It is well known that cardiovascular disease is less frequent in premenopausal women compared with men but rises rapidly in postmenopausal women. Such early observations led to the hypothesis that estrogen therapy will reduce the risk of postmenopausal women developing cardiovascular disease. However, observational studies have led to conflicting results, with some studies reporting reductions in cardiovascular disease in postmenopausal women taking estrogens, whereas others observed no beneficial effects. Rather, increases in the risk of coronary heart disease and stroke have been reported, particularly for women who are older and those with a long hormone-free interval. Such findings have been reported, particularly for women who are older and those with a long hormone-free interval. Some studies indicate that estrogen therapy is associated with reductions in cardiovascular risk, whereas others observed no beneficial effects. Rather, increases in the risk of coronary heart disease and stroke have been reported, particularly for women who are older and those with a long hormone-free interval.

Estrogen activates multiple signaling pathways in most target cells and tissues, including those within the cardiovascular system. Functional ERs, ERα and ERβ, are expressed on cardiomyocytes in the heart and by endothelial and smooth muscle cells within blood vessels. Early studies indicated that ERs are ligand-activated transcription factors, which exist primarily in the nucleus complexed with chaperones. On estrogen binding changes in receptor conformation leads to chaperone dissociation and receptor dimerization, followed by DNA binding at proximal promoter sites, where recruitment of coactivators or corepressors leads to gene activation. These nuclear events usually require hours or days for maximal gene activation.

ER-mediated genomic activation can also be upregulated by growth factor signaling pathways via ER phosphorylation mediated by kinases. ERs also have the ability to signal rapidly, in an apparent nonnuclear manner, by activating specific kinases and their effector molecules. Nonnuclear (ie, membrane) ER signaling activates endothelial NO synthase and promotes endothelial cell growth and migration. In endothelial cells, membrane ERs, which do not possess a transmembrane domain, are mostly located within caveolae/lipid rafts (ie, specialized cholesterol-rich membrane organelles that compartmentalize signal transduction molecules), with ERs complexed with caveolin-1, Gαi, and striatin. Striatin is a member of the WD (tryptophan [W], aspartic acid [D]) repeat protein family containing a caveolin-binding domain as well as a calmodulin binding domain and serves as a molecular anchor and scaffold for assembly of proteins required for rapid estrogen-induced signaling. In the study by Moens and associates in this issue of Circulation, the actions of this receptor complex are defined using a novel transgenic mouse expressing a disrupting peptide consisting of the striatin-binding domain within ERα. This peptide prevents complex formation between ERα and ERβ and striatin and inhibits membrane ER signaling. In this mouse model rapid ERα signaling is lost; specifically, estrogen is unable to initiate phosphorylation of protein kinase B and extracellular signal regulated kinase and elevate endothelial NO synthase gene transcription. Using aortic tissue they examine the importance of rapid signaling for transcriptional responses of vascular tissue to estrogen. Inhibiting membrane ER signaling resulted in fewer genes being regulated by estrogen with many implicated in vascular development, function, and disease. This is consistent with recent findings in MCF-7 breast cancer cells where nuclear and membrane ER signaling contribute to gene expression. About 50% of differentially regulated genes showed opposite effects in aortas from wild-type and transgenic mice, and many estrogen nonregulated or downregulated genes were upregulated when membrane estrogen signaling was inhibited, indicating significant cross talk between nuclear and membrane ER signaling processes. Overall, they demonstrate that rapid signaling plays a major role in determining the extent and pattern of estrogen-mediated vascular gene responses. Because intact aortic tissue was used it is not possible to assign particular estrogen-mediated gene responses to smooth muscle cells, endothelial cells, or adventitial fibroblasts, but many are likely attributable to smooth muscle cells, the most abundant cell type in the aorta. It would be of interest to confirm that smooth muscle cells account for most of the observed effects and also determine the extent to which these responses are apparent in vivo in female ovariectomized mice chronically treated with estro-
ERs.ERs.4 Macrophages, lymphocytes, megakaryocytes, and platelets all express ERs and are important participants in vascular pathologies. They also demonstrate that this pathway influences the extent and pattern of gene activation by nuclear receptors and corepressor characteristics and transcription factor (TF) function as well as vascular cell function. Moens and associates demonstrate that rapid striatin-dependent membrane ER signaling by estrogen is vasoprotective, regulating endothelial and vascular smooth muscle cell function in vivo. They also demonstrate that this pathway influences the extent and pattern of gene activation by nuclear ERs.5 Macrophages, lymphocytes, megakaryocytes, and platelets all express ERs and are important participants in vascular pathologies. The significance of rapid striatin-dependent membrane ER signaling in regulating their function remains to be determined. ER indicates estrogen receptor; eNOS, endothelial NO synthase; Akt, protein kinase B; PI3K, phosphatidylinositol 3-kinase; and MAPK, mitogen-activated protein kinase.

Figure. ER signaling in vascular cells. ERs are ligand-activated transcription factors that translocate to the nucleus on binding estrogen (E) to regulate gene expression. They bind to estrogen response elements (ERE), displace corepressors (CoR), and recruit coactivators (CoA). Estrogen also binds to ERs at the cell membrane, within caveolae where the receptor exists as a complex with other proteins, including Gai, caveolin-1 (Cav-1), and striatin, and rapidly activates various kinases, including Akt, PI3K, and MAPK altering coactivator and corepressor characteristics and transcription factor (TF) function as well as vascular cell function. Moens and associates demonstrate that rapid striatin-dependent membrane ER signaling by estrogen is vasoprotective, regulating endothelial and vascular smooth muscle cell function in vivo. They also demonstrate that this pathway influences the extent and pattern of gene activation by nuclear ERs. They identify transcription factors, signaling molecules, cytokines, and chemokines as well as molecules involved in immune responses.7 Although not specifically studied, the authors propose that changes in transcription factor characteristics induced by kinases activated by rapid membrane ER signaling account for the ability of this signaling system to alter gene expression. Their analysis of differentially expressed genes identifying signaling pathways overrepresented in the microarray data supports this hypothesis.

The studies of Moens and associates also have important implications for vascular remodeling. They demonstrate that inhibition of platelet-derived growth factor–stimulated vascular smooth muscle cell proliferation and endothelial cell migration are highly dependent on membrane ER signaling. To determine the in vivo relevance of the in vitro findings the authors examine the effects of inhibiting membrane estrogen signaling on vessel structure after carotid artery injury. They demonstrate that inhibiting membrane ER in the injured arteries attenuates estrogen-mediated reductions in smooth muscle cell proliferation. Furthermore, the estrogen-mediated reduction in media thickness was also attenuated. Previously, an estrogen dendrimer conjugate that activates membrane ER without initiating nuclear ER signaling was shown to attenuate intima development in injured arteries.11

This study by Moens and associates makes several important advances in our understanding of rapid membrane ER–initiated cardiovascular effects of estrogens. First, the study definitively establishes that striatin-dependent membrane ER signaling is critical for vascular estrogen responses and for determining overall ER-mediated vascular gene responses, including those important for vascular function and disease. Second, the study demonstrates the importance of this signaling system in determining blood vessel responses to injury in vivo. However, although the study demonstrates the importance of striatin-dependent membrane ER signaling in endothelial cells and vascular smooth muscle in response to vessel injury (see Figure), further studies will be required to obtain a more comprehensive picture as to the overall importance of this signaling pathway in protecting against more complex vascular disorders such as atherosclerosis, instances where inflammation regulated by immune cells influences disease outcome. Estrogen regulates macrophage characteristics and activity via ERα-dependent signaling, including their phenotype, phagocytic capacity, and expression of BAFF (B cell activating factor belonging to the tumor necrosis family), a cytokine critical for survival of proatherogenic B2 cells,12–14 but the importance of striatin-dependent membrane ER signaling has not been investigated. This also applies to CD4+ T cells, where estrogen enhances responsiveness.15 Because estrogen can also influence thrombomodulin,16 it will also be important to determine whether the striatin-dependent ER signaling pathway influences megakaryocytes and the platelet proteome.
The findings of Moens and associates clearly establish an important role for estrogen-mediated, rapid striatin-dependent membrane ER signaling in blood vessels, which regulates gene expression and initiates vasoprotective effects in mice. The elegant study is an important step forward in more clearly defining membrane ER–dependent mechanisms by which estrogen regulates blood vessel responses in vivo. However, the clinical relevance of the findings remains to be explored and will require additional studies in human blood vessels. This is particularly important given the disparity between the beneficial effects of estrogen therapy in many animal models of vascular disease and humans.

Sources of Funding

This work was supported by a grant from the National Health and Medical Research Council of Australia, No 1030515.

Disclosures

None.

References


Key Words: Editorials, Estrogens, Hormones, Signal transduction, Vasculature.
Striatin-Dependent Membrane Estrogen Receptor Signaling and Vasoprotection by Estrogens
Alexander Bobik

Circulation. 2012;126:1941-1943; originally published online September 20, 2012;
doi: 10.1161/CIRCULATIONAHA.112.138958

Circulation is published by the American Heart Association, 7272 Greenville Avenue, Dallas, TX 75231
Copyright © 2012 American Heart Association, Inc. All rights reserved.
Print ISSN: 0009-7322. Online ISSN: 1524-4539

The online version of this article, along with updated information and services, is located on the World Wide Web at:
http://circ.ahajournals.org/content/126/16/1941

Permissions: Requests for permissions to reproduce figures, tables, or portions of articles originally published in Circulation can be obtained via RightsLink, a service of the Copyright Clearance Center, not the Editorial Office. Once the online version of the published article for which permission is being requested is located, click Request Permissions in the middle column of the Web page under Services. Further information about this process is available in the Permissions and Rights Question and Answer document.

Reprints: Information about reprints can be found online at:
http://www.lww.com/reprints

Subscriptions: Information about subscribing to Circulation is online at:
http://circ.ahajournals.org//subscriptions/