ANGIOGRAPHY OF THE CORONARY CIRCULATION IN LIVING DOGS USING TIMED DIASTOLIC INJECTIONS

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Reliable demonstration of the coronary arteries in the living is possible if special techniques are used. A historical summary and review of various methods will be found in publications by Dotter and Frische (1958) and Michell (1960). In a previous communication from this department (Sloman and Jefferson, 1960) a technique of coronary arteriography in living dogs was described using acetyl-choline cardiac arrest. It was thought, however, that this procedure was potentially dangerous and a safer method was sought.

The present investigation was undertaken to try the effect of timing injections of radio-opaque medium to occur in diastole, a method suggested by Richards and Thal (1958). Maximal coronary flow occurs during ventricular diastole, while flow may be actually reversed in systole (Green *et al.*, 1935; Gregg, 1950). Therefore, medium injected into the root of the aorta during diastole should result in good coronary artery filling, whereas systolic injection should produce poor opacification.

MATERIAL AND METHODS

Angiograms were carried out in twenty-five unselected mongrel dogs with body weights ranging from 13.5 to 23 kilograms. No premedication was given. General anaesthesia was induced with 2.5 per cent sodium thiopentone, the animals were intubated, and respiration was controlled with an intermittent positive pressure respirator (Beaver Mk. 11).† Light anaesthesia was maintained with a two-to-one nitrous oxide and oxygen mixture and small additional doses of sodium thiopentone. The heart rate ranged from 140–170 beats a minute, but in order to reproduce conditions simulating those found in humans, it was reduced to 90–120 beats a minute with prostigmine given intravenously in intermittent doses of 0.5 mg. Prostigmine usually caused micturition, defaecation, and intense salivation, and coupling occurred in about half the animals. Small doses of intravenous pethidine restored sinus rhythm in all the dogs except two, in whom coupling ceased following procaine amide. Bronchospasm was never encountered. More recently we gave morphine sulphate intramuscularly in a dose of 1.0 mg. per kilogram body weight after the induction of general anaesthesia. This drug has a strong vagotonic action in dogs (Rowe *et al.*, 1956) and enabled the heart rate to be controlled with much smaller amounts of prostigmine.

Both common carotid arteries were exposed and a cardiac catheter was passed down each vessel into the ascending aorta under X-ray screen control. The catheter for angiography was a number 8 with blocked end-hole and four spirally-placed side-holes. The other catheter was used to monitor the central aortic pressure. Drugs were given into the femoral vein. The radio-opaque medium was hypaque 85 per cent or urografin 76 per cent given in doses of 1 ml. per kilogram body weight.

Special apparatus for angiography consisted of an automatic timing device triggered by the R wave of the electrocardiogram, and pneumatic injector. The automatic timing device enabled

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† Made by Talley Anaesthetic Equipment Ltd., 37a New Cavendish Street, W.1.

one or more injections of medium to be given at any required phase of the cardiac cycle. In addition, single radiographs could be taken automatically or a serial changer started in relation to the injection. A modification of the circuit to enable multiple injections to be given is described in the appendix (p. 16). Injection pressure could be varied from 50–150 pounds per square inch. The duration of each injection was recorded by placing a microphone on the barrel of the injector. When multiple injections were given, a second microphone was placed alongside the “exhaust” electromagnetic valve placed in the air-line of the injector. An automatic indication of the moment of each X-ray exposure was made through the operation of a relay in the X-ray apparatus. The electrocardiogram was continuously observed on a cathode ray tube, and recordings of the electrocardiogram, central aortic pressure, time of injection of medium and indication of the moment of X-ray exposure were made during each angiogram on a Cambridge multi-channel recorder.

Ciné-radiography was performed with a 5-inch Philips intensifier and a 35 mm. Arriflex camera. The single radiographs were exposed in the cassette tunnel housed beneath the base-plate of the image amplifier. For serial radiography a Schönander 12 in. $\times$ 10 in. cut film changer was employed at an exposure rate of 6 films a second. The same G.R. generator supplied the current for the Schönander as for the ciné-radiography. Whichever of the three radiographic techniques was used, the films were taken in one plane only, and the best projection was found to be the 45° left anterior oblique.

FIG. 1.—Recordings of injection time, central aortic pressure, E.C. and Schönander film exposures. The period of injection occurred between the two upright lines interrupting the thick line above the record of the aortic pressure, and is seen to take place in diastole. Each interrupted line at the bottom of the figure represents the exposure of 1 Schönander film.

FIG. 2.—The first Schönander film in Fig. 1 exposed at the end of the diastolic injection. Good proximal filling of the coronary arteries.

FIG. 3.—The sixth Schönander film in Fig. 1 exposed at the end of the first diastole following the injection. Good distal filling of the coronary arteries.

FIG. 4.—Recordings showing two successive diastolic injections and Schönander film exposures.

FIG. 5.—The third Schönander film in Fig. 4 exposed at the end of the second diastolic period of injection. Complete coronary artery filling.

FIG. 6.—Recordings showing two successive diastolic injections and a single film exposed at the end of the second diastolic period of injection. The exposure corresponds to the beginning of the line at the bottom of the figure.

FIG. 7.—The single film exposed in Fig. 6. Complete coronary artery filling.

FIG. 8.—Recordings showing three successive diastolic injections and a single film exposed at the end of the third diastolic period of injection.

FIG. 9.—The single film exposed in Fig. 8. Complete coronary artery filling.

RESULTS

Positioning of the catheter was critical. It was advanced down the ascending aorta so that the tip was up against the aortic valve, when the movements of the valve could be felt distinctly by the operator's hand. The catheter was then withdrawn about half a centimeter. Higher positioning resulted in poor coronary opacification. There was a small rise in the central aortic pressure confined to the period of injection, rarely amounting to more than 20 mm. Hg. In over 200 angiograms, there were no arrhythmias, changes in heart rate, S-T segment shift or T wave changes, and there were no deaths attributable to the injection of medium.

Early experiments were made with single injections of medium using ciné-radiography. Because of the relatively poor definition and the fact that the small field would not cover the whole coronary tree in the human, this technique was abandoned in favour of the serial changer or single films.

It was confirmed that systolic injections resulted in poor coronary artery filling, whereas diastolic injections gave good opacification. It was observed that films exposed at the end of the same diastolic period as the injection showed the best filling of the proximal part of the coronary arteries, whereas on films taken towards the end of the next diastole there was good distal filling, with dilution of medium proximally (Fig. 1, 2, 3). It was then found that division of the medium into two equal parts with injection in each of two successive diastolic periods and an exposure made at the end of the second diastole resulted in a radiograph showing filling of both proximal and distal branches of the coronary vessels (Fig. 4, 5, 6, and 7). Division of the dose of medium into three parts and injecting over three diastoles resulted in rather more filling of the fine distal branches (Fig. 8 and 9). Visualization of the whole coronary tree was consistently as good on the single film exposed at the end of the second or third diastoles as on the Schönander film of similar timing (Fig. 5 and 7).

DISCUSSION

Injections of radio-opaque medium into the root of the aorta of the dog, timed to occur in diastole, produced consistent filling of the coronary arteries apparently without myocardial damage as shown by absence of change on the electrocardiogram. Division of the dose of medium into two or three equal portions and injecting it over two or three successive diastolic periods, enabled the whole of the coronary tree to be visualized on one X-ray film, thus simplifying the radiographic apparatus and reducing irradiation. There was slightly better filling of the fine distal radicals of the coronary tree when three injections were given.

In the application of this method of coronary angiography to man, we believe that treble injections will be necessary because it is impossible, with catheters and injectors now available, to give the required amount of medium in two diastoles, unless there is bradycardia.

SUMMARY

Diastolic injection of radio-opaque medium in dogs results in consistent opacification of the coronary arteries. Multiple diastolic injections enable the whole of the coronary tree to be visualized on one single X-ray film.

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APPENDIX

The circuit of the timing mechanism is shown in Fig. 10. This circuit is a modification of one previously published (Davies and Michell, 1960) and it enables the pneumatic injector to be stopped in mid-stroke and to be re-started at a given time after the next R-wave. This is achieved by fitting both inlet and exhaust electromagnetic valves to the injector and by allowing the injector piston to trip a micro-switch as it passes a pre-determined point in its stroke. The pulse from this micro-switch re-sets the bi-stable transistor pair X_3 and X_4 so that the circuit is ready to operate the injector again after the R-wave. The remainder of the circuit is similar to the one previously described except that the magnetic valves are now controlled through the relay RLE which in turn is operated by a "Schmitt" type transistor pair X_6 and X_7 . This gives a fast positive start and arrest of the injector stroke.

FIG. 10.—Circuit diagram of Timing Device.

- S₁ Initiate automatic injection sequence.
S₂ Mains on-off.
S₃ Initiate injection sequence not controlled by R-wave.
S₄ Energize electromagnetic valves.
V_a Inlet valve.
V_b Exhaust valve.