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APOLLO 15

VIBROCARDIOGRAPHY

The Cardiovascular Laboratory utilizes vibrocardiography as a non-invasive method of measuring mechanical events of the cardiac cycle. The technique, based on that described by Agress (Am. J. Cardiol., 4:184, 1959; Am. J. Cardiol., 8:22, 1961), has been used in most of the lower body negative pressure (LBNP) tests carried out in the Cardiovascular Laboratory during the past three years. Pre- and postflight vibrocardiograms (VbCG) during the LBNP procedure were obtained on flight crews for the first time in association with the Apollo 15 flight.

The technique employs a capacitance microphone and, therefore, responds to displacement of the chest wall associated with cardiac contraction and relaxation. The frequency response ranges from 0.1 to 200 Hz, although the strip-chart recorder cuts off the upper limit to about 100 Hz. Since nearly all the energy of precordial vibrations lies in the frequencies below 30 Hz, the resulting output from the microphone resembles that of the ballistocardiograph. Characteristic waves are associated with the beginning of cardiac contraction, the buildup of pressure in the left ventricle to aortic diastolic pressure and opening of the aortic valve, and the subsequent ejection into the aorta and closing of the aortic valve. When recorded simultaneously with an ECG, the electromechanical interval can also be measured.

The technique is readily adaptable to LBNP testing since the subject remains essentially motionless. The position of the microphone is rather critical. Our practice has been to place it in the 4th interspace slightly to the left of the left sternal border. Some manipulation with microphone positioning is often necessary to obtain optimal quality of the waveform. This can usually be achieved however in somewhat less than a minute. The protocol adopted requires a 10-second tracing with paper speed at 100 mm./sec. taken at the end of each minute of the 25-minute LBNP procedure. In the analysis two successive complexes whose waveforms are characteristic are selected for measurement as shown in the attached records from Apollo crewmen. The means of the two sets of values for the individual systolic intervals required are determined for each minute.

During the past two years an increasing number of reports have appeared in the literature that external, non-invasive methods for determining systolic time intervals correlate well with those obtained from intra-ventricular and intra-aortic pressure changes. Most of these investigators have used phonocardiograms and external tracings of the carotid artery pulsation to determine the systolic intervals. In contrast, the vibrocardiogram produces characteristic waveforms associated with isovolumic contraction and ejection and thus offers the operational advantage of a single sensor. Disadvantages include critical placement of the capacitance microphone on the chest and a more complex waveform. The latter feature makes analysis time consuming and requires considerable training and experience on the part of the technicians who identify and measure the systolic events. The Cardiovascular Laboratory personnel have acquired the expertise necessary to produce reliable and consistent measurements.

While use of the formula developed by Agress for estimating cardiac output from the VbCG has produced values which show the expected directional changes during LBNP, our interest in the technique has focused more on the actual changes in duration of isovolumic contraction times (ICT) and ejection times (ET) during the course of the LBNP test.

During LBNP each increment of negative pressure typically results in a slight increase in duration of the isovolumic contraction time (ICT or IVCT) and a shortening of the left ventricular ejection time (ET or LVET). The latter interval shows a high direct correlation with stroke volume and varies inversely, though not in a straight-line relationship, with heart rate. Similar changes have been shown to occur during head-up tilting or venous congestion of the extremities produced by tourniquets. In contrast, during exercise, while ET decreases as heart rate rises, ICT either remains unchanged or decreases slightly.

Changes in ICT reflect changes in myocardial contractility providing end-diastolic pressure, or pre-load, and aortic pressure or after-load, remain constant. Venous return to the left ventricle is a primary determinant of end-diastolic pressure. Rapid venous return implies a larger volume of blood in the left ventricle and greater stretching of cardiac muscle fibers during diastole. Under these conditions muscle fibers contract more forcefully and rapidly, the gradient of pressure between end-diastolic pressure and aortic diastolic pressure is reduced (assuming constant diastolic pressure), and ICT is shortened. Conversely, inadequate ventricular filling is associated with reduced stretching of muscle fibers, less forceful and slower contraction, and prolongation of ICT.

During preflight LBNP tests, Apollo 15 astronauts exhibited the expected lengthening of ICT and shortening of ET. Greater increases in ICT and shortening of ET and, as usual, greater increases of heart rate during LBNP were observed postflight. The assumption that venous return to the heart and filling of the left ventricle are reduced to a greater degree during LBNP postflight as compared to preflight is strengthened by the observation that chest X-rays postflight have quite consistently shown decreased cardiothoracic ratios. This factor alone would tend to increase ICT. Reduced myocardial contractility would also cause prolongation of ICT. At this stage, while we can be quite confident that reduced ventricular filling is present postflight as compared to preflight, reduced myocardial contractility as a contributory factor cannot, unfortunately, be excluded with the same degree of confidence.