aortic wall measurements to be made in Fig. 2 and 3a.

The size of the descending thoracic aorta was also studied in 12 control patients undergoing routine echocardiography. Their ages ranged from 33 years to 76 years.

Results

Satisfactory tracings of the descending thoracic aorta with the balloon *in situ* were recorded in 8 out

FIG. 1 Echogram from descending aorta with balloon in place. For the first 6 cardiac cycles, the balloon is pumping in a 1:1 ratio. The ratio then changes to 2:1 to show the difference in the radial artery pressures. Diastolic augmentation occurs with inflation of the balloon, and is followed by a sudden pressure drop on deflation.

ECG = electrocardiogram; PLVW = posterior left ventricular wall; AWDA = anterior wall descending aorta; IAB = intra-aortic balloon; PWDA = posterior wall descending aorta; RAP = radial artery pressure.

of the 9 patients. The ninth patient was obese, and the descending aorta was never visualized, because of ultrasound wave attenuation.

A characteristic echocardiographic trace of the descending aorta with the intra-aortic balloon *in situ* is seen in Fig. 1. The electrocardiogram, posterior left ventricular wall, descending thoracic aorta, intra-aortic balloon, and radial artery pressure are recorded on the same time trace. The echogram clearly shows the movements of the balloon; inflation is rapid and this is represented by sudden movement of the balloon echoes from the middle of the aortic lumen to an 'open' position against the aortic walls. The reverse happens on deflation. Accurate timing of these events is determined from the echogram and can be related to the electrocardiogram, aortic valve, and posterior left ventricular wall movement, and the arterial pressure tracings. In Fig. 1 the radial artery tracings are delayed by 0.15 s. The diastolic augmentation caused by the intra-aortic balloon can be clearly seen on the recording. Also in Fig. 1 the movement of the posterior left ventricular wall can be correlated with balloon function. At the end of the systole, the

left ventricle is in full contraction, and at this point, i.e. the beginning of diastole, the balloon inflates. Similarly, movement of the balloon can be related to the aortic valve in another patient (Fig. 2). This tracing shows that aortic valve opening coincides with deflation of the balloon. Also, on aortic valve closure at the onset of diastole, the balloon simultaneously inflates.

The diameter of the descending thoracic aorta can be measured from the echogram. In the 8 patients with satisfactory tracings, the average internal diameter was 2.5 cm (range 2.3 cm to 2.75 cm). The average size of the descending aorta in the 12 control patients was 2.4 cm (range 1.8 cm to 3.1 cm). These values closely correspond to those obtained from the patients on the intra-aortic balloon.

In one patient, the aortic balloon inflated slowly and did not occlude the aortic lumen (Fig. 3a); multiple echoes which are seen around the deflated balloon could have been caused by abnormal blood turbulence. The impaired balloon function was created by a faulty connexion resulting in a leak. Fig. 3b is recorded from the same patient

after the leak had been repaired. There is now rapid inflation with the balloon properly positioned against the aortic wall. The multiple echoes have cleared.

FIG. 2 A composite trace formed from two records taken within seconds in the same patient, to show the relation of opening and closure of the aortic valve to deflation and inflation of the balloon.

AWAA=anterior wall ascending aorta; AV=aortic valve; PWAA=posterior wall ascending aorta; MV=mitral valve. See Fig. 1 for other abbreviations.

Discussion

This study has shown that an echogram of the intra-aortic balloon can be obtained. The characteristic pattern is described and this gives information about balloon function, its relation to the cardiac cycle and electrocardiogram, and its correlation with arterial pressures. It is, therefore, possible to adjust the balloon's action by reference to the heart movements rather than the delayed pressure trace. Effective counterpulsation necessitates inflation of the balloon immediately after aortic valve closure, and deflation when left ventricular ejection starts (this coinciding with aortic valve opening). The electrocardiogram and the arterial pressure trace, though helpful are not absolutely accurate, as the interval between the QRS and the aortic valve opening depends on the inotropic state of the ventricle and this varies from patient to patient and in the same patient at different times.

The pressure wave is similarly affected by the delay. A further error is introduced by mechanical transmission from the machine to the balloon. Echocardiography of the intra-aortic balloon avoids all these errors, and thus, direct visualization may well be advantageous in producing maximum mechanical efficiency and the best clinical result. As seen in Fig. 3a and b the correction of unsatisfactory balloon function was the direct result of the echocardiographic examination.

The diameter of the thoracic aorta is an important consideration when considering a patient for counterpulsation. The choice of appropriate balloon diameter will vary from patient to patient and in the same patient, depending on mean aortic pressure and the elasticity of the vessel. To date, the choice of the correct intra-aortic balloon size for the patient has been based on indirect information. This has included estimating the size of the aorta from the calibre of the femoral artery (Bregman, Kripke, and Goetz, 1970; Buckley *et al.*, 1972) or from body weight (Kantrowitz *et al.*, 1968b). Ultrasound recordings give direct information on the size of the descending aorta, so that the correct intra-aortic balloon diameter can be chosen. They will also show any changes in the aortic size during counterpulsation.

Experimentally, it has been shown in calves that, for any given arterial pressure or aortic size, the greatest augmentation in mean aortic diastolic pressure was achieved with complete occlusion. Thus, the importance of the critical relation between the intra-aortic balloon and the aortic diameter at any one time has been clearly established (Weber, Janicki, and Walker, 1972).

It follows, therefore, if the aorta is too dilated, poor diastolic augmentation will result. Conversely,

FIG. 3 a) Tracing from a patient with an intra-aortic balloon which failed to inflate rapidly due to a leak. b) Satisfactory tracing after this had been repaired.

if the aorta is too small, a frequent occurrence in young people, the balloon will interfere with blood flow even in the deflated position. This results in an increased aortic pressure in systole and an increase in left ventricular load. In doubtful cases, it is advisable to measure the size of the descending aorta before balloon insertion. This can be achieved in the majority of patients by a non-invasive echogram.

References

- Bregman, D., Kripke, D. C., and Goetz, R. H. (1970). The effect of synchronous unidirectional intra-aortic balloon pumping on hemodynamics and coronary blood flow in cardiogenic shock. *Transactions. American Society for Artificial Internal Organs*, **16**, 439.
- Buckley, M. J., Craver, J. M., Gold, H. K., Mundth, E. D., Daggett, W. M., and Austen, W. G. (1972). Intra-aortic balloon pump assist for cardiogenic shock after cardiopulmonary bypass. *Circulation*, **46**, Suppl. II, 76.
- Dunkman, W. B., Leinbach, R. C., Buckley, M. J., Mundth, E. D., Kantrowitz, A. R., Austen, W. G., and Sanders, C. A. (1972). Clinical and hemodynamic results of intra-aortic balloon pumping and surgery for cardiogenic shock. *Circulation*, **46**, 465.
- Kantrowitz, A., and Kantrowitz, A. (1953). Experimental augmentation of coronary flow by retardation of the arterial pressure pulse. *Surgery*, **34**, 678.
- Kantrowitz, A., Tjonneland, S., Freed, P. S., Phillips, S. J., Butner, A. N., and Sherman, J. L. (1968a). Initial clinical experience with intraaortic balloon pumping in cardiogenic shock. *Journal of the American Medical Association*, **203**, 113.
- Kantrowitz, A., Tjonneland, S., Krakauer, J. S., Phillips, S. J., Freed, P. S., and Butner, A. N. (1968b). Mechanical intraaortic cardiac assistance in cardiogenic shock. Hemodynamic effects. *Archives of Surgery*, **97**, 1000.
- Mouloupoulos, S. D., Topaz, S., and Kolff, W. J. (1962). Diastolic balloon pumping (with carbon dioxide) in the aorta - a mechanical assistance to the failing circulation. *American Heart Journal*, **63**, 669.
- Weber, K. T., Janicki, J. S., and Walker, A. A. (1972). Intra-aortic balloon pumping: an analysis of several variables affecting balloon performance. *Transactions. American Society for Artificial Internal Organs*, **18**, 486.

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