Early Atherosclerotic Lesions Spiraling Through the Femoral Artery

Peter J.W. Wensing, Louis Meiss, Willem P.T.M. Mali, Berend Hillen

Abstract—Atherosclerosis is common in the adductor hiatus region. The aim of this study was to evaluate atherosclerosis in relation to morphological structure of the femoropopliteal region. Two anatomic features are thought to play an important role in the origin of these lesions: (1) curvature of the vessel, which may lead to unfavorable local hemodynamic factors that change during leg flexion; and (2) abrupt changes in stiffness of surrounding tissues of the vessel. The distal part of 23 postmortem femoral arteries were investigated. Cross sections were obtained every 1 mm over a length of 100 mm. For each cross section, lesion thickness was measured at 12 points along the circumference of the vessel. No apparent relation was found between surrounding structures of the femoral artery and location of atherosclerotic lesions. Three-dimensional reconstructions showed that atherosclerotic lesions were spiraling through the artery in 18 of 23 cases. Spiraling atherosclerotic lesions may be consistent with expected flow patterns in this part of the femoral artery. (Arterioscler Thromb Vasc Biol. 1998;18:1554-1558.)

Key Words: atherosclerosis ■ femoral artery ■ adductor hiatus

In the past 40 years, several investigations on atherosclerosis in the femoropopliteal region have been conducted. Lindbom1 angiographically and histologically studied 356 limbs after autopsy and angiographically studied 295 limbs of living people. He identified two principal sites for femoropopliteal occlusions, the main one in the adductor region and the other in the popliteal artery above the level of the knee joint. Lindbom’s findings were confirmed by Dunlop and Santos2 and Mavor.3 Watt4 stated, after comparing all previous studies, that between 60% and 70% of all femoropopliteal occlusions are located in the adductor region. He also asserted that both the left and right femoral arteries in one person are about equally affected with atherosclerosis. Scholten et al.5,6 using duplex imaging to localize both the adductor canal hiatus and femoropopliteal occlusions, found 72% of occlusions in the femoropopliteal region at the level of the adductor canal hiatus.

The causative mechanism for this phenomenon is not known. The general assumption is that, besides general atherogenic causes, local anatomic factors play an important role in the genesis of atherosclerosis at this site. These factors may include surrounding structures, branches, and local morphological characteristics of the vessel. It is noteworthy that in this region the physical properties of the surrounding tissues are dissimilar. In the adductor canal, the femoral artery is surrounded by the firm muscles of the thigh (Figure 1a). When it leaves the canal, the artery crosses the sharp edge of the aponeurosis of the great adductor muscle (Figure 1b) and enters the soft, fatty tissue of the popliteal fossa (Figure 1c).

Dunlop and Santos2 and Palma7 suggested that the cause of occlusions at this site is the repeated trauma created by the pulsatile movements of the arterial wall, where it lies in intimate contact with the aponeurosis of the great adductor muscle. This could cause intimal hemorrhage, which would be the origin of atherosclerotic lesions.

Barker8 stated that perivascular manipulations or stresses could be an initiating event in atherogenesis caused by hypoxia of the vessel wall due to obstruction of the vasa vasorum. Watt4 suggested unfavorable hemodynamic circumstances, such as the S-shaped configuration of the femoropopliteal artery or frequent branching in this area, as possible contributors to the origin of atherosclerosis. The relation between hemodynamics and atherosclerosis was originally postulated by Caro9,10 and subsequently described by Zarins et al.11 McMillan,12 and Yamamoto et al.13 Atherosclerotic lesions tend to develop where wall shear stresses are low.

To understand the origin of atherosclerosis in this area and the roles some of the above-mentioned factors may play, accurate descriptions of both the morphological characteristics and the atherosclerotic lesions is imperative. The purpose of this study was to map the location and extent of early atherosclerotic lesions in the adductor canal and adductor hiatus and to determine whether a relation exists between the location of the early plaques and surrounding structures, such as the aponeurosis of the great adductor muscle, the adductor canal hiatus, and the femoropopliteal vein and its branches.
After dissection, the arteries were infused with liquid Technovit 7001 glycolmethacrylate under a physiological pressure of 7001 mm Hg to obtain the original lumen diameter and to avoid shrinking. After hardening of the Technovit solution, the arteries were fixed in 4% formalin, pH 7.4. After fixation, vessels were decalcified in a 10% EDTA solution for 5 consecutive days and then dehydrated in an alcohol sequence ranging from 70% to 100%.

Segments of 100 mm were selected, with parts ranging from 70 mm proximal to the adductor canal hiatus to 30 mm distal to the adductor canal hiatus. Selected parts were embedded in Technovit 7100 hydroxyethylmethacrylate. Five-micrometer sections were taken every 0.5 mm for histological analysis. Sections were stained with Verhoeff’s elastic tissue stain and studied microscopically (magnification ×15 to 20). Locations of atherosclerotic lesions were recorded.

In the second group, the vessels were not reconstructed to obtain original lumen diameter, but all embalming procedures were performed at a pressure of 160 mm Hg. Procedures for dissecting and sectioning the vessels were the same as in the first group. Arteries of the third group were decalcified by using the same procedure used in the first two groups.

Vessels were embedded in a mixture of liquefied polyethylene-glycol 1000 and polyethylene-glycol 400 in a 4:1 ratio at a temperature of 40°C. After the polyethylene-glycol mixture hardened, vessels were cut perpendicular to the long axis in 1.5-mm sections using an electric slicer. The 1.5-mm sections were stained with Lawson’s elastic tissue stain and studied microscopically (magnification ×15 to 20). This procedure allowed us to record the thickness and location of lesions relative to the surrounding structures of the vessel.

Methods

Materials

All arteries were taken from donated corpses and divided into three groups. The first group, which consisted of four femoral arteries dissected within 24 hours after death, was studied histologically. Because of a shortage of fresh material, the second group, which contained six vessels, was taken from donated corpses that had been embalmed; this group was also studied histologically. The third group, containing 13 vessels from embalmed, donated corpses, was studied only macroscopically to reduce the workload. In total, 23 vessels (7 pairs of arteries and 9 single arteries) were studied. Careful comparisons of the observations in the different groups were made to justify an accumulation of the groups. Mean age was 80.5 years (range 70–96 years). The 23 arteries included 13 vessels from embalmed, donated corpses that had been embalmed; this group was also studied histologically. The third group were decalcified by using the same procedure used in the first two groups.

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Methods

For quantitative analysis, all selected segments were studied the same way. Each vessel was evaluated individually. The thickness of atherosclerotic lesions was recorded at 12 points along the circumference of the lumen by using the internal elastic lamina as a baseline measure. The first point was always on the lateral side of the artery (both left and right), and the next point was in the ventral direction. All measurements were entered into a database.

The location and severity of atherosclerotic lesions in nonembalmed and embalmed corpses were determined in the same way. Although some shrinking is to be expected and some vessels from embalmed corpses had cutting artifacts, these did not influence localization of the lesions, and it was always possible to reconstruct the lesions and obtain reliable measurements.

Radial Distribution

The first goal was to establish whether a predilection site for the atherosclerotic lesions could be determined along the circumference of the vessel. For each of the 12 locations in all vessels, the measurements were summed. This reduced the information on radial distribution to 12 figures for each vessel (one figure for each location). To compare the vessels, results were standardized for each vessel; ie, the atherosclerosis of every measure point was expressed as a percentage of the collective lesions in one particular artery (Figure 3a).

To evaluate a preferential location of atherosclerosis on the circumference of the vessel, data from all arteries were combined. This reduced the overall results to 12 figures. Each of the 12 locations was represented by a percentage of the total sum of all measurements. In addition, pairs of arteries from the same corpse were compared.

The next data analysis focused on the area where the aponeurosis of the great adductor muscle crosses the artery. In all vessels, this area was evaluated as described above.

Longitudinal Distribution

To investigate whether there was a preferred location or pattern for atherosclerosis along the length of these 100-mm segments, the sum of all measurements was calculated every 5 mm, reducing the information to 19 figures. Measurements were expressed as percentages to allow comparisons between arteries (Figure 3b).
Three-dimensional Distribution

Three-dimensional reconstructions were drawn of every segment to see if there was any relation between the radial and longitudinal distributions. The reconstruction was drawn in one plane as if the artery had been cut along its longitudinal axis and unfolded. The results of all measurements were drawn twice next to each other so that the artificially disturbed continuity would be visually restored, making the figures easier to understand. In this plane, lesions appeared as elevations, with thicker lesions having higher elevations. This method of quantification made the atherosclerotic area look like a mountain landscape (Figure 4).

Results

Atherosclerotic lesions in these vessels consisted mostly of fibrous material and had hardly any cholesterol debris (Figure 2). This observation is in agreement with those of Ross and Glomset and Ross et al. Pairs of arteries from the same corpse were about equally affected, which is consistent with the results of Watt.

Radial Distribution

The results for each artery revealed large variation. If the atherosclerotic lesions were equally distributed, each of the 12 locations would represent 8.3% of the entire amount of atherosclerosis. However, we found atherosclerosis ranging from 1 to 22%. The combined results of all vessels showed less variation. Again, if equally distributed, the mean would be 8.3% for each of the 12 locations. The amount of atherosclerosis varied from 6.8% to 10.7%. This way of calculating made it clear that in these 100-mm-long segments, no common, preferred location in the radial distribution of atherosclerosis could be established. Also, no relation with surrounding tissues was found (Figure 3a).

Pairs of arteries from the same body had a striking resemblance in circumferential location and extent of atherosclerosis in 3 of 7 pairs (Figure 3a). Three other pairs matched more or less. One pair showed no resemblance at all.

In the 20-mm-long segments where the aponeurosis of the adductor muscle crosses the artery (adductor hiatus), no apparent preferred location could be established. For individual vessels, there was considerable variation between the

Figure 2. Micrograph of a transverse section in the distal femoral artery (magnification ×15) showing an early atherosclerotic lesion consisting of fibrous tissue. There is no calcification or cholesterol debris (arrows).

Figure 3. a, Radial distribution of atherosclerotic lesions. The gray rectangles represent mean lesion thickness of all investigated arteries for each of the 12 locations. (If equally divided, the mean would be 8.3% for each location.) The 2 lines represent the left and right arteries. b, Longitudinal distribution of atherosclerotic lesions from the distal to the proximal end. The gray rectangles represent mean lesion thickness of all investigated arteries for each of the 19 locations. (If equally divided, the mean would be 5.3% for each location.) The 2 lines represent the left and right arteries. These are examples of pairs of arteries in which there was good correlation of lesion distribution between the left and right arteries.
different locations (range 0% to 25%, mean 8.3%). In the combined results of all vessels, the amount of atherosclerosis varied from 6.5% to 10.4%. This result was comparable with that of the 100-mm segments. No relation with the aponeurosis of the great adductor muscle could be found. In comparisons of left and right arteries from the same corpse, the same pairs mentioned above had the same correlations.

Longitudinal Distribution
Large variations in the longitudinal distribution of atherosclerosis became clear and ranged from 0% to 16%. If the atherosclerosis had been equally divided along the length of the artery, the percentage for every 5-mm segment would have been 5.3%.

When the results of all vessels were combined, no preferred location for atherosclerosis in relation to surrounding tissues was established. Percentages ranged from 3.8% to 6.2% (Figure 3b). These calculated data were also used to compare the pairs of arteries. Four of the 7 pairs matched, 2 pairs matched more or less, and 1 pair did not match at all (Figure 3b).

Three-dimensional Distribution
In the three-dimensional reconstructions, in which lesions were projected onto a plane representing the vessel wall, the lesions ran diagonally from one side to the other in 18 of 23 cases (Figure 4a and 4b). This was more evident in some cases than in others. In a complete lumen reconstruction, the lesions spiral through the artery. The pitch of these helices ranged from 14 to 33 mm (33° to 60°) for one complete rotation. No correlation in the direction of the helix between the different vessel segments was found. The direction of the helix was clockwise in 9 of the 11 left arteries and counterclockwise in the remaining 2. The direction was counterclockwise in 4 of the 7 right arteries and clockwise in the remaining 3.

Discussion
The main finding in this study is a preferential helical pattern in the localization of atherosclerotic lesions in the adductor canal. In 18 of 23 vessels, lesions had followed a spiral pattern through the artery. There was no preferred location in the radial or longitudinal distribution of atherosclerosis. A similar phenomenon was observed by Fox et al,16 who described a spiral pattern of early fatty lesions in the left anterior descending coronary artery. No apparent relation with the surrounding structures was found. A direct relation with the aponeurosis of the great adductor muscle, as described by Palma,7 could not be established. This makes the theories of microtrauma to the vessel wall and obstruction of the vasa vasorum causing hypoxia unlikely.

A relation between localization of atherosclerotic lesions and hemodynamics seems more likely. Cornhill et al17 investigated the topography of early atherosclerotic lesions in human aortas. Their results also indicate that hemodynamics play a role in the initiation and localization of atherosclerosis. Various authors have described the relation between atherosclerosis and shear stress on the vessel wall.9–13

Atherosclerotic lesions develop where wall shear stresses are low. These shear stresses are determined by local hemodynamic factors (eg, blood flow velocity and artery geometry). The morphological characteristics of a vessel have great influence on local hemodynamics. Because the adductor region is close to the knee joint, flexion of the leg influences local morphological features of the femoropopliteal artery. This certainly will have dramatic effects on the hemodynamic circumstances. Both Watt4 and Lindbom1 speculated on the influence of leg flexion on atherogenesis in the adductor and popliteal region. They described possible changes in morphological characteristics of the artery during leg flexion. In vivo studies by Wensing et al18 using magnetic resonance angiography revealed that the distal part of the femoral artery curls up in the adductor canal during leg flexion. This phenomenon increases with age, and in older subjects, these small curves do not disappear completely when the leg is extended.

If there is a relation between hemodynamics and atherosclerosis in the femoral artery, spiraling flow and helical low
wall shear stresses are to be expected. Such phenomena have been described by Frazin et al.20 and Kilner et al.21 but no detailed investigations have been conducted. Stonebridge and Brophy21 observed spiral flow in infrarougal vessels with fiberoptic angioscopy. In 51 of 75 examined vessels, they found ribbing and spiral folds in endoluminal surfaces, even in normal and minimally diseased arteries. Finlay et al.22 described a helical arrangement of the endothelium in human cerebral arteries. The mean pitch was 14.5°, and left- and right-sided angles were equally divided. He also expects external dynamic or mechanical factors to play a role in this phenomenon.

Mathematical computations by Hoogstraten et al.23 showed that blood flow in an artery with two successive, gentle bends, as occur in the femoral artery, is complicated. Flow in the second bend is influenced strongly by the first bend. Using magnetic resonance flowmetry in a model of a tortuous femoral artery, Wensing and Scholten24 identified helical flow patterns. These findings all support the theory that hemodynamics and atherosclerosis are closely related.

It seems probable that the left and right legs from one person will have general symmetry and therefore the same changes in morphological features during leg flexion. It is to be expected that identical anatomic and physiological conditions will cause comparable atherosclerotic lesions in the left and right legs. This could account for the fact that 6 out of 7 pairs of arteries were closely correlated in localization and extent of atherosclerotic lesions.

De Souza25 described a free-gliding mechanism in the longitudinal and transversal directions of the femoral vessels in the adductor canal. This mechanism seems to be impaired in older people. If this is true, then the femoral artery will be fixed in the adductor canal and leg flexion will have less influence on the morphological characteristics of the vessel. Not only is the artery fixed but also its flow profile and pattern of low wall shear stresses. From a hemodynamic viewpoint, this could benefit atherogenesis at this location.

No differentiation between men and women was made because the aim of this study was not to investigate general atherogenic factors but to study the effect of local anatomic factors on the onset of early atherosclerotic lesions. The topography of the adductor canal region is not expected to show large variations between sexes.

In conclusion, although mapping of early atherosclerotic lesions revealed no apparent relation with surrounding structures, a preferential helical distribution of the lesions was established.

References
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