to those engaged in cardiac catheterization that this procedure may lead to left-sided embolism in patients with predominant right-to-left shunts, and that a complicated episode of coronary embolization, with resultant myocardial infarction, may go undiagnosed in the absence of specific clinical manifestations. An additional point of interest is the unusually long survival of the patient with the particular type of malformations present.

Summary

A case of fatal coronary-artery embolism with myocardial infarction in a sixteen-year-old girl with Type 1 persistent truncus arteriosus is presented. The possible paradoxical nature of the embolus and the relation of the embolic episode to cardiac catheterization are discussed.

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THE MECHANISM OF THE PRODUCTION OF DUROZIEZ'S MURMUR*

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According to the description of Duroziez, as presented by Major[1] and by Willius and Keys,[2] the intermittent to-and-fro crural murmur associated with aortic insufficiency is produced by blood flow into the lower extremity during systole and back from the extremity toward the aorta during diastole. Although this may seem elementary there has been a considerable amount of investigation attempting to prove or disprove this hypothesis, and varying explanations have been suggested. Thus, Blumgart and Ernstene[3] concluded, in 1933, that the diastolic portion of Duroziez's murmur arose either from backflow in the femoral artery during diastole, as seen in severe aortic insufficiency, or from continuing forward flow during diastole, as seen in thyrotoxicosis, anemia, fever or peripheral vasodilatation from heat. They stated that these two mechanisms could be differentiated simply at the bedside in the following manner: if the diastolic murmur was accentuated by pressure on the artery proximal to the site of auscultation and abolished by a peripheral tourniquet or immersion of the extremity in cold water, it was due to continuing forward flow from vasodilatation; and, on the other hand, if the murmur was due to backflow, it was accentuated by pressure distal to the point of auscultation as well as by application of a tourniquet distal to the auscultation site and by immersion of the extremity in cold water. Luisada,[4] in reviewing the literature, indicated that there were inconsistencies between the results obtained by Blumgart and Ernstene and those of others who did similar experiments before them. In his own experiments Luisada demonstrated phonocardiographically that the diastolic murmur occurred at the "predicrotic notch" and was later at a more distal site in the artery than in a more proximal site. From this he concluded that the diastolic murmur was due to continuing forward flow during diastole not only in subjects with peripheral vasodilatation but also in those with aortic insufficiency. Since the evidence presented by previous investigators is indirect and inferential, and since current textbooks[5,6] carry opposing and therefore confusing explanations of the Duroziez murmur, the present experiments were undertaken.

Material and Methods

For preliminary testing of feasibility of the procedure a Cournand needle was placed percutaneously in the femoral artery of an anesthetized dog and a cineangiogram was recorded at 60 frames per second during infusion of contrast substance (85 per cent diatrizoate methylglucamine‖). Since it was clearly possible to follow the direction of blood flow in the femoral artery by observation of the concomitant movement of the radiopaque liquid in the normal

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Supported in part by grants from the National Heart Institute, National Institutes of Health, United States Public Health Service, and the Wisconsin Heart Association.

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‖In the form of Cardiografin, E. R. Squibb and Sons, New York City.

animal the infusion and filming were repeated after deliberate destruction of the aortic valve by means of a destructive instrument passed down the carotid artery to tear the valve. The amount of retrograde flow in the femoral artery increased sharply in the dog after this procedure and encouraged us to extend our observations to human subjects.

A series of 8 human subjects were then selected for study. On careful examination 3 of them presented Duroziez's murmur, and 5 did not. Of the subjects with Duroziez's murmur 1 had severe aortic insufficiency, 1 a large patent ductus arteriosus, and the third aortic insufficiency with a defect of the ventricular septum. Although a considerable effort was made to find patients with severe anemia and thyrotoxicosis who presented a typical example of Duroziez's murmur, no such subject was found during the time of this study. One subject with a hemoglobin of 5 to 6 gm. per 100 ml. was subjected to infusion of contrast material into the femoral artery even though no such murmur was present. Of the other 4 subjects without Duroziez's murmur, 2 were catheterized because of a defect of the atrial septum and a third because of a defect of the ventricular septum. The fourth was a normal volunteer (G.G.R.). All served as subjects for this investigation of femoral arterial flow during cardiac catheterization except the volunteer, who had the infusion into the brachial artery as an isolated procedure.

In each of the 8 human subjects used for this study a Cournand needle was inserted percutaneously into the femoral or brachial artery and attached by plastic tubing to a constant injection apparatus capable of infusing a continuous stream of contrast substance. During the injection of contrast substance at 20 ml. per minute cineangiograms were recorded at 60 frames per second. Thus, it was possible to record the movement of contrast substance as it was infused into the artery and hence to determine direction of blood flow. In the patient with patent ductus arteriosus the study was repeated after surgical correction of the lesion when the Duroziez murmur was markedly reduced.

In most subjects the infusion had to be discontinued shortly after its onset because of acute pain in the extremity into which the contrast substance was infused. This reaction caused no long-range disability and disappeared shortly after stopping the infusion. It did not interfere with the study except so far as it reduced the number of subjects studied and limited the length of observation and frequency of repeated studies. The infusion into the brachial artery was accompanied by considerable pain and followed by residual tenderness of the fingertips and nail beds. Deep-bluish, painful discolorations were noted in the fingers, especially the pads of the distal phalanges, approximately eight hours after the infusion, becoming progressively more apparent during the succeeding day and then slowly fading. Although no permanent damage resulted it was not thought advisable to repeat the observations in other subjects. This reaction may well have been exaggerated by repetition of the infusion during heating of the hand and forearm by an electric blanket after the extremity was already painful from the control injection. The severity of the reaction was considerably less in the lower extremity than in the upper, presumably since the dilution of the contrast material is greater in the thigh, leg and foot and no residuals were produced.

In 1 patient with a defect of the atrial septum the lower extremity was heated with an electric blanket before infusion of contrast substance and subsequently cooled by application of alcohol to its surface. When the extremity was thoroughly chilled contrast substance was infused again. Auscultation in this subject revealed that the systolic murmur became much louder and longer during application of heat, but no diastolic murmur appeared until after the extremity had been cooled by sponging with cold alcohol. No adverse reaction occurred.

Results

Infusion of contrast substance into the femoral arteries of anesthetized normal animals revealed that during systole the contrast substance washed rapidly toward the periphery whereas during diastole forward flow ceased and the contrast substance became progressively more dense in the artery at the point of the needle tip, moving slightly retrograde and diffusing slowly centrally and peripherally along the femoral artery. In all cases retrograde flow was relatively small but distinctly present. Indeed, retrograde flow was interrupted suddenly, apparently in relation to aortic-valve closure, with a brief rebound of forward flow as might correspond to the dicrotic notch on a pulse tracing. When the aortic valve was destroyed the excursion of the contrast substance immediately became greater not only with a greater forward surge during systole but also with considerable backflow during diastole uninterrupted by aortic-valve closure. This pattern was seen in both dogs in which the experiment was performed. An attempt has been made to present these motions graphically in Figure 1.

In human subjects without disease of the aortic valve or a shunt flowing from the proximal part of the aorta in diastole the femoral-blood-flow pattern was similar to that seen in the normal dog. The pattern of flow is indicated diagrammatically in Figure 1. Thus, during systole, the blood and contrast substance moved rapidly toward the periphery, and during diastole, flow reversed temporarily for a small

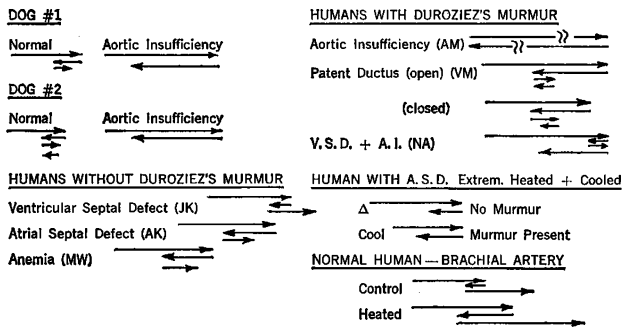

FIGURE 1. *Patterns of Flow Observed.*

The arrows indicate the direction of flow of contrast material infused into the femoral artery. In each case the upper arrow indicates flow during systole. The subsequent arrows indicate directional changes in flow, and the length of the arrow is related to the rate and apparent distance of flow. The lower-right-hand data under "normal human" refer to the movement of blood in the brachial artery whereas all the other data in the figure were observed in the femoral artery.

distance, again with a forward "bounce" apparently related to the dicrotic notch and produced by aortic-valve closure. This pattern was seen in the patients with defects of the atrial and ventricular septums and anemia. It should be emphasized that these subjects had no Duroziez murmur.

In the human subject with Duroziez's murmur who had severe aortic insufficiency there was very rapid forward flow in the femoral artery during systole, and marked backflow occurred during diastole. The contrast material appeared to be carried by retrograde flow from the femoral infusion site to the distal end of the abdominal aorta.

In the patient with a patent ductus arteriosus who had Duroziez's murmur forward flow of contrast substance in the femoral artery during systole was very rapid, and the excursion of forward flow considerable. During diastole the contrast substance passed quickly in a retrograde direction through the femoral and external iliac arteries, approaching the distal end of the aorta and indicating considerable backward flow. After surgical division of the ductus arteriosus, Duroziez's murmur was markedly reduced. The repeat study was made within the first ten days after operation, when the patient was anemic and still weak from the procedure. At that time the forward flow was considerable, and there was moderate backflow, but it was reduced as compared to the preoperative examination when the ductus was open.

In the third subject with Duroziez's murmur (aortic insufficiency and defect of the ventricular septum) the degree of aortic incompetence was less than that in the subject with pure aortic insufficiency, and the retrograde flow in the femoral artery, although clearly present, appeared to be correspondingly less in amount.

In the patient with a defect of the atrial septum an attempt was made to induce Duroziez's murmur through local heating by an electric blanket. Although the leg and thigh were heated until they were very warm to touch and perspired profusely, and although the systolic murmur grew louder and longer on compression, no to-and-fro murmur could be produced. Cineangiography at the point of maximal heating revealed an amount of backflow that was considered normal. Forward flow, however, was considered to be much more rapid during systole. The extremity was then cooled by removal of the blanket and sponging of the skin of the leg and thigh with cold water and alcohol until it was quite cool and somewhat cyanotic. At this time Duroziez's to-and-fro murmur was heard intermittently, and cineangiography revealed that the amount of forward flow was reduced whereas backflow was markedly increased.

Although a systolic murmur was produced in the brachial artery of normal subjects by proper compression with the stethoscope, and although the murmur became much louder and longer during and after heating, it was never considered to be to and fro in quality. Rather, the sound resembled that of an arteriovenous fistula with a continuous murmur or a murmur briefly interrupted near the time of the dicrotic notch. Cineangiography in the upper extremity revealed a prominent forward systolic rush of blood, interrupted temporarily by backflow at what was considered to be the dicrotic notch, and then a continuing forward flow during diastole. After heating the upper-extremity forward flow increased during both systole and diastole, but this flow was still briefly reversed near the time of aortic-valve closure.

DISCUSSION

In all subjects in this series some retrograde flow appeared to occur in the femoral artery, as judged by the movement of contrast substance infused at a constant rate into its lumen. In the normal dog this retrograde flow increased sharply when the aortic valve was rendered incompetent. In the human subjects in this series with a typical to-and-fro femoral Duroziez murmur, infusion of contrast substance into the femoral artery revealed a markedly greater backflow of the contrast material during diastole as compared to those without such a murmur. Furthermore, the flow during systole was greatly accelerated in those with Duroziez's murmur, and hence the total excursion of the contrast substance in the peripheral artery was considerably increased when both forward and backward motion was taken into account. It appeared that there was sufficient backflow past the site of compression of the femoral artery to account for the production of a diastolic-flow murmur.

Since patients with anemia, thyrotoxicosis and infection who were examined clinically during this study were not found to have a typical Duroziez murmur in the femoral artery it was not possible to investigate the murmur by this technic, and consequently, its mechanism in such subjects could not be elucidated. In many anemic or thyrotoxic persons a loud systolic murmur could easily be produced by compression of the femoral artery, and a low rumbling murmur continuing throughout several heart cycles could be heard intermittently. This murmur tended to occur as compression was released (as described by Duroziez[2]) and was attributed by us, without much evidence, to outflow of venous blood from the extremity during relief of temporary venous obstruction. Although no true to-and-fro femoral murmur could be heard in these subjects, it should be noted that retrograde femoral flow occurred in all the experimental subjects and could conceivably have been greater in those with very hyperactive circulation.

In the only subject in whom a faint Duroziez murmur was produced by cooling of an extremity after it had recently been heated, cineangiography revealed a considerable amount of retrograde femoral flow. It is realized that this constitutes a highly artificial situation in which severe vasoconstriction is induced in a single extremity whereas the rest of the body was not cooled. Presumably, under these circumstances blood flowed out of the cooled thigh and leg during diastole and passed into other, less constricted vascular beds. This is believed to be an unusual circumstance that does not bear directly on Duroziez's murmur as it is usually found. When both systolic and diastolic murmurs were produced in the brachial artery by heating of the hand and forearm, cineangiography demonstrated what was considered to be enough forward flow in diastole to explain the production of the sound.

The present studies indicate that in the circumstances in which Duroziez's murmur was heard, backflow of blood was demonstrable in the femoral artery. They do not explain the observations of others relating to the spontaneous appearance of Duroziez's murmur in anemia, thyrotoxicosis and other conditions and probably should not be extrapolated beyond the area to which the study was applied. Observations during local heating of the upper extremity are consistent with the previous studies of Blumgart and Ernstene[3] in that continuing forward flow is demonstrated both during systole and diastole.

Summary and Conclusions

The mechanism of Duroziez's murmur in the femoral artery was studied by cineangiographic observation of the motion of contrast substance infused continuously into the femoral artery.

In the normal dog, blood flow in the femoral artery appears to be chiefly toward the periphery, but a small amount of retrograde flow is present. When the aortic valve is made incompetent both forward and backward flow in the femoral artery increases markedly.

In the human subject without aortic insufficiency or a left-to-right shunt originating from the central aorta minimal retrograde flow was noted in the femoral artery.

In patients with Duroziez's murmur due to aortic insufficiency and patent ductus arteriosus there was a considerable increase in both forward and backward flow in the femoral artery that seemed sufficient to account for the characteristic to-and-fro murmur.

During heating of the upper extremity continuing forward flow during diastole was demonstrated. This suggests that the prolonged systolic and diastolic murmur produced by local heating is different from the Duroziez femoral murmur of aortic insufficiency and that it is due to continuing forward flow.

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