

A simple versatile pulse duplicator

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Recent developments in the surgery of the heart valves have made the pulse duplicator an indispensable research tool; the duplicator also provides a useful aid in the teaching of the movements of normal and pathological heart valves.

Many types have been described in the literature, and a review (Austen, Shaw, Scanrell, and Thurlbeck, 1958; Barnard, McKenzie, and de Villiers, 1959; Björk, Intonti, and Meissl, 1962; Callaghan, Willans, and Cardozo, 1961; Davila, Trout, Sunner, and Glover, 1956; Ebert, Morrow, and Austen, 1963; Goodale and Shaw, 1955; Harken, Soroff, Taylor, Lefemine, Gupta, and Lunzer, 1960; Hudspeth and Cordell, 1963; Jacobson, 1961; Kelley, Goodale, and Castleman, 1960; Kolff, 1961; Leyse, Quinton, Blumberg, Harrison, May, and Merendino, 1961; Marx, Baldwin, and Kittle, 1959; McMillan, Daley, and Matthews, 1952; McMillan, 1955; Quinton, Ofstun, Leyse, Wintersheid, Harrison, and Merendino, 1961; Smith, Essex, and Baldes, 1950; Soroff, 1961; Starkey, Sirak, Collins, and Hagan, 1963; Starr, Schnabel, and Mayock, 1953; Wessel, Kezdi, and Lewis, 1962) shows that in most instances the description of the pulse duplicators gives insufficient detail for their construction. It was therefore felt reasonable to describe in detail yet another simple versatile duplicator which has been developed in our research laboratories. It is hoped that other workers in this field might be spared much useful time in planning the purely technical aspects of these machines. This apparatus has the following advantages:

1. Simplicity of design and cheapness in construction.
2. The action of the cardiac valves can be observed or photographed from their superior and inferior aspects.
3. The pulsatile force applied to the heart can be either gas or water. The water can be applied to the surface of the heart (external duplicator) or through the heart (internal duplicator).

4. The viewing chambers can be used without the compression chamber (*vide infra*) to allow the rapid positioning of the heart and to check the technique of placing prosthetic or transplanted aortic valves.

5. One viewing chamber can be used clinically and in the experimental animal to observe the functioning of any cardiac valve *in situ*.

THE PULSE DUPLICATOR

The apparatus consists of a heart chamber (Fig. 1) with two detachable viewing chambers (Fig. 2), a peripheral circulation circuit (Figs. 3, 5, and 6), and an electrical system to control the pulsatile force applied to the heart (Fig. 4).

The heart chamber is a perspex cylinder (Fig. 1,C) with two openings (1, 2) at its lower part to allow the inflow and outflow of the compressing fluid. A third opening in its base (3), which can be sealed off, is used to introduce a ventricular cannula (V) when water is pumped intermittently through the apex of the left ventricle. The top part of the cylinder is made air-tight by five thumb screws (4, 5) and a rubber 'O' ring (G). It has two large threaded orifices into which the viewing chambers (M and A) can be screwed. The two perspex viewing chambers (Fig. 2) are of equal dimensions. Their surface is cylindrical and their interior is a truncated cone. Double metal locking screws (6 and 7) are fixed to the truncated base, permitting it to hold different sizes of 'mitral' or 'aortic' perspex cannulae (8) over rubber 'O' rings (G). On the side of the cylinder there is a $\frac{1}{2}$ -in. opening (9) to connect the viewing chamber to the 'peripheral circulation' circuit, and another (10) for pressure recordings and removal of air from the circuit. The aortic and mitral cannulae are of different lengths and diameters to fit the dimensions of the heart studied. The table below Fig. 1 gives the exact relations between each pair.

The peripheral circulation (Fig. 3) consists of a reservoir (R) (1 litre capacity) from which water flows into the atrial viewing chamber (M) through the left heart into the aortic viewing chamber (A) and back into the reservoir through a length of

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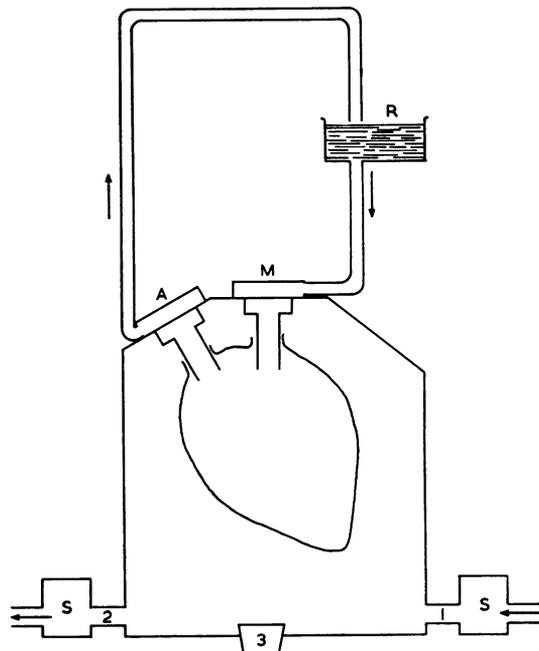
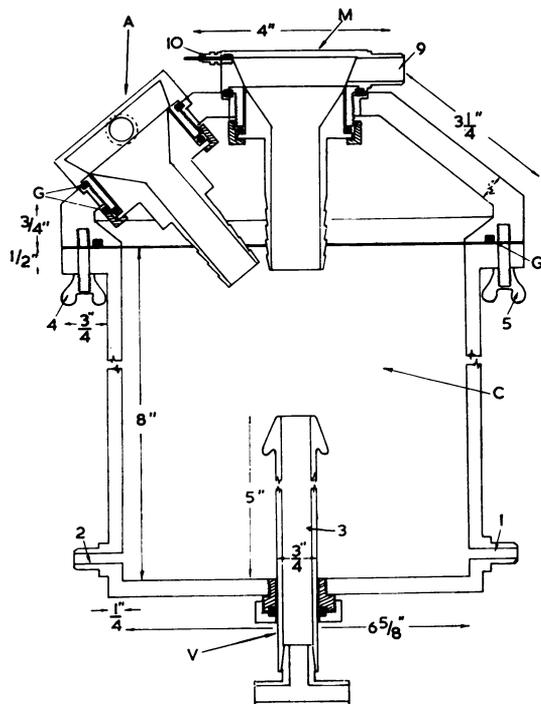


FIG. 3. The external pulse duplicator.

	Cannulae Sizes (cm.)			
	Mitral		Aortic	
	Length	Diameter	Length	Diameter
1	7.5	2.0	6.5	1.5
2	6.5	3.0	6.0	2.0
3	5.0	4.0	4.5	3.0
4	3.5	5.0	3.0	4.0

FIG. 1. Diagram of the complete pulse duplicator. Cross section drawn to scale.

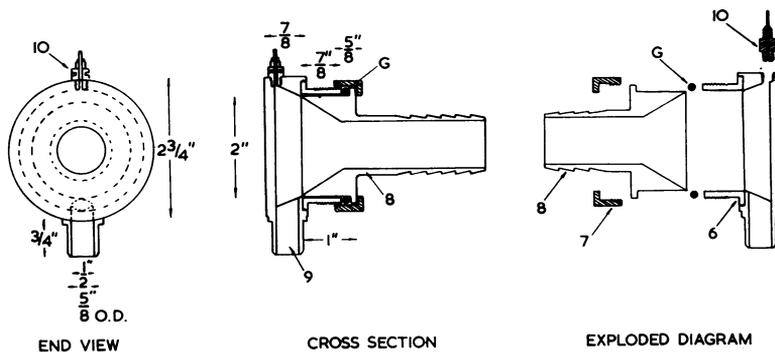
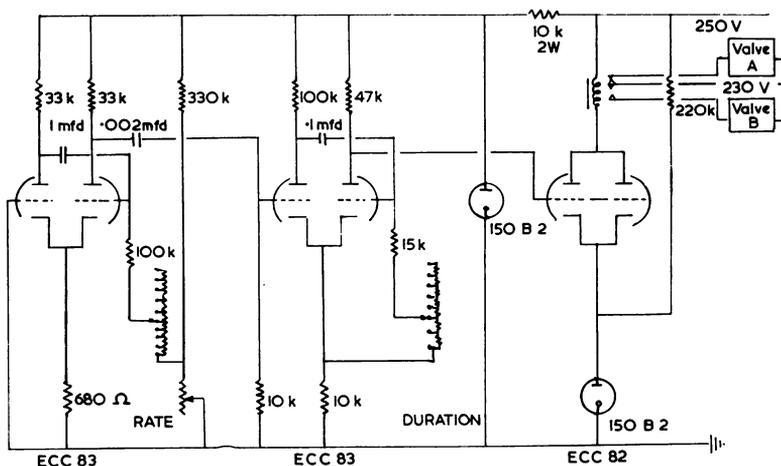


FIG. 2. Cross section of end view and side view of viewing chambers drawn to scale.

FIG. 4. Circuit of the solenoid valve controller.



plastic tubing whose height can be varied. A screw clamp placed on this tubing controls the degree of peripheral resistance.

The pulsatile force can be either tap water, using mains pressure, or compressed gas (air or oxygen) from a cylinder or wall supply. Two solenoid valves¹ are placed at the inlet and outlet orifices of the heart chamber (1 and 2 in Figs. 3 and 5). These are operated by an electronically-timed control which varies the rate and duration of systole and diastole (Fig. 4). When one valve is opened, the other is closed. When the inlet valve is opened, the pressure rises inside the chamber, compressing the heart (systole); when the outlet valve opens, the pressure drops to atmospheric level, and the heart fills by gravity with water from the reservoir (diastole). Observing the valvular movements and the pressure tracing on the oscilloscope, the inlet pressure is adjusted until physiological tracings are obtained.

The flow is up to 3 l./minute. For larger flows the apparatus should be used as an internal pulse duplicator (Fig. 5). The apex of the left ventricle is cannulated (V) and held in position with a jubilee clip. The vertical stem of a T tube is attached to the ventricular cannula (V). A solenoid valve (S) is attached to each side arm of the T tube and one of the valves to the water tap.

In cases where the duplicator is intended to be used as a rapid and simple test of the positioning of a prosthetic or transplanted aortic valve, observing at the same time its ventricular aspect, the apparatus can be simplified as follows. The two viewing chambers and cannulae are held in a horizontal position with two standard laboratory

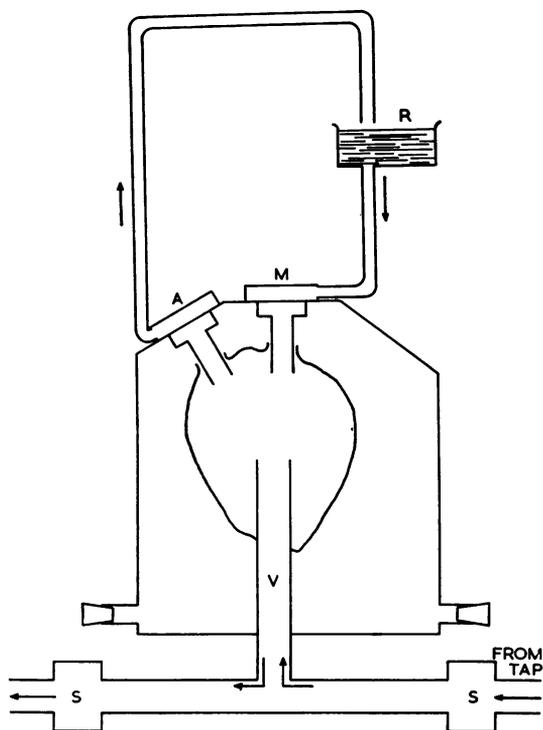


FIG. 5. The internal pulse duplicator.

¹ Ether Ltd., Stevenage, Herts. Code No. 5 DN-205, AC. $\frac{1}{4}$ in. diameter. 30 PSI Air.

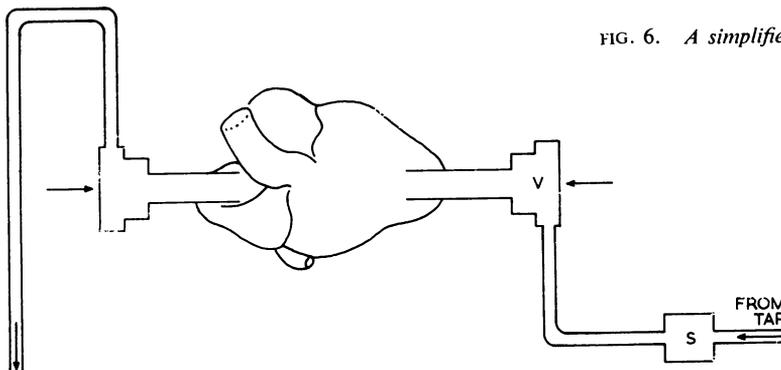


FIG. 6. A simplified version of the internal duplicator.

clamps. Pulsatile flow is obtained with a solenoid valve placed between the water tap and the ventricular viewing chamber (Fig. 6). Flows up to 6 l./min. can easily be obtained.

It is often difficult to judge at operation the competence of a repair or totally replaced aortic valve. After partial closure of the aortotomy, one of the viewing chambers, together with the cannula of the appropriate size, is introduced just distal to the valve, allowing the valvular movements to be easily observed. Intermittent flow can be established using methods already described elsewhere (Ebert et al., 1963; Hudspeth and Cordell, 1963). The competence of the valve can be observed in the viewing chamber and recorded on the oscilloscope. A similar arrangement can be used for viewing the mitral valve during surgery.

SUMMARY

A simple, versatile, and inexpensive pulse duplicator is described. Details and drawings are given for its construction. Its many uses are detailed. A bibliography of the relevant literature is given.

We should like to thank Mr. M. Richings for constructing the electronic timer.

We appreciate the help of the Medical Research Council in providing a grant towards this project.

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