

GRAFT OF THE VENA CAVA ON THE ABDOMINAL AORTA.

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I. INTRODUCTION.—The operation consisted of transplanting between the cut ends of the abdominal aorta a segment of vena cava. Its purpose was to study the details of the technic of the graft of a large vein on the aortic trunk and its remote results. It is important to know whether venous segments can replace parts of the aorta as successfully as parts of smaller arteries, the carotid for instance. Five years ago, I advocated the use of venous grafting in the treatment of aneurisms and of certain traumatic lesions of arteries.¹ It was warranted by the results of experiments that I had performed in 1902 in Lyons with Morel² and in 1905 in Chicago with Guthrie.³ These experiments had shown that arteriovenous anastomoses made with a proper technic remain normal, and that a vein, transplanted on an artery, reacts against the increase of blood-pressure by thickening its wall. They demonstrated that veins can be safely grafted on arteries. At this time, it was believed that the successful arterial transplantation of a vein was not possible. Exner⁴ had attempted several times to graft a segment of jugular vein on the carotid artery. The vein always became occluded. The results of Hoepfner⁵ and of Goyanes⁶ had also been negative. Payr⁷ concluded that thrombosis was due to the action of the arterial blood-pressure on the thin venous wall, and that this biological factor rendered impossible the success of a venous transplantation. A short time afterwards, I was able to repeat these experiments at the University of Chicago. I found immediately that the thrombosis observed by previous experimenters was not due to a

biological but merely to a surgical cause, and that, with a proper technic, positive results could easily be obtained. Our experiments of 1905 and 1906 showed that arteriovenous anastomosis remained normal after twenty months. They also permitted the study of anatomical modifications of the venous wall under the influence of the increased blood-pressure. Eight months after the graft of a segment of jugular on the carotid, the circulation was found to be normal through the vein, the wall of which had become as resistant as an arterial wall.⁸ It was, therefore, certain that veins followed the law of adaptation of organ to function, and that they could, when they were compelled to do so, play the rôle of arteries. In other experiments, made in 1907 and 1908 at the Rockefeller Institute, I was able to follow more closely the histological evolution of segments of jugular vein transplanted on the carotid, and observe that twenty months after the operation the venous segment was still in excellent condition.

These results have been confirmed by other experimenters in America and Europe. In 1907, in the laboratory of Harvey Cushing at Johns Hopkins University, Watts⁹ performed several times the graft of a segment of jugular vein on the carotid artery. He found that the vein adapted itself to arterial function. Stich,¹⁰ during the experiments made in 1907 and 1908 in the Klinik of Garré, was able to follow the evolution of a venous segment grafted on a carotid artery for 409 days. Fischer and Schmieden¹¹ also obtained positive results. In 1909, at the Pasteur Institute, Frouin¹² performed some arteriovenous anastomoses which became occluded after a few months. He did not realize that the occlusion was due to his defective technic, and concluded that it was the normal evolution of the anastomoses.

The information given by these experiments has been used only twice in human surgery. Goyanes performed, in 1906, an incomplete transplantation of the popliteal vein on the popliteal artery after extirpation of an aneurism, and his patient recovered. In 1907 in a case of axillary aneurism, Lexer¹³ performed a graft of a segment of saphenous vein,

but his patient, whose general condition was very bad, died after a short time. On human beings, the technic of the arteriovenous anastomoses is easier than on dogs. They should be as successful, if they are performed with a proper technic and when the anatomical conditions of the artery allow it.

From an experimental stand-point the transplantation of venous segments can yield excellent results, even after a long time, when the operation is performed on dogs' carotid arteries. It is important to know whether these results will be different in case of larger and more friable vessels in which the blood-pressure is higher.

II. TECHNIC AND EXPERIMENTS.—The animals were etherized and their abdomens opened by a transverse semicircular laparotomy. The graft of the vena cava to the aorta was composed of four stages.

1. *Extirpation of a Segment of Vena Cava.*—At a short distance below the mouth of the renal veins, the vena cava was dissected and isolated between two ligatures. A venous segment very much longer than the arterial segment to be replaced was resected. It was then washed in Locke's solution, and deposited in a jar of vaseline.

2. *Temporary Hæmostasis, Section, and Resection of the Aorta.*—The abdominal aorta was dissected at the level of the genital arteries. The lumbar collateral branches were forcibly pressed or ligated. Between two Crile forceps, a long segment of aorta was isolated and a small part of it resected. As soon as the aorta was cut, the blood was washed out by an injection of Locke's solution. The vessel and the operative region were covered with vaseline, and isolated from the surrounding structures by black Japanese silk towels.

3. *Graft of the Vena Cava.*—The venous segment was removed from its jar, and interposed between the cut ends of the aorta, after the vaseline had been expressed from its lumen. The anastomoses were made by the ordinary method. Straight Kirby needles, No. 16, and fine silk threads, sterilized in vaseline, were used. The ends of the vessels were united by

three retaining stitches and a continuous through-and-through suture. As the diameter of the vena cava was larger than the diameter of the aorta, the calibre of the vena cava was progressively reduced. This could be done easily by leaving a larger distance between the stitches on the vein than on the artery. In order to secure an accurate approximation of the internal surfaces and a narrow scar, the edge of the vein was slightly eversed, the stitches were as loose as possible, and great care was taken not to include any connective tissue in the line of suture.

4. *Re-establishment of the Circulation.*—The Crile forceps placed on the lower end of the aorta was removed, and the blood entered the grafted segment. The sutures and the ligatures of the collateral branches of the vena cava were examined. The anastomoses were slightly compressed with dry gauze pads. The upper forceps were removed and the circulation re-established. After an arteriovenous anastomosis, the lines of sutures leak more or less for a few minutes, after which the hemorrhage stops spontaneously. If after two or three minutes there is still some hemorrhage, one or two stitches are added. The operation must not be ended before it is certain that not a drop of blood is oozing from the lines of suture. When the condition of the circulation was normal, the operation was completed by suture of the lumbar peritoneum and the closing of the abdominal section by four or five planes of suture. The animals were dressed and after a few hours allowed to walk and eat as usual.

Three experiments were performed on two cats and one dog.

Experiment 1: Transplantation of a segment of vena cava between the cut ends of the abdominal aorta.

Large yellow male cat. July 10, 1907. Dissection of the vena cava below the renal arteries. A segment three centimetres long is extirpated. Resection of the right kidney. Dissection and section of the aorta a few centimetres below the renal arteries. Graft between the ends of the segment of vena cava. July 15: Cat in normal condition. Normal pulsations of the femoral arteries. October 1: Cat in excellent health. No change in the femoral pulse. April 15, 1908: Femoral pulse normal. Cat slightly ill. April 25: Cat is sick. Femoral pulse normal. May 1,

1908: Pulse has disappeared. Animal walks normally. May 8: The animal is very sick. No femoral pulse. Killed by chloroform.

Autopsy.—Pyelonephritis, with perinephritic abscess. Obliteration of the transplanted segment by a clot of recent formation which is adherent to the wall. The aorta above and below the transplanted segment is normal. The calibre of the segment is almost the same as it was at the time of the operation. There is no sclerosis of the surrounding connective tissue. The venous wall is about the same thickness as the aortic wall. The internal surface of the lower part of the transplanted segment is smooth and glistening. On the upper part it is covered by a red clot, which is adherent to the wall at about one centimetre below the upper anastomosis. Both anastomoses are in perfect condition, smooth and glistening, and almost invisible. *Histological Examination.*—A small piece of the wall is cut at the level of the lower anastomosis. Section 97. Hæmatoxylin eosin and Weigert's elastic tissue stain. Longitudinal section of the vessel, showing the lower anastomosis and the adjoining parts of the aorta and vena cava. The wall of the vena cava is a little thicker than the wall of the aorta. The aortic wall is normal. Venous wall is composed of connective tissue with a few elongated cells. There are apparently no muscular cells. The union of the vena cava and of the aorta is very smooth. The aortic wall is slightly everted outward at the point of union. Very few elastic fibres in the venous wall, which is almost entirely composed of connective tissue.

Experiment 2: Resection of a small segment of the aorta of a cat. Graft of a segment of vena cava.

Large white male cat, very old. March 24, 1909, 10 A.M. Extirpation of a segment of vena cava of about 35 millimetres, just below the renal vein. Resection of a short segment of aorta at the level of the spermatic arteries. Graft of the vena cava between the cut ends. 3 P.M.: Animal walks about its cage. April 20: Femoral pulse normal. Animal is very fat and in good health. May 20: Animal is sick. Femoral pulse normal. May 25: Animal died.

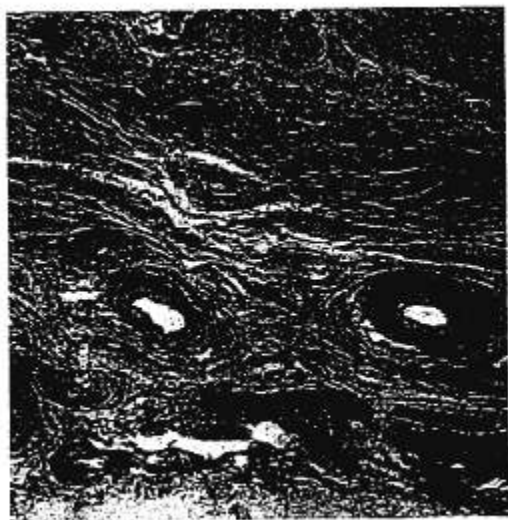
Autopsy.—Sclerosis of the kidneys. Fatty degeneration of the liver. *Macroscopical Examination.*—The transplanted segment is 34 millimetres long. Its calibre is larger than the calibre of the aorta. It does not seem more dilated than at the time of the operation. The walls of the aorta and vena cava are about of the same thickness. The internal surface is glistening, and slightly irregular. The anastomoses are excellent, without dilatation or stenosis. *Microscopical Examination.*—Hæmatoxylin eosin and Weigert elastic tissue stain. On a cross section of the transplanted segment, at about its middle part, the wall is composed of two parts—external and internal. The external coat is a very thick and well-vascularized adventitia; the internal part is composed of the media and of the intima. The media consists chiefly of very dense connective tissue and of elongated cell nuclei. Longitudinal section of the upper anastomoses shows the media of the aorta slightly bent outward and in perfect union with the vein (Fig. 1). There are no elastic fibres in the venous wall (Fig. 2).

FIG. 1.



Longitudinal section of the upper arteriovenous anastomosis. Experiment 2.

FIG. 2.



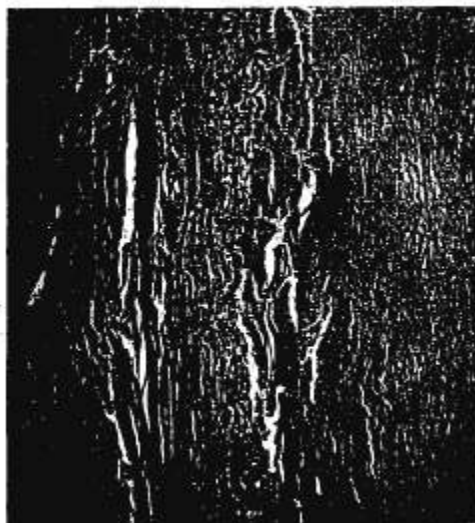
Same section stained by Weigert method.

FIG. 3.



Segment of vena cava transplanted on the abdominal aorta. Experiment 3. Fourteen months after the operation.

FIG. 4.



Venous wall, fourteen months after the transplantation. Experiment 3.

Experiment 3: Resection of a segment of the abdominal aorta patched with peritoneum. Graft of a segment of vena cava.

Middle-sized white bitch. November 24, 1908. Dissection of the abdominal aorta, a piece of which had been resected twenty-two months ago and replaced by a patch of peritoneum. Section of a segment of vena cava below the renal arteries. Resection of the patched segment of the aorta. Graft of the vein between the cut ends of the aorta.

November 25, 1908: Animal in good condition. Her hind legs are swollen. December 5, 1908: Oedema has disappeared almost completely. Animal in excellent condition. July, 1909: Animal normal. Normal femoral pulse. January 13, 1910: Animal died at the farm after an illness of a few days.

Autopsy.—Double pneumonia. Dissection of the aorta and of the venous segment which is 36 millimetres long. Its calibre has not markedly increased. The wall is very much thicker and a little transparent. The internal surface of both vessels is perfectly smooth and glistening, and anastomoses are excellent (Fig. 3). *Microscopical Examination.*—Intima a little thickened. The interstitial connective tissue has very much increased. The muscle-fibres are normal and seem to be increased in number. Very marked thickening of the adventitia (Fig. 4).

III. RESULTS.—The three animals which underwent the transplantation of the vena cava on the abdominal aorta were in normal condition a few hours after the operation and recovered without any complication. In Experiment 3, the posterior limbs of the dog became swollen on account of the ligature of the vena cava but, after a short time, the oedema disappeared completely. No modification of the femoral pulse was observed. The causes, which after several months brought about, directly or indirectly, the death of the animals are completely independent of the operations. In Experiment 1, the cat was chloroformed ten months after the operation because he had developed pyelonephritis. The cat of Experiment 2 was very old. Three months after the operation, he became sick and died. The autopsy showed fatty degeneration of the liver and sclerosis of both kidneys. The dog of Experiment 3 lived in perfect health for fourteen months and then died of pneumonia in a few days.

Therefore, three months, ten months, and fourteen months after the operation the abdominal aorta of the animals and its venous segment were extirpated for the study of the anastomosis and of the venous wall.

Before longitudinal opening of the vessel the anastomoses

could not be precisely located. There was no hardening of the wall at their level. The surrounding connective tissue was not sclerosed. In Experiment 1, the segment was occluded by a clot of recent formation. But, both anastomoses were normal. Their lumen was free. The scar was indistinct. The exact location of the anastomosis was determined by the difference in color between the venous and the aortic walls. In Experiment 2, there was a linear scar. In Experiment 3, the scar was also very narrow and almost invisible (Fig. 3). But the location of the anastomoses was easily detected because the aortic wall assumed a white color while the venous wall was slightly bluish. The union between the ends of the aorta and the segment of vena cava was very intimate. The media of the aorta bent slightly outward and ended abruptly. On its internal surface, the intima increased progressively in thickness, the artery united itself to the vein without interposition of scar tissue. The histological appearance of the anastomoses after the operation shows that the results are definitive (Figs. 1 and 2). The secondary occlusions observed by Frouin are certainly the result of a fault of technic. When an arterio-venous anastomosis is made by a proper method, no modification of its lumen can occur even after a long time.

The venous segment underwent a slight increase of its calibre and a very marked thickening of its wall (Fig. 3). In every experiment its diameter appeared to be slightly enlarged. The changes of the wall were very marked. In Experiment 1, the venous segment was occluded by a clot of recent formation, which developed after the occurrence of pyelonephritis. Above and below the thrombus, the venous wall was smooth and glistening. In Experiments 2 and 3, the internal surface of the wall was perfectly smooth. There was a slight difference in color between the aortic and venous walls. The wall of the vena cava was a little thicker than the arterial wall. It had lost all elasticity, and did not contract when the circulation was stopped. It was composed in Experiments 1 and 2 of dense connective tissue, the adventitia and the media being very much increased. Development of new elastic fibres was not observed (Fig. 2). In Experiment 1, the muscle-

fibre nuclei disappeared. In Experiment 3, the muscle-fibres were found normal (Fig. 4). The thickening of the wall was due chiefly to a very marked sclerosis of the adventitia and of the media. It seemed that the number of the muscle-fibres had increased.

The adaptive changes of the vein begin immediately after its grafting on the artery. The wall thickens. There is, at first, an increase in the connective tissue, and probably also an increase in the number of the muscular fibres. Stich has observed the development of new elastic fibres. I observed it also in a few cases. But often, as it is shown in Experiments 1 and 2, there is no production of new elastic fibres. The elastic framework of the aorta stops abruptly at the point of anastomosis, and the venous wall is seen completely lacking in elastic tissue (Fig. 2). It seems that the first changes undergone by the vein can be compared to hypermyotrophy observed by Russell¹⁴ in the first stage of certain forms of arteriosclerosis. It is a functional hypertrophy due to the increase of blood-pressure. It is not due to a change of nutrition produced by the arterial blood, because I found changes of the same nature in arteries in which the pressure was slightly raised, without any modification of the blood.

It is then certain that the first result of the increase of blood-pressure is an hypertrophy of the wall as it was shown long ago by Adami.¹⁵ The vein has a tendency to become an artery. My experiments demonstrate that it can play perfectly its rôle. But it is possible that in some cases the wall undergoes a progressive sclerosis and that the muscle-fibres disappear completely after a few months. Four months after the transplantation of a segment of jugular on the carotid artery, I extirpated a small part of the wall and sutured the opening. The wall was very thick and composed of a sclerosed media containing normal muscle-fibres and of a greatly hypertrophied adventitia. Twenty months after the operation, the wall was examined again and modified. Sclerosis had increased and all the muscle had disappeared. This change did not interfere at all with the functions of the vena segment. Many experiments have shown that the presence of muscular

or elastic fibres is not necessary to the normal function of an artery. However, sclerosis of the wall may lead to atheromatous changes, although it has not yet been observed. But it will be necessary to keep under observation animals with veins transplanted on arteries for eight or ten years in order to be sure that these degenerative changes do not occur. The knowledge of the remote results of these operations will decide whether fresh veins or arteries, fresh or preserved in cold storage, must be selected as grafts.

IV. CONCLUSIONS.—The transplantation of the vena cava on the aorta is not a dangerous operation. The three animals operated on recovered without incident.

The venous wall reacts against the arterial blood-pressure by thickening its wall.

The condition of the venous wall and of the anastomoses examined fourteen months after the operation shows that, for a long time, a segment of vena cava can functionate as a part of the abdominal aorta.

It is probable that in the treatment of aneurism, rupture of large arteries, embolus, and localized arteritis, the transplantation of venous segments can be used safely, but it must be emphasized that without a proper technic, the results of the operation will be disastrous.

LITERATURE.

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