Method for Experimental Constriction of Arteries with Polyvinyl Alcohol Sponge

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Many experimental procedures for local reduction of an arterial lumen have been described. The purposes of experimental arterial stenosis have, in the past, included attempts to develop methods for gradual occlusion of diseased vessels, study of the effects of ischemia on various organs, especially the kidney, and simulation of coarctation of the aorta, as well as study of the effects of stenosis on the structure of the arterial wall. Methods that have been used to produce arterial stenosis may be divided into 2 broad groups: those in which the lumen of the artery is gradually decreased over a period of time, and those in which the arterial lumen is narrowed abruptly. The former group includes placement of irritant substances, such as cellophane, or polyethylene with dicetyl phosphate, about an artery to cause an inflammatory and proliferative reaction that gradually obliterates the lumen. Ameroid, a casein plastic that produces a similar response in the tissues, swells in water to produce mechanical occlusion as well. These means do not permit selection of an end-point short of complete occlusion of the artery. Gradual stenosis of predetermined severity has been accomplished by placing a silk ligature about an artery to cause an inflammatory and proliferative reaction that gradually obliterates the lumen. Ameroid, a casein plastic that produces a similar response in the tissues, swells in water to produce mechanical occlusion as well. The reported degree of narrowing produced by plastic reconstruction of a blood vessel wall has fluctuated within wide limits. This method of arterial constriction seems incapable of precise control.

Efforts to diminish an arterial lumen by inserting constricting devices into the artery have resulted in thrombosis. Sealy and McSwain simulated coarctation of the thoracic aorta in dogs by substituting constricted lucite tubes for resected segments of aorta. Clatworthy, and associates, combined plastic operations on the aorta with the use of irritant substances in young pups to produce severe degrees of aortic stenosis in the dogs as they grew larger.

None of the methods described seemed suitable for our purpose, which was to produce severe constriction of the external iliac arteries of dogs for a relatively long time in order to study the morphologic reaction of the arteries to reduced blood flow. Our aim in these experiments was to reduce the lumen of each experimental artery locally to less than
Figure 1

a. Strip of surgical ivalon sponge, b. Stainless steel mold. Note the polished tapered shaft in the recess into which the plastic sponge is tightly wound, as in (c) and (d). The plastic is held in place by several layers of gauze until fused by boiling, and (e) needles are inserted to form holes to facilitate suturing. A completed constricting device is shown in (f), which indicates also the method of suturing through the preformed needle holes. A device is shown end on in (g), and cut longitudinally to show the smooth lumen in (h).

25 per cent of its original cross section, and to maintain the stenosis for as long as 18 months. This aim was accomplished by means of constricting devices prepared from a plastic sponge, formalinized polyvinyl alcohol (surgical ivalon), by the following method.

Methods

Molds to provide a recess 1 cm. long into which polyvinyl alcohol sponge was to be compressed were fashioned to precise dimensions* from stainless steel rods, as in figure 1. The shaft that traversed the recess was smoothly tapered by lathe to a thin central portion. This shaft was given the approximate profile of a shallow hyperbola. A slit wide enough to accept a No. 10 Bard-Parker scalpel blade was cut into the steel shaft on each side of the polished recess, to provide a space through which the plastic ring could be cut from the mold.

To form the constricting device, a 15 × 1.5 × 0.3 cm. strip of moist surgical ivalon sponge that had been washed in running distilled water for 4 hours was wound tightly into the polished recess and was covered by several layers of gauze bandage, also tightly wound. Two small curved needles were inserted through the gauze and through the moist plastic to preform needle holes for subsequent suture of the constrictor. Fusion of the ivalon layers, fixation in the desired shape, and sterilization were accomplished by boiling the mold with compressed ivalon and inserted needles in distilled water for 30 minutes.

The sterile device was taken to the operating room, where the needles were removed, the gauze was unwound, and the constrictor was cut from the mold. Much of the adventitia was stripped from a short segment of the dog's external iliac artery. The molded plastic unit, which retained some elasticity, was slipped over the artery and was closed with sutures of 00 silk through the 2 preformed needle holes.

Molds for our experiments were made in 4 sizes, to provide nearly equal degrees of stenosis in the external iliac arteries of dogs varying considerably in size. Constricting units with a central lumen 1.30, 1.55, 1.80 and 2.10 mm. in diameter, respectively, were provided by these molds. The larger luminal diameters at the ends of the constrictors were 3.0, 4.0, 4.5 and 5.0 mm., respectively.

Experimental Application

In each dog, the desired severe degree of arterial stenosis was achieved as follows: a constricting unit estimated to be the proper size to produce the desired degree of luminal reduction was placed around the external iliac artery. This had 1 of 2 results: either it completely occluded the vessel, or else it permitted some flow of blood to continue. If the artery was completely occluded, a lumen was assured either by removing the constrictor and applying one of the next larger size, or by dissecting additional tissue from the adventitia of the artery and reapplying the constrictor that had previously occluded the vessel.

If the constrictor originally selected permitted flow of blood to continue, it was removed and one of smaller size was placed about the artery. If this smaller constrictor stopped the flow of blood through the artery, a lumen was assured by removing the smaller constrictor and reapplying the constricting unit that had previously permitted flow of blood, or else by dissecting additional tissue from the adventitia and again putting the smaller constrictor, which had previously caused occlusion, about the artery. Thus, a constricting unit that reduced the lumen maximally but did not occlude the artery was used in each instance.

Flow of blood through the constricting segment was demonstrated in each dog prior to termination of the operation. The external iliac artery was

We are indebted to the Section of Engineering of the Mayo Clinic for construction of the stainless steel molds to our specifications.
Experimental Arterial Constriction

Figure 2
Aortograms showing constricted external iliac artery in a dog. a. Six months after operation, b. Eighteen months after operation. The slight increase in diameter of the stenotic segment during the intervening year is attributed to atrophy of the arterial wall under the plastic constrictor.

Results

We placed 56 ivalon constrictors prepared in this manner on the external iliac arteries of 45 dogs. Six of the dogs were killed 18 months after production of their experimental arterial stenosis, 6 dogs were killed 1 year after arterial constriction, and 33 dogs were allowed to survive for shorter intervals. The cross sectional area of the residual arterial lumen in the constricted segment, estimated from aortograms made in 41 of the 45 dogs, varied from 2.6 to 27 per cent of the normal artery (figs. 2 and 3), the average being 9 per cent.

Each of the dogs walked normally on the day following the operation. No atrophic changes were detected in the hind limbs during the period of these experiments. The femoral pulse on the experimental side was palpably diminished. The mean blood pressure on the experimental side, measured intra-arterially distal to the constriction in 13 dogs, varied from 2.6 to 27 per cent of the cross sectional area of lumen of the opposite normal artery (figs. 2 and 3), the average being 9 per cent.

No instance of arterial rupture or of hemorrhage was encountered. Fifty-four of the 56 constricted segments of artery remained patent throughout the experimental period. In 2 dogs, the experimental artery became occluded. A bland thrombus had apparently originated within a segment of traumatized artery proximal to the constriction in 1 dog. A second occlusion was caused by thrombosis of the artery within an abscess that surrounded the plastic constrictor.

Histologic Observations

The wall of the artery within each plastic device had a number of relatively uniform longitudinal folds. The internal elastic lamina assumed a bizarre, redundant appearance. The arterial wall slowly but progressively atrophied in the central, maximally compressed part of the stenotic segment where, in time, it was found composed only of elastic fibers and small amounts of collagen (fig. 4). Atrophy beneath the ivalon was much less rapid than that described beneath rigid constricting bands. Six months after placement...
Figure 4

Cross sections of external iliac artery of a dog, each magnified X 200. The lumen of each artery is at the top, and the media is marked with an M. a. Normal artery. b. Central segment from within an ilon constrictor which had been in place for 2 months. The smooth muscle of the media shows little loss. Note the redundant folds of internal elastic membrane, covered by endothelium. c. Similar artery 6 months after operation. Here, the media is considerably thinned. d. Similar artery 18 months after operation. All smooth muscle has disappeared, and the media can no longer be recognized.

of the constrictor, smooth muscle of the media, although reduced in amount, was present in a continuous layer throughout the entire length of each stenotic segment. Smooth muscle had disappeared completely from the central, maximally constricted portion of each of 6 arteries constricted for 18 months, and was present in the narrow central part of only 1 of 6 vessels constricted for 12 months. After 12 months, the media had atrophied completely in most constricted segments, and was recognizable only as a zone of relatively fine elastic fibers between the internal elastic membrane and the coarse elastic fibers of the ad-
ventitia. Loss of collagen and elastic tissue from the adventitia was also apparent. These atrophic changes in the vessel wall caused the lumen of the constricted segment of artery to become slightly larger, in time, than it had been earlier in the experiments.

Endothelium lined the constricted vessel in all instances, even when all other cellular elements had been lost. In several vessels, tears in the internal elastic membrane were covered by small organized mural thrombi within the constricted lumen. These had not caused complete obstruction except in the 1 case previously mentioned, in which the thrombus apparently originated proximal to the constrictor.

Several factors may explain the failure of these vessels to rupture. The plastic devices are not rigid; moist ivalon maintains some elasticity even when tightly compressed. The slow rate of atrophic change, as compared to the rapid local degeneration of an artery compressed by a metal band or clamp, may be due to this same feature. More significant, we believe, is the tapered lumen of the constricting unit, which prevents shearing action of the pulse on the artery wall.

**Summary**

Simple plastic constricting devices for producing experimental arterial stenosis may be prepared from formalinized polyvinyl alcohol (surgical ivalon) sponge. Not a single instance of arterial rupture, a common sequel of stenosis produced by rigid devices, was encountered in 56 experiments.

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Early Stages in the Development of Collateral Circulation to the Lung in the Rat—pp. 353-376

Summarium in Interlingua

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2. Pre-existente arterias nutritional del reveste-mento de musculo cardiac super le venas pulmonar se allarga per le mesme processo.

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4. Vasos se forma in adhesiones pleural e pote suppler sanguine al pulmon ab le arterias intercostal.

5. Nove arterias bronchial se forma in regiones ubi nulle formation de tissu de granulation es presente e responsable pro le stimulation de lor disveloppamento. Le primordio initial consiste de un solide corda cellular que es tosto eircumdate de un invelope de cellulas fusiforme representante le primordio del tunica media. Secundarimente le corda cellular es differentiate in un tubo endothelial per le formation del passage interior.

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