RELATIONSHIP BETWEEN ANASTOMOTIC
HEMODYNAMICS AND
INTIMAL THICKENING

Intimal thickening is a characteristic of the normal adaptive and healing response of arteries and usually is self-limiting. Under certain circumstances, however, intimal proliferation is progressive and results in lumen stenosis. Such intimal hyperplasia is particularly prominent at prosthetic vascular graft anastomoses in lower extremity bypasses and frequently leads to graft failure. The precise factors that regulate and control intimal thickness are incompletely understood but include hemodynamic forces. Wall shear stress has been shown to be inversely related to intimal thickness in both human and experimental arteries. In the human carotid artery intimal thickness and plaque localization is related to low wall shear stress.¹ In experi-
mental aortic coarctations in monkeys, intimal thickening is inhibited in areas of high shear stress and promoted in areas of low wall shear stress. Oscillation of wall shear stress direction and increased particle residence time have also been implicated in intimal thickening. These hemodynamic factors are strongly influenced by changes in blood flow and heart rate, which are dependent on activity levels and exercise. Thus an improved understanding of anastomotic hemodynamic conditions under varying flow conditions may lead to new insights into the mechanism and control of intimal hyperplasia.

The purpose of this investigation is to (1) characterize the near-wall flow field in model end-to-side anastomoses and to relate the findings to experimental anastomotic intimal thickening, and (2) to determine the influence of exercise flow conditions on the anastomotic flow field.

Method

Iliofemoral bypass grafts were constructed in mongrel dogs with saphenous vein grafts and polytetrafluoroethylene prostheses. In vivo flow conditions were measured with an electromagnetic flowmeter and pulsed Doppler ultrasonography, and the vessels were then pressure-perfusion fixed, excised, and cast to preserve in vivo geometry. Intimal thickening was assessed in chronic experiments in which animals were fed an atherogenic diet for 8 weeks. After pressure-perfusion fixation, each anastomosis was serially sectioned, and the distribution of lesions was mapped by use of quantitative morphometry and three-dimensional reconstruction.

Data from casts of animal anastomoses were used to construct two large-scale (7.5 times in vivo dimensions) transparent silicone rubber models of the distal end-to-side anastomosis. The graft-to-host vessel diameter ratio was 1:1, and the hood length-to-vessel diameter ratio was 4:1 and 8:1.

The models were placed in a pulsatile flow system that allowed physiologic flow waveforms to be used. Flow patterns were visualized by the injection of small (500 μm) almost neutrally buoyant particles illuminated with either flood lights or helium-neon laser light. Standard VHS video and 35 mm photography were used to record particle motion. Pulsatile flow conditions were modeled after measured canine femoral artery flow waveforms. The anastomotic flow field was assessed under simulated resting and exercise flow conditions. Resting flow conditions were defined as a heart rate of 80 beats/minute and a peak Reynolds number of 750. Exercise flow conditions were defined as a heart rate of 140 beats/minute and a peak Reynolds number of 1500. During exercise there was a two and one-half-fold increase in mean flow compared to resting.

Results

Flow patterns in the area of end-to-side anastomoses are remarkably complex. Under resting conditions a large area of flow separation develops in the anastomotic sinus with flow stasis and prominent, particle trapping. This was most prominent in the proximal portion of the anastomosis. Particles also accumulated at the lateral walls. In the distal portion of the anastomosis, where flow exited into the distal outflow artery, there was rapid flow and short particle residence times. Particles tended to reside in the anastomosis for extended periods, even to the point of permanent accumulation along the side wall. Along the floor of the anastomosis in the host vessel oscillation of shear stress was prominent whereas wall shear stress was unidirectional distally.

Under exercise conditions, the area of flow separation was significantly reduced and anastomotic stasis was virtually eliminated. Trapped particles along the lateral walls began to clear immediately as a result of more vigorous secondary flow patterns. All particles were gone within 5 to 6 pulsatile cycles of exercise flow. The wall shear was notably larger in magnitude, and relatively strong vortices were created which removed stagnant particles and cleared out the anastomotic region. Along the floor of the anastomosis, the area subjected to oscillating shear stress was reduced.

Histologic sections revealed intimal thickening at the suture line along the lateral wall of the anastomotic sinus in a region of prolonged particle residence time as well as along the floor of the anastomosis in the region of flow separation and shear stress oscillation. Exercise conditions decreased particle residence time significantly and increased the levels of wall shear stress, both at the lateral walls of the sinus as well as along the floor where the maximum flow velocities entering the anastomosis were directed.

Discussion

These results indicate that hemodynamic characteristics known to promote intimal thickening, namely low wall shear stress, flow separation, increased particle residence time, and oscillation in shear stress are present within vascular graft anastomoses. These factors may play a role in intimal thickening. However, the precise role these factors play, if any, in anastomotic intimal hyperplasia are unknown. It is known, however, that the normal artery wall requires an optimum wall shear for homeostasis, and that the artery wall remodels its structure if wall shear departs from this value over a sustained period of time. The focal nature of intimal thickening, intimal hyperplasia, and atherosclerosis may well be related artery wall responses to local conditions of exposure to low wall shear. Furthermore, the eventual evolution of a developing plaque, at least until it reaches certain limits, may be influenced by the local shear stress and the residence time of atherogenic substances. Although excessive intimal thickening appears to be prevented in arteries where the mean wall shear stress exceeds approximately 15 dynes/cm², recent studies in our laboratory suggest that the determining factor may be the maximum wall shear experienced during the cycle regardless of direction and not simply the mean shear value.

The conditions of low wall shear stress and flow stasis that exist at rest in our model anastomoses were reversed...
during exercise. Similar elimination of adverse hemodynamic conditions have been demonstrated in an aortic model under exercise flow conditions. Since stasis has been related not only to intimal thickening but also to graft thrombosis, a structured program of exercise that would periodically "clear" the anastomosis may be beneficial in extending graft patency and minimizing intimal thickening. The amount, frequency and duration of exercise periods necessary for clinical benefit requires further investigation.

Christopher K. Zarins, MD
Don P. Giddens, PhD
University of Chicago
Chicago, Ill.

REFERENCES:


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