The thin layer of cells that lines the interior of blood vessels, known as the endothelium, plays a complex role in vascular biology. The endothelium mediates blood vessel tone, hemostasis, neutrophil recruitment, hormone trafficking, and fluid filtration. Endothelial dysfunction, as defined by a lack of NO, has been linked to a variety of disease states, including atherosclerosis, diabetes mellitus, coronary artery disease, hypertension, and hypercholesterolemia. Indeed, restoration of endothelial function is one of the earliest recognizable benefits of statin therapy. In 1995, James Liao and colleagues published a study in the JCI demonstrating that NO is a vascular protective factor that limits endothelial activation and prevents leukocyte adhesion to the vessel wall.

The idea that endothelium-derived NO could modulate leukocyte adhesion was first demonstrated by Kubes and colleagues, who showed that inhibitors of eNOS could increase neutrophil adherence to mesenteric venules (4). But the precise mechanism by which NO prevents leukocyte recruitment to the vascular wall was not known. To address this question, we first demonstrated that NO donors suppressed the expression of VCAM-1, ICAM-1, and E-selectin in response to a variety of proinflammatory cytokines. These results suggested a central mechanism for anti-inflammatory effects of NO. Because the induction of these cellular adhesion molecules was mediated, in part, through the activation of the transcription factor, NF-κB (5), we postulated that NO prevented endothelial cell activation through inhibition of NF-κB. Using VCAM-1 expression as a marker of endothelial cell activation, we found that NO donors could inhibit cytokine-induced endothelial cell activation and monocyte adhesion under nonstatic conditions via inhibition of NF-κB (1). These findings indicated that exogenous NO could have therapeutic benefits in vascular inflammatory diseases, and subsequent studies have shown amelioration of atherosclerosis and other vascular diseases with NO donor therapy (6).

An important unresolved question at that time was whether endothelial dysfunction or endothelial cell activation was the primary initiator of atherosclerosis. Endothelial cell activation by proinflammatory cytokines could clearly lead to endothelial dysfunction by inhibiting eNOS expression (7) and decreasing NO bioavailability through the induction of ROS (8). It was unclear how the endothelium was activated prior to the recruitment of inflammatory cells. A clue to this puzzle came from the seminal work of Li and colleagues, who showed that hypercholesterolemia brought on by an atherogenic diet could rapidly induce VCAM-1 expression in the rabbit endothelium (9). Additionally, hypercholesterolemia had previously been shown to produce endothelial dysfunction, in part, through inhibiting eNOS activity and/or NO bioavailability (10, 11).

Based upon these observations, we investigated whether endothelial dysfunction could lead to endothelial cell activation in the absence of cytokines. We found that suppression of basal eNOS activity by L-NG-arginine methyl ester (L-NAME) led to rapid induction of VCAM-1 expression and increased monocyte adhesion (1), indicating that endogenous endothelium-derived NO could basally and tonically inhibit endothelial cell activation. These findings provided a mechanistic link by which mediators of endothelial dysfunction, such as hypercholesterolemia, smoking, or oxidative stress, could induce or enhance endothelial cell activation, leading to increased vasoconstriction, smooth muscle proliferation, platelet aggregation, leukocyte adhesion, LDL oxidation, and MMP activation (Figure 1). These results also suggested that areas of turbulent flow in the vessel wall, which would have less endothelium-derived NO, would be more prone to endothelial cell activation and atherosclerosis. Indeed, atherosclerotic lesions tend to develop in areas of vascular branching that are exposed to turbulent rather than laminar flow, and mice with targeted deletion of eNOS develop increased atherosclerosis and vascular inflammation (12).

Since the publication of our study, the known vascular protective role of endothelium-derived NO has expanded beyond its inhibitory effects on endothelial-leukocyte interaction and leukocyte trafficking to include inhibitory effects on platelet reactivity, smooth muscle contraction and

Conflict of interest: The author has declared that no conflict of interest exists.

Citation for this article: J Clin Invest. 2013;123(2):540–541. doi:10.1172/JCI66843.
proliferation, and modulation of vascular matrix remodeling and angiogenesis. Conditions, such as laminar flow, or pharmacological agents, such as estrogens, HMG-CoA reductase inhibitors (statins), and angiotensin-converting enzyme inhibitors, which enhance endothelium-derived NO, have generally been found to be vascular protective and potentially antiatherogenic. In contrast, antiangiogenic therapies, which impair endothelium-derived NO through inhibition of VEGF signaling, occasionally cause endothelial dysfunction and hypertension in patients with cancer (13).

Acknowledgments

J.K. Liao is supported by grants from the NIH (HL052233, NS070001, DK086005).

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