In this journal, 14 years ago, Price et al reported that 2 weeks of warfarin treatment in young rats caused massive focal calcification of the artery media. It had been known for years that warfarin could induce mineral deposition in the arteries of rodents, and the phenomenon was so robust that warfarin was often used as an experimental model for vascular calcification, but the mechanism was unknown.

See accompanying article on page 237

In this issue, Tantisattamo et al provide evidence from a large sample of patients that the prevalence of vascular calcification detected by mammography is greater in women taking warfarin therapy. If one accepts the fair assumption that calcification of arteries in breast tissue reflects that occurring in other arteries of rodents, and the phenomenon was so robust that warfarin was often used as an experimental model for vascular calcification, but the mechanism was unknown.

Their work ties together a series of previous laboratory observations. Twenty-one years ago, calcified human carotid atherosclerotic plaque were found to express osteogenic differentiation factors, including bone morphogenetic protein (BMP)-2. Four years later, skeletal biologists found, unexpectedly, that mice deficient in a cartilage protein, matrix Gla protein (MGP), develop widespread aortic and arterial calcification. How MGP could inhibit mineralization was uncertain, but such γ-carboxyglutamic acid (Gla)–containing proteins are known for their ability to bind calcium and hydroxypapatite, so it was surmised that MGP inhibits mineralization by directly binding and limiting calcium mineral crystal growth, which it may in part. However, the late Marshall Urist, in his work leading to the discovery of BMP activity (before the protein had been purified), noted—as a methodological aside—that extraction of BMP activity from skeletal bone was extremely difficult unless MGP was removed first. On the basis of that clue, Boström et al tested and found that MGP binds BMP and inhibits its osteoinductive function. Importantly, Schurgers et al demonstrated that MGP function depends on its γ-carboxyglutamatic acid residues. These residues arise via a post-translational modification that requires an enzyme that, in turn, requires vitamin K as a cofactor. Warfarin blocks this action of vitamin K on γ-carboxylation in general although its intended targets are Gla proteins other than MGP. Altogether, these observations indicate that warfarin blocks activation of matrix Gla protein, preventing both its opposition to BMP and preventing its direct opposition to mineral apposition. In effect, canceling out the double negatives, warfarin enables mineralization.

To project other possible consequences of MGP dysfunction in the context of warfarin, one may again consider the extreme case of the MGP knockout mouse. Unexpectedly, these mice develop widespread arteriovenous malformations (AVMs) in lungs, kidneys, and brain, resulting in an increased risk for intracranial bleeding and stroke. These knockout mice also have excessive angiogenic sprouting, which may result in a more friable vasculature. AVMs are also found in hereditary hemorrhagic telangiectasia (HHT) 1 and 2, which results from mutations in the endoglin (Eng; HHT1) or activin receptor-like kinase 1 (Alk1; HHT2) genes. Endoglin is a coreceptor required for ALK1 signaling. However, because the prevalence of AVMs in both mice and humans with HHT is significantly <100%, it has been suggested that a secondary insult is necessary to trigger AVMs in subjects with HHT. Because MGP is a downstream target of ALK1 in a feedback loop responsive to BMP activity, it is likely that alterations in ALK1 also alter the MGP response. In adult life, although the level of BMP activity may be so low as to have little or no consequence, a secondary insult may occur to induce BMP, such as inflammation, disturbed flow, or vascular trauma. In that case, without the customary MGP response as mediated by ALK1, there is unopposed action of BMP, which may trigger initiation of AVMs and pathological neoangiogenesis.

Altogether, these considerations raise a speculative concern that patients on warfarin may have increased propensity for developing AVMs or abnormal angiogenesis, perhaps more fragile microvasculature, and thereby, an increased risk of bleeding. Such vascular abnormalities may contribute to the dramatic increase in risk of intracranial hemorrhage seen with higher doses of warfarin, which has been generally attributed to impaired coagulation. Such an effect of warfarin on the vasculature may even diminish the capacity of vitamin K as an antidote. Interestingly, in excess, MGP prevents the completion of development of the pulmonary arterial tree in mice, suggesting that MGP, although first recognized as a cartilage matrix protein, may serve as a key safeguard for the competence and solvency of the vasculature.

Finally, it is important to bear in mind the clinical benefits of warfarin in preventing thrombotic events, such as in patients with atrial fibrillation, prosthetic cardiac valves, and deep vein thrombosis. There are now alternative anticoagulants that act through mechanisms other than vitamin K antagonism. However, their
effects on vascular calcification have not been analyzed. Further clinical research—similarly controlled for renal disease and atherosclerotic risk factors—is warranted to test for effects of warfarin and alternative anticoagulants, not only on coronary, carotid, and aortic calcification but also on angiogenesis, arteriovenous malformations, and other vascular pathology.

Sources of Funding
We acknowledge research funding from National Institutes of Health grants from the Heart, Lung and Blood Institute (HL114709, HL118650 for Dr Demer and HL30568, HL81397, and HL112839 for Dr Boström), as well as from the Institute for Diabetes and Digestive and Kidney Disease (grant DK081346 for Dr Demer).

References


Key Words: matrix Gla protein ◼ vascular calcification ◼ warfarin
Conflicting Forces of Warfarin and Matrix Gla Protein in the Artery Wall
Linda L. Demer and Kristina I. Boström

Arterioscler Thromb Vasc Biol. 2015;35:9-10
doi: 10.1161/ATVBAHA.114.304793
Arteriosclerosis, Thrombosis, and Vascular Biology is published by the American Heart Association, 7272 Greenville Avenue, Dallas, TX 75231
Copyright © 2014 American Heart Association, Inc. All rights reserved.
Print ISSN: 1079-5642. Online ISSN: 1524-4636

The online version of this article, along with updated information and services, is located on the World Wide Web at:
http://atvb.ahajournals.org/content/35/1/9

Permissions: Requests for permissions to reproduce figures, tables, or portions of articles originally published in Arteriosclerosis, Thrombosis, and Vascular Biology 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 Arteriosclerosis, Thrombosis, and Vascular Biology is online at:
http://atvb.ahajournals.org//subscriptions/