PARTIAL, PROGRESSIVE AND COMPLETE OCCLUSION
OF THE AORTA AND OTHER LARGE ARTERIES
IN THE DOG BY MEANS OF THE METAL BAND.¹

By W. S. HALSTED,
Professor of Surgery, Johns Hopkins University.

Plates XI-XIII.

At the meeting of the Johns Hopkins Hospital Medical Society,
March 20, 1905, a brief preliminary report was made of the results of
experiments in occlusion upon the abdominal aorta and other arteries
of sixty-three dogs, conducted during the previous winter and autumn
by Dr. W. F. M. Sowers and me.² During the following year
these investigations were continued with the assistance of Dr. E. H.
Richardson, thirty-nine dogs being operated upon. With the aid
of a modified Brauer apparatus devised by Dr. Follis and Dr. Fisher
we were able successfully to constrict the thoracic aorta both in
animals and man. In June, 1906, at the meeting of the American
Medical Association in Boston, attention was again called to our
work, the results to date being given in merest outline.³ During
the following two years, the exigencies of the surgical clinic seemed
to demand experimental investigation in another direction and hence
only a little time was found for prosecuting the arterial work under
consideration, although several problems which have arisen in con-
nection with it we regard with unabated interest; and with the solu-
tion of these we are again concerning ourselves. In the meantime,
however, a number of experiments have been made, and several
animals which were for many months under observation have fur-
nished additional facts worthy of record. The method of applying
the band has been improved and modified and new instruments for
rolling it devised. The full report of this work will probably be

¹ Received for publication, January 14, 1909.
² Johns Hopkins Hospital Bulletin, 1905, xvi, 345.
³ Jour. of the Amer. Med. Assoc., 1906, xlvii, 2147.
Occlusion of the Aorta in the Dog.

published during the year in the Johns Hopkins Hospital Reports.

The incentive to the work was the desire, experienced by so many surgeons of the past and present, to be able to occlude safely the abdominal aorta in the hope of curing thereby aneurisms of this vessel and of the common iliac arteries. I shall write later of the attempts of Dubois, Assalini, Bujalsky, Pirogoff, Luigi Porta, Cooper and Keen to compress gradually the abdominal aorta by means of specially devised instruments which, passed through an incision in the abdominal wall, carried a snare of silk, catgut or metal which might at any moment be tightened or loosened at will. A fault common to all of the methods hitherto devised is seemingly an insurmountable one—the difficulty of preventing sepsis in the track of an instrument maintaining direct communication for days or even weeks with the air. A better method might, we thought, be one permitting, in each entre-act, complete closure of the wound. The material compressing the aorta should not be bulky nor endanger by its form or substance the adjacent parts; and it should admit of easy readjustment at subsequent operations, should they be indicated. Metal bands of silver and then of aluminium were employed with the hope that the amount of constriction might be regulated to a nicety at prospective subsequent operations as well as at the primary one. With the aid of an ingenious clock-maker, an instrument was devised to curl a metal strip, in perfect cylinder-form, about the vessel.

The tightening of the band is completed with the fingers; but in the early experiments, when the metal employed was too thick and the bands too broad, the aid of tweezers was required. We observed the first group of dogs with some apprehension, fearing that the edges of the band would cut the much constricted and powerfully pulsating aorta, and were considering ways to obviate, if necessary, this danger. On the twelfth day after operation a dog died of hemorrhage, the result of ulceration at the upper edge of the band. The experiments were thereupon discontinued for a while, to await results in the other dogs carrying aortic bands. Further cases of hemorrhage not occurring, we resumed, in a few weeks, the experiments. About three months later we investigated, at second operations and at autopsy, the resultant conditions and found that the
aortic wall where the band had embraced it was, in each instance of complete occlusion, atrophied, being reduced in some cases to a film-like thinness. Notwithstanding these somewhat discouraging observations the experiments were continued as actively as time permitted in the hope that, with an improved technique, derived from greater experience, particularly with reference to precision in the determination of the degree of closure brought about as the rolling (tightening) of the band proceeded, the walls of the arteries might retain their vitality even in the case of complete arterial occlusion (vide Cases 27 and 28). By reducing the width and length of the band and the thickness of the metal, we were able with the fingers, and with ease, to occlude the artery to the extent desired. From the first experiment we have endeavored, in each instance, to roll the band as perfectly (as cylindrically) as possible, flattening of it being assiduously guarded against. To control with accuracy the amount of blood-flow under the band, the rolling must go on smoothly and under the perfect command of the operator. The thrills of various strength, the point at which the pulse disappears, are carefully noted in the course of the act of constricting the vessel; and, finally, when complete occlusion is desired, the pulse being no longer distinguishable, the filling or not of the artery below the band, between it and a fine clamp placed central to the first distal branch is our only clue as to the patency of the artery.

With the use of silk or even silver wire such delicate manipulation and determination were found impossible, irrespective of the great danger of injury to the vessel-wall from attempts to draw just a shade tighter a half-knotted thread which has constricted the vessel almost to the occlusion point.

At the time of my first report (March, 1905) we stated that:

(1) If applied tightly enough to interrupt completely the circulation, the band had usually caused atrophy and frequently complete absorption of the aortic wall. In such cases hemorrhage was invariably prevented by the formation of connective tissue enclosing the band.

(2) Thrombosis had not been observed in a single instance, either in the cases of complete occlusion in which the arterial wall under the band was found so greatly thinned, or in those in which it had

*Lec. cit.*
been absorbed. (3) In a few cases (vide No. 28) aortic walls drawn together so snugly that at autopsy water could not be forced through with a syringe were, on division of the band, found to be normal and could be easily smoothed out and the full lumen re-established. But in these earlier cases of complete occlusion the aortic wall had almost invariably atrophied, having been so tightly constricted as to be deprived of its blood supply, and hence the "ideal obliteration" (reported the following year) by adhesion of the folded intima and the conversion of the constricted portion of the artery into a solid fibrous cylinder (vide Plate III, Fig. 2a), could not have taken place. (4) The less snugly, the loosely and the very loosely applied bands might remain on the aorta, femorals and carotids for months without apparent injury to the walls of these vessels, either externally or internally. For example, the band after one hundred days would be seen shimmering brightly under a quite normal-looking peritoneum, having caused, as a rule, little if any reaction, and could be as easily removed from the wall of the artery as when originally applied. (5) We were encouraged to believe that there might be a place in surgery for the partially occluding band, and reported its application to the common carotid artery in the human subject and the manifestation, thereupon, of slight brain symptoms which persisted for several months. In this case the band was rolled more tightly than intended. It might easily have been removed and reapplied but, as I stated at the time, our notions being somewhat vague as to the precise amount of constriction to be desired and being unable to determine accurately the blood pressure distal to the band we decided not to disturb it and to note results. On the appearance of the head symptoms I did not relieve the constriction, believing that they would probably disappear; furthermore, I was not perfectly sure that, rather than good, harm might not result from the release of the carotid.

Subsequently (in June, 1906), in the report made in Boston before the Section on Surgery and Anatomy of the American Medical Association, the following newly observed facts were emphasized:

1. The blood pressure in the aorta below the band is lowered in proportion to the amount of the occlusion. The rise in pressure
below the band is, at first, rapid, but varies considerably in the different dogs. For example, in one dog, a rise below the band of ten millimeters (Hg. manometer) was noted in ten minutes, whereas, in another dog, two hours were required for a rise of fifteen millimeters. For the return of the normal pulse wave and of the normal blood pressure as many as seven months have been insufficient (vide history of Dog No. 96).  

2. Partially occluding bands produced as a rule no macroscopic alteration in the aortic wall under the band even after seven and eight months (vide Plate III, Fig. 1). Under completely occluding bands the arterial wall had (to the date of the second communication referred to) usually atrophied and in the course of weeks or months been absorbed. "When the lumen had been, perhaps, not quite occluded, complete obliteration might result spontaneously with the conversion of the arterial wall embraced by the band into a solid cylinder of living tissue. This may," I stated, "be considered the ideal closure of an artery." Although this form of arterial closure had occurred only thrice in the long series of experiments, it might, I thought, be accomplished frequently, and ultimately the band might be applied with such nicety that, unaided, further, by the surgeon, a partial would be likely to proceed to total occlusion.

3. "The Effects on the Spinal Cord and Its Coverings.—The study of the spinal cords was entrusted to Mr. P. K. Gilman (later Dr. Gilman and member of my staff), who discovered, in a number of instances, about three months after operation, a deposit of extradural fat about the cord below the site of the aortic band. In three

Since this statement was made we have had several opportunities to verify it, and have noted in a dog with partially occluding band on the thoracic aorta, after seven months, a difference of 30 millimeters or more in the pressure immediately above and immediately below the band. Of particular interest are the careful observations of Dr. Percy M. Dawson on the femoral and carotid pressures in Dog No. 96 of this series, reported below.

We have not as yet learned to determine with the greatest precision the degree of arterial occlusion effected, nor am I convinced that in all of the cases in which the "ideal occlusion" has resulted (we have now five such observations) there may not have been, at the outset, complete obliteration of the lumen (vide history of Dog No. 27).

These proved to be cases in which total or almost total occlusion had been made.
cases the production of fat was so great that it filled, seemingly under considerable tension, the vertebral canal.”

If these observations should prove to be correct, Mr. Gilman has made a discovery of wide significance.

4. That in the human subject I had partially occluded the innominate artery once and the common carotid four times.\(^8\) In the case of a large popliteal aneurism I had employed the metal band to occlude completely the femoral artery. In the case of a woman asphyxiated to unconsciousness by an aneurism of the aortic arch, I had exposed, carefully and freely and without puncturing either pleural cavity, the heart and arch of the aorta, hoping to be able to encircle with a band the aortic arch between the regions of the innominate and left carotid arteries, but the aneurism was so extensive and the patient’s condition so desperate as to defeat the earnest and prolonged endeavor to execute the procedure.

**THE ALUMINIUM BAND AND THE MANNER OF ITS APPLICATION TO THE ARTERY.**

We have tested only two of the metals, silver and aluminium, with reference to their adaptability to the procedure under consideration. After a few experiments with the former it was discarded. The greater weight and value of the silver (there is great waste in its use) and the inconstant results obtained as to nicety in rolling, particularly after repeated boilings, are the principal factors which led to its disuse. The aluminium, usually purchased in sheets of about 25 degrees of thickness (American scale) should be cut, before being rolled down to the thinness desired, into strips of convenient length, and of width not greater than three quarters of an inch. If much wider, the strips warp inconveniently and have to be cut to waste in the selection of flat and regular parts for band material. It is well to stamp each strip with the numbers indicating the thickness of the metal and to have on hand a liberal supply of the various thicknesses from No. 25 to No. 46. The finest numbers

\(^8\)The aluminium band has now been successfully applied in man to the common carotid artery twelve times, and once each to the thoracic aorta, the abdominal aorta, the common iliac, the femoral, and the innominate arteries. These cases will be reported later in the *Amer. Jour. of the Med. Sciences.*
we have used on the very small femoral and renal arteries of the
dog. In the average dog for the abdominal aorta Nos. 34 to 35
are suitable, and for the thoracic aorta Nos. 33 and 34 we have
used most frequently. In the human subject for the abdominal
aorta below an aneurism near its bifurcation No. 33 sufficed, but
ordinarily a heavier size would be required; for the common iliac
No. 32 answered the purpose admirably; for the thoracic aorta
Nos. 22 to 25 perhaps; for the common carotid we have almost
invariably selected No. 33. The length of the band should be about
that of the circumference of the full artery. The width varies from
about 2 mm. for the renal arteries in the dog to about 1 cm. for
the thoracic aorta and innominate artery in man. Fig. b, Plate XI,
depicts a band suitable in width for the human carotid and for the
average dog's abdominal aorta. The band in this illustration we
should now regard as too long for its breadth by approximately one
third. It is best to sterilize the aluminium only once. It may
become too brittle for perfect rolling by repeated boilings. When
rolled down on the artery enough almost to obliterate the pulse, a
band of seemingly proper dimensions has rarely described more
than two complete circles. The filing or "manicuring" of the
band is of very great importance. It should be curved like a finger
nail at the forward end and at the other cut precisely at right angles
to its long axis. With a file the edges should be made perfectly
smooth, but not sharp, and the rounded end symmetrical. A care-
fully filed band coils more easily both in the instrument and under
the fingers, and, what is more important, is not likely to cut the
artery. The aorta is the only vessel that I have seen cut itself on
the band, and then, with the exception, perhaps, of two very young
dogs or puppies, only when the band was badly filed or clumsily
rolled, as in the early experiments, especially those in which forceps
were employed to supplement the work of the fingers in tightening
the too broad and too heavy bands at that time employed. Silk
ligatures, even when occluding the aorta only partially, have in my
experiments repeatedly cut entirely through the aorta, and without
causing the death of the animal. They may leave in their wake
various forms of diaphragm which more or less obstruct the lumen
of this artery. I shall refer to a case of this kind depicted in Plate
XII, Figs. 5 and 6.
Occlusion of the Aorta in the Dog.

The Band Curler.—The original instrument (vide Plate XI) had, we soon discovered, three major faults. It was (1) too broad at the arterial end, (2) the band lacked anterior support as it was being pressed onward by the driving blade, a (magnified a'), and (3) the latter did not always engage the former, owing to the fact that it was too springy and was insufficiently linked to its fellow on which it glides. To remedy the tendency for the band to buckle forward, one was compelled to support it with the finger during the process of curling. This was occasionally a difficult and usually an awkward performance.

Plate XI, Fig. 2 shows an improved and satisfactory band roller or curler. In the full length drawing the instrument is not loaded; in the abbreviated sketch the band projects from the end, half curled. The principal defects of the old instrument have been remedied in the new. Buckling of the band is prevented by the boxing; the driving-plate can not spring away from its fellow, and the width of the instrument has been sufficiently reduced to permit it to be passed freely between the closely given off branches of the abdominal and thoracic aortas. When the thinner bands are used it is sometimes necessary to give the faintest tip backwards to each of the two right-angled corners of the band to insure its engagement in the downward thrust of the piston or driving blade. After it has encircled the artery the band may, if its corners have been bent, be freshly squared with the scissors before being curled tighter by the fingers. This is not, however, necessary. The curler being armed with the carefully filed band of correct proportions the plunger is made to engage the band and to force its convex end into sight before the instrument is passed under the artery. In Plate XI, Fig. 1, the act of curling the band about the artery is shown, after the old manner, in its first stage. As the curling proceeds the instrument is gradually withdrawn. In arranging for the tightening of the band, its convex end should lie on the wall of the artery and be overlapped by the square end. With a very little practice one learns to avoid bending or flattening the band in the process of tightening it. The band should be long enough to encircle the artery in the expanded state of the latter and the metal should be sufficiently thick and wide to sustain the curl given it. If perfectly rolled the inside and outside
circles of the metal touch each other at all points of the surfaces of contact and, in consequence, the cohesion force is greatest. The artery should be raised from its bed by two tapes held far enough apart to leave uncovered sufficient free space on the artery for the occupancy of the band. Traction on the upper tape should be made to interrupt the blood current and thus to reduce the size of the vessel. A band curler should be selected (we have, at present, four sizes of this instrument) which might make the metal describe a circle smaller than the distended or full artery but a little larger than the empty one; then, with the return of the blood current, the artery expands and may fill the band quite snugly.

After complete occlusion of the abdominal aorta the femoral pulse does not, usually, return for weeks or even months. And after incomplete occlusion of the thoracic aorta (Dog 96) the femoral pulse may be hardly discernible after seven months. The anastomotic circulation takes place through the vasa vasorum as discovered and so beautifully depicted by Luigi Porta,9 and by way of the internal mammary and epigastric arteries as especially emphasized by Kast.10 We have repeatedly observed the great increase in the vascularity of the abdominal wall, particularly on splitting the recti muscles but also in making mid-line incisions at operations subsequent to the one at which the band was applied.

Dog No. 2.—Large, savage, collie-like dog. Operation I. Morphia and ether.11 November 4, 1904. Silver band, partially occluding the vessel, applied to the abdominal aorta below (?) the inferior mesenteric artery. Radicles of thoracic duct not injured. Pulse in femorals easily countable at end of operation, though much reduced in volume.

November 6, 1904. Dog in good condition, rather dull, walks about without apparent weakness in hind legs. Tests such as running up stairs were not made.

November 10, 1904. Apparently perfectly well. Is quite savage and threatens to bite when cage is entered.

December 8, 1904. Vigorous femoral pulse but seemingly weaker than might be expected in so large a dog. Health has been perfect. Operation II. Morphia and ether. Complete occlusion of aorta about 1 cm. above the silver band by heavy black silk ligature. The silver band glistened through a very thin and apparently normal peritoneum. It had excited little or no irritation.

9 Luigi Porta, Delle alterazioni patologiche delle arterie per la legatura e la torsione, Milan, 1845.
10 Kast, Deut. Zeit. für Chirurgie, 1879, xii, 405.
11 All the animals were anaesthetized in the same way preparatory to operation.
On coming out of ether the dog showed signs of unusual excitement. Respirations, 136 per minute. One hour after operation dog was able to climb a flight of stairs. The hind legs were, however, in spastic condition, flexed on the abdomen, at the knees and hips, and very much weaker than the fore legs.

December 10, 1904. Dog is dull. Hind legs are dragged in walking but are not completely paralyzed. Movements still spastic.

December 14, 1904. Is lively and seems quite well. Bladder and rectum function normally. Scratches himself with left hind leg without apparent weakness.

January 27, 1905. Femoral pulses not yet definitely palpable but the arteries have become quite full.

February 1, 1905. Femoral pulse faint and not countable.

February 20, 1905. Fair pulse, countable.

March 6, 1905. Found dead. Was not observed yesterday (Sunday). Autopsy.—A large flat cork causing intestinal obstruction is the cause of death. The silk ligature above the band has cut almost through the aorta, its track being apparently healed; part of the loop projects into a little cavity, with newly formed walls of connective tissue, adjacent to and in front of the wall of the aorta. A filmy substance, like decolorized blood clot, is adherent to the track taken by the ligature in its course through the artery. The aorta under the band is a little thinned. Its endothelial lining seems normal.

In the light of subsequent experience it seems probable that the thinning of the aorta may have been caused by the ligature applied so close above the band—by its interference with the circulation in the arterial wall.

Dog No. 6.—November 19, 1904. Black bitch, length 31 inches. Operation I. Closure of abdominal aorta with aluminium band 1 cm. in width.

The pulse pressure in the left femoral artery as recorded by an assistant:

<table>
<thead>
<tr>
<th>Event</th>
<th>Pulse Pressure</th>
</tr>
</thead>
<tbody>
<tr>
<td>Before operation</td>
<td>150 mm</td>
</tr>
<tr>
<td>After abdomen was opened</td>
<td>130 mm</td>
</tr>
<tr>
<td>Band incompletely tightened</td>
<td>80 mm</td>
</tr>
<tr>
<td>Tightening of band completed</td>
<td>20 mm</td>
</tr>
<tr>
<td>After abdominal manipulations ended</td>
<td>25 mm</td>
</tr>
<tr>
<td>After closure of abdomen</td>
<td>30 mm</td>
</tr>
</tbody>
</table>

The operators could not feel the aortic pulse below the band after it was completely curled, hence I have doubt as to the accuracy of the three observations on pulse pressure in the femoral artery made after the final tightening of the band.

November 21, 1904. Femoral pulse doubtful. Dog ran easily on level and mounted the first steps of a flight of stairs without definite signs of weakness. Her hind legs gave out before the top steps were reached. Temperature forefeet, 70°; hind feet, 66°, Fahrenheit.

November 22, 1904. Hind legs still weak. Sits down after slight exercise. Pulse in femora!s doubtful. Surface temperature of hind-flanks, 95°; fore-flanks, 97°; pads of feet, hind 97°; front, 71°.

November 25, 1904. Temperature axilla, 98.5°; groin, 95.5°. Hind legs less weak. Dog in good spirits. Operation II, 11:30 A. M. Ligature of black silk
obliterating aorta applied below the band. 3 P. M., bladder not distended. Bitch has showed no excitement since operation. Temperature, axilla, 96°; groin, 93° F.

December 13, 1904. Slightly stiff in hind legs. Dog is dull and indisposed to walk much. We attributed the condition of the dog in part to one-half grain of morphia administered before operation.

December 14, 1904. Movements in hind legs greatly improved. Dog walks with ease but is a little depressed and sits down frequently.

December 19, 1904. Perfectly well and active.

December 28, 1904. Well and active.

January 7, 1905. Well.

January 12, 1905. Well.

January 19, 1905. Well and strong. Faint femoral pulse observed for the first time since the first operation performed two months ago.


February 1, 1905. Femoral pulse countable but is still very small.

March 6, 1905. Dog well but quite thin. Killed with ether. Femoral and thoracic conditions normal. On palpating aorta a small nodule is felt at site of ligature. The band is found directly in line of the aorta above the ligature and filling completely a new-formed connective tissue cavity. The arterial wall under the band has been completely absorbed and the aortic wall above the band is continuous with the new connective tissue which forms a strong capsule about the band. The capsule of fibrous tissue fits the band so closely that no blood has escaped from the patulous aorta above into the space between the band and the connective tissue which enclosed it. The arterial lumen just below the band has been obliterated by the silk ligature which has cut entirely through the arterial wall and is enclosed in a hard nodule of connective tissue.

Dog 20.—Small puppy, male. December 10, 1904. 11 A. M. Operation Aluminium band applied above the inferior mesenteric artery. In exposing the artery the sigmoid flexure was pulled to the right. The band had been cut too long. It rolled beautifully to a certain point and then, before the aortic pulse could be obliterated the metal cylinder began to flatten. The pulse then became entirely obliterated but some sort of pulse-shock could be felt for a distance of 1 cm. or more below the band. 1.30 P. M., dog runs about, but his hind legs are very weak, though not completely paralyzed.

December 19, 1904. Hind legs stronger.

December 20, 1904. Dog does not seem well. Is quite thin and disinclined to walk. Can, however, stand and uses his hind legs in walking fairly well.

December 23, 1904. Not so well.

December 26, 1904. Quite ill.

December 27. Dead.

Autopsy.—The abdominal wound had opened down to the peritoneum but was well sealed by omentum and the subperitoneal flap of fat. There is no peritonitis. The portion of the fleum lying in the pelvis, and the sigmoid flexure exhibit punctate hemorrhages in the fat along the vessels. The sigmoid flexure is particularly hemorrhagic and probably the cause of the bloody fluid in the pelvis. There is some blood escaping from the anus. The jejunum, at a point near the aorta where it may well have been pressed upon by the retractors and gauze, is also indurated and dark. The bladder is empty. The band has excited very little reaction. The peritoneum and fat over it are still unimitted.
Occlusion of the Aorta in the Dog.

Dog No. 27.—Small, black puppy. December 26, 1904. Operation. A very broad band (7 mm. in width) was placed on the aorta about 1 cm. below the inferior mesenteric artery and rolled by tweezers until the demonstration of a pulse below the band was questionable. We attempted in this case, prior to the application of the band, to produce occlusion by silver wire wrapped several times about the artery and over a small copper rod (the rod to be afterwards withdrawn), thinking that the size of the lumen might in such cases be definitely regulated by the use of rods of various sizes. After several trials we were convinced that the liability of injury to the artery was too great, at least much greater than with the employment of the band. The wrapping of the wire was also troublesome. Hence the project was abandoned.

December 28, 1904. Walks fairly well but has definite weakness in hind legs. Has fluid stools which contain a few drops of blood.

January 5, 1905. Weak and emaciated. A very small, not countable, femoral pulse has developed. Dog uses hind legs a little better.


January 27, 1905. It is possible to-day for the first time to count the femoral pulse; it is still very small.

February 13, 1905. Condition practically unchanged.

February 20, 1905. Seems a little better. Femoral pulse still very small, but countable.

February 23, 1905. Improvement continues. Femoral artery feels fuller.

April 10, 1905. Dog is very thin and has the mange. Etherized. A very faint femoral pulse was demonstrable on dissection of the artery, but through the skin it was not definitely palpable. Dog killed.

Autopsy.—Peritoneal cavity normal.

The aortic band shimmers quite clearly through the peritoneum, but about 1 cm. below the band is a very delicate stellar cicatrix. The aorta was split to the band from both ends and the band itself divided. The vessel is entirely obliterated and the length of the obliterated portion corresponds exactly to the width of the band. The portion of the aorta enclosed by the band has become converted into a solid fibrous cord (vide Plate XII, Fig. 4a). Outside the band is a peculiar, soft, yellowish-white material, about one drop in quantity, resembling aleuronat. The hard, white, living cord, into which the occluded portion of the aorta has been converted, is 2 mm. in diameter. The band, an unusually broad and thick one, had been in place three and one-half months and might, without doing harm, have remained indefinitely. The form of the fibrous cord, so exactly cylindrical, under the band, is evidence that perfection in curling may be accomplished even with tweezers. Without especial effort to bring it about we have in five instances obtained this ideal
form of obliteration—for times in the aorta and once in the renal artery—and always in cases in which the completeness of the closure was in doubt at the time of operation. This case should be contrasted with Case No. 28, that of a small puppy whose aorta, though of intention completely closed by the band, was not found converted into a fibrous cord under the metal. To our surprise, it presented no internal adhesions whatever on being laid open, although so tightly constricted that not a drop of water could be forced through this portion of the vessel while the band was in place. The foldings of the aortic wall under the band could be smoothed out so completely that no trace of them remained, nor was there any abnormality of the wall to indicate that a band had been applied. We must bear in mind that in Dog 28 only twenty-two days had elapsed from operation to autopsy, whereas in the cases cited of fibrous cylinder formation, the dogs had carried their bands for several months.

Dog No. 28—Small, black puppy, male. December 26, 1904. Operation. Aluminium band rolled (with tweezers) until pulse seemed to be obliterated.

December 28, 1904. Dog seems fairly well, but marked weakness and stiffness in hind legs.

January 7, 1905. Dog cross and disinclined to respond to attentions. Hind legs possibly a little less stiff.

January 12, 1905. Slight improvement noted.

January 17, 1905. Dog looks badly. Is greatly emaciated. Indisposed to move and hence the power in hind legs was not tested.

January 18, 1905. Great emaciation.

Autopsy.—Peritoneal cavity normal. Band shimmers through a perfectly normal-looking peritoneum. No trace of peritoneal or other scar over band. The healing about the band is the most absolutely perfect that we have as yet seen.

With a syringe connected to the aorta above the band we are unable to force water through the site of obstruction. On removing the band we find, to our surprise, that not only could the point of a scissors readily be passed through the constricted part but that the aortic wall under the band could be so perfectly smoothed out that not a trace of the foldings or wrinklings of the lining remained. Nor was there apparent the slightest thinning or alteration in the wall of the vessel at the site of the band. We have not as yet had the time to complete experiments undertaken with a view to ac-
counting for the difference in the condition of the aorta at the site of constriction in the cases (Nos. 27 and 28) referred to.

Dog 30.—Medium-sized collie bitch. December 27, 1904. Operation I. Aluminium band tightened until the pulse was greatly reduced but not apparently obliterated. There was sufficient pulse just prior to the final tightening to give a faint thrill.


January 7, 1905. No weakness in hind legs.


January 23, 1905. Operation II. 11 A.M. There were a few adhesions ofomentum in the neighborhood of the band, which prevented the metal from shimmering in the usual manner through the peritoneum. Pulse below the band is feeble but perfectly definite. When the pulse just above the band is obliterated with the finger the pulse below the band disappears. We concluded consequently that the band had not completely closed the lumen of the aorta. Ligation with heavy black silk 3 or 4 mm. above band. Much to our astonishment the pulse, easily appreciable by finger, reappeared below the band in less than 30 seconds after the aorta was ligated. It seems almost inconceivable that a ligature applied so close above the band should have had such a marked influence on the pulse below it. We have made this observation in a number of cases in which we were quite sure that no vessel of a size to be appreciated was given off from the aorta between the ligature and the band.

The almost immediate reappearance of the pulse after the application of the ligature indicates that the anastomotic circulation was already quite well established, for a pulse large enough to be appreciated by the finger has not been observed by us before the termination of the operation, after complete closure of the aorta in one act. We have, however, noted that within a minute after ligation of the abdominal aorta a faint pulse below the ligature can be seen (not felt), provided the aorta is cut open.

January 23, 1905. 3 P.M., Dog runs about. Weakness of hind legs not apparent.

January 24, 1905. A very faint femoral pulse can be felt very high up on the femoral arteries. No weakness of hind legs.

January 27, 1905. Pulse more easily felt but still feeble.

February 1, 1905. Femoral pulse can be counted. The artery is not full.


March 10, 1905. Femoral pulse still small. Dog is thin but looks well. Ether administered. Abdomen opened. Small indurated area about the ligature and the band. A definite pulse below the band is promptly shut off by pressure immediately above the band and at higher points, as noted in history of Dog No. 6. A ligature was applied about 3 cm. above the band and tests for a pulse below
the band were made for three minutes but it had not returned in this period of
time. The dog was then killed. Above the ligature the aorta was entirely oc-
ccluded in a conical manner. The ligature lies in a small cavity lined with granu-
lations. Below the band the aorta is closed off by a small transparent film. The
band lies in a connective tissue cavity and contains merely a film of opaque secre-
tion. The aortic wall under the band has consequently been entirely absorbed.
Between the two cavities a piece of aorta 13 mm. in length is felt with a partly
organized clot which is translucent except for a red dot about 1 mm. broad, in its
center.

It is evident that at the first operation I was probably mistaken
in believing that the artery was not obliterated by the constricting
band. It would, a priori, seem reasonable to presume that a band
though not altogether occluding the artery, might, nevertheless, so
greatly interfere with the circulation of its wall as to lead to necro-
sis, but the findings in Dog. No. 28 would seem to make such a view
untenable. It seems, however, not unlikely that the necrosis of the
wall of the aorta may not have supervened until at the second opera-
tion the ligation with silk a few millimeters above the band was
made. If this were the case it may be that our impression that the
pulse had not been obliterated by the band at the first operation was
correct.

**Thoracic Aorta Partially Occluded by Aluminium Band.**—Dog
No. 96.—Medium-sized Newfoundland bitch. May 22,
1906. 
**Operation.** Assisted by Drs. Richardson and Gilman. Lungs in-
flated during the operation through tracheotomy tube. Incision
through seventh interspace. Ribs separated as usual with self-
xerting retractor. Exposure of aorta very satisfactory. Alumi-
nium band, thickness No. 32, width 6 mm., applied just above high-
est point of diaphragm. Band was tightened until a continuous
thrust below the band was produced.

May 24, 1906. Slight stiffness in hind legs.
May 27, 1906. Cheerful; runs about freely. Percussion reveals no thoracic
signs. Chest not auscultated.
June 1, 1906. Dog is lively and well.
June 3, 1906. I went to Boston.
June 11, 1906. On my return from Boston to-day dog was reported well. I
did not visit her.
June 14, 1906. On visiting dog surprised to find that she is emaciated, low
spirited and very weak. Lies in corner of kennel unless aroused. The keeper
Occlusion of the Aorta in the Dog.

states that, suddenly, two nights ago the dog became paralyzed. He assured me that she was perfectly well the preceding day. Has made no observations as to her stools, urine or feeding. I placed her at once in a separate room for observation. Find that she can raise herself on hind legs and totter about with hind legs stiff and held apart. Power in hind legs quickly becomes completely exhausted.


June 16, 1906. Improving. Has some appetite and a stronger gait. The femoral artery is fairly full but a pulse is not palpable.

June 18, 1906. Stronger and in fairly good spirits. Is as lively as hind legs permit but still has difficulty in getting in a standing position; but when balance has been obtained runs about quite well, but for a few moments only, the hind legs weakening rapidly, then a few steps alternating with dragging. Femoral arteries full and quite tense but no pulse is as yet discoverable although carefully palpated for by several observers.

June 19, 1906. At times there seemed to me to be a faint pulse in the femoral artery. Dog much livelier, eats better and gait is improved. She still experiences considerable difficulty in raising herself upon her hind legs, and after running five or six seconds flops down behind. She is up again immediately and again collapses as to hind legs. At no time have the stools been bloody or tarry. There has been no evidence either of retention of urine or difficulty in micturition. The dog is to be kept all summer under careful observation.

December 21, 1906. Since the last note the dog has been well but is still weak in the hind legs. No observations of especial interest were made during the summer. Careful examination by Dr. Sowers, Watts and myself determine that a femoral pulse is present but not easily countable, although it is now seven months since the operation. Only the lightest pressure of the fingers can detect this femoral pulse. Ether is administered and the dog brought into the surgical amphitheatre for demonstration to the class. The over-pressure box of Drs. Follis and Fisher was successfully employed throughout the observations which follow. On opening the chest the left lung and pleura were normal. The band is seen shimmering clearly through the thin and normal-looking pleura covering it. A very pronounced thrill is felt below the band on the thoracic aorta, just as at the termination of the first operation, hence our belief that the artery had suddenly closed about three weeks after the first operation and during my absence in Boston is proved to be incorrect. Dr. Percy M. Dawson then made the following observations upon the blood pressure in the carotid and femoral arteries.
"Upon the circulation of this animal observations were made in the physiologic laboratory and were reported as follows:

<table>
<thead>
<tr>
<th></th>
<th>Maximum Pressure</th>
<th>Mean Pressure</th>
<th>Minimum Pressure</th>
<th>Pulse Pressure</th>
</tr>
</thead>
<tbody>
<tr>
<td>Femoral</td>
<td>116</td>
<td>96</td>
<td>88</td>
<td>28</td>
</tr>
<tr>
<td>Carotid</td>
<td>160</td>
<td>113</td>
<td>83</td>
<td>77</td>
</tr>
</tbody>
</table>

These figures should be compared with values obtained in normal animals, namely,

<table>
<thead>
<tr>
<th></th>
<th>Maximum Pressure</th>
<th>Mean Pressure</th>
<th>Minimum Pressure</th>
<th>Pulse Pressure</th>
</tr>
</thead>
<tbody>
<tr>
<td>Femoral</td>
<td>188</td>
<td>120</td>
<td>95</td>
<td>93</td>
</tr>
<tr>
<td>Carotid</td>
<td>162</td>
<td>122</td>
<td>103</td>
<td>49</td>
</tr>
</tbody>
</table>

"The pressure curves were also obtained and showed a total disappearance of the dicrotic elevation from the femoral pulse whereas in normal animals the dicrotic is more marked in the femoral than in the carotid artery so that hyperdicrotism is more readily obtained in the former than in the latter."

"All these changes are to be attributed to the constriction due to the band and are in complete accord with the unpublished experiments performed in this laboratory in which the aorta was partially occluded for the purpose of studying the relation of the carotid and femoral pulses.

"Considerable variations occur in the velocity of the pulse wave in different dogs. Nevertheless it is safe to say that a velocity of only 556 cm. per second as was found in this animal, owes its small value to the aortic constriction."

Dr. Richardson and I, by the Huertle method with hypodermic needle, observed, much to our surprise, that whereas the manometer registered 126 mm. above the band, it registered only 94 below it. It seems remarkable that after so long a period (approximately seven months) there should be such a difference in the blood pressure above and below the band. Just before death the aorta was completely divided below the band to determine the degree of patency of this vessel at the constricted point. The heart pumped through the band a small stream as large, perhaps, as that furnished by the human radial artery.

\(^{19}\text{Amer. Jour. of Physiol., 1906, xv, 244.}\)

\(^{20}\text{Amer. Med., 1906, i, 152.}\)
Occlusion of the Aorta in the Dog.

Autopsy.—There is a very great difference in the size and thickness of the thoracic aorta above and below the band. The wall of the artery above the band appears to be twice as thick and much stiffer than the arterial wall below it. There is also great dilation of the artery above the band. There are no visible calcareous plaques. On cutting through the artery and band in the usual way, the probe point of a scissors being passed into the lumen of the vessel, there is found to be no adhesion between the folded surfaces although, until the artery is spread quite flat, the foldings and creasings of the intima are evident. Were it not for the presence of the band which reveals its form from within by pressure on the wall of the artery from without it might be difficult if not impossible to determine with the naked eye differences so far as the free surface of the intima is concerned, below and beneath the band. The lining of the aorta under the metal seems perfectly normal, as indeed does the entire thickness of the arterial wall. The spinal cord was excised by Dr. Gilman in my presence. As to the extradural fat formation in this case a report will be made later.

EXPLANATION OF PLATES.

PLATE XI.

Fig. 1. Drawn in 1905. The original band roller in the act of curling a metal strip about an artery; a, the tip of the driving blade enlarged; b, the metal strip; c, the band slightly tightened with the fingers as when a degree of incomplete occlusion is desired. The proportions depicted are those observed at the time the drawing was made. We should now regard the length of the metal strip as about one-third too great for its width as well as for the size of the artery represented.

Fig. 2. The improved band roller—the size usually employed in the experimental work. The instrument shown in full length is unloaded. In the abbreviated cut the band is about to be expelled from the roller. This band is broad enough for the abdominal aorta in man, and the diameter of the circle is too short for a vessel requiring such a broad band.

PLATE XII.

Fig. 3. Aorta of dog after partial occlusion by band for one month. The band (b), in outline, is seen through the vessel's wall. Fig. 4. Aorta of Dog 27 converted into a solid cylinder (a), the band (b) having embraced the artery for three and one-half months.

Figs. 5 and 6. An aorta about which a partially occluding ligature of silk had been placed. In Fig. 5, the wall of the artery is divided anteriorly only enough
to expose the diaphragm formed in the track of the ligature and perforated by two holes, $a$ and $a'$. The silk ligature, at $b$, is more plainly seen in Fig. 6, in which the diaphragm has been divided as far as and into the anterior perforation.

PLATE XIII.

Fig. 7. The kidneys of a dog six months after the application of an occluding band to the renal artery of one of them. The band, spread out, lies in situ under the right renal artery which had become converted into a solid cylinder at this point, but was collapsed both proximal and distal to the occluding metal. Contrast the renal arteries of the two sides.