Report No. 3
RF Project 2045

THE OHIO STATE UNIVERSITY

RESEARCH FOUNDATION

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CARDIOVASCULAR EFFECTS OF VIBRATION

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NATIONAL AERONAUTICS AND SPACE ADMINISTRATION
Washington D. C. 20546

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REPORT

By

THE OHIO STATE UNIVERSITY
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ENVIRONMENTAL MEDICINE LABORATORY
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To NATIONAL AERONAUTICS AND SPACE ADMINISTRATION

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On CARDIOVASCULAR EFFECTS OF VIBRATION

For the period 1 August 1966 - 31 December 1966

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Department of Preventive Medicine

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SECTION I

A. PRESENT STATUS—DEVELOPMENT OF TEMPORARY, VERY-LOW-FREQUENCY, HIGH-AMPLITUDE, VIBRATION CAPABILITY

In previous reports, equipment and techniques have been described which generally make it possible to obtain ECG tracings from human subjects, while they are being vibrated, which are sufficiently free of electrical noise to permit clinical research evaluation. Evaluation is made either directly from the recorded ECG tracing or after subjecting the magnetic tape recording of the ECG signal to noise-cancelling procedures.

Protocol calls for utilizing the equipment and techniques developed to search for significant ECG changes in a number of subjects subjected to a variety of vibration intensities, particularly limiting vibration intensities in the profile of vibration of NASA spacecraft. This includes severe or moderately severe vibration in the frequency range from less than 1 Hz to 20 Hz.

Our laboratory shake table is capable of vibrating human subjects at severe vibration intensities at frequencies from 3 to 20 Hz and at less severe intensities at frequencies less than 3 Hz. It is not capable of producing severe or moderately severe vibration from 0.5 to 3 Hz. Since this frequency range is included in NASA profile and is important from a cardiovascular standpoint, it became necessary to develop the lacking vibration capability. The equipment developed to temporarily meet the need is shown in Figs. 1 and 2 before and during operation. The equipment configuration generally resembles a playground swing. The side ropes of the swing, which are elastic (airplane tow cord), are fed through pulleys in two block-and-tackle arrangements. The free end of the elastic rope feeds out of the upper pulleys. The "swing" seat is fastened to the lower pulleys. In the laboratory, the upper pulleys are suspended from the rafters, The subject can either stand or sit on the "swing seat" platform, An operator pulls the subject to a predetermined height by pulling on the free elastic ropes, He then imparts rhythmic pull to the free elastic ropes which excites and maintains vertical vibration to the system at a resonant frequency which is a function of (a) the weight of the subject and equipment; (b) the spring constant of the rope, which depends on the height to which the subject is pulled; and (c) the dampening characteristics of the system. Excessive swinging of the subject is prevented by an assistant operator who restrains the swinging tendency with two ropes fastened to the platform.

The few ECGs which have been obtained so far using the temporary equipment show no significant change from normal. Moderate noise which requires computer treatment before reading is present in the y axis lead.

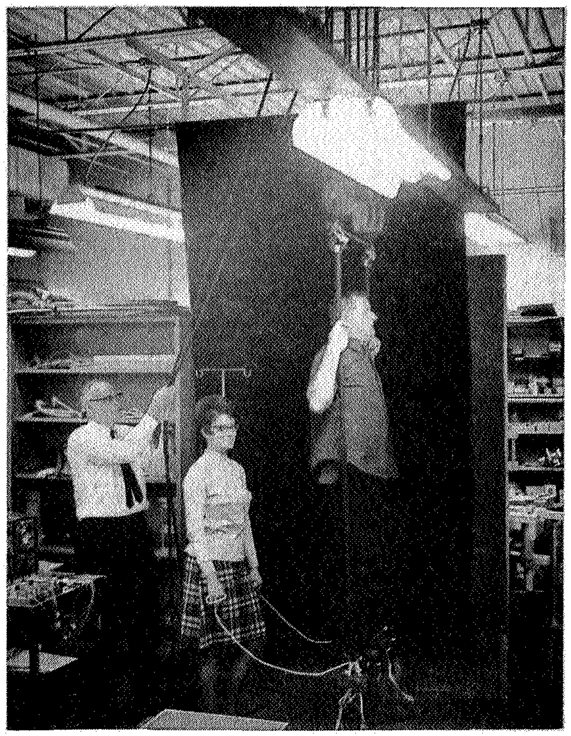

Fig. 1 - Temporary equipment to vibrate human subjects at low frequency, high amplitude

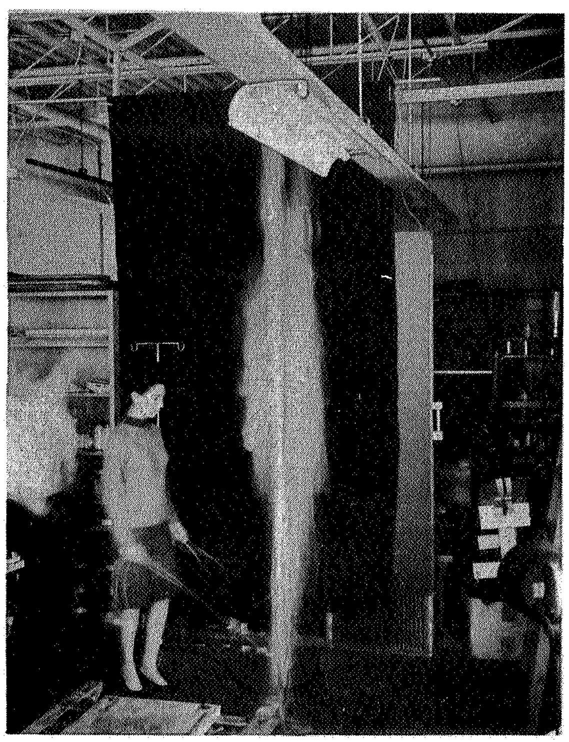

Fig. 2 - Stroboscopic picture of temporary vibration equipment in operation

B. MODIFICATION OF FRANK'S TECHNIQUE FOR LOCATION OF THE HORIZONTAL LINE OF CENTER OF HEART FOR ORTHOGONAL ECG LEAD PLACEMENT

The Frank[1] orthogonal lead system calls for certain electrodes to be placed on a horizontal plane which passes through the electrical center of the heart. Electrode placement is important and it is recommended by Frank that the horizontal plane should be located using an electrocardiograph exploring electrode technique which he describes. We have confirmed, after experimentation, the importance of the electrode placement and the need to employ the exploring electrode techniques to determine the heart electrical center horizontal plane. We have developed an experimental modification of the equipment which (a) eliminates the need for grounding the operator, (b) uses fixed electrodes, and (c) performs electrode manipulation through a switchbox. The method itself is not changed. Figure 3 shows wiring diagram for the switchbox; Fig. 4 shows electrode placement on the subject. Seven fixed electrodes are used which are connected to the switchbox, incorporating Frank's vector balancing bridge. It is possible to estimate the heart line of center with manipulations of only the switch and potentiometer. It is generally necessary and desirable to change electrode placement at least once. When using NASA electrodes, this is relatively simple. Heart center location using the modified equipment requires at least as much time as location using the Frank equipment.

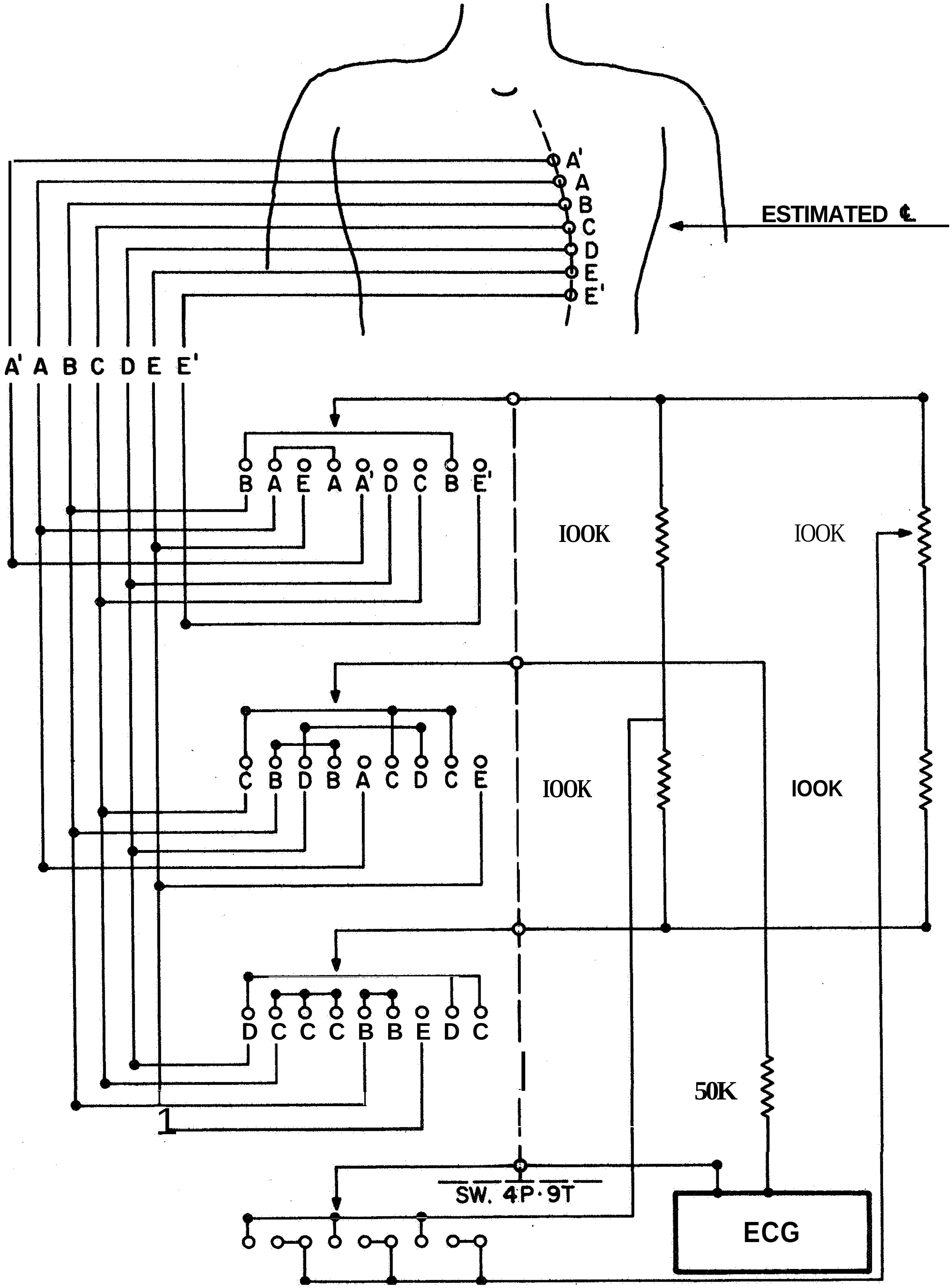

Fig. 3 - Wiring diagram for switchbox for heart electrical center determination using method described by Frank[1]

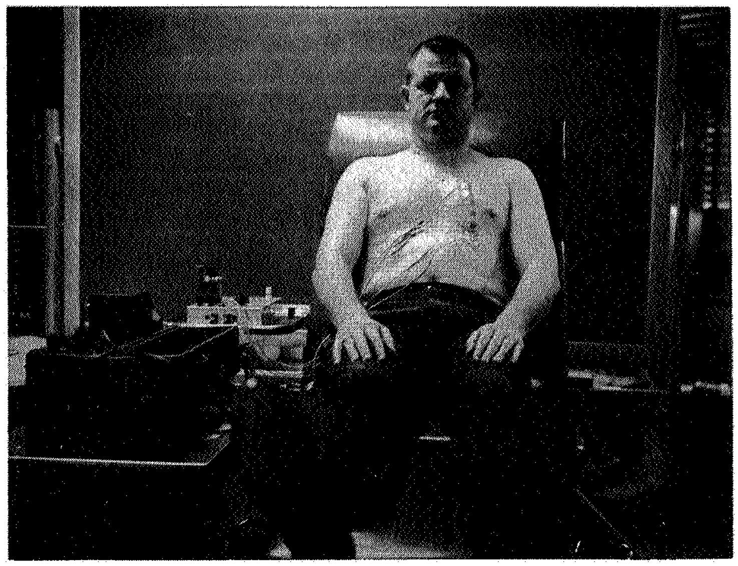

Fig. 4 - Subject wired **for** heart electrical center determination

SECTION II

ANIMAL STUDY OF CARDIOVASCULAR CHANGES ASSOCIATED WITH VIBRATION

As a continuation of previous animal experimentation, a well-conditioned mongrel dog, 18 Kg male, approximately 3 years old was used to further study the mechanism of transitory cardiovascular changes previously observed and reported in NASA reports 1 and 2. The experimental techniques used have been previously described.[2] Briefly, the dog is anesthetized, placed on the shake table, and catheters inserted in the left ventricle and in both femoral arteries. Information necessary to determine heart rate, systemic arterial pressure, cardiac output, and peripheral vascular resistance is obtained in recorded form. Medicaments were administered in accordance with prearranged protocol and measurements were taken under vibrating and non-vibrating conditions. Table I shows values and changes in measurements for various conditions. Figure 5 shows representative tracings obtained during the experiment,

SUMMARY

1. Vibration of the unmedicated dog caused

   a. ↓ PVR

   b. ↑ C.O.

   c. ↓ $\overline{\text{SAP}}$

   d. t H.R.

2, Propranolol reduced the effects of vibration but did not alter their direction.

3. Phenoxybenzamine abolished the response to vibration.

CONCLUSIONS AND EXPLANATION

Vibration causes primarily a reduction in peripheral vascular resistance, a fall in arterial pressure, and a reflex tachycardia with increase in cardiac output. Beta blockade did not alter significantly the response to vibration.

Alpha blockade caused apparent total arterial dilatation, and vibration did not alter hemodynamics,

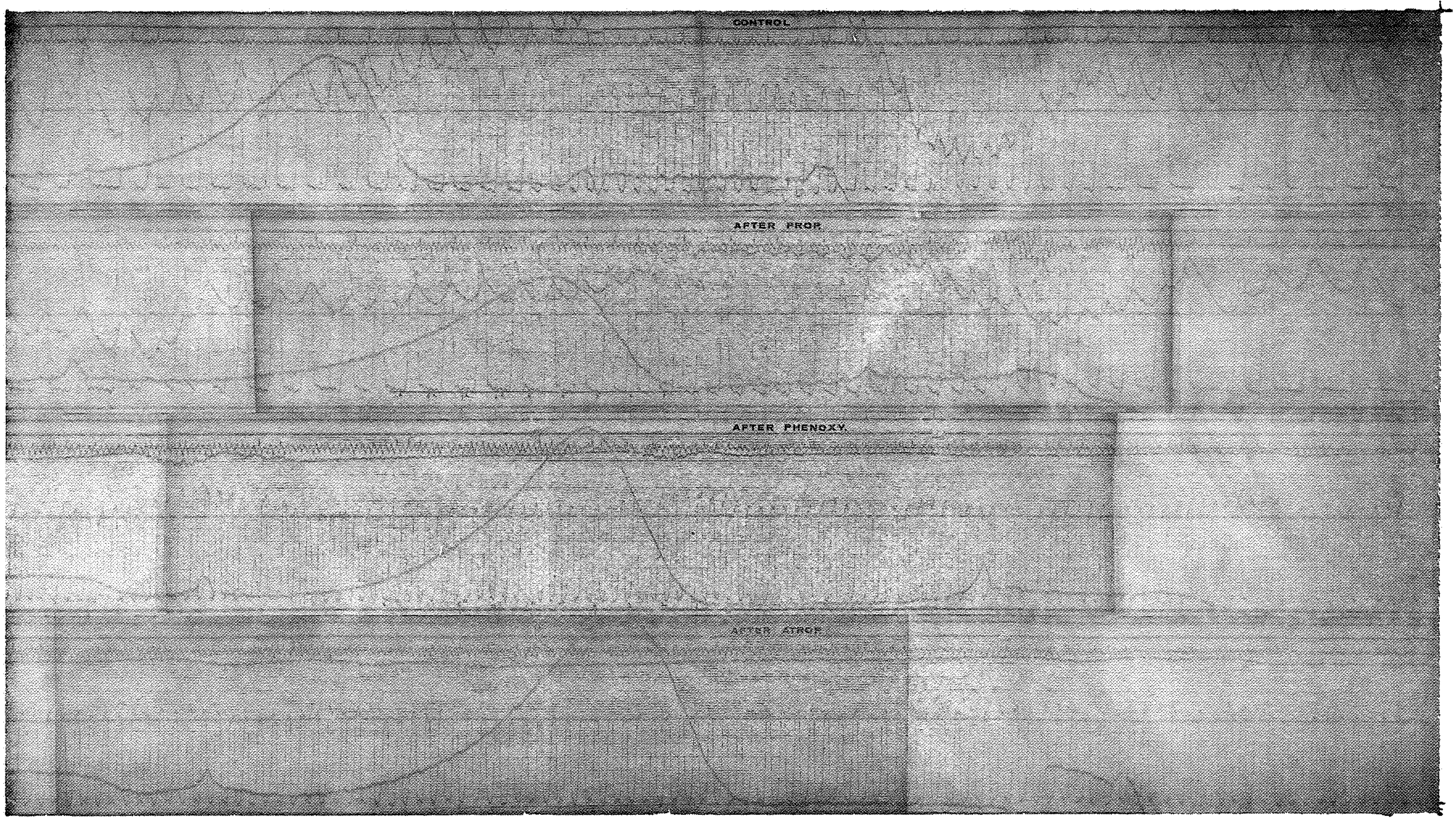

Fig. 5 - Representative traces obtained during experiment

(Trace reads from right to left. Records are from top to bottom: Lead 2 ECG, Left ventricular pressure curve, and indicator dilution curve. The first 4-5 seconds of the record are control, after which vibrations at 7 cycles per second begin. Undulations on the ECG trace appear at the onset of vibration.)

TABLE I

	(mm Hg) SAP	(L/min) C.O.	(units) PVR	(breaths /min) H.R.	(mm Hg) EDP
Control No Vibration	125	1.4	89	70	6.5
Vibration No Drugs	95	2.9	33	130	5.0
Control After Propranolol	140	1.1	127	50	6.5
Vibration Post Propranolol	125	1.8	69	85	6.0
Control Post Phenoxybenzamine	75	1.4	54	160	4.5
Vibration Post Phenoxybenzamine	75	1.3	57	160	4.0
Control Post Atropine	70	1.2	58	140	4.5
Vibration Post Atropine	75	1.2	62	140	445

KEY: PVR = peripheral vascular resistance
C.O.= cardiac output
$\overline{SAP}$ = systemic arterial pressure, mean
H.R.= heart rate
EDP = end diastolic pressure

We may conclude that vibration overrides existing alpha adrenergic-induced vasomotor tone and that it will not cause dilatation in excess of that caused by removing alpha stimulation,

It appears that the primary effect of vibration is to cause vasodilatation (more correctly, absence of vasoconstrictioh) with tachycardia and increased cardiac output as sequallae.

Additional experiments are contemplated to corroborate these results in a greater number (approx. 6) of equally well-conditioned dogs. We intend to record not only C.O., LVP, dLVP/dt, and FAP, but also pulmonary arterial pressure and femoral arterial blood flow fromwhich pressure-flow relations may be estimated. We hope, also, to monitor tissue pO_2 and pCO_2 as well as A-V differences to elucidate any possible direct, local effects of vibration.

SECTION III

ATRAUMATIC MEASUREMENT OF BLOOD PRESSURE OF HUMAN SUBJECTS WHILE THEY ARE BEING VIBRATED--THE PROBLEM

In our laboratory, experimental work on blood pressure and vibration has so far been confined mainly to animals. The development of the Peiper vibration-compensated catheter and the results of animal experimentation with it have enabled us to anticipate that in man there may be some generally small, except when modified by emotional factors, transient or persistent blood pressure changes associated with vibration. Such changes can only be searched for atraumatically. As a result of discussions and, thought and a review of the literature, the following list of requirements for a suitable atraumatic blood pressure system has been formulated.

1. To be acceptable, any atraumatic method of blood pressure measurement used must give results which correlate well under non-vibrating conditions with results obtained using the cuff method (manual or automatic).

2. The above correlation shall be sufficiently stable that repeated simultaneous determinations by the two methods shall be sensibly the sane. over broad blood pressure ranges produced in a variety of ways on a variety of subjects.

3. Automatic or manual cuff blood pressure measurements can probably be used as a periodic check for any method developed, provided such checks are so timed and at infrequent enough intervals to minimally interfere with the subject's attention, performance, or comfort.

4. The sensor used must not interfere with the subject's attention, performance, or comfort; it must be capable of operating essentially continuously and produce calibrated analog systolic and diastolic blood pressure signals.

5. Probably the transducer should operate from the sane artery that is occluded for the cuff method or from a nearby point so that the pressure contour of both should be as similar as practical.

6. To assure reasonable stability, the transducers will probably need to be attached in such a way as not to interfere with the normal physical or physiological responses of local tissue.

7. The type and frequency response of the transducer(s) and the choice of frequencies used will probably be an important factor in establishing stable correlation if such exists.

8. Correlations to establish the degree of relationship between pulse curves and direct blood pressure measurements have not included very low frequencies; this should be investigated.

9. Various types of transducers, surface, plethysmograph, etc. should be investigated theoretically and experimentally.

Most of the equipment is at hand to pursue research along the lines suggested by the requirements. The investigation will require the use of special low-frequency transducers, narrow-band variable filters, and analog and digital computer techniques. As indicated, some earlier abandoned techniques of promise will be reinvestigated.

REFERENCES

1. Frank, Ernest, "An Accurate, Clinically Practical System For Spatial Vectrocardiography," Circulation 13 (1956), 737-749.

2. Roberts, L. B., and Dines, J. H., "Cardiovascular Effects of Vibration," Semi-Annual Report No. 1, NASA Grant No. NGR 36-008-041, The Ohio State University Research Foundation, 18 March 1966.

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