Angiography of the Minute Vessels of the Lung*

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The specific functions of the lung take place in the area of the terminal vascular bed of the pulmonary arterial system. Many important diseases affect principally this terminal vascular bed and/or the immediately adjacent arterioles and venules. Pulmonary hypertension, for example, may be based upon specific structural or functional defects in these fine vessels. Minute pulmonary emboli, pulmonary fibrosis and diffuse emphysema are disease entities difficult to evaluate. The dynamic effects of drugs upon fine pulmonary vasculature at present must be largely inferred by studying pulmonary arterial pressures and flows and left atrial pressures.

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Direct visual evidence of dynamic changes is meager. Perhaps a greater understanding of some of these problems could be obtained if the terminal vascular bed of the lung could be visualized more adequately.

While angiographic study of the capillary network of the lungs is as yet impossible, the arterioles leading to this network and the venules draining it can be studied by taking advantage of certain technical developments in the art of arteriography. Since these are very fine vessels, of the order of 500 microns and less, and since some are located at a considerable distance from the chest wall, in large, obese, or emphysematous individuals, the images of these fine vessels are often blurred and poorly defined. This is because of the large

**Figure 1:** A roentgen tube with a large focal spot casts a wider penumbra than a smaller focal spot tube; in addition, objects smaller than the focal spot are not clearly seen because of the phenomenon of "undercutting."
penumbra cast by standard roentgen tubes with large focal spots, and because of the phenomenon of "undercutting" (Fig. 1).

A technique has been available for approximately a decade, which makes possible direct roentgenographic magnification of the x-ray image. This became practical only after the development of roentgen tubes possessing focal spots very much finer than earlier ones. These are of the order of 0.3 mm. or less, instead of 1.5 to 2.0 mm. in conventional roentgen tubes. By using such a fine source of x-rays, it became possible to move the object toward the roentgen source and away from the x-ray film. Within certain limits, an enlarged image of the object could thus be obtained, without an objectional penumbra. Also, the phenomenon of undercutting could be considerably minimized.

Until recently, this technique was applied by radiologists only for bony or soft tissue problems; for example, to delineate hairline fractures more clearly, or to enhance bony detail in certain difficult areas such as the lumbar vertebral bodies. Occasionally it was suggested for thoracic roentgenograms, especially in infants. It has been found recently that this technique can also be applied to angiography in animals. However, the current which can be used with roentgen tubes having ultra fine focal spots is ordinarily limited by problems of heat dissipation from the anode, to 20 milliamperes. This seriously hampers the usefulness of this technique for angiography in man. Hence a roentgen tube was especially constructed with an ultra fine focal spot (0.3 mm.) capable of carrying 12 times this amount of current (up to 250 MA) and made available for a preliminary study of the fine vasculature in animals and in man for a limited time. (The filament life of this special tube was 10½ hours at the maximum permissible milliamperes.) Pulmonary angiograms were made in ten animals and six patients, using this special tube, and compared with pulmonary angiograms made by ordinary techniques in an equal number of animals and patients.

**Method**

Mongrel dogs under pentobarbital sodium (Nembutal) anesthesia were placed upon a horizontal radiolucent table top supported by scissors-type automobile jacks especially adapted for this purpose, which in turn rested upon the top of a regular x-ray table. A large-bore (No. 9 or No. 10) NIH catheter was placed into the right atrium via an external jugular vein in the neck under fluoroscopic guidance. The table-top was then shifted to position the animal's chest over a Schonander rapid film changer, and then elevated approximately 16 to 18 inches above the film changer. Using an imaginary point midway between the anterior and posterior surfaces of the chest as the "object," the height of the tube was then adjusted to give a target-object distance of approximately 20 inches and a target-film distance of approximately 40 inches. A test film was taken for position and to establish the most nearly ideal radiographic factors. A bolus of radiopaque material (usually sodium diprotrizoate and diatrozio [Ditrioton]) in an amount of 1.5 ml. per kg. of body weight was then injected rapidly with an automatic pressure injector† using 20 lb. pressure per square inch; the film changer was simultaneously turned on synchronizing multiple x-ray exposures and film changes. The rate of filming varied from 1.5 to 3 per second. Usually the animal was rendered apneic during the filming by inflating the lungs with manual pressure on an inflated rubber bag attached to an endotracheal tube previously inserted into the animal's trachea. Angiograms made by ordinary roentgen tubes, using the conventional target-object-film relationships were also made and compared with those obtained by direct roentgenographic

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Figure 2: A—Relative positions of target (roentgen tube), object (patient's lungs) and film (Schonander rapid film-changer) in conventional pulmonary angiography in the antero-posterior plane. B—Relative positions of target, object, and film when using direct roentgenographic magnification. Scissors-type automobile jack serves to elevate patient to desired position.

Figure 3: Portion of canine pulmonary angiogram: A—Angiogram made with 1.5 mm. focal spot tube, conventional technique; enlarged photographically to same size as B. B—Angiogram of same animal made with 0.3 mm. focal spot tube, using technique of direct roentgenographic magnification. Note enhancement of detail in B compared with A, without objectionable grid lines or film grain.
ANGIOGRAPHY OF THE MINUTE VESSELS OF LUNG

Figure 4:
A. Arterial phase; B. Capillary phase; C. Venous phase. Three seconds elapsed between each of these films. X-ray factors: 250 MA, 1/60 sec., 100 K V.
magnification by photographically enlarging ordinary angiograms.

In patients, essentially the same techniques were used. In half the patients, the special fine focal spot tube was used without elevating the Schonander table-top, so that no magnification resulted. This allowed a direct comparison of angiograms made with the fine focal-spot tube, and with the conventional tube (Fig. 2A). The remaining patients were elevated over the Schonander film changer (Fig. 2B) and magnified angiograms of a portion of the lung field (usually the upper or lower half of one lung) were obtained, using the fine focal-spot tube. Usually, 60 to 100 ml. of sodium diprotrizoate and diatrizoate were injected, using a Gidlund†† high pressure manually-operated syringe.

**RESULTS**

In animals, usually, but not invariably, the fine pulmonary vasculature was much better seen using direct roentgenographic

††Westinghouse Electric Corporation.

**Figure 5:** Portion of canine pulmonary angiogram made by technique of direct roentgenographic magnification to twice normal size, showing fine reticular pattern during capillary phase of filling. Note tip of No. 9 NIH catheter in right lower corner.

**Figure 6:** Portion of pulmonary angiogram made in a patient using direct roentgenographic magnification to twice normal size. A=Arterial phase (upper); B=Capillary phase (center); C=Venous phase (lower). Two seconds elapsed between film A and B; 1.5 seconds between B and C. X-ray factors: 100 MA, 1/3 sec., 74 KV, 0.3 mm. focal spot tube.
magnification than using conventional techniques (Figs. 3A and 3B). It soon became apparent that three distinct phases of vascular filling could be distinguished: an arterial phase, a capillary phase, and a venous phase (Fig. 4). During the first phase, the arterial radicles were filled to the periphery of the lung fields but no evidence of venous filling was visible. During the third or venous phase, the major veins were filled and there was little residual radiopaque medium in the arteries. During the middle phase, there was evidence of considerable radiopaque medium in both the major veins and arteries. In addition, myriad very fine vessels momentarily became opacified. A reticular pattern was sometimes apparent. This was true in the animals (Fig. 5) as well as in the patients (Fig. 6)—but demonstrable clearly only using direct roentgenographic magnification (Fig. 7). (The term “capillary phase” is used to identify the time interval during which capillary filling is taking place. One does not mean to imply that vessels of capillary size can be identified on the angiograms made during this phase of filling.)

In preliminary dynamic studies of the effects of drugs, serotonin was found to diminish filling of the fine vessels as well as the major ones markedly, while speeding up circulation time through the lungs.

**Discussion**

There seems to be little doubt that the smaller the focal spot of the x-ray tube used for roentgenography, the less will be the unsharpness of the x-ray image provided motion is minimal and films and screens optimal. In roentgenograms of bone, this characteristic can be used to advantage to obtain roentgenograms by direct magnification, with useful enhancement of detail. Under certain circumstances, it appears that similar enhancement of detail can be obtained in angiography, provided that the exposure can be made rapidly enough to prevent blurring due to motion. This requires the use of a much more powerful x-ray tube with a...
fine focal spot than the 20MA fine-spot tubes presently available. Such a tube was available in this study; it allowed us to visualize detail we had not been able to see before. A reticular vascular pattern of fine vessels could be demonstrated, confirming in part the post mortem studies of Fridkin.8

Study of the pulmonary vasculature has been greatly hampered in the past by the relative unresponsiveness of the pulmonary vessels to drugs, and by the difficulties in determining pulmonary vascular resistance with accuracy. Pulmonary angiography has been used in the past largely for the study of the major pulmonary arterial trunks.9 10 Functionally, however, the finest vessels are the more significant ones. If it can be shown that the fine vessels of the lungs can be opacified consistently and reproducibly, and if changes in the fine vasculature can be demonstrated as a result of disease process, or of the influence of drugs, an important additional tool for the study of the pulmonary circulation will be available. We believe that such a tool is at hand now for angiography of the minute vessels of the lungs. Perhaps it will be possible to demonstrate the physiologic arteriovenous communications suggested by the work of Niden and Aviado.11 Such studies will require the use of a high-powered fine focal spot x-ray tube, preferably with direct roentgenographic magnification, as well as careful monitoring of intrapulmonary pressures.

It should be mentioned that on 14" x 14" cut films, only about half of one lung field can be seen, in the adult, using 2X magnification. It should also be pointed out that the radiopaque medium itself may affect the caliber of fine pulmonary vessels. This problem is the object of presently continuing studies.

SUMMARY

A specially constructed roentgen tube with a fine focal spot (0.3 mm.) has made it possible to demonstrate very fine pulmonary vessels on pulmonary angiograms in intact animals and in man, using the established technique of direct roentgenographic magnification. Arterial, capillary, and venous phases of filling can be identified. The most minute pulmonary vessels which can be visualized by this technique suggest a reticular pattern. Early studies demonstrate that visualization of the fine vessels of the lungs can be importantly influenced by certain drugs.

RESUMEN

Un tubo de rayos X, especialmente construido con punto focal de 0.3 mm., ha hecho posible demostrar vasos pulmonares muy finos en los angiogramas en animales sanos y en el hombre usando la técnica ya establecida de la magnificación. Se pueden identificar las fases de llenado arterial, capilar y venoso. Los vasos más pequeños que se pueden descubrir por esta técnica sugieren un aspecto reticular. Los estudios iniciales demuestran que la visualización de los vasos finos del pulmón puede ser influenciada considerablemente por ciertas drogas.

ZUSAMMENFASSUNG


REFERENCES

5 Morgan, R. H.: "An Analysis of the Physical Factors Controlling the Diagnostic Quality of

TOTAL BODY PERFUSION BY SMALL BUBBLE TYPE PUMP OXYGENATOR

The simplified total body perfusion method originally described by Zahli consists of utilizing a small priming volume, hemodilution of the body by 5 per cent glucose solution and/or low molecular weight plasma expanders, and a reduced flow perfusion (300 ml/kg/min.) at moderate body hypothermia of about 30°C. of the esophageal temperature. Cooling and rewarming are performed by the partial bypass. The venous blood from the superior vena cava through the right atrial appendage and from the inferior vena cava through the external iliac vein is drained into the oxygenator by gravity drainage. The advantages of this method are the reduced requirement for blood with the lessened likelihood of transfusion complications such as hemorrhagic diathesis, hepatitis. The metabolic acidosis, indicating tissue hypoxia, is very slight and easily reversed, in spite of such reduced perfusion rate. Twenty-five clinical cases with various congenital heart diseases have been operated in the authors' clinic. In all instances, the postoperative course, including a patient whose total bypass was prolonged for one hour, were uneventful.

USE OF INDIRECT MASSAGE OF THE HEART IN EXPERIMENTAL LETHAL ELECTROTRAUMA

The article discussed the results of experimental investigations pertinent to the restoration of vital functions of the organism after lethal electrotrauma with the aid of indirect massage of the heart and other components of the resuscitation technique - artificial respiration, defibrillation, administration of adrenaline and intra-arterial transfusion of blood. Experiments were staged on 15 dogs. Indirect massage of the heart was started 40-60 seconds after the infliction of electrotrauma. During cardiac massage in a number of dogs, artificial respiration was effected by means of a respirator. Twenty to 25 minutes after the beginning of massage, defibrillation of the heart was carried out. An effective activity of the heart was restored as a result of subsequent massage and intravenous administration of adrenaline or intra-arterial blood transfusion. The author is of the opinion that indirect massage of the heart may be employed as a premedicinal aid during death from electric current.

MYOCARDIAL ACTOMYSIN AND MYOSIN AFTER SHOCK, ACUTE HEMORRHAGE, ACUTE HYPOXIA AND CARDIOPULMONARY BYPASS

Decreases in cardiac efficiency have been observed in experimental endotoxic shock, acute hemorrhage and cardiopulmonary bypass. Diminished coronary blood flow, tissue anoxia, or metabolic alteration may affect the contractile protein which, in turn, causes cardiac inefficiency. Cardiac actomyosin and myosin were extracted with Gua-Straub solution, and intrinsic viscosity, ATP (adenosinetriphosphate) activity, ATP sensitivity, the rate of ATP hydrolysis, and myosin-ATPase activity were determined. Under these experimental conditions, both myosin and actin were altered. Acute hypoxia was produced in dogs and the physicochemical properties of actomyosin and myosin were studied. During acute hypoxia, the myosin-ATPase was affected, but actin appeared to remain unaltered. These changes of actomyosin and myosin may cause insufficient energy utilization by the contractile system and thereby affect the cardiac efficiency.


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