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BLOOD PRESSURE SIMULATION MODEL : A TEACHING AID*

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Abstract: A mechanical blood pressure simulation model has been designed and developed by superimposing intermittent pressure on a steady pressure in a fluid filled closed rubber bladder. As a result, pulsatile pressure waves are generated in the bladder. By adjusting the magnitudes of constant pressure and intermittent pressure a 'simulated blood pressure' profile may be generated in the closed bladder with clearly three identifiable components i.e. systolic, diastolic and pulse pressure. The model consists of two bladders, a rubber bag and a motor which produces up and down movements. The pressure is recorded on a manometer and a biorite simultaneously. The device is simple, sturdy and inexpensive and may be used as adjunct for laboratory teaching in physiology and related sciences.

Key words: simulation, blood pressure, model, undergraduate teaching, psychomotor skill, postgraduate teaching

INTRODUCTION

Recording of blood pressure (BP) by direct arterial cannulation is a well established and widely used technique in laboratory experiments on animals. To demonstrate or to learn these psychomotor skills one requires experiments on animals like cats or dogs. Recently scientific community has been facing difficulties in conducting animal experimentations because of scarcity in animal availability and agitation by antivivisectionists. This article describes an inexpensive, functional blood pressure simulation device, which can be used for demonstrating to the undergraduates students how to record blood pressure by a direct method, and observe the effects of certain variables such as heart rate, stroke volume and diameter of vessels on blood pressure. To the postgraduate students it can help in teaching psychomotor skills pertaining to arterial cannulation and recording of blood pressure.

The device produces pulsatile pressure waves in a closed system which has an artery like extension in the form of a rubber tube. The basal pressure (simulates diastolic pressure) and pulse pressure (peak represents systolic pressure) can be precisely regulated manually. Somewhat similar device (1) using bladders filled with fluid/air has been found capable of measuring hand grip tension and body weight.

Design

The model operates on the principle of pressure dynamics and is capable of generating pulsatile pressure waves in a closed system without fluid flow. These pressure waves simulate arterial pressure fluctuations in terms of amplitude and pulse pressure. The model consists of a fluid filled closed system onto which two external pressures are applied - one, constant pressure and the other, intermittent pressure at fixed frequency. The former pressure determines the mean amplitude of pressure in fluid filled closed pressure system and the latter one determines the magnitude of fluctuations. The steady pressure simulates diastolic pressure and peak of intermittent pressure simulates the systolic pressure. Thus, the combination of these two gives pulsatile pressure waves which simulate blood pressure in terms of diastolic, systolic and pulse pressures at a given frequency.

A flexible rubber tube connected to the fluid filled bladder simulates artery.

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Description (Figure 1 and 2)

The model consists of two football bladders A and B of equal size (capacity 1500 ml, size 21x10.8 cms). These two are enclosed in a tough but compressible rubber bag C (dimensions : 23x15x7.5 cms, wall thickness 6 mm, capacity 1250 ml, ovoid in shape). Using tubes and three way stoppers bladder A is connected to manometer and transducer; and to the rubber tube, simulating the artery, which is clamped at one end. When used, this bladder and series of tubes (Fig. 1 see A and I) are filled with red colored water and this acts as fluid filled pressure system. The other bladder B is connected to inflation bulb of sphygmomanometer (J). When this bulb is pressed, air is pushed into bladder B, thus inflating the bladder B. The tough compressible bag C is intermittently pressed by a mechanical device attached to a motor, as shown in (Fig. 1; D,M,E).

In the present model, conventional motor driven respiratory pump (INCO, Ambala Cantt, India) was used with some mechanical modification. This modification involves fixing a wooden plate at lower moving part of the pump. This plate presses the tough bag C intermittently. The respiratory pump was used for its easy availability in physiology and pharmacology laboratories, and it has provision for regulation of magnitude of displacements also. In the absence of the respiratory pump a motor can be used with provision of mechanical attachment which produces up and down movements. These up and down displacements, when applied to steady pressure, can produce intermittent pressure changes. Pressure in the system can be monitored simultaneously on both a manometer and a biorite or a polyrite.

Working

Setting up the device : Before setting up the device, the bladders and all tubes should be checked for leakage, and the rubber tube (I) should be rinsed with paraffin oil so as to make its inner surface smooth like that of an artery. The bladder A and connecting tubes are to be filled with about 350 to 400 ml of red colored water. Mercury manometer and pressure transducer are connected. The bridge of biorite is balanced and sensitivity adjusted so as to give full scale deflection for pressure range of 0 to 150 mm Hg. By using inflation bulb, air is pushed into bladder B which inflates it and if inflation is continued, it starts exerting pressure onto fluid filled bladder A. This

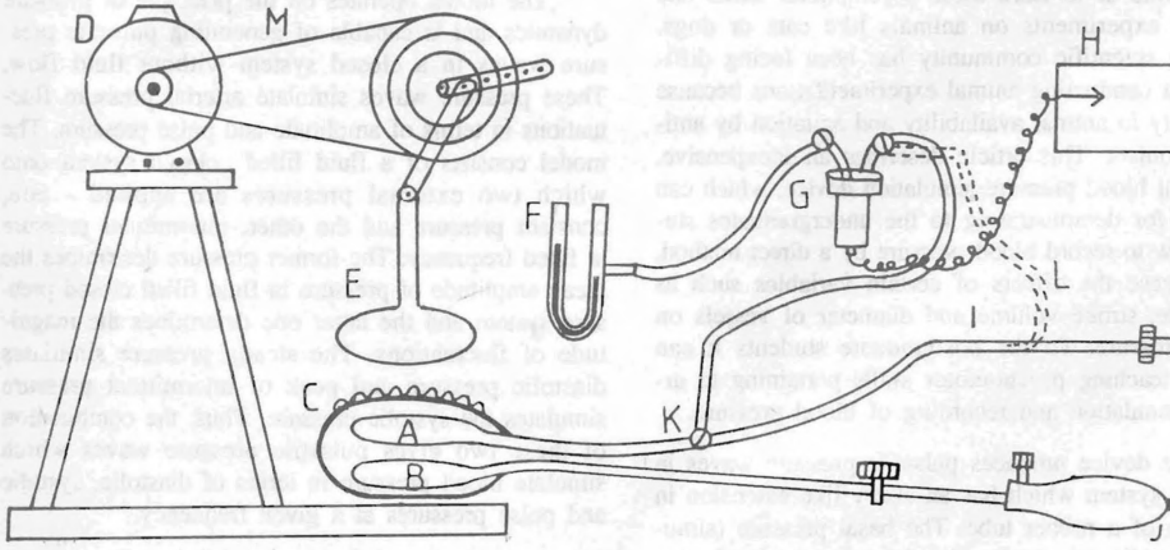
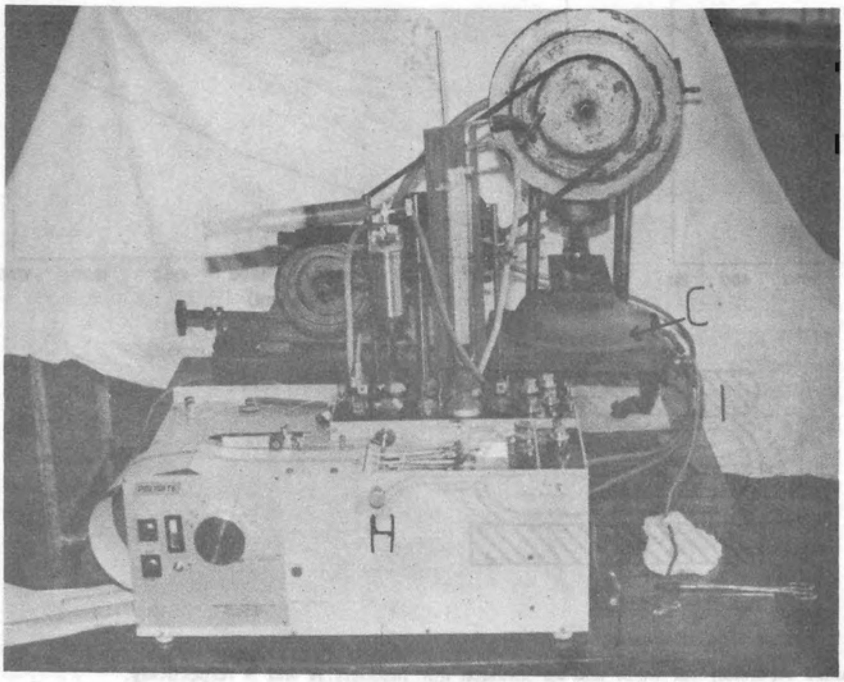


Fig. 1 : **Set up for simulation model for blood pressure (schematic). The rubber bladders A (fluid filled) and B (air filled under pressure) are enclosed in thick rubber bag C. The motor D generates up and down movements in plate E. This produces pulsatile pressure waves in bladder A and connecting tubes I & L, which is recorded on mercury manometer F and biorite H. Inflation bulb J is used to raise pressure in bladder B. Tube I simulates an artery which shows indwelling catheter L. M is belt, K is three way stopper, and G is a pressure transducer.**



pressure can be monitored on manometer. It may be raised to 140 or 150 and pen deflections are again checked for showing deflection from 0 to 150 mm of Hg. It should be made sure that the pen deflection falls well within its lower and upper limits. The thick bag C is kept under plate E which will provide intermittent pressure. To start with, the displacement of plate E should be kept at minimum. The motor, when it is switched on, produces some fluctuations in the mercury column in the manometer. One can gradually increase the magnitude of displacement so as to attain fluctuations in the mercury column to the value of pulse pressure, that is 40 mm Hg.

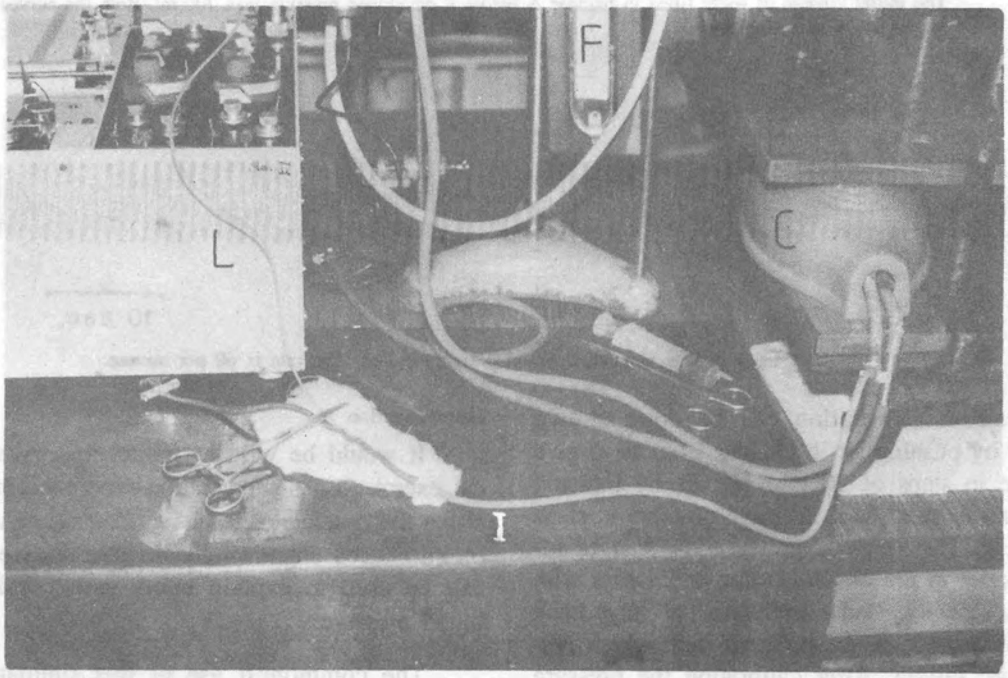


Fig. 2 : Simulation model for blood pressure in operation. Fig. A is whole set up and Fig. B is close-up of simulated artery with indwelling catheter. Refer Fig. 1 for various parts.

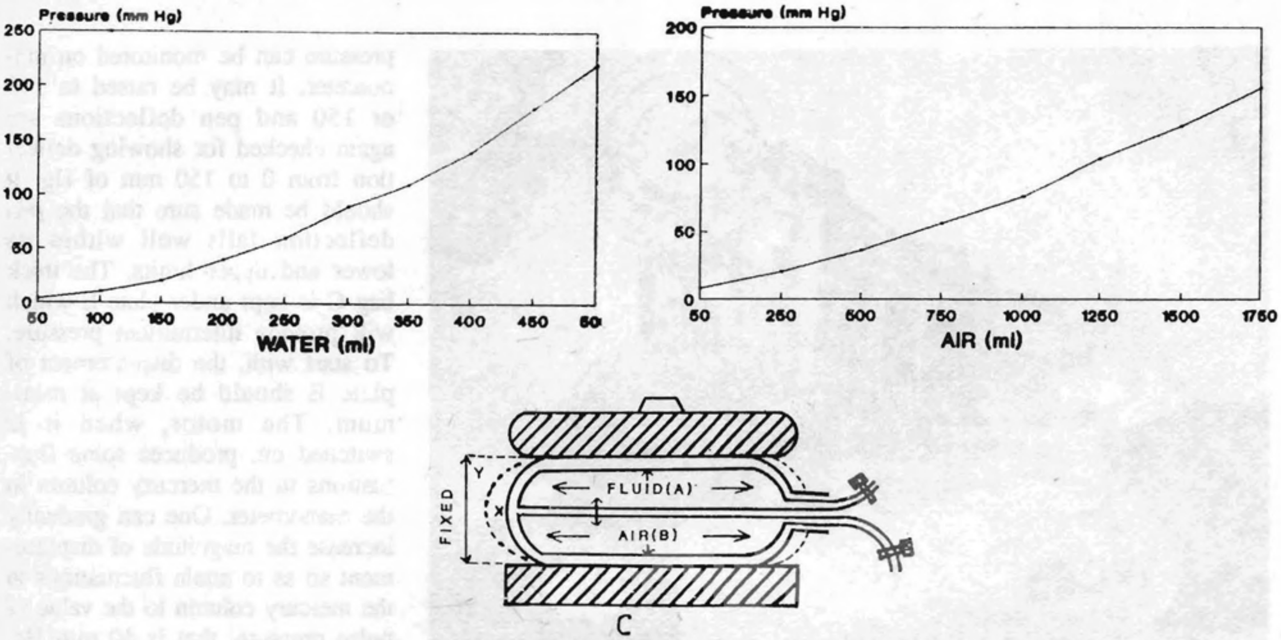


Fig. 3 : Distensibility curves obtained separately for water and air infusion into bladders A and B respectively. The Fig. C shows the pattern of distension in bag C (x is initial position, y final position; schematic). The initial volume of water filled in baldder A before it developed pressure was 700 ml. Both the curves are linear in operating range.

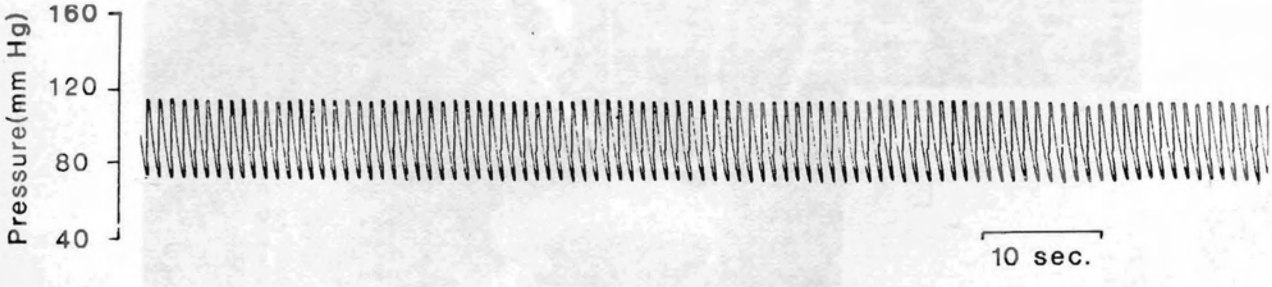


Fig. 4 : The tracing depicts simulatied blood pressure record. The rate is 60 per minute.

Calibration: Calibration can be done in two ways: either by pushing air in bladder B so as to give pressure rise in steps of 20 mm Hg; or by infusing fluid into bladder A so as to increase pressure in steps of 20 mm Hg. The stepwise pressure rise can be recorded on paper in the biorite. Doing calibration with air is easy and quick, and raised pressure stays back since there is a valve in the inflation bulb which prevents pressure falling. After calibration the pressure can again be raised to approx. 80 mm Hg and the set up is ready for demonstration.

Demonstration

It would be wise to frame objectives of practical exercise on demonstration/experiment as it would shape the contents of teaching. Content variability may be introduced unknowingly because the present model can be used to explain many variables influencing blood pressure.

The commonest use of this simulation model would be demonstration of method of measuring blood pressure by direct method. The target students may be undergraduates or postgraduates; the level of discussion will depend upon the target.

Before students arrive one should check for calibration and values of pressure that model is generating. If values are not in the normal range, these may be adjusted so that they fall in normal range. Students are first explained the various parts of the model and their respective roles. The calibration can be done in front of the students and they may be aksed to calculate pressure change for unit displacement of the pen. The rubber tube can be catheterized observing all precautions. The catheter is then connected to the pressure transducer. Pressure tracing on paper may be explained in terms of systolic and diastolic pressure. Students may be asked to calculate values for systolic, diastolic and pulse pressure. Students can confirm their findings by direct visualization on manometer.

The postgraduate students can be asked to practice catheterization on a fresh rubber tube. The tube is disposable and should be changed before the next demonstration. Postgraduates may also be trained on the use of biorite.

Measures of variability

The present simulation model can meet the expectations of the experimenter to demonstrate changes in the range, and the model's stability, and capacity to withstand the pressure. The range of operation for pressure can vary from as low as 0 mm Hg to 200 mm Hg. It is stable provided there is no leakage, and has been tested to withstand pressures upto 250 mm Hg. The two graphs (Fig. 3A and 3B) describe the distensibility of the bladders within the thick bag. The pressure responses to volume of air and fluid injected are linear within the normal range of blood pressure. The effect of ratio of fluid in bladder A and air in bladder B is another factor worth considering. The model works better with a ratio greater than 1 : 1, because air is more compressible than fluid and larger displacements are required to give similar pressure changes. Since the effective volume available inside the thick bag is approx. 700 ml, it is suggested to use more than 350 ml fluid in bladder A.

Performance

The record obtained from the model is shown in Fig. 4. The following are the measures of performance.

Stability and reproducibility : The pressure generated in the system is stable. Leakproof bladder and tubes are essential for this stability. The fluid filled bladder and tubes should have no air. The mechanical outfit of motor should have no undesirable loose part(s). The model has been run continuously for upto 2 hours without any significant changes in its performance. However, continuous running for prolonged periods is not likely to be ordinarily required. Once the model is set up the motor can be stopped and run as and when required. The model gives reproducible results.

Range: The pressure profile falling in the normal range of BP can be generated as the model allows precise control over these values over a wide range. The frequency of pressure waves in the experiment was kept at 60 per minute, as it was the maximum range available with the respiratory pump.

Applications

The model can be used as an adjunct to the teaching of cardiovascular function for two purposes; firstly for strengthening new theoretical concepts; and secondly for imparting certain psychomotor skills.

The Model may be used :

1. to demonstrate the direct method of measurement of BP.
2. to impart psychomotor skills of arterial cannulation and recording of BP.
3. to demonstrate the effect of certain variables on the BP, such as amplitude of displacement (simulating stroke volume), frequency of displacement (simulating heart rate), and lumen diameter of tube (simulating peripheral resistance).
4. to assess above mentioned objectives.

Defining specific learning objectives before each exercise may impart a significant degree of objectivity for teaching and assessment. For enhancing reliability and validity procedural standardization should be done (2).

DISCUSSION

Simulation models have played a significant role in growth of scientific knowledge (3). Mathematical modeling has unquestionably assumed an increasingly important role in modern physiology research. The areas of mechanical simulation modeling and computer simulation appear good for conventional physiology teaching both theory and laboratory. The center for Educational Development at the University of Illinois, College of Medicine, Chicago has developed a simulation laboratory which greatly helps students to sharpen their clinical skills using various types of simulations (4). However, there have been very few such serious attempts to tap this unlimited resource for teaching physiology (5). Moreover, in recent times this need has become urgent because of rising cost of animals, non-availability of animals, and especially the clamour of anti-vivisectionists. All these factors, along with students' reluctance to handle animals, are compelling teachers to reduce animal experimentation in laboratory teaching in general. The present simulation model for blood pressure will fill a real need in the current situation. The model described in this article can be used in laboratory teaching in physiology and pharmacology.

Simulators are abstractions of real experiments and possess many special features namely cost-effectiveness, suitability for repetitive exercises and freedom from risk. They permit simplification (focuses on specific element without the confusion of encountering the entire supersystem) and include all features of individualized instruction exercises. The instructional effectiveness of such devices has already been proved in an early experimental study (6), which indicated that students who used instructional simulations alongwith traditional methods (lectures and clinical demonstration) performed better in the skills of physical examination on real patients against those who learned such skills through traditional methods.

This blood pressure simulation model is based on fundamental principles of pressure dynamics and its distribution in cavity and tubes. Since the cardiovascular system has to observe the fundamental principles, these principles can best be explained by using this model. This method of providing explanations, along with practical demonstration, will greatly help students in reinforcing theoretical concepts in cardiovascular physiology. By using this model students can be demonstrated the concepts of blood pressure, diastolic pressure, systolic pressure and pulse pressure. The model further can be made more complex and effects of using higher frequency (simulating tachycardia), different degrees of displacement (simulating stroke volume), varying lumen diameter of tube (simulating peripheral resistance) and arterial compression (vasoconstriction) can be demonstrated. Postgraduate students can also sharpen their psychomotor skills by repeating experiments many times.

Physical simulators score higher than their counter parts like 'substitute laboratory', computer aided learning packages and mathematical models for the purpose of laboratory teaching. This model provides repetitive first hand experience and correct feedback; thus it occupies a better place in Dale's cone of experience to help develop psychomotor learning (7). It should therefore be more effective in imparting both psychomotor skills and reinforcing theoretical concepts.

The future development of the model appears quite promising. It may be made more complex to increase its versatility and applications by infusing more technology which provides precise control on rate, force, size of bladders, number of chambers, number and lumen diameter of tubes (simulating vessels), etc. Once developed, this will be able to decipher many aspects of pressure dynamics of cardiovascular system. It can also be modified to provide pulsatile flow and used to explain flow-pressure dynamics and principles of hemodynamics. A more complex model may be developed which may show the effect of volume depletion on blood pressure and may predict the value of required vasoconstriction that can correct fall in BP. Perhaps by using this modified model one may be able to predict the amount of vasoactive drug and/or volume required to restore the BP. If chip is made available to control all these complex functions, we will be able to tap the mathematical ingenuity of models proposed by Grodins (8). Then these models will not only be limited to laboratory teaching but may provide practical explanation to complexity of control systems and tools to verify new hypotheses.

A recent National Institute of Health report (9) on modeling in biomedical research concludes, "while quantitative models will in no way replace experimental mammals and higher animals, they do provide - and will provide in even greater abundance during the decades to come - new insights, new opportunities undreamt of earlier, for the alleviation of human suffering caused by disease".

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