AM 66-36

CLINICAL AVIATION MEDICINE RESEARCH:

Comparison of Simultaneous Measurements of Intra-Aortic and Auscultatory Blood Pressures With Pressure-Flow Dynamics During Rest and Exercise

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FEDERAL AIR SURGEON

October 1966

FEDERAL AVIATION AGENCY
Office of Aviation Medicine

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CLINICAL AVIATION MEDICINE RESEARCH:

COMPARISON OF SIMULTANEOUS MEASUREMENTS OF INTRA-AORTIC AND AUSCULTATORY BLOOD PRESSURES WITH PRESSURE-FLOW DYNAMICS DURING REST AND EXERCISE*

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Indirect measurements of blood pressure by auscultation during exercise are frequently used in making an assessment of work capacity. Such measurements may not accurately reflect the maximal and minimal blood pressures in the aorta during the cardiac cycle. Bordley et al. (3) found a discrepancy of ±8 mm Hg in individual readings of the systolic and diastolic pressures between simultaneously recorded direct and indirect measurements during rest. Berliner et al. (1) found that with auscultation the systolic pressure was consistently lower and the diastolic pressure higher than those values obtained by direct measurement. He emphasized, however, that the errors were minor and that the auscultatory method was a reliable technique if it was practiced carefully. Henschel et al. (9) reported close approximation between auscultatory and direct pressure recordings from the radial artery at rest, but observed discrepancies between the two techniques during light and moderate exercise.

Earlier investigators, using the auscultatory method, have demonstrated increased systolic pressures with increasing levels of work (4) (6). Direct pressure measurements using Cournand needles in either the brachial or radial artery seem to have confirmed these observations (2, 7, 13). Recently, however, Tabakin et al. (12) reported only minor increases in systolic blood pressure with direct recordings even during exercise requiring three liters of oxygen intake.

The purpose of this investigation was to compare directly measured aortic pressures with those measured simultaneously by auscultation of the brachial artery during various physiological states ranging from rest to work intensities up to aerobic limits and to study the pattern of pressure and flow dynamics during these same conditions.

PROCEDURES

Two presumably healthy men, 40 and 57 years of age, participated in the experiments. Each performed several control trials on a Godart bicycle ergometer in preparation for the actual experiment. During these trials all of the procedures except catheterization were done. On the day of the catheterization, the subjects reported to the laboratory 5 hours after eating a light breakfast. They were anticoagulated with 100 mg sodium heparin administered intravenously and chest electrodes were attached for recording a single lead electrocardiogram. The subjects then reclined on a fluoroscopy table for surgery.

Number 7 Cournand catheters were inserted into an antecubital vein and the brachial artery of the right arm. The arterial catheter was advanced into the ascending aorta and placed approximately six cm. above the aortic valve. A ligature was placed at the arteriotomy site to stabilize the catheter. The venous catheter was advanced into the main pulmonary artery and was stabilized by a ligature at the site of the venotomy. All tracings were made on an Electronics for Medicine recorder.

*This work was supported in part by the PHS Research Grant Number HE-06286-04 from the National Heart Institute.

During each minute of a ten-minute period of supine rest, five minutes of sitting, and four levels of work, the intra-aorta pressure was recorded and the auscultatory blood pressure was determined from the left arm in the sequence of systolic pressure, 15-second pulse-count and diastolic pressure. Respiratory gas exchange was measured from samples of air collected during the entire 10 minutes of supine rest and 5 minutes of sitting and the last 2 minutes of each level of "steady state" work. Inspiratory volumes were recorded from a Tissot spirometer. Blood samples for determination of the arterial and venous oxygen content were taken at the beginning of the final minute of each experimental situation. Cardiac output was calculated by the direct Fick technique (11).

Exercise on the ergometer was performed with slight differences in procedures and sequences of work intensities. Subject A began working at 366 mkg/min for a six-minute period, continued pedalling while the intensity was increased to 1525 mkg during the next minute, and maintained this level of work for six minutes. The exercise was stopped, and he sat, recovering, on the bicycle for five minutes. Two additional levels of work were performed continuously, for six minutes each, at intensities of 765 and 1220 mkg respectively.

Subject B performed four consecutive six-minute periods of work without a rest interval at levels of 490, 980, 1470, and 980 mkg/min respectively. The remainder of the procedure was the same as for subject A.

RESULTS

Systolic Blood Pressure

The directly measured systolic blood pressure values (Table 1) represent the means of the peaks of the last 30 to 40 pressure pulses recorded in the last minute of each experimental state. The systolic pressure was higher at each level of increased energy expenditure. Relatively small differences were observed between the directly and indirectly measured presssures for subject A.

In subject B, there was close agreement between the two methods of measurement during rest, sitting and at the submaximal energy demands. At the peak oxygen requirement there was a discrepancy of 16 mm Hg between the two methods. The variation was 12 mm Hg when he repeated six minutes of work at 980 mkg.

Two values for systolic pressure were recorded for each subject during maximal work. At these levels of work, sounds were detected at 190 mm Hg for subject A and 236 mm Hg for subject B which disappeared momentarily before being heard regularly at 180 and 230 mm Hg, respectively. These observations are supported by the variations in pressure patterns recorded from the aorta, an example of which is shown in Figure 1. At rest (left panel, Fig. 1), the peak systolic pressures were consistent from stroke-to-stroke with very little fluctuation in the base-line of the curve. At intermediate work loads (middle panel, Fig. 1), peak pressures varied from 177 to 150 mm Hg, a finding which seemed to be related to respiratory activity. The change in peak pressure from stroke-to-stroke was small. In maximum exercise (right panel, Fig. 1), the effects of the breathing cycle are present but not as well defined. Periodic changes in systolic pressure from stroke-to-stroke of as much as 40 mm Hg are present which could account for the observed auscultatory phenomenon. The rapid and sizeable stroke-to-stroke pressure changes could be due to sudden alterations in the rhythm of breathing and possibly due to actual variations of the systolic stroke-volume from beat-to-beat.

Diastolic Blood Pressure

There were greater variations between intraaortic and auscultatory determinations when diastolic blood pressure recordings were compared (Table 1). These direct measurements represent the means of the tracings of the last 30 to 40 pulse patterns in the last minute of each experimental state. The maximum difference between the two techniques never exceeded 7.3 mm Hg in subject A. The auscultatory determinations were higher than the intra-aortic measurements in five of the six experimental states. The cessation of sound was used to identify his diastolic blood pressure since muffling of the sound did not occur.

In subject B, in whom the muffling of sound was used as the criterion for establishing diastolic pressure, the indirect measurements underestimated the intra-aortic measurements from 3 to 15 mm Hg.

Pressure-Flow Dynamics

At his peak energy expenditure, which was about 10 times that of supine rest, subject A had a three-fold increase in the cardiac output and the (a-v) oxygen difference (Table 2). Stroke volume increased 21% and 43% above the values recorded during supine rest and sitting, respectively. The mean aortic pressure also increased, but the peripheral resistance decreased about 50% below the value of supine rest.

Similar changes occurred in subject B during pared (Table 1). These direct measurements had nearly a four-fold increase in cardiac output at a peak oxygen intake nearly 12 times that of his resting value. The peak (a-v) oxygen difference was 2 volumes percent higher than that recorded for subject A; the stroke volume increased 18 and 11% above the resting and sitting values, respectively, and peripheral resistance also decreased approximately 50% below the value recorded at rest.

DISCUSSION

Although the studies were limited to two subjects, several pertinent observations were made. A carefully monitored auscultatory systolic blood pressure will closely approximate that value recorded by direct measurement from the ascending aorta during rest and exercise. The differences between the two techniques was 6.1 mm Hg or less in ten of the twelve experiments states studied. Only in subject B at the two high work loads did larger discrepancies appear. That greater differences might be expected for higher work loads is not borne out by the data for subject A or by previous work from Henschel et al. (9). The latter study failed to demonstrate any differences in mean pressure between the values recorded by auscultation and by direct recording (radial artery) during the maximal treadmill work used. Statistically significant differences ($p < .05$) in mean pressure values were observed at two lighter levels of energy expenditure; the differences were 8 mm Hg in each instance. Neither our data nor that of Henschel et al. (9) compromise the value of auscultatory systolic blood pressure measurements for evaluating cardiovascular responses during exercise tests.

The value of auscultatory diastolic blood pressure measurements is not well-defined. In subject A, measurements indicated that the cessation of sound occurred before minimal central aorta pressure was attained. On the other hand, the data for subject B showed that minimal aortic pressure was reached before a muffling of sound was detected. Henschel et al. (9) reported discrepancies in diastolic blood pressure values similar to those observed in subject B. We agree with these investigators that an indirectly measured diastolic blood pressure should be excluded from consideration in establishing cardiovascular fitness criteria.

The observed increase in systolic blood pressure with increasing energy demands is in agreement with the findings of other investigators who recorded pressures directly, either from an indwelling needle or a catheter in the brachial artery. These results conflict with the observations of Tabakin et al. (12), who failed to record significant increases in systolic blood pressure during heavy work.

The flow changes recorded during work in these two subjects further substantiate the findings of other investigators (5) (8) (10) that cardiac output is augmented, not only by an increase in pulse rate and (a-v) oxygen difference, but also by an increase in stroke volume. The increase in systolic stroke volume was less in the person who had the greatest (a-v) oxygen difference.

ACKNOWLEDGEMENTS

The authors wish to express their gratitude to Paul Dolan, Anita Poarch, Kamal Shanbour, Don Rowlan and Gayla Ritter for their assistance in performing these studies.

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TABLE 1

Comparison of Blood Pressures Determined Simultaneously by Intra-Aortic Recording and Ausculation

Experimental Condition	Systolic pressure		Diastolic Pressure	
	Direct Recording mean ± 1 SD	Auscultation	Direct Recording mean ± 1 SD	Auscultation
Subject A				
Supine Rest	140.7±1.5	140	82.0±2.6	88
Sitting	153.7±6.4	149	95.3±4.3	100
336 mkg	159.9±8.0	165	89.7±5.9	97
1525 mkg	202.6±11.8	200	91.6±6.4	92
765 mkg	158.3±8.9	160	84.6±4.1	82
1220 mkg	180.5±11.3	190-180	81.6±6.6	88
Subject B				
Supine Rest	132.1±2.2	126	88.8±1.7	80
Sitting	143.8±4.4	138	91.5±3.7	80
490 mkg	162.0±8.1	166	91.4±7.0	88-80
980 mkg	213.1±11.2	218	94.7±6.3	88
1470 mkg	220.0±16.9	236-230	105.7±12.4	90-80
980 mkg	227.6±14.5	214-198	93.0±8.1	80

TABLE 1 — Comparison of Blood Pressures Determined Simultaneously by Intra-Aortic Recording and Auscultation.

TABLE 2

Cardiovascular and Metabolic Responses During Bicycle Work by the Two Subjects

Condition	Heart Rate per minute	$\dot{V}O_2$ ml/min.	(a-v) oxygen difference Vol. %	Cardiac Output L/min.	Stroke Volume ml	Mean Aortic Pressure mm Hg	Total Peripheral Resistance dynes sec-cm^{-5}
Subject A — 40 year old w/m 81 kg							
Supine Rest	84	322	4.0	8.0	97	106	1047
Sitting	100	438	6.3	7.0	70	......	....
336 mkg	128	1072	8.2	13.1	102	119	715
765 mkg	152	1885	11.9	15.8	104	112	568
1220 mkg	172	2550	13.6	18.8	109	120	511
1525 mkg	180	3110	14.0	22.2	123	140	509
Subject B — 57 year old w/m 74 kg							
Supine Rest	62	252	4.5	5.6	90	112	1492.9
Sitting	68	336	5.0	6.7	99	......	....
490 mkg	108	1275	11.9	10.7	99	120	897.1
980 mkg	149	2099	13.8	15.2	102	137	721.0
1470 mkg	172	2971	16.0	19.2	112	150	624.8
980 mkg	166	2357	15.4	15.3	92	134	700.0

TABLE 2 – Cardiovascular and Metabolic Responses during Bicycle Work by the Two Subjects.

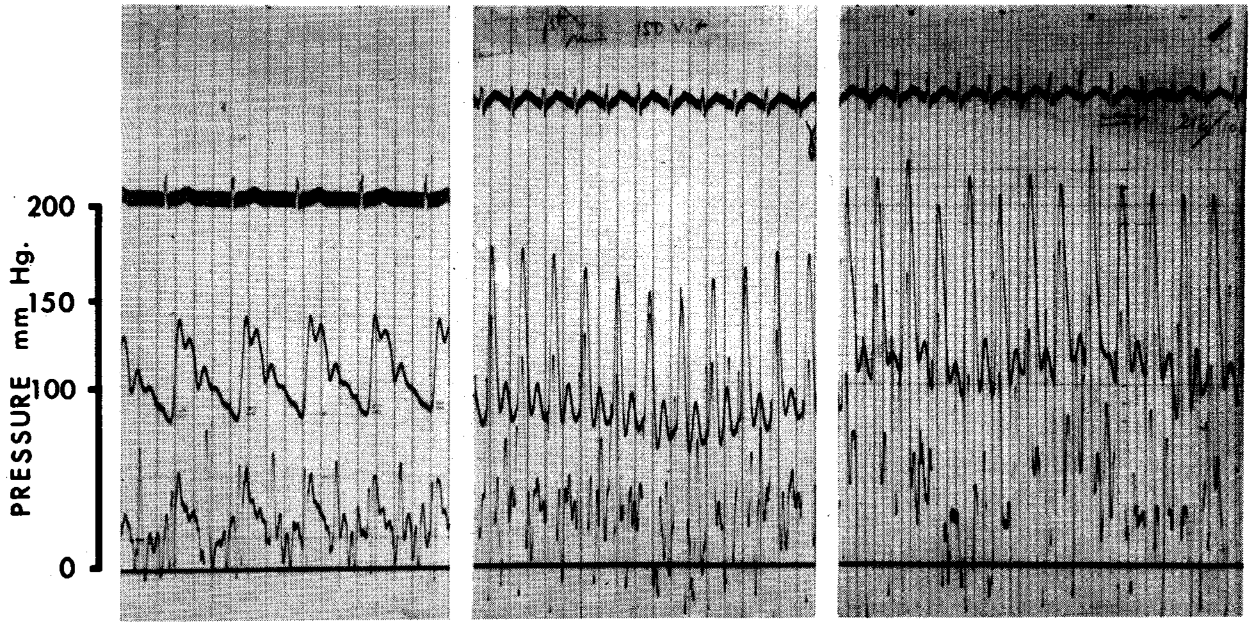

FIGURE 1 – Representative Intra-Aortic Pressure Tracings During Suprine Rest (left panel), Moderate Exercise (middle panel) and Maximal Exercise, right panel).