EXPERIMENTAL OPERATIONS ON THE SIGMOID VALVES OF THE PULMONARY ARTERY.*

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PLATES 3 TO 5.

The purpose of the following study was to ascertain whether and to what extent intracardiac operations could be performed with safety. The technique that has been described and employed by various experimenters and surgeons is unsatisfactory, because it involves the introduction of sharp instruments into the cavities of the heart, without the control of the eye or the finger. Thus far no operations have been devised which permit, for example, the cauterization of infected valves, the suture of the foramen ovale, or of two valves in a case of insufficiency, and still other plastic operations. The operations mentioned form a different class from those which have so far been performed, because they involve the stoppage of the circulation through the cavities of the heart and the passage of air into the cardiac cavities, and require great speed of execution. Hence it is hardly to be expected that a technique making possible and safe such operations as these will be perfected soon. It may even be regarded as extremely doubtful whether this class of operations may ever be applicable to human surgery. And yet their future cannot be predicted, and I have, therefore, attempted to develop methods for the execution of these operations. For the preliminary studies the sigmoid valves of the pulmonary artery were selected, because the opening of the right cavities of the heart is less dangerous than the opening of the left cavities.

METHODS.

The preparation of the animals is similar to that already described.1 After the thoracic cavity has been opened in the anesthe-

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Operations on Sigmoid Valves of Pulmonary Artery.

tized animal by a left transverse thoracotomy, the pericardium incised, and the anterior part of the heart exposed, the operation is started. The operation consists of four stages: (1) the stoppage of the circulation of the heart, (2) the opening of the pulmonary artery, (3) the performance of the intracardiac operation and the closing of the pulmonary artery, and finally (4) the reestablishment of the circulation through the heart.

The Stoppage of the Circulation of the Heart.—This has already been performed in many different ways. We ourselves have used all known methods of stopping the circulation through the heart. Finally, we adopted the method of clamping in mass the pedicle of the heart by means of large soft-jawed forceps. The heart was not taken out of the pericardium, but the incision of the pericardium was large enough to permit of the easy introduction of one of the jaws of the forceps under the pedicle. The forceps was a Doyen, the jaws of which were covered with rubber. One of the jaws was introduced into the pericardium under the pedicle and directed from the right to the left side by the index finger of the operator. Before clamping, the position of the forceps was carefully examined. The handling of the forceps and of the pedicle was always very gentle. Care was taken not to produce any compression of the veins before the time of the clamping. It is important for the heart to be in normal condition before clamping the pedicle, a result obtained by overventilating the blood, which is easily accomplished by means of the Meltzer-Auer apparatus. It was noticed that if the heart is clamped before it is in excellent condition the interruption of the circulation is less safe than when the heart is filled with well oxygenated blood. The advantage of using the Meltzer-Auer method in this operation is that it permits of an acceleration of the oxygenation of the blood at will. When everything is ready for the operation the forceps is rapidly clamped and, without a second being wasted, the heart or the vessel is opened and the operation started.

When these precautions are taken it is possible to clamp the pedicle of the heart for as long as two and a half or three minutes without subsequent trouble. As soon as the clamp is removed the heart resumes pulsation, and after a short time the pulsations are again
normal. In no case was there any need of massaging the heart when the interruption of the circulation did not exceed two and one half minutes; this period probably allows of a considerable margin of safety and it would doubtless be possible to prolong the operation slightly without excessive danger. But two and one half minutes appear to be sufficient time for the performance on the valves of several operations.

The above technique may appear to be somewhat crude, but experience has shown that it is simpler than the separate clamping of the arterial and venous pedicles, and requires less handling of the heart, which is an important consideration. Moreover, traumatism of the anatomical structures of the pedicle is slight, on account of the large quantity of tissue which is taken up between the jaws of the forceps and which renders their action less rough.

The Opening of the Pulmonary Artery.—The pulmonary orifice is exposed by means of an incision made through the anterior wall of the artery at the level of or a little above its junction with the heart. The incision is made with sharp scissors, or is begun with sharp scissors and finished with blunt scissors. The wall of the pulmonary artery is perforated about one and one half or two centimeters above the point of insertion of the sigmoid valves and incised from above downwards with one cut of the scissors. The location and the length of the incision vary according to the purpose. When the incision is located above the anterior valve it is not prolonged below the level of the insertion of the valve, in order not to incise the sigmoid. When the incision is made further on the left side of the artery at the level of the junction of the anterior and left sigmoids of the valve it can be prolonged further on to the cardiac wall, and an incision four centimeters in length, half on the heart and half on the pulmonary artery, could be made without danger. The short incision made above the orifice is kept open by two forceps put on the edges, when the valves are sufficiently widely exposed to be cauterized. But through such an opening it is impossible to perform a suture of the valves. Hence for these cases a long incision is made at the union of the anterior and left sigmoids (figures 1 and 2), which permits a large opening of the pulmonary artery and the possibility of operating easily on the valves
Operations on Sigmoid Valves of Pulmonary Artery.

themselves. It is not necessary to cut exactly at the point of insertion of the valves. If the incision is located near the point of insertion of the valves it does not produce a marked degree of insufficiency. Moreover, the left side of the arterial cone is not covered by large branches of the right coronary artery, and the section of the wall and its suture can be made without danger to the circulation.

Immediately on opening the pulmonary artery a large quantity of dark blood is expelled from the heart, and consequently the operating field must be narrowly walled off by the silk and cotton padded towels, in order to prevent the escape of the blood into the pleura.

The Performance of the Intracardiac Operation and the Closing of the Pulmonary Artery.—As soon as the incision is complete its edges are retracted by two mosquito forceps, the blood is sponged, and the valves are exposed. Air always enters the right ventricle. No special care is taken of this, since no complications due to the air emboli through the lungs were ever observed to follow. Three kinds of operation were performed: cauterization, suture and section, and suture of the valves. The cauterization of the valves was performed with the fine point of the thermocautery. The points of insertion of the valves, their free edge, or their internal surface were cauterized. The suture of the valves was made with a straight needle No. 16 and fine silk sterilized in vaselin. The left and right valves were united by one stitch (figure 3) at a distance of about two millimeters from the insertion to the arterial wall. This produced stenosis of the pulmonary orifice. Section and suture of one sigmoid valve were made in the following way: The sigmoid valves having been exposed by a long incision through the orifice, the right sigmoid was cut in its middle with the scissors, as far as the insertion to the arterial wall (figures 4 and 5). Afterwards the edges of the wound were united near the margin of the valve by a stitch made with straight needles No. 16 and silk sterilized in vaselin.

The operation completed, the pulmonary artery is sutured. In order not to lose any time a needle No. 12 with China silk No. 1 was kept ready. A minute piece of muscle had been fixed at the end of the thread, in order that no time should be spent in making a knot after the first stitch was made; the incision is closed with a con-
tinuous through and through suture. The time occupied by the
incision of the pulmonary artery, the operation itself, and the suture
of the artery varied between one minute and fifty seconds and three
minutes.

Reëstablishment of the Circulation through the Heart.—As soon
as the suture of the pulmonary artery is complete the clamp is re-
moved. Generally during the period of the interruption of the cir-
culation the heart is still beating feebly, but it may have stopped
completely. As soon as the blood is allowed to flow from the ves-
sel into the heart the pulsations recommence, weak at first, but very
soon become quite normal. When the interruption of the circula-
tion did not last more than two or two and one half minutes there
was no need of massage; after a few minutes the heart had recov-
ered its normal pulsations. A gauze sponge was always applied to
the line of suture and a slight degree of compression made during a
few minutes. When, after that time, there was still some leakage
at the line of suture, one or two complementary stitches were added.
Care was taken not to close the pericardium before the line of suture
was absolutely without leakage. Then suture of the pericardium
and of the thoracic wall is made, according to the ordinary method.
The animal is dressed and taken care of as described in a previous
article.²

EXPERIMENTAL.

The experiments were performed on ten medium sized dogs.
Nine of these animals were young adult dogs in good health, and
one was a dog about seven or eight years old. In three instances the
operations consisted of exploration, suture, or section and suture
of the sigmoid valves; in seven instances the sigmoid valves were
cauterized.

Experiment I. Exploration of the Sigmoid Valves of the Pulmonary Artery.
—Black long haired dog. March 10, 1913. Etherization by the Meltzer-Auer
method. Transverse left thoracotomy by the ordinary technique. Incision of
the pericardium. Clamping of the pedicle of the heart with a soft-jawed forceps
protected with rubber. Incision of the anterior wall of the pulmonary artery just
above the sigmoid valves. The edges of the opening were retracted with two
forceps. The sigmoid valves of the pulmonary artery could easily be seen and

² Tuffier and Carrel, loc. cit.
Operations on Sigmoid Valves of Pulmonary Artery.

handled with the fingers or with the forceps. Then the incision of the pulmonary artery was closed by means of a continuous suture with China silk and a needle No. 12. The clamp was removed and the circulation reestablished. The interruption lasted two minutes and fifty seconds. The pulsation of the heart started immediately without massage. After a few minutes it was normal. Closing of the pericardium and of the thoracic cavity by the ordinary method. The animal had no shock and walked about half an hour after the operation. During the afternoon it ate and drank as usual. May 20. Animal is still entirely normal.

Experiment 2. Suture of the Sigmoid Valves of the Pulmonary Artery.—Black and white long haired male setter dog. March 12, 1914. Etherization by the Meltzer-Auer method. Transverse left thoracotomy by the ordinary method and clamping of the pedicle of the heart. Section of the wall of the pulmonary artery and of the cardiac wall at the point of union of the anterior and left sigmoid valves. The valves were widely exposed by retraction of the edges of the wound by two forceps, and the right and left sigmoids were united at a distance of about 2 mm. from their insertion to the wall by a stitch made with a straight needle (Kirby No. 16). Then the edges of the incision of the pulmonary artery were sutured by the ordinary method. The clamp was removed after an interruption of the circulation lasting two minutes and twenty-five seconds. The pulsation of the heart started immediately without massage. Then the pericardium and the thoracic cavity were closed. After the operation the animal recovered, as in experiment 1. May 20, 1914. Animal is still in normal condition.

Experiment 3. Section and Suture of the Right Sigmoid Valve and of the Pulmonary Artery.—Yellow and white male fox-terrier, about seven or eight years old. March 17, 1914. Etherization by the Meltzer-Auer method. Opening of the chest by left transverse thoracotomy. Section of the pulmonary artery just above the pulmonary orifice, after the pedicle of the heart had been clamped. The sigmoid valves were exposed by retraction of the edges of the incision by two forceps. Then the scissors were introduced into the artery and the right sigmoid valve was completely sectioned in its middle. Next, the edges of the valve were approximated at the upper end of the incision by one stitch made with a needle No. 16 and fine silk sterilized in vaselin. The pulmonary artery was closed by the ordinary method and the circulation was reestablished after an interruption of two minutes and thirty seconds. The operation was completed in the ordinary way and the animal not only sustained no shock but remained in excellent condition. May 20, 1914. Animal still is in excellent health. Slight diastolic murmur.

Experiment 4. Cauterization of the Sigmoid Valves of the Pulmonary Artery.—Young brindle female bulldog. April 14, 1914. Etherization by the Meltzer-Auer method. Transverse thoracotomy and clamping of the pedicle of the heart by the ordinary method. Incision of the pulmonary artery just above the pulmonary orifice. The edges of the incision were retracted by two forceps and the sigmoid valves widely exposed. The blood was removed with sponges and the edges of the left and right sigmoid valves were cauterized with the thermocautery. Then the wall of the pulmonary artery was closed and the circulation reestablished after an interruption of two minutes. The operation was completed by the ordinary method. The animal sustained no shock and remained
in excellent condition, as in the preceding experiments. May 20, 1914. Animal
is still in normal condition.

Experiment 5. Cauterization of the Sigmoid Valves of the Pulmonary Ar-
tery.—Brindle female mongrel. April 20, 1914. Etherization by the Meltzer-
Auer method. All the details of the operation were identical with those given
in experiment 4. The interruption of the circulation lasted two minutes and five
seconds. After the operation the animal remained in excellent condition. May

Autopsy.—Pneumonia, pericardial adhesions. Valves normal. Pulmonary
incision healed, without deposit of fibrin.

Experiment 6. Cauterization of the Sigmoid Valves of the Pulmonary Ar-
tery.—Brindle female mongrel. April 22, 1914. Etherization by the Meltzer-
Auer method. Transverse thoracotomy and clamping of the pedicle of the heart
by the ordinary method. Incision of the pulmonary artery just above the middle
part of the anterior sigmoid valve. The incision was made as far as the base
of the sigmoid sinus. Cauterization of the anterior sigmoid and of the point
of insertion of the right and left sigmoids. Suture of the pulmonary artery
and reestablishment of the circulation after an interruption of two minutes and
fifty seconds. Pulsation of the heart weak at first, normal after a few minutes.
During the suture of the pericardium a small branch of the anterior coronary
artery was wounded by the point of the needle. The hemorrhage was stopped
by suture of the endocardium in front of the vessel. Hemorrhage ceased. The
operation was completed in the ordinary way. The animal had no shock and
in the afternoon was in excellent condition. April 28. Animal sick. April 29.
Died.

Autopsy.—Wound infection; purulent pleurisy; no pericarditis, but pericardiac
adhesions. Interior of heart normal; no thrombosis of pulmonary artery; thin
layer of fibrin on the lower part of the line of suture; sigmoid valves normal;
no deposit of fibrin at cauterized points (figure 6).

Experiment 7. Cauterization of the Sigmoid Valves of the Pulmonary Ar-
tery.—White and black mongrel. April 23, 1914. Etherization by the Meltzer-
Auer method. The technique of the operation was identical with that used in
experiment 6. But after the circulation had been interrupted and the pulsation
of the heart had recommenced, fibrillary contractions suddenly appeared and the
animal died. The fibrillary contractions were probably due to the fact that the
incision had been made too low on the anterior part of the heart and that a
depth stitch possibly included a branch of the coronary artery.

Experiment 8. Cauterization of the Sigmoid Valves of the Pulmonary Ar-
tery.—White female fox-terrier. April 28, 1914. Etherization by the Meltzer-
Auer method. Incision of the skin at 10.10 A.M. Opening of the chest by trans-
verse thoracotomy on the left side at 10.18. The pedicle of the heart was clamped
at 10.30. The incision of the pulmonary artery, the cauterization of the valves,
and the closing of the pulmonary artery were performed with the ordinary
technique. The interruption of the circulation lasted one minute and fifty sec-
onds. The operation was completed at 10.45. The animal was in excellent con-

Experiment 9. Cauterization of the Sigmoid Valves of the Pulmonary Artery.
—White and yellow male fox-terrier. April 29, 1914. Etherization by the Meltzer-
Operations on Sigmoid Valves of Pulmonary Artery.

Auer method. Transverse thoracotomy. The heart was clamped for two minutes, during which time the incision of the pulmonary artery, cauterization of the valves, and suture of the arterial wall were made. The operation was completed and the dressing made. Same technique as in experiment 6. Animal was in excellent condition. May 20. Animal still normal.

Experiment 10. Cauterization of the Sigmoid Valves of the Pulmonary Artery.—White fox-terrier with brindle spots. April 30, 1914. Etherization by the Meltzer-Auer method. The technique was exactly the same as in experiment 9. At 11 a.m. incision of the skin. At 11.05 opening of the chest. At 11.09 opening of the pericardium. At 11.15 clamping of the heart, which lasted one minute and fifty seconds. During this period the pulmonary artery was cut, the valve cauterized, and the arterial wall sutured. At 11.27 the suture of the muscles was made, and at 11.32 the operation was completed. The animal was in normal condition. May 20. Animal is still normal.

RESULTS.

The results of these operations must be considered from the standpoint both of the general condition of the animals and of the modifications of the sigmoid valves of the pulmonary artery. Out of ten animals operated upon, three died and seven recovered and remained in excellent condition. The deaths were due to different causes. In experiment 5 the animal recovered completely and was apparently normal sixteen days after the operation. Then it sickened and died of pneumonia twenty days after the operation. In experiment 6 the cause of death which occurred seven days after the operation was a purulent pleurisy. In experiment 7 the animal died on the operating table of fibrillary contractions of the heart. It is probable that some of the causes of death can be eliminated. The infection of the thoracic wall and the purulent pleurisy, as well as the pneumonia which occurred in experiment 5, are preventable complications. They were caused by faulty technique which can be avoided. In all instances in which a few persons only were present in the operating room, the operation could be conducted with great care and all the animals recovered. It is probable that the proportion of deaths obtained in the first series of experiments will be much lower in the future. The general condition of the animals that survived was excellent. They sustained no shock; usually one hour after the operation they walked about, and three or four hours afterwards they ate and drank. These results were observed not only on young dogs, but also on a dog seven or eight
Alexis Carrel.

years old. All the animals were operated upon more than one month ago, and are at present normal.

The local modifications brought about by the operations were studied on the two specimens taken from animals 5 and 6, and also from the clinical examination of the seven surviving animals. The heart taken from animal 6 showed the result of the cauterization of the sigmoid valves of the pulmonary artery seven days after the operation. There were pericardiac adhesions on the anterior wall of the heart, but the heart itself was apparently normal. No thrombosis of the pulmonary artery existed. Above the anterior valve was the cicatrice of an incision one and one half centimeters long, which extended almost to the bottom of the sigmoid sinus (figure 6). The lower part of the incision was covered by a thin film of fibrin. In the upper part the stitches could be seen; the union of the edges of the wound was perfect. The margin of the anterior valve was irregular, owing probably to the fact that it had been cauterized. But there was no apparent deposit of fibrin. The left and right valves were normal. In experiment 5 the specimen showed the result of the operation after twenty-two days. The anterior and posterior parts of the heart were almost completely adherent to the pericardium. The cicatrice of the incision was seen just above the anterior valve near its left insertion in the anterior wall. It was entirely cicatrized, the stitches could not be seen, being covered by a smooth, glistening membrane. The margin of the right sigmoid was slightly irregular, owing probably to the cauterization. The two other sigmoids were normal. The examination of the two specimens demonstrated that it was possible to make a section of the wall of the pulmonary artery without injuring the valves, and that the cauterization of the valves does not produce thrombosis.

The condition of the heart of the seven animals that remained in good health was examined clinically. Six of the animals were entirely normal. In experiment 3 the animal presented a slight diastolic murmur. This animal had undergone a section of the right sigmoid valve and suture of the valve by one stitch placed near the margin. It is probable that the bottom of the valve did not unite and that a slight amount of insufficiency persisted.
Operations on Sigmoid Valves of Pulmonary Artery.

CONCLUSION.

Incision, suture, and cauterization of the sigmoid valves of the pulmonary artery have been performed successfully in dogs. In the first series of ten animals, there were only three accidents, probably from largely preventable causes, leading to the death of the animals.

EXPLANATION OF PLATES.

Plate 3.

Fig. 1. Incision of the pulmonary artery at the union of the anterior and left sigmoid valves.

Plate 4.

Fig. 2. Same as figure 1.
Fig. 3. Suture of the right and left sigmoid valves.
Figs. 4 and 5. Section and suture of the right sigmoid valve.

Plate 5.

Fig. 6. Specimen taken seven days after the cauterization of the sigmoid valves.
FIG. 1.
(Carrel: Operations on Sigmoid Valves of Pulmonary Artery.)
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Fig. 6.
(Carrel: Operations on Sigmoid Valves of Pulmonary Artery.)