The pathogenesis of dissecting aneurysm of the aorta is a disputed question. There are two chief theories of origin: The first postulates that dissection is the result of an intimal tear which allows blood access to the media; the second suggests that dissection follows rupture of the vasa vasorum with the formation of a medial hematoma. According to the latter and more popular concept, an intimal tear if present is secondary. Both theories postulate medial degeneration as a requisite for dissection. Arguments for and against these hypotheses have been summarized elsewhere. While either mechanism may initiate aortic dissection, rupture of the vasa vasorum is the obvious explanation in those cases without intimal tears.

Gerbasio and Blain were unable to produce dissecting aneurysm in either rabbits or dogs by incising the intima and media and separating them from the adventitia for a short distance. Blanton et al. successfully produced dissection in dogs by producing a cleavage plane within the media, excising a small ellipse from the inner wall of the aorta, and suturing the inner lip to the adjacent aortic wall to maintain the opening in a funnel-like position. Dissection occurred in 13 of 26 dogs and always extended distally to the site of the intimal opening, the proximal segment remaining collapsed. The time required for production of dissection varied from two to three minutes, but was shortened to a period of only four or five seconds by the administration of a vasopressor drug (levarterenol). Failure to produce dissection was generally due either to internal rupture of the sac during preparation or hypotension resulting from hemorrhage.

Wartman and Laipply were unable to produce dissecting aneurysm by the injection of homologous blood into the media of the aorta in dogs. The small hematomas produced (1 to 5 mm. in diameter) became organized and were replaced by scar tissue in a few weeks.

Gross observations have suggested that the media of the aorta is loosely held together. Thus, when a cleavage plane is developed, the layers can be readily separated manually in the normal aorta and even more easily when medial degeneration is present. However, experimental studies in which water was injected into the media through a hypodermic needle have revealed that the cohesion between the layers is remarkably strong. The pressure required to produce dissection varied from 230 to 975 mm. Hg, with a mean of 566 mm. Hg. It was concluded that the normal aortic wall is sufficiently strong to withstand any pressure which might result from blood's gaining access to the media through an intimal defect. The results were interpreted as evidence that the media must be extensively and markedly weakened by disease before spontaneous dissection can occur.

Experiments performed on human aortas by the present authors suggest that the laws of fluid flow play an important role in the extension of dissection.

**Methods**

Initially, the present authors tried a modification of the technique of Milazzo in which the force required to produce separation of the layers...
of the aorta using strips 3.5 mm. in width was determined with a torsion dynamometer. The method was abandoned when it became apparent that wide variations in results were obtained. High values were frequently the result of such uncontrollable factors as resistance resulting from penetrating vessels and elastic laminae bridging between one layer of the media and another. The water-injection method was found to give more consistent results and simulated more closely spontaneously occurring dissecting aneurysm, the fluid tending to follow the path of least resistance.

The material includes aortas from 63 patients in the first 11 decades of life who died of natural causes from January, 1957 to July, 1959. There were 31 males and 32 females in this study. There were nine Negroes, five Mexicans, and the remainder were Caucasians.

The longitudinally opened and unfixed aorta was washed with tap water and laid flat, with the adventitia facing up. A 20- or 21-gauge needle with a standard bevel was generally used in aortas from adults, and a smaller needle (25 gauge) in aortas from infants and children. The needle was inserted for a distance of from 1 to 2 cm. into the outer third of the media, parallel to the adventitia, and a hemostat was placed transversely across the site of entry of the needle to prevent retrograde leakage. Pressure was provided by means of a 10-cc. Luer-Lok syringe attached by a 2-foot length of rubber tubing to a hypodermic needle. A mercury manometer registering to 800 mm. Hg was connected to the tubing near its midportion. The pressure was increased at increments of 5 to 10 mm. Hg at intervals of 5 to 10 seconds until the endpoint was reached, as indicated by the development of a bleb more than 1 cm. in diameter. The endpoint was usually sharp, a rapidly expanding bleb developing within two seconds. Four determinations were performed at each of four segments of the aorta—ascending, arch, descending, and abdominal—making a total of 16 determinations on each aorta.

Results

In table 1 is shown the range in pressure required to initiate dissection within different segments of the aorta in each decade studied. From four readings taken for a particular segment of the aorta in each case, a mean was determined. These means were then averaged with the means for corresponding segments of the aortas of other cases in the same decade, and this figure has been labeled the “mean” on the table. In the right-hand column is the overall mean, calculated by averaging the means of the four segments from all cases in each decade.

EFFECT OF VARIATIONS IN TECHNIQUE

No difference was noted in the pressure required to initiate dissection of the aorta by varying the size of the hypodermic needle from 20 to 25 gauge. Since standard needles have their opening on the beveled side, a needle was prepared with a double bevel with the opening on the end to see whether the position of the opening affected the dissecting pressure. The results were not influenced by either the direction in which the needle was inserted or the direction or shape of the bevel. Histological sections confirmed the impression that most of the injections were performed in the zone between the middle and outer third of the media, although some were made into the inner or outer media. No stratum was found within the media which was more susceptible to dissection than any other, confirming the similar observation of Milazzo. No significant difference was noted in the pressure required in different segments of the aorta studied. This is in contrast to the observations of Robertson and Smith who found a decreasing gradient from above downward.

The length of time that the aorta was exposed to the dissecting pressure had some effect on the pressure required, although this effect was generally noted only when the pressure was maintained for considerable periods of time. Thus, an aorta which resisted dissection with a pressure of less than 450 mm. Hg would dissect if a pressure of 430 mm. Hg were maintained for an hour or more. Since each determination was performed within a minute or less, the duration of exposure to the pressure was essentially constant throughout the study.

EFFECT OF AGE, SEX, AND RACE

The lowest pressures required to produce dissection (320 to 520 mm. Hg) in the first four decades of life were higher than the systolic pressure generally encountered even in severe hypertension. There was no significant


TABLE 1

Pressures (mm. Hg) Required to Produce Dissection of the Media of the Aorta

<table>
<thead>
<tr>
<th>Age (years)</th>
<th>Number of cases</th>
<th>Ascending arch</th>
<th>Transverse arch</th>
<th>Descending thoracic</th>
<th>Abdominal</th>
<th>Overall mean</th>
</tr>
</thead>
<tbody>
<tr>
<td>0-9</td>
<td>2</td>
<td>320-610</td>
<td>360-510</td>
<td>440-500</td>
<td>500-700</td>
<td>499</td>
</tr>
<tr>
<td></td>
<td>Range</td>
<td>Mean</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>10-19</td>
<td>2</td>
<td>520-890</td>
<td>490-690</td>
<td>480-690</td>
<td>410-780</td>
<td>562</td>
</tr>
<tr>
<td></td>
<td>Range</td>
<td>Mean</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>20-29</td>
<td>7</td>
<td>420-890</td>
<td>430-780</td>
<td>420-680</td>
<td>350-780</td>
<td>586</td>
</tr>
<tr>
<td></td>
<td>Range</td>
<td>Mean</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>30-39</td>
<td>5</td>
<td>410-780</td>
<td>390-650</td>
<td>330-620</td>
<td>380-730</td>
<td>524</td>
</tr>
<tr>
<td></td>
<td>Range</td>
<td>Mean</td>
<td></td>
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<td></td>
<td></td>
</tr>
<tr>
<td>40-49</td>
<td>10</td>
<td>500-800</td>
<td>500-800</td>
<td>400-800</td>
<td>200-800</td>
<td>529</td>
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<td>50-59</td>
<td>9</td>
<td>250-800</td>
<td>250-800</td>
<td>240-800</td>
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<td>478</td>
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<td></td>
<td>Range</td>
<td>Mean</td>
<td></td>
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<td></td>
<td></td>
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<tr>
<td>60-69</td>
<td>8</td>
<td>210-710</td>
<td>190-800</td>
<td>180-800</td>
<td>210-700</td>
<td>421</td>
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<tr>
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<td>Range</td>
<td>Mean</td>
<td></td>
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<td></td>
<td></td>
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<tr>
<td>70-79</td>
<td>8</td>
<td>300-650</td>
<td>290-780</td>
<td>280-690</td>
<td>260-800</td>
<td>474</td>
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<td>Mean</td>
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<tr>
<td>80-89</td>
<td>8</td>
<td>240-780</td>
<td>210-760</td>
<td>240-700</td>
<td>180-750</td>
<td>434</td>
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<tr>
<td></td>
<td>Range</td>
<td>Mean</td>
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<tr>
<td>90-99</td>
<td>3</td>
<td>250-740</td>
<td>250-630</td>
<td>250-520</td>
<td>220-650</td>
<td>431</td>
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<td></td>
<td>Range</td>
<td>Mean</td>
<td></td>
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<td></td>
</tr>
<tr>
<td>100 or over</td>
<td>1</td>
<td>220-270</td>
<td>220-360</td>
<td>230-370</td>
<td>220-490</td>
<td>290</td>
</tr>
<tr>
<td></td>
<td>Range</td>
<td>Mean</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

difference in the mean pressures required to produce dissection when the cases were separated by either sex or race.

EFFECT OF POSTMORTEM CHANGES

The majority of determinations were performed within 24 hours following death, although the range varied from three hours to five and a half days. The bodies were kept in refrigerated vaults at a temperature of 4 C. prior to autopsy. Experimental dissection of the aorta was usually performed within two hours after autopsy. Analysis of the data comparing the overall mean pressure required to initiate dissection plotted against the time following death failed to reveal any relationship. The resistance to dissection of two aortas obtained five days after death was within the range for fresher aortas. These observations confirm those of Robertson and Smith that the cohesive strength of the aorta is not progressively impaired by postmortem changes, at least during the first few days after death in bodies maintained under refrigeration.

Circulation Research, Volume X, June 1968
EFFECT OF SPONTANEOUS DISSECTING ANEURYSM

Two instances of spontaneous dissecting aneurysm were included in this study; both with dissection involving the descending thoracic and abdominal aorta. In the first, occurring in a 48-year-old male, the lowest pressure necessary to produce dissection was 300 mm. Hg. A similar or lower pressure was required to initiate dissection in four of the nine other cases in the same decade; the overall mean dissecting pressure of 460 mm. Hg in this aorta was not significantly different from the overall mean of 498 for the entire group in the same decade. The second instance occurred in a 68-year-old male, whose lowest dissecting pressure of 180 mm. Hg was less than that encountered among seven other cases in the same decade. The overall mean of 296 mm. Hg in this case was significantly lower than the 431 overall mean for all cases in the same decade. In these two cases of dissecting aneurysm, there were no significant differences in the pressures required to produce dissection in various segments whether injection was performed in the intact ascending portion or arch of the aorta or through a stratum in the media that paralleled the spontaneous dissection.

EFFECT OF OTHER CONDITIONS

A comparison of the pressures required to produce dissection in the media overlying atherosclerotic plaques failed to reveal any significant differences. Attenuation of the media was frequent in severely involved specimens, making insertion of the needle technically difficult, but no tendency to easy separation of the media was found. The study included 15 instances of hypertensive heart disease, all in individuals under the age of 40. A comparison by decades of the overall mean of the pressures required to produce dissection in the aortas of patients known to have been hypertensive with those known to be normotensive revealed that a higher pressure (averaging 39 mm. Hg) was required in the aortas of hypertensive individuals in the ages 40 through 89.

Aortas from two females in the postpartum state were studied, one 23 and the other 26 years of age. The overall mean dissecting pressure of 555 mm. Hg in the first instance and 652 in the second is compared to the overall mean of 576 mm. Hg for the five other individuals in the same decade. There was no evidence that any loss of cohesive strength of the media occurred concurrent with pregnancy in the postpartum state.

Four aortas with syphilitic stigmata demonstrated a resistance to intramural dissection considerably above the mean for their age group and were therefore excluded from the table. In one such case, it was impossible to produce intramural dissection at any of the four levels studied with pressures of less than 800 mm. Hg. Pressures necessary to produce dissection would be expected to be higher in syphilitic aortitis because, as Loeschke observed, this disease produces scars that extend transversely across the elastic laminae, tending to bind the layers of the aorta together, and may actually protect against spontaneous dissection.

STUDIES OF THE DOG AORTA

Aortas from two mongrel female dogs, approximately a year and a half old and weighing 35 and 45 pounds, were studied with the injection technique. The range in pressure required to produce dissection was essentially similar to that in the human, with no significant difference in various segments. The overall mean in the first dog was 505 mm. Hg, and in the second, 586 mm. Hg, pressures which are essentially similar to those required in humans in the second and third decades.

HISTOLOGICAL STUDIES

A circumferential section of the aorta was taken at each of the four levels studied in 42 cases, sections generally being taken through areas of mechanical dissection. Routine staining with hematoxylin and eosin was performed, and frequently toluidine blue stains for the presence of ground substance. In the aortas of 13 individuals 40 years of age or less, no significant lesions were observed. Of 12 aortas in individuals between the ages of 41 and 60, focal loss of muscle cells involving...
PRESSURE DISSECTION OF AORTA

the middle or outer third of the media of the ascending portion or aortic arch was present in two, each of whom had a history of antecedent hypertension. Sclerosis of the vasa vasorum was encountered in three instances and in each was associated with clinical hypertension. Of 17 aortas from individuals over the age of 60, focal loss of muscle cells was observed in five and was usually situated in the middle or outer third of the media. This lesion involved the ascending aorta in four instances and the descending thoracic aorta in one. Four of the five with muscle cell loss had stigmata of hypertension. Lesions of the vasa vasorum ranging from slight to severe sclerosis were present in 14 of the 17 cases.

Little correlation could be determined between the microscopic findings and the ease of mechanical dissection. In no instance did the plane of the dissection coincide with a zone of muscle loss. Since the needle was placed blindly, the location of the tip was purely a matter of chance. Although it is presumed that a zone of muscle loss would dissect more easily than a normal area, it was not possible to prove this point. Although the group is small, it is apparent that areas of muscle cell loss are frequently encountered in random sections of the aorta and increase in frequency with age and in association with hypertension. The ease of dissection could not be correlated with the amount of ground substance in the interstitial tissue of the media. The aorta with the greatest increase in ground substance in the media as judged from the routine hematoxylin and eosin stains had a moderate reduction in the pressure required to produce dissection, with a mean of 352 mm. Hg for all segments, contrasting with an overall mean of 431 for the entire decade. Toluidine blue stains in this case revealed that at least half of the interstitial material was not metachromatic and probably represented a serous accumulation. It seems likely that changes in ground substances may be qualitative as well as quantitative, so that routine histological stains may not indicate the cohesive strength of the media.

Discussion

The data presented confirm those of previous investigators that the pressure required to initiate dissection of the aorta by the injection of water is generally high. The lowest pressure required in aortas from individuals below the age of 40 was generally higher than the systemic blood pressure even in patients with severe hypertension. From the age of 40 and onward, the lowest pressure required fell within the range encountered in hypertensive patients. Since the blood pressure within the vasa vasorum is probably no more than half that in the aorta, the systemic pressure required to initiate medial dissection by rupture of the vasa vasorum would have to be about twice the lowest pressure that produces medial dissection of the aorta experimentally. In the present study in aortas in the 40- to 99-year age groups, this would mean a minimum pressure in the neighborhood of two times 180 mm. Hg, or 360 mm. Hg, a pressure that is rarely encountered in the human either at rest or during strenuous exercise.

The apparent paradox of an aorta's being able to withstand any dissecting pressure which the heart is able to generate, and yet being dissected from one end to the other by rupture of vasa vasorum, the intraluminal pressure of which is lower than that in the aorta, can be explained by the laws of fluid mechanics. It must be postulated that an initial rupture of one or more vasa occurs in a focus of medial degeneration. The focus, consisting of lesions of muscle or elastic tissue and strategically located between the middle and outer third of the media, the depth to which the vasa normally penetrate, permits rupture of either normal or diseased vasa to give rise to a small bleblike hematoma. Such a sac will behave like a small aneurysm and will be affected by the laws of fluid flow. According to the law of Laplace, which may be applied to either aneurysms or cylindrical vessels, the tangential tension on a vessel wall is equal to the pressure times the radius. Thus, if the pressure remains constant, the tension on the wall will vary directly with the radius.
the pressure is reduced one-half, the tension on the wall will remain the same if the sac is twice as large. Thus there is an inverse relation between the diameter of an aneurysmal bleb and the pressure required to produce it. For example, in one instance in the present study, the pressure required to initiate dissection was 450 mm. Hg. After a 1-cm. bleb had formed, extension of dissection occurred when the pressure was reduced to 290 mm. Hg; when the bleb enlarged to 2 cm. in diameter, a pressure of only 90 mm. Hg was sufficient to cause further extension. Assuming that hemorrhage from vasa vasorum initiates dissection in the human aorta, the development of a hematoma with a diameter of 2 cm. or more practically assures further dissection providing the pressure within the vasa is maintained.

Admittedly, the pressure required to initiate dissection within an excised and longitudinally opened segment of aorta may differ from that required in vivo. The use of water as a dissecting medium in this study provided an effective pressure which was undoubtedly greater than would have been produced by the more viscous blood. Furthermore, the complex circulatory phenomena normally present in the aorta during life, including intraluminal pressure under cyclic variations and pulsation of flow, were not reproduced in this experimental study. Although the pressure relationships are admittedly more complex in vivo, it seems likely that the laws of fluid flow which have been shown to play an important part in the enlargement of a medial bleb may similarly operate in spontaneously occurring dissecting medial hematomas.

Sufficient pressure is generated in an expanding bleb to cause extension of dissection into areas of the media which are histologically normal. This may explain the frequent finding of an histologically normal aorta in cases of dissecting aneurysm. In Hurley's recent study, no medial lesion was found in over half the cases; the lesions encountered in the remainder were approximately as frequent in controls. In our review, 16 per cent of the cases with microscopic studies had been classified as histologically normal. Unless multiple sections are taken at close intervals throughout the extent of dissection, focal lesions may readily be overlooked.

It appears that extensive weakening of the media, as postulated by Robertson and Smith, is not essential to extension of dissection. The presence of intraluminal pressure may inhibit the bulging of the aneurysm into the lumen of the aorta, but will not prevent lateral spread. As long as the blood remains fluid within the bleb, it will continue to exert a hydraulic effect. Clotting within the sac may be inhibited by the ground substance of the aorta, since chondroitin sulfate B, the chief acid mucopolysaccharide of the human aorta, has been shown to have an anticoagulant effect. We have observed that the resistance of the aorta to mechanical dissection is greatly increased at the aorta ring and to a lesser extent at the sites of penetration of the wall by the intercostal and lumbar arteries. However, these vessels frequently cannot withstand the pressures generated in an expanding bleb and their intramural portions rupture, although they still maintain their connection with the outer wall of the aorta. When this occurs in spontaneously occurring dissecting aneurysm, the inner orifices of these vessels allow blood under systemic pressure to flow directly into the dissecting channel.

Summary

The pressure required to produce intramural dissection was determined by injection of water into the media of strips of aorta obtained at postmortem examination. The mean pressure required reached a maximum in the second and third decades and decreased gradually thereafter. No differences in the pressure required was noted when comparisons were made by race, sex, different segments of the aorta, different strata of the media, or in the region of atherosclerotic lesions. Pregnancy (postpartum state) did not decrease the resistance in two instances. A slight increase in the pressure required was observed.
PRESSURE DISSECTION OF AORTA

in the aortas of patients with hypertensive disease, and a marked increase was encountered in the presence of syphilitic aortitis. The resistance of the aorta in spontaneously occurring dissecting aneurysm was variable; one case had a normal resistance while the other was impaired.

The authors postulate that a solitary focus of medial degeneration strategically located is an adequate stimulus for dissection. Subsequently, rupture of vasa vasorum into this weakened area results in a rapidly expanding bleb. The pressure required to produce further enlargement of the bleb will vary inversely with its diameter, thus tending to extend the dissection. This mechanism may explain the frequent finding of an histologically normal aorta in random sections from cases with extensive intramural dissection.

Acknowledgment

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Experimental Dissection of Media of Aorta by Pressure: ITS RELATION TO SPONTANEOUS DISSECTING ANEURYSM
Albert E. Hirst, Jr. and Varner J. Johns, Jr.

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