18

FRACTURE OF ARTERIES

OSKAR KLOTZ
(From the Pathological Laboratories, University of Pittsburgh, Pittsburgh, Pa.)

Reprinted from
THE JOURNAL OF MEDICAL RESEARCH, VOLUME XXXIV., No. 3
(New Series, Vol. XXIX., No. 3), pp. 495-507, July, 1916

BOSTON
MASSACHUSETTS
U.S.A.

FRACTURE OF ARTERIES.*

OSKAR KLOTZ.

(*From the Pathological Laboratories, University of Pittsburgh, Pittsburgh, Pa.*)

Calcification of the media is one of the most common pathological processes found in the peripheral arteries. This condition is a degenerative process in which the tissue of the part is destroyed and replaced by an inert deposit of calcium salts. The extent of the deposit varies greatly. In its early stages we may see the antecedent degenerative changes in elastic fibers and muscle cells, followed by a gradual accumulation of calcium salts in the dead areas with the final development of a hard plaque visible to the naked eye. These patches of degeneration and deposit usually lie in the middle of the media, but again may be situated along the inner border close to the intima so that the process of calcification involves the internal elastic lamina. As the condition progresses the medial plaque continues to extend laterally in a circular fashion until an annular band encircles the artery. Such complete bands are not uncommon in the vessels of the legs and forearms.

These medial deposits are quite independent of inflammatory changes in the arterial wall, and they do not bear any direct association in their development with thickenings of the intima. In the absence of any associated pathological process in the other coats of the artery, as well as the lack of inflammation in the vicinity of the injured area, it would appear that the lesion is purely a degenerative one resulting from the stress, overstrain, and fatigue of the active components of the media. As we have said, it is the muscle tissue usually, and at times the elastic fibers, which show the earliest evidences of degeneration at a period before there is any precipitation of calcium salts. The muscle fibers often show deposits of fat droplets within them, and later a disintegration of their substance. The elastic fibrils become

* Received for publication May 26, 1916.

more diffuse in their staining, lose their specificity for the elastin reaction, and later accumulate granular deposits of lime.

The functional fatigue of the arterial musculature appears to result from the unusual activity of the tissues which are supplied by the particular artery. The regulation of the blood supply to any part is dependent upon the control of the blood flow by the musculature of the peripheral arteries. In a much overworked organ or tissue this control of the circulation eventually leads to fatigue of the musculature of the media, which when driven to excess, shows evidence of degeneration. The results of overtaxation of the media are more frequent in the right radial and branchial arteries than in the left. Likewise the external iliac is more markedly affected than the internal, and the femorals with their branches commonly show all grades of medial calcification in men who are active and about much upon their feet. These medial calcifications are more rarely seen in the abdominal arteries. I have repeatedly cut a sclerosed mesenteric, splenic, or renal artery expecting to find advanced medial degeneration, to be disappointed in the unusually healthy appearance of the microscopic sections, save for some fibrous tissue in the intima and adventitia, or evidence of medial hypertrophy. The coronary arteries of the heart, too, do not commonly show this lesion, and it is decidedly unusual in the vessels of the brain.

Now, although the end result in this medial lesion (calcification) is much like that in the intima of the aorta, the processes in these two tissues are quite different. In the intima of the aorta the calcareous process is preceded and also accompanied by atheroma. Thus the early precipitation of calcium salts is associated with much fat accumulation, and this usually continues, so that we find the gritty deposit mixed with a greasy and cholesterin-containing material. As the calcium salts in the intima increase, the gritty masses fuse until calcareous plaques are formed. These, however, nearly always continue to be surrounded by atheromatous material. We cannot agree with MacCordick,

who can see no difference in the nature of the calcium deposits in the media and intima. MacCordick claims that both of these calcareous deposits occur in the nature of a mortar-like material, which during life is soft and pliable. Our experience has shown that the atheromatous substance of the aortic intima is not uncommonly of a gritty, mortar-like consistence, but we have never been able to demonstrate this character in the calcareous deposits of the media of the peripheral arteries.

In the routine examination of the peripheral arteries, and particularly those of the extremities, a great many specimens are encountered showing different grades of calcareous deposits. The lesion of the media is easily recognized in the hematoxylin-stained specimens. The process being a purely degenerative one is devoid of evidence of any inflammatory exudate. Commonly the process begins in the mid-zone of the media where a small patch of muscle cells is found to have undergone necrosis. The staining quality has changed much and the involved tissue is devoid of nuclei. A curious feature in connection with the necrosis of the media with calcification is that, with the death of the muscle cells, there is a simultaneous laying down of calcium salts which obscures the necrotic tissues of the part. One finds that the area is permeated with fine dust-like granules which stain blue with hematoxylin and for the most part turn black with silver nitrate. These calcium granules encroach directly upon the neighboring muscle tissue which still appears healthy. The occasional elastic fibers, which are present in the peripheral arteries, also show the presence of calcium salts where they encroach upon the medial necrosis.

These areas of early calcification begin in focal lesions of microscopic size. Several areas of degeneration not uncommonly occupy the media within short distances of each other and, as they enlarge, fuse to form continuous streaks of necrosis, which extend laterally rather than longitudinally in the arterial coat. As the necrosis continues the progressive involvement of the media leads to the death of muscle cells in whose place the granular calcium deposit is found.

During the early stages of calcification an actual hardening of the artery is not perceptible. Where, however, necrosis is more advanced and of longer standing, and particularly where the calcareous process forms an annular ring through the media, the appearance of the involved areas differs considerably. In these advanced lesions the calcium salts no longer appear in the fine dust-like granules lying in an indefinite matrix, but they appear to fuse into a more solid mass, with crystalline characters. These crystals react less actively to the presence of hematoxylin and instead of being blue are purple, red or even colorless. The central portions of the crystals commonly give no reaction with hematoxylin.

These calcareous masses, though lying in a living tissue and representing inert foreign bodies, frequently lead to no response in the neighboring tissues. They persist for years and continue to occupy more and more of the media. Even when they occur in the central zone of the media, there remains a living portion of the media on both their inner and outer borders. These zones of living muscle are found even when the entire artery is encircled by a calcareous ring. In the very advanced lesions the inner zone of the media may also be occupied so that the calcified plaque is in direct contact with the internal elastic lamina. It is unusual to have the deposit of lime overstep this boundary. More commonly when calcareous masses appear within the intima they develop independently of the calcareous process in the media. It has always appeared remarkable to me that such extensive degenerative processes showed so little change in their immediate neighborhood. The muscle fibers in direct contact with the borders of these calcareous masses often show no evidence of degeneration.

Although the deposit of calcium salts may for a long time remain the only evidence of change in the arterial wall, gradually there develops in a certain number of cases a metamorphosis of the surrounding tissue in which bony plaques are found. The simple presence of small bony islands becomes increasingly more frequent with advancing age. These islands may represent an immature bony

structure of an osteoid type, but not uncommonly consist of true bone trabeculæ with calcium salts in the matrix. In the majority of instances these bony masses form irregular islands in close apposition to the calcareous deposits in the media. In many instances no evidence of trauma at the point of bone formation can be observed in the arterial wall. All authors have commented upon this association of bone development with the preceding presence of a calcareous deposit. It is, however, to be remembered that in experimental animals bone and cartilage may be induced in the arteries, in the absence of a preceding process of calcification. Harvey obtained such by painting the aorta of rabbits with silver nitrate.

In the human arteries where the bone trabeculæ develop after medial calcification there is always an antecedent process of vascularization which initiates the tissue metaplasia. Orth was among the first to call attention to this primary tissue change, which developed in the vicinity of the calcareous mass. Since then it has been described by O'Brien, Cohn, Moenckeberg, Rohmer, Bunting, and others. Some have suggested that the vascularity of the tissue represented an injury induced either through minor external factors or through the effect of irritation brought about by the presence of the calcareous deposit upon the surrounding living tissue. The reaction is commonly encountered without any evidence of an inflammatory exudate and without any sign of injury to the neighboring tissues. Fibroblasts are often seen. Numerous capillaries develop in the loose fibrous stroma immediately surrounding the calcified area. With the appearance of the blood capillaries there is a disappearance of the neighboring muscle cells, so that the calcareous structure becomes bounded by a type of granulation tissue. The capillaries are derived from the vasa vasorum. These can often be seen advancing inwards from the outer coat of the artery towards the medial degeneration. In studying this newly-developed tissue it would appear that the fibroblasts have, for the most part, their origin from the perivascular fibrous tissue of the vasa vasorum.

This process of vascularization is frequently limited to a single small area along the calcareous nodule. By no means does the entire deposit become surrounded by this granulation tissue. At times the end of an area of medial calcification alone shows this proliferative tissue change.

It is within the vascularized area lying close to the deposit of calcium salts that the osteoid tissue makes its appearance. The bony material is laid down in the interstitial tissue between the capillary loops, and the new connective tissue appears to take a prominent part in developing the matrix. Through metaplasia the connective tissue cells enter into bone formation and become the osteoblasts which are permanently arranged in the lacunæ of the new tissue. Subsequently calcium salts impregnate the groundwork. The shape of the new bone trabeculæ is in part dependent upon the presence of neighboring capillaries, around which the new structure is built.

The presence of such bone deposits without evidence of definite injury may be observed in the vessels of the extremities and occasionally in those of the thyroid, ovary, and eye. We have observed a similar reaction, though accompanied by a much greater amount of dense fibrous tissue in the vicinity of a ligature about a calcified popliteal artery. In this instance fibrosis had developed on the inner surface of the artery, as well as in the adventitia. Fragments of the former medial calcareous deposits were found in the fibrous mass and about them there were small islands of bone.

We have had an opportunity of studying a great number of specimens showing calcareous degeneration of the media. Some of these have been examined after removing the calcium salts, but the best results have been obtained when decalcification has not been carried out. It is difficult to handle this material without inducing artefacts by the ordinary methods of histological technic. Artificial fractures are easily obtained in these hard rings when cutting frozen sections. Nevertheless, as we shall point out, there is evidence that fractures of them do occur during life and may be recognized by reactionary tissue changes about the point

of fracture. The majority of the calcified peripheral vessels which we have examined were of the characters above described. The most striking feature of them was the extent of the calcareous process in the absence of reactionary changes in their vicinity. In 1914 my attention was called to a definite proliferative response in a calcified media by Prof. J. J. Mackenzie of the University of Toronto. He showed me a specimen demonstrating a fracture of a calcareous ring in the periphery artery, about which a mild inflammatory process was associated with callus formation. Since then we have studied a considerable number of arteries of old people and those from cases of diabetic gangrene and have found three in which evidences of traumatic disturbance of the calcareous process was followed by local reactionary change and callus formation.

These three specimens were obtained from elderly individuals (60, 69, 72 years). The fractures occurred in the arteries of the lower extremities, twice in the posterior tibial artery, and once in the popliteal, just behind the knee. The appearance was virtually the same in all cases. The annular calcareous deposit was of a dense crystalline character without any evidence of atheroma. At one point the ring was broken, and between the fractured ends was an organizing tissue with fibroblasts and capillaries. Close to each end of the calcareous mass was a closely-attached osteoid tissue containing osteoblasts and some calcium salts. This living bone was easily differentiated from the neighboring areas of calcification. The bony spicules were surrounded by many thin capillaries, which frequently lay in indentations in their structure. The fibroblasts appeared to have their processes enter directly into the substance of the newly-formed bone. This vascularized connective tissue formed a considerable and relatively bulky mass, both on the inner and outer surface of the fractured rings. Some of the proliferative reaction entered into the deep portion of the intima. In one specimen the area of response showed the presence of blood pigment, and in applying the iron reaction to the tissue, a positive test was obtained not only in the granular deposit of

blood pigment, but also within the bony trabeculæ. This hemorrhage had probably been a secondary occurrence subsequent to the development of the vascular callus, though it is possible that some vascular tissue had been present about the calcareous deposit prior to the fracture.

In none of the specimens was there evidence of displacement of the fractured ring. Apparently, the blood pressure within the artery restored the wall to its original shape, and the ends of the fragments were returned and in close apposition. As far as could be determined in the tissue, the soft structures lying to the inner side of the calcareous ring were uninjured, there being no thrombus deposit upon the intimal surface. It would appear that following upon the fracture a definite tissue reaction had occurred about the injury, in which fibroblasts and new-formed blood vessels were the most prominent. Associated with this response there was also a dissolution of some of the calcareous materials at the ends of the fracture, which was filled in by callus. There was nothing to indicate that these fragments had been drawn apart to leave a space at the time of injury. It appears more probable that during the formation of callus, cellular activity had also led to a removal of the calcium salts between the broken fragments. The bony structures which were found in the callus had developed by a process of metaplasia, and, similar to the bone which otherwise forms in arteries, had been closely applied to the calcium deposit.

The formation of bone within the arteries is brought about by a process not uncommonly seen in other tissues. The process is usually one of a primary calcareous degeneration, followed by an unusual vascularization around the area of deposit. It is in this vascular tissue that a metaplasia of the connective tissue leads to bone formation. This process has recently been studied in the ovary by Moschowitz.

Relatively few cases of fracture of the arteries have been described. The first of these was by Howse (1877), who reported a rupture of the axillary artery in a man of thirty-six, with extensive hemorrhage into the axilla. The patient died after twenty-five days and the torn artery was found

amidst a mass of organizing blood clot. Granulation tissue surrounded the artery, while the vessel wall itself at the point of injury grated under the knife. The calcified masses were shown to contain true bone with evidence of proliferation of the surrounding tissue. In 1886 Paul gave a very clear description of primary calcification of the media of arteries similar to the lesions described by Moenckeberg in 1903. He clearly distinguished this process from the inflammatory reactions as seen in the intima. He also noted that true ossification is not uncommon in the vessels showing simple calcareous deposits. Thromboses of the arteries, he states, frequently occur as a result of the irritation induced by the presence of the hard plates in the arterial wall. In his study he found fractures with the development of callus a common occurrence. This callus, at times, showed the presence of true bone. Bunting (1906) reporting upon the development of bone in the deep intima of the aorta of a man aged seventy-two, commented upon the evidence of trauma, hemorrhage, and inflammation in the vicinity of advanced atheromatous processes. He believed that the products of degeneration act as an irritant upon neighboring tissues and lead to the production of the granulation tissue. He also suggested that trauma may be a factor in stimulating callus about old calcareous deposits with the subsequent development of bone. In a discussion upon the development of cartilage and bone in sclerotic arteries Buerger and Oppenheimer (1908) referred to the possible influence of trauma and irritation as factors in stimulating the vascular tissue antecedent to the osseous deposit. They gave, however, no evidence of actual injury imposed upon the arterial wall. They point out that bone formation is much more frequent in the peripheral arteries than is usually recognized. Some of their illustrations suggest previous fracture in the calcareous plates. Thus we have found reference to true fracture and callus formation by only two authors.

The finding of definite fractures of calcified masses in arteries has another interesting bearing. MacCordick claimed that the calcareous deposits occurring in areas of

degeneration in arteries were not of a hard brittle nature, but in the form of a mortar-like material. This, he claimed, was the reason why surgeons were able successfully to ligate the hard arteries of elderly people. Our evidence here is to indicate the firm crystalline character of advanced medial sclerosis, not as a mortar-like paste, but in a fixed and rigid state. The presence of true fractures with callus formation is the evidence that during life the pipe-stem walls of the arteries are not apparent, but real. That the surgeon may successfully ligate these rigid arteries lies in the fact that there is healthy tissue on each side of the calcareous ring, and when his ligature closes upon and fractures the calcareous plates, the inner and outer coat of the artery are sufficient to withstand the blood pressure with little danger of spontaneous rupture. As was seen in one of our cases, organization took place in the fractures induced by ligature, not unlike the production of callus with its accompanying bone. It is, of course, to be remembered that all areas of calcification of the media do not present themselves as a crystalline deposit. In the early stages the calcium salts are laid down as a fine granular deposit, not unlike sand, through the area of degenerating muscle cells. In this stage the deposit is gritty, but I would not say mortar-like.

In two of the arteries, in which we noted the presence of fracture, the vessels were deeply seated and not readily exposed to the influence of external trauma. These vessels (posterior tibial) lie in a muscular bed where spontaneous injury may readily be received. The primary degenerative processes which eventuate in the calcareous rigidity, place the vessels at a disadvantage in their relation to the neighboring muscular structures. The sclerosed peripheral vessels lose their normal elasticity and cannot accommodate themselves to the pressure of muscular contractions of the surrounding tissues. Moreover, there is an actual lengthening of the sclerosed vessels so that their course is tortuous and no longer in the normal grooves between the muscle folds. Under these conditions the vessels may easily suffer injury

through muscular contraction and unusual bending when accommodating themselves to alteration in the pressure of the surrounding tissue. Thus it seems probable that fractures occurring in deeply-seated calcified arteries, and particularly where the vessels are surrounded by an active muscular tissue, result spontaneously as the effect of local conditions rather than from external trauma.

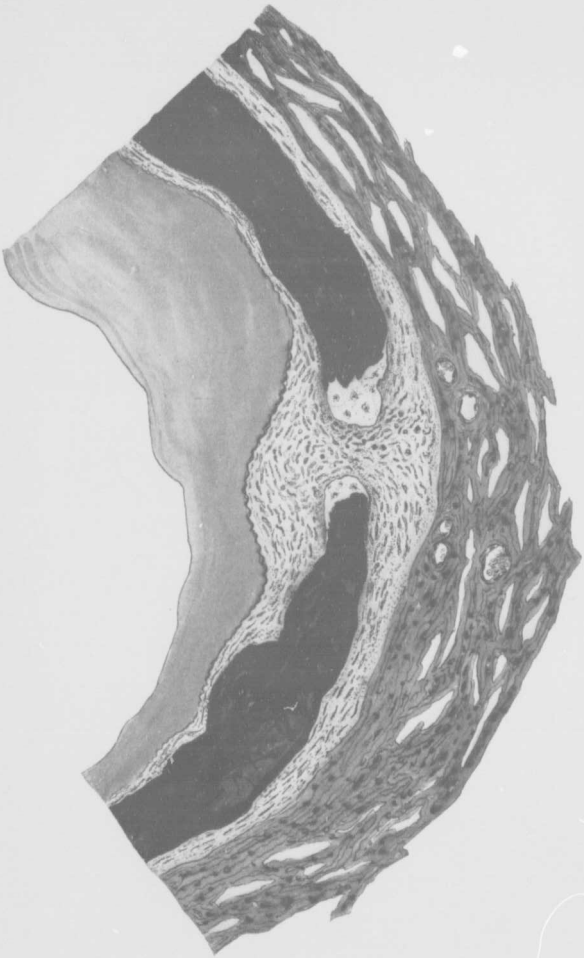
On the other hand, the fracture found in the calcified popliteal artery was probably not the result of muscular action, but due to the bending of the joint immediately in front of it. Here, however, where the vessel lies in a more exposed position, it is possible that an injury might have been received from without. Under normal conditions the arteries, as they pass various joints, lie in a loose tissue which permits them to assume easy curves during flexion, or they are placed along the outer borders of the joints where kinking of their walls cannot readily occur. As, however, the vessels become more sclerosed there is greater difficulty in moulding them for the various positions of the joint, and when an artery suffers advanced calcification acute flexion may fracture some of the calcareous rings, particularly when the tortuous course of the vessel does not permit it to move readily nor to adapt a more easy curve in the surrounding tissues. That direct trauma may lead to a fracture of a calcified artery we do not doubt, but at present it is not possible to say how frequently this actually occurs. As, however, such fractures do not necessarily entail any serious after result they give no clinical indications of their presence. In each of our cases there was no evidence that the intima had been torn and we have no history that the injury was accompanied by pain. The amount of callus which develops about the end of fractures is not sufficiently great to permit its detection in the deep-lying vessels. In the presence of a well-marked layer of living tissue on the inner side of the calcareous ring it is probably infrequent that the fracture leads to a perforation of the lumen. It is more probable that, with the distortion of the vessel at the time of injury, the inner layer of tissue becomes separated from

the calcareous masses in the media, and that with the release of the mechanical influence on the arterial wall the blood pressure smooths out the lumen.

Thus fractures of the arteries may occur through muscular activity, the flexion of joints, and direct trauma imposed upon the vessel walls. The repair of these fractures is brought about by a grade of inflammation in which fibroblasts and blood capillaries take a great part and simulate a reaction comparable to that seen in callus. These processes of repair are not uncommonly accompanied by the formation of bone at the ends of the broken calcareous rings.

BIBLIOGRAPHY.

Buerger and Oppenheimer. Jour. Exper. Med., 1908, x, 353.
Bunting. Jour. Exper. Med., 1906, viii, 365.
Cohn. Inaug. Disser. Hoenigsberg, 1886.
Harvey. Jour. Med. Res., 1907, xvii, 25.
Howse. Trans. Path. Soc., London, 1877, xxviii, 90.
MacCordick. Brit. Med. Jour., 1913, ii, 980.
Moenckeberg. Virchow's Archiv., 1903, clxxii, 141.
Moschowitz. Bulletin Johns Hopkins Hospital, 1916, xxvii, 71.
O'Brien. Inaug. Disser. Wurzburg , 1902.
Paul. Trans. Path. Soc., London, 1886, xxxvii, 216.
Rohmer. Virchow's Archiv., 1901, clxvi, 13.



FRACTURE OF CALCAREOUS RING OF MEDIA WITH CALLUS FORMATION.