Maintenance of the Circulation in Cardiac Asystole by the Mechanical Pulsator*

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Acute myocardial insufficiency either as the result of vascular occlusion or surgical operation, can produce inadequate body perfusion. This may be of a self-limited duration, but the period remains unknown. The present status of poor cardiac output appears to be progressive and potentiating, with deterioration of many organ systems leading to the patient's demise. If the circulation can be supported for a short period of time (six to eight hours) myocardial and extravascular organ circulation may permit their survival. This period of myocardial insufficiency, supported by a mechanical aid, may be all that is needed for a patient's recovery. Various methods are now in study: 1) assisted circulatory support, 2) left heart bypass, or 3) a myocardial replacement-mechanical heart. These methods at present have some disadvantages, viz., a large operative procedure or total body heparinization for prolonged periods.

The problem of maintaining adequate systemic circulation during cardiac standstill by mechanical means has created interest among research workers. Bencini1 in 1956 employed mechanical pneumomassage of the heart in dogs. Vineberg2 in 1957 reported his experimental work on the canine heart. Difficulties arose because of resultant high venous and pulmonary artery pressure and impaired coronary circulation.

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Figure 1: Photograph of the case. (A) Rubber tube for supplying a pneumatic pulse to the bellows. (B) Rubber button on the bellows to provide fixed angular location. (C) Oblong orifice near the base through which the great vessels pass.

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EXPERIMENTAL METHOD

Apparatus. The apparatus consists of a heart-shaped plastic enclosure with an oblong orifice near the base through which the great vessels pass. From the base end of this orifice, a closable slot continues toward the apex. Means are provided so that this slot can be easily opened to admit the heart and then securely closed. A thin, curved rubber bellows lies closely against the left inside wall of the case in contact with the left ventricle. A rubber tube for supplying a pneumatic pulse to the bellows passes through the case and extends outward through the chest wall for connection with the air pulse supply. A small rubber button on the bellows also passes through the case to provide fixed angular location (Fig. 1).

Figure 2 is a cross-section through the case around the heart. One can see the bellows in close proximity with the left ventricle.

An air tube connects at one end to the bellows tube and at the other to the rotary air pulsing valve. This valve is in turn connected to a continuous low pressure air supply. Each time the valve rotates, the bellows is connected to the air supply for about one-third of a revolution. For the remaining two-thirds of the revolution, the rotary valve vents the bellows to the atmosphere. Thus, the bellows is inflated to compress the left ventricle for the systolic one-third of the cycle and the air in the bellows is then released to the atmosphere for the diastolic two-thirds of the cycle. The transmission can be varied to change the time rate of the cycle from zero to 250 rpm. An adjustable flow valve between the air pressure supply and the rotary pulsing valve varies the pressure which can be supplied to the bellows from zero to 200 mm of Hg. This means of supplying the air pulse has been quite effective and reliable. However, other means may be employed.
and are being developed for different uses of the apparatus.

Procedure. Experimental studies were made on 70 mongrel dogs. The dogs were anesthetized using thiopental sodium (sodium Pentothal). Respiration was maintained by intermittent positive pressure when the chest was open. The chest was entered through the left, fifth intercostal space and the heart delivered outside the pericardial sac. The cardiac case was put on the heart, closed and pulsation started with the cardiac pulsator described. The time rate of the pulse was varied to synchronize the mechanical pulsation with the heart beat. When synchronism was attained the femoral pressure became much higher. However, synchronism could not be maintained with the present apparatus, resulting in a considerable fluctuation of femoral pressure. Next, the heart was fibrillated with an electric shock and the mechanical pulsation resumed. Figure 3 is a photograph of a dog being pulsated. His circulation is being maintained entirely by the mechanical pulsator. The heart is fibrillating and therefore pumps no blood. This has been frequently demonstrated by stopping the mechanical pulsation which causes the femoral pressure to immediately fall to zero. On restarting the mechanical pulsation, the femoral pressure immediately rises to its former level.

The rate of pulsation was generally about 100 per minute, although higher and lower rates were sometimes employed. The pulse pressure applied to the bellows was generally about 150 mm Hg, although higher and lower pressures were used. The periods of pulsation varied from 1½ to 6½ hours, after which the heart was defibrillated and the chest closed.

During the pulsation, femoral artery, and occasionally left atrial pressures were monitored; \( \text{pO}_2 \), \( \text{pCO}_2 \), pH and electrolytes were monitored at hourly intervals in many of the experiments.

Histologic examination of the heart, lung, kidney and liver was made at the time of sacrifice of the experimental animal.

Results

Table 1 summarizes the results obtained.

Of the 70 experiments performed, 67 were successfully completed. Forty-six animals in which a satisfactory experiment was completed survived for 48 hours or longer. This period was taken to indicate satisfactory recovery if the animal appeared normal in all of its functions. Table 1 shows per cent survivals in the respective groups.

Figure 3: Photograph of a dog that is being pulsed. Arrow points to the tube through which a pneumatic pulse is being supplied. The dog's circulation is being maintained entirely by the mechanical pulsator.
MAINTENANCE OF CIRCULATION IN CARDIAC ASYSTOLE

Pulmonary artery and left atrial pressures were found to remain within normal range in 22 of the 24 experiments in which they were monitored. In 47 of the 70 experiments performed, pO₂, pCO₂, pH and electrolytes of the arterial blood were monitored. A mild metabolic acidosis occurred in 35 animals but this was readily corrected with small amounts of sodium bicarbonate (20-40 mEq).

The femoral artery pressures recorded during pulsation ranged between 80/44 mm Hg and 190/105 mm Hg with mean pressures being between 55 mm Hg and 105 mm Hg. In most of the experiments, the femoral systolic pressure was 100 mm Hg or higher (Figs. 4 and 5).

DISCUSSION

The results of these experiments would indicate that it is possible to maintain adequate systemic circulation over a period of several hours during periods of cardiac insufficiency (fibrillation or arrest) in order to maintain life. The fact that no damage was found in either the blood elements or the cardiac musculature following such periods of artificial heart function, encourages our belief that this method may be useful in clinical application. In view of the frequency of need for cardiac support following cardiac surgery and myocardial damage following infarction, the need for a means of maintaining adequate circulation for varying periods of time is quite obvious. At the present time, E. F. Andrews Laboratories, in cooperation with the Department of Surgery of the University of Chicago, is developing apparatus for clinical application of the principle demonstrated in the animal experimentation described.

CONCLUSIONS

1. A mechanical cardiac pulsator has been developed which may allow quick and easy application in patients with myocardial infarction or cardiac arrest.

2. No damage was found in either the blood element or the cardiac musculature after employing the mechanical cardiac pulsator.

3. Most animals survived 48 hours or longer following 1⅔-6½ hours of cardiac pulsation. Several animals were followed up for as long as seven months.

![Figure 4: Tracing of systemic pressure. (A) Indicates point of fibrillation. (B) Indicates start of mechanical pulsation.](http://journal.publications.chestnet.org/pdfaccess.ashx?url=/data/journals/chest/21448/ on 04/27/2017)
Figure 5: This illustrates the higher systemic pressure obtained with assisted pulsation. The tracing between the arrows was taken when the heart was not assisted with a mechanical pulsator.

4. Steps are being taken to make clinical application of the principle demonstrated in animal experimentation.

Resumen

1. Se describe un pulsador mecánico susceptible de rápida y fácil aplicación en casos de infarto o paro cardíaco.
2. No se ha observado efecto nocivo alguno para la sangre o el miocardio, atribuible al empleo del pulsador cardíaco mecánico.
3. La mayor parte de los animales a que se aplicó sobrevivieron 48 o más horas después de 1½ a 6½ horas de pulsación mecánica. Varios animales fueron observados hasta siete meses.
4. Estamos en vías de aplicar en la clínica humana el principio demostrado en animales de experimentación.

Resumé

1. Un pulsateur cardiaque mécanique a été réalisé, qui permet une application rapide et facile chez les malades ayant un infarctus du myocarde ou un arrêt cardiaque.
2. Il n'a pas été trouvé des lésions soit dans l'élément sanguin ou dans la musculature cardiaque après avoir utilisé le pulsateur cardiaque mécanique.
3. La plupart des animaux ont survécu 48 heures ou plus, après une pulsation cardiaque allant de 1h 30 à 6h 30. Plusieurs animaux ont été suivis, le délai le plus long étant de 7 mois.
4. Les tentatives sont faites pour l'application clinique de ce principe démontré en expérimentation animale.

Zusammenfassung

1. Ein mechanischer Herzpulsator wurde entwickelt, der sowohl eine schnelle wie leichte Anwendung bei Patienten mit Myocardinfarkt oder Herzstillstand erlaubt.
2. Weder im strömenden Blut noch im der Herzmuskulatur wurde eine Schädigung ermittelt nach Verwendung des mechanischen Herzpulsators.
3. Die meisten Tiere überlebten 48 Stunden oder mehr im Anschluß an eine 1½ bis 6½-stündige cardiale Pulsation. Mehrere Tiere wurden nicht weniger als 7 monatelang weiter beobachtet.
4. Es werden Schritte zum gegenwärtigen Zeitpunkt unternommen, um eine klinische Anwendung der Prinzipien zu ermöglichen, die bei den Tier-Experimenten gewonnen wurden.

References


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