

Dual Anticoagulant and Antiplatelet Therapy for Coronary Artery Disease and Peripheral Artery Disease Patients

Nigel Mackman, Henri M.H. Spronk, George A. Stouffer, Hugo ten Cate

Atherosclerosis is an arterial disease that progresses with age and affects many people in the world.¹ In the United States and Western Europe, cardiovascular disease (CVD) caused by atherosclerosis is the leading cause of death. In advanced atherosclerosis, there is narrowing of the arterial lumen to the extent that tissue ischemia can occur when metabolic demands increase (eg, coronary ischemia with angina). In severe cases, acute rupture or erosion of atherosclerotic plaques lead to the rapid formation of intravascular thrombi, a process referred to as atherothrombosis. Clinical manifestations of atherothrombosis occur in the heart (coronary artery disease [CAD] and myocardial infarction [MI]), brain (ischemic stroke), and peripheral arteries (peripheral artery disease [PAD]). CAD can be divided into stable disease and unstable disease that includes acute coronary syndrome (ACS) with ST-segment–elevation MI (STEMI) or non-STEMI.

Arterial thrombi are primarily composed of platelets (so-called white clots).² However, cross-linked fibrin strands stabilize the clot. Plaques contain many platelet activators, including collagen (Figure). In addition, plaques contain high levels of tissue factor that activates the coagulation cascade (Figure). Importantly, platelets and the coagulation cascade are activated in parallel, and there is crosstalk between the 2 pathways. For instance, thrombin is a potent activator of human platelets through cleavage of protease-activated receptors (PARs; PAR1 and PAR4),^{3,4} and fibrinogen is used to bridge activated platelets. Conversely, activated platelets enhance coagulation by providing coagulation factors and by presenting a negatively charged phospholipid surface that facilitates the assembly of cofactor/coagulation protease complexes and thrombin generation.

Platelet inhibitors are the primary therapy used to prevent arterial thrombosis in CVD patients.^{5,6} The standard medical treatment for ACS patients and patients receiving percutaneous coronary intervention (PCI) with an intracoronary stent is dual antiplatelet therapy (DAPT) with aspirin and a P2Y12 inhibitor.⁵ Aspirin irreversibly inhibits cyclooxygenase-1 and prevents platelet-dependent thromboxane formation. P2Y12 inhibitors include thienopyridines, such as clopidogrel and

prasugrel, and cyclopentyltriazolopyrimidine-type inhibitors, such as ticagrelor.⁷ Clopidogrel and prasugrel are prodrugs that require activation by cytochrome P450 enzymes in the liver. Ticagrelor is a direct acting noncompetitive inhibitor of P2Y12.

DAPT is recommended for a minimum of 6 months in patients with stable CAD receiving a drug-eluting stent and for 12 months in patients with ACS (the majority of whom undergo PCI with stenting).⁸ After this time, therapy can be changed to a single antiplatelet agent depending on the balance between risk of recurrent ischemic event versus risk of bleeding with DAPT. Despite continued antiplatelet therapy, patients remain at risk for recurrent cardiovascular events, particularly in those at highest risk, such as patients with diabetes mellitus, PAD, and complex CAD. The current recommended treatment for patients with stable CAD is low-dose aspirin or clopidogrel if they do not tolerate aspirin.⁹ The recommended treatment for patients with PAD is single antiplatelet therapy.¹⁰ However, despite antiplatelet therapy, ≈2% to 5% of CAD and PAD patients annually have major adverse cardiovascular events.^{11–15}

Clinical trials have compared the efficacy and safety of different antiplatelet agents and combinations of antiplatelet agents in CVD patients, attempting to find more effective and safer strategies to prevent recurrent atherothrombotic events (Table). A recent review discusses these different trials in detail.¹⁶ In this brief review, we selected a few trials to illustrate differences between trials and the relationship between efficacy and safety. Comparison of different trials is difficult because they are performed at different times and include different groups of patients.

The TRITON-TIMI 38 trial (Trial to Assess Improvement in Therapeutic Outcomes by Optimizing Platelet Inhibition with Prasugrel- Thrombolysis in Myocardial Infarction 38) enrolled >13 000 patients with ACS (either STEMI or non-STEMI) of which 99% underwent PCI. The more potent P2Y12 blocker prasugrel was superior to clopidogrel in reducing the combined end point of vascular death, MI, or stroke in patients with ACS, but there was a higher rate of bleeding with

Received on: December 20, 2017; final version accepted on: January 31, 2018.

From the Thrombosis and Hemostasis Program, Division of Hematology and Oncology (N.M.) and Division of Cardiology (G.A.S.), Department of Medicine, McAllister Heart Institute, University of North Carolina at Chapel Hill; and Laboratory for Clinical Thrombosis and Haemostasis, Thrombosis Expert Centre, Department of Internal Medicine (H.M.H.S., H.t.C.) and Department of Biochemistry (H.M.H.S., H.t.C.), Cardiovascular School of Medicine (Cardiovascular Research Institute Maastricht), Maastricht University Medical Centre, the Netherlands.

Correspondence to Nigel Mackman, PhD, Division of Hematology and Oncology, Department of Medicine, 111 Mason Farm Rd, 2312C, Medical Biomolecular Research Bldg, CB number 7126, University of North Carolina at Chapel Hill, Chapel Hill, NC 27599. E-mail nmackman@med.unc.edu

Visual Overview—An online [visual overview](#) is available for this article. (*Arterioscler Thromb Vasc Biol.* 2018;38:726-732. DOI: 10.1161/ATVBAHA.117.310048.)

© 2018 American Heart Association, Inc.

Arterioscler Thromb Vasc Biol is available at <http://atvb.ahajournals.org>

DOI: 10.1161/ATVBAHA.117.310048



Nonstandard Abbreviations and Acronyms

ACS	acute coronary syndrome
ApoE	apolipoprotein E
APT	antiplatelet therapy
CAD	coronary artery disease
CVD	cardiovascular disease
DAPT	dual antiplatelet therapy
DOAC	direct oral anticoagulant
FXa	factor Xa
MI	myocardial infarction
PAD	peripheral artery disease
PAR	protease-activated receptor
PCI	percutaneous coronary intervention
STEMI	ST-segment–elevation myocardial infarction

prasugrel (Table).^{17,18} In contrast, prasugrel was not superior to clopidogrel in reducing cardiovascular death in patients with non-STEMI ACS who did not undergo revascularization in the TRILOGY ACS trial (Targeted Platelet Inhibition to Clarify the Optimal Strategy to Medically Manage Acute Coronary Syndrome Patients; Table).¹⁹ In the PLATO trial (Platelet Inhibitor and Patients Outcomes), the direct acting P2Y₁₂ blocker ticagrelor was superior to clopidogrel in >18 000 patients with ACS (either STEMI or non-STEMI) undergoing PCI who were treated with aspirin but not in the EUCLID trial (Examining Use of Ticagrelor in Peripheral Artery Disease) in which patients with symptomatic PAD were treated with

P2Y₁₂ inhibitor monotherapy (Table).^{13,17} However, the beneficial effect of ticagrelor in PLATO was driven by a reduction in MI and vascular death, whereas there was no difference in stroke.¹⁷ In addition to differences in receptor-binding kinetics, part of the difference in efficacy between clopidogrel and ticagrelor in ACS patients treated with PCI may be because of a lack of response to clopidogrel. Clopidogrel must be metabolized to an active form via a pathway that involves the CYP2C19 pathway, resulting in a broad variation in concentrations of the active metabolite. Recently, the IGNITE study (Implementing Genomics in Practice) showed a higher risk for major adverse cardiovascular events in patients with a CYP2C19 loss-of-function allele if clopidogrel versus alternative therapy was prescribed.²⁰

Because of the lack of optimal protection of single antiplatelet therapy in patients with stable CAD or risk factors, the use of DAPT was studied in the CHARISMA trial (Clopidogrel for High Atherothrombotic Risk and Ischemic Stabilization, Management, and Avoidance). This study of >15 000 patients showed that adding clopidogrel to aspirin did not reduce the risk of cardiovascular death, MI, or stroke compared with aspirin alone.²¹ Although there was no benefit in patients with CAD risk factors, a subgroup analysis of patients with prior MI, stroke, or PAD (9478 patients) found a significant reduction in death without an increase in major bleeding in the patients treated with DAPT compared with aspirin alone.²² The PEGASUS-TIMI 54 trial (Prevention of Cardiovascular Events in Patients With a Prior Heart Attack Using Ticagrelor Compared to Placebo in a Background of

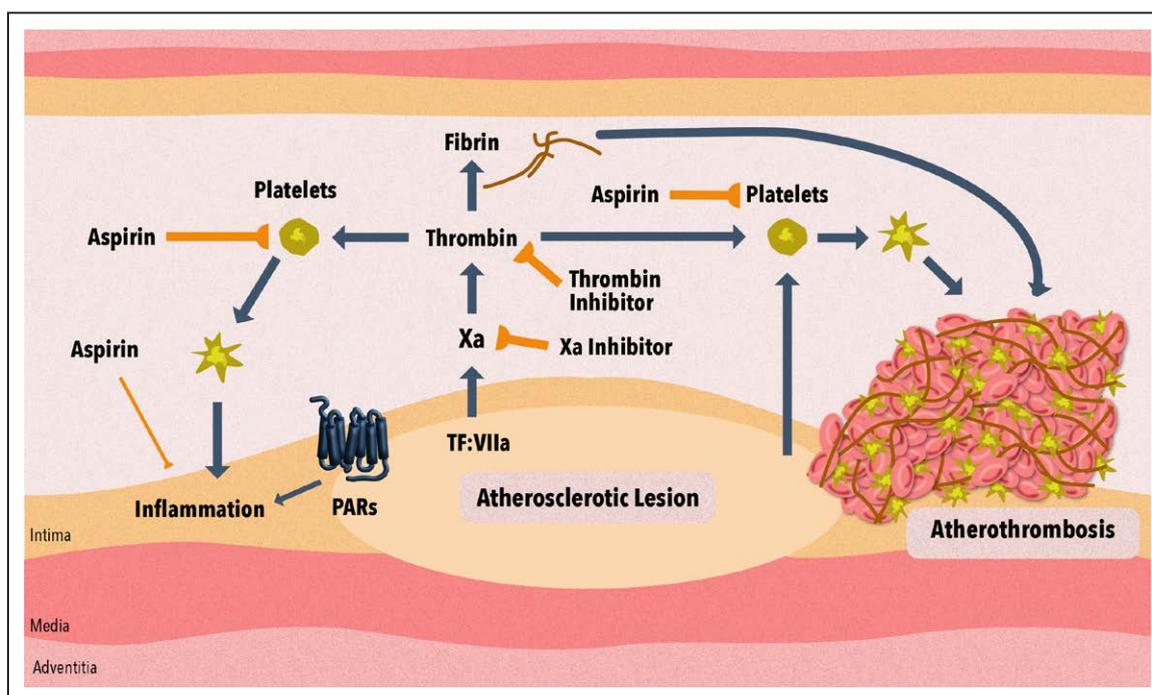


Figure. Role of platelets and the coagulation cascade in atherothrombosis and vascular inflammation. Atherothrombosis involves atherosclerotic plaque rupture or erosion and the formation of an intravascular thrombus. The atherosclerotic plaque contains agents, such as collagen, that activate platelets, and tissue factor (TF) that activates the coagulation cascade. Aspirin reduces the thrombus by inhibiting platelet activation. Anticoagulants reduce the thrombus by inhibiting fibrin generation and also by reducing thrombin activation of platelets. These inhibitors include the thrombin inhibitor dabigatran etexilate and the factor Xa inhibitors rivaroxaban, apixaban, edoxaban, or betrixaban. Activated platelets and activation of protease-activated receptors (PARs) by coagulation proteases may also increase inflammation in the vessel wall. Aspirin and anticoagulants may also reduce vascular inflammation and limit the progression of atherosclerosis.

Table. Effect of Different Single and Combined Antithrombotic Drugs on Thrombotic Events and Bleeding in Patients With CVD

Name of Trial	Patient Group	No. of Patients	Therapeutic Strategy	Efficacy	Safety	Reference
CHARISMA	CVD	15 603	ASA vs ASA+clopidogrel	No effect on CV death	Similar bleeding	Bhatt et al ²²
TRITON-TIMI 38	ACS with PCI	13 608	Prasugrel vs clopidogrel	Decrease in CV death	Increased bleeding	Wiviott et al ¹⁸
PLATO	ACS with or without ST elevation	18 624	Ticagrelor vs clopidogrel	Decrease in CV death	Similar bleeding	Wallentin et al ¹⁷
TRILOGY ACS	Unstable angina or MI with or without ST elevation	7 243	Prasugrel vs clopidogrel	No effect on CV death	Similar bleeding	Roe et al ¹⁹
PEGASUS-TIMI 54	MI within 3 y	21 162	Aspirin vs aspirin+ticagrelor	Reduced CV death	Increased bleeding	Bonaca et al ²³
EUCLID	Symptomatic PAD	13 885	Ticagrelor vs clopidogrel	No effect on CV death	Similar bleeding	Hiatt et al ¹³
TRA 2P-TIMI 50	History of MI, ischemic stroke, or PAD	26 449	Aspirin vs aspirin/DAPT+vorapaxar	Reduced CV death in patients with stable atherosclerosis	Increased bleeding and ICH	Morrow et al ²⁶
TRACER	ACS without ST elevation	12 944	Aspirin vs aspirin/DAPT+vorapaxar	No effect on CV death	Increased bleeding and ICH	Tricoci et al ²⁵
APPRAISE-2	Recent ACS and 2 risk factors	7 392	DAPT vs DAPT+apixaban	No effect on CV death	Increased bleeding	Alexander et al ²⁰
ATLAS ACS 2-TIMI 51	ACS	15 526	DAPT vs DAPT+rivaroxaban	Reduced CV death*	Increased bleeding	Hanson et al ²²
COMPASS	Stable atherosclerotic disease, CAD, and PAD	27 395	Aspirin vs aspirin+rivaroxaban	Reduced CV death*	Increased bleeding	Eikelboom et al ³⁵

This table shows a select group of the different clinical trials. Details of each study are provided in the original references. ACS indicates acute coronary syndrome; APPRAISE-2, Apixaban for Prevention of Acute Ischemic Events 2; ATLAS ACS 2-TIMI 51, Anti-Xa Therapy to Lower Cardiovascular Events in Addition to Standard Therapy in Subjects With Acute Coronary Syndrome-Thrombolysis in Myocardial Infarction 51; CAD, coronary arterial disease; CHARISMA, Clopidogrel for High Atherothrombotic Risk and Ischemic Stabilization, Management, and Avoidance; CVD, cardiovascular disease; COMPASS, Cardiovascular Outcomes for People Using Anticoagulation Strategies; DAPT, dual antiplatelet therapy; EUCLID, Examining Use of Ticagrelor in Peripheral Artery Disease; ICH, Intracerebral hemorrhage; MI, myocardial infarction; PAD, peripheral arterial disease; PCI, percutaneous coronary intervention; PEGASUS-TIMI 54, Prevention of Cardiovascular Events in Patients With a Prior Heart Attack Using Ticagrelor Compared to Placebo in a Background of Aspirin-Thrombolysis in Myocardial Infarction 54; PLATO, Platelet Inhibitor and Patients Outcomes; TRA 2P-TIMI 50, Thrombin Receptor Antagonist in Secondary Prevention of Atherothrombotic Ischemic Events-Thrombolysis in Myocardial Infarction 50; TRACER, Thrombin Receptor Antagonist for Clinical Event Reduction in Acute Coronary Syndrome; TRILOGY ACS, Targeted Platelet Inhibition to Clarify the Optimal Strategy to Medically Manage Acute Coronary Syndrome Patients; and TRITON-TIMI 38, Trial to Assess Improvement in Therapeutic Outcomes by Optimizing Platelet Inhibition with Prasugrel-Thrombolysis in Myocardial Infarction 38.

*Reduced the composite end point of death from CV causes, MI, or stroke.

Aspirin-Thrombolysis in Myocardial Infarction 54) investigated the effect of DAPT beyond 1 year in patients with a prior MI and found that addition of ticagrelor to aspirin reduced cardiovascular death in patients but significantly increased major bleeding.²³

Vorapaxar is a PAR1 inhibitor that represents a new class of antiplatelet therapy.²⁴ Two studies determined the effect of triple antiplatelet therapy on CVD patients by adding vorapaxar on top of standard antiplatelet therapy. The TRACER trial (Thrombin Receptor Antagonist for Clinical Event Reduction in Acute Coronary Syndrome) found that vorapaxar did not reduce cardiovascular death in ACS patients but increased intracranial hemorrhage.²⁵ The TRA 2P-TIMI 50 (Thrombin Receptor Antagonist in Secondary Prevention of Atherothrombotic Ischemic Events-Thrombolysis in Myocardial Infarction 50) observed a reduced risk of cardiovascular death in triple therapy patients with stable atherosclerosis but was stopped because of the risk of intracranial bleeding (Table).^{25,26} Interestingly, in the TRA 2P-TIMI 50

trial, 14% of the patients had PAD, and although vorapaxar had no effect on the composite end point of cardiovascular death, MI or stroke, vorapaxar significantly reduced acute limb ischemic events and peripheral revascularization in PAD patients compared with placebo.^{15,26} These studies indicate that, in general, an intensification of antiplatelet therapy is associated with increased efficacy but often with increased bleeding.

An alternative strategy to prevent thromboembolic events in CVD patients is to add an anticoagulant agent to standard antiplatelet therapy. Early studies evaluated warfarin in ACS patients. Warfarin is a vitamin K antagonist that reduces blood coagulation by inhibiting the formation of γ -carboxyglutamic domains on the coagulation factors prothrombin, factor VII, factor IX, and factor X. A meta-analysis of 10 trials found that ACS patients receiving aspirin and warfarin had a decrease in MI and ischemic stroke but at the cost of an increase in major bleeding compared with patients receiving aspirin alone.²⁷ These studies were performed before the widespread usage

of PCI and DAPT in patients with ACS and thus do not reflect current practice.

Recently, a new family of anticoagulants has been developed that are called direct oral anticoagulants (DOACs) because they directly bind and inhibit either thrombin or factor.²⁸ DOACs consist of the thrombin inhibitor dabigatran etexilate and the factor Xa (FXa) inhibitors apixaban, rivaroxaban, edoxaban, and betrixaban.²⁸ Importantly, DOACs have lower rates of intracerebral bleeding compared with vitamin K antagonists.²⁹ However, the major side effect of all antithrombotic agents is bleeding because both platelets and the coagulation protease cascade are required for hemostasis.

The concept of combined antiplatelet and anticoagulant agents for the secondary prevention of atherothrombotic events has been revisited since the approval of DOACs because they have a lower risk of intracerebral bleeding compared with vitamin K antagonists.²⁸ Two trials have analyzed the effect of adding 2 different FXa inhibitors to standard antiplatelet therapy in ACS patients (Table). In APPRAISE-2 (Apixaban for Prevention of Acute Ischemic Events 2), the addition of apixaban to DAPT did not significantly affect the primary outcome of cardiovascular death (7.5% versus 7.9%) but significantly increased major bleeding, which led to the termination of the study.³⁰ The dose of apixaban used in this trial was 5 mg BID, which is the same dose used to treat patients with venous thromboembolism or atrial fibrillation. In ATLAS ACS 2-TIMI 51 (Anti-Xa Therapy to Lower Cardiovascular Events in Addition to Standard Therapy in Subjects With Acute Coronary Syndrome-Thrombolysis in Myocardial Infarction 51), ACS patients received low doses of rivaroxaban (2.5 or 5 mg BID),³¹ which are lower than the therapeutic doses used to treat patients with venous thromboembolism or prevent thromboembolic stroke in atrial fibrillation (20 mg QD). Both low doses of rivaroxaban reduced the primary end point of cardiovascular death, MI, or stroke when compared with placebo. Importantly, the 2.5 mg BID dose of rivaroxaban significantly reduced cardiovascular death (2.7% versus 4.1%) compared with standard antiplatelet therapy alone, whereas no survival benefit was observed with the 5 mg BID dose. Compared with placebo, rivaroxaban was associated with increased rates of major bleeding and intracranial hemorrhage but not fatal bleeding. This study indicates that addition of rivaroxaban at a dose of 2.5 mg BID to standard antiplatelet therapy reduced death in ACS patients but at the cost of increased bleeding. Rivaroxaban is approved together with antiplatelet therapy for ACS in Europe but not in the United States.

It is intriguing that the lower dose of rivaroxaban improved survival, whereas the higher dose did not have this effect. This result has to be interpreted cautiously as the study was not designed nor powered to look at differences in death between the 2 doses. It is interesting, however, to speculate on possible causes. One potential explanation is that this effect is because of the higher rates of bleeding with rivaroxaban 5 mg BID compared with 2.5 mg BID. Another explanation is that thrombin can act as both a procoagulant and an anticoagulant. When thrombin binds its receptor thrombomodulin on

endothelial cells, it changes its substrate specificity and is able to activate the APC (activated protein C). Indeed, infusion of a low dose of thrombin into baboons increases levels of APC.³² In addition to its anticoagulant activity, APC has anti-inflammatory and cytoprotective activities.^{33,34} Therefore, it is possible that thrombin-dependent generation of the APC and its vascular protective functions is preserved with a low dose of rivaroxaban. It would be interesting to test this hypothesis by measuring levels of plasma APC in patients treated with 2.5 mg BID and 5 mg BID doses of rivaroxaban.

The standard therapy for patients with stable CAD and PAD is treatment with a single antiplatelet agent, such as aspirin or clopidogrel. To determine whether outcomes would be improved by adding an anticoagulant, the recent COMPASS trial (Cardiovascular Outcomes for People Using Anticoagulation Strategies) compared the effect of aspirin alone (100 mg QD), rivaroxaban alone (5 mg BID), or aspirin (100 mg QD) plus rivaroxaban (2.5 mg BID) in stable CAD and PAD patients.³⁵ Importantly, the composite of cardiovascular death, stroke, or MI was significantly decreased in the rivaroxaban-plus-aspirin group compared with the aspirin group (4.1% versus 5.4%). However, there was a significant increase in major bleeding (3.1% versus 1.9%).³⁵ Interestingly, rivaroxaban alone also reduced the primary outcome of cardiovascular death, MI, or stroke compared with aspirin, but this reduction was not statistically significant ($P=0.12$). Similar results were observed when the stable CAD patients (24 824 patients) and the PAD patients (7470 patients) were analyzed separately, although the net clinical benefit was stronger in PAD compared with CAD patients.^{36,37}

The combination of rivaroxaban plus aspirin was associated with fewer cardiovascular deaths and death from any cause than aspirin alone. What is the mechanism by which rivaroxaban plus aspirin reduced death in stable CAD and PAD patients compared with aspirin alone? The simplest explanation is that the combination of an anticoagulant agent and an antiplatelet agent has superior antithrombotic activity compared with aspirin alone in preventing major thrombotic events. Anticoagulants, such as rivaroxaban, not only reduce fibrin generation but also indirectly inhibit platelet activation by reducing the amount of thrombin (Figure). This hypothesis is supported by the reduction in ischemic end points in the COMPASS trial.

Interestingly, the combination of rivaroxaban and aspirin significantly reduced major adverse limb events in the PAD patients compared with aspirin alone.³⁷ Similarly, PAD patients treated with the PAR1 inhibitor vorapaxar had a significant reduction in acute limb ischemic events and revascularization compared with placebo.¹⁵ At present, the relative contribution of thrombotic events and vascular inflammation to vascular pathogenesis in PAD patients are not well understood.

It is intriguing to speculate that dual aspirin and rivaroxaban therapy in the COMPASS trial has an effect beyond simply reducing thrombosis. Platelets and activation of PARs by coagulation proteases can enhance inflammation and atherosclerosis. Aspirin has anti-inflammatory activity, and blocking FXa would reduce PAR signaling (Figure). In mouse studies, a deficiency of P-selectin, P2Y12, or CalDAG-GEFI,

which is required for calcium-dependent platelet activation, is associated with reduced atherosclerosis.^{38–40} Mouse studies have also shown that thrombin and FXa inhibitors stabilize plaques by reducing plaque inflammation and increasing the fibrous cap.⁴¹ An early study found that the thrombin inhibitor melagatran reduced atherosclerosis in ApoE^{-/-} (apolipoprotein E) mice, and this was associated with reduced MMP9 (matrix metalloproteinase 9) expression and an increase in the fibrous cap.⁴² Similar results were observed with the thrombin inhibitor dabigatran.^{43–45} Importantly, rivaroxaban also reduced atherosclerosis in ApoE^{-/-} mice, and this was associated with reduced levels of MMP9 and macrophages.⁴⁶ A further study found that rivaroxaban did not affect established lesions in ApoE^{-/-} mice but decreased inflammatory mediators and increased plaque stability.⁴⁷ However, thrombin and FXa inhibitors may not be equal because FXa is upstream of thrombin and is a more potent activator of PAR2 than thrombin. For instance, in a mouse model of sickle cell disease, we found that rivaroxaban but not dabigatran reduced IL-6 (interleukin 6) expression.⁴⁸ Furthermore, we and others found that PAR2^{-/-} mice but not PAR1^{-/-} mice have reduced atherosclerosis in ApoE^{-/-} and Ldlr^{-/-} models⁴⁹ (Owens and Mackman, unpublished data, 2016).

Despite these interesting mouse studies, we need clinical data on the plaques themselves and levels of circulating biomarkers before we can conclude that the protection by dual aspirin-plus-rivaroxaban therapy observed in COMPASS trial is because of effects beyond simply antithrombotic activity.

DOACs target coagulation proteins in the common pathway of the coagulation protease cascade. This pathway is essential for hemostasis because in mice deficiencies in prothrombin, factor V, or factor X leads to fatal bleeding.^{50–53} The use of DOACs are associated with an increased risk of bleeding, and this has led to the search for new, safer targets for anticoagulant therapy. One such target is factor XI, which is near the top of the intrinsic pathway of the coagulation protease cascade. One recent small phase II proof-of-concept study found that reducing levels of factor XI using an antisense oligonucleotide led to a reduction in VTE in patients undergoing total knee arthroplasty with less bleeding than patients receiving the low-molecular-weight heparin enoxaparin.⁵⁴ This suggests that targeting factor XIa might have a larger therapeutic window (efficacy versus safety) than targeting FXa.⁵⁵ However, these studies need to be confirmed in larger studies. An intriguing possibility is that addition of a factor XIa inhibitor to aspirin in patients with CAD or PAD will reduce cardiovascular death without increasing bleeding.

Antiplatelet agents have been the cornerstone of therapy for preventing ischemic events and death in CVD patients. Intensification of antiplatelet therapy with more potent antiplatelet agents or combinations of antiplatelet agents reduces thrombotic events and cardiovascular death in CVD patients. However, this is often associated with an increase in bleeding, such as that seen in studies with triple antiplatelet therapy, because platelets are essential for hemostasis. The ATLAS ACS 2-TMI 51 and COMPASS trials show that addition of low doses of the FXa inhibitor rivaroxaban to antiplatelet agents can have a beneficial effect on ischemic events in CVD

patients, although there is an increase in bleeding. Future challenges include (1) finding patients who will benefit most from combined antiplatelet and anticoagulant therapy; (2) what are the optimal doses of each agent; (3) what are the best anticoagulant and antiplatelet drugs; and (4) understanding of the mechanisms by which this dual therapy protects CVD patients.

Acknowledgments

Dr Mackman, H.M.H. Spronk, G.A. Stouffer, and H. ten Cate wrote the article.

Sources of Funding

Dr Mackman was supported by grants from the National Institutes of Health and the John C. Parker Professorship. H. ten Cate and H.M.H. Spronk are supported by grants from the Cardio Vascular Research Network grants RACE-5 and CONTRAST from the Netherlands Heart Foundation.

Disclosures

Dr Mackman is a consultant for Bayer and Janssen Pharmaceuticals. H.M.H. Spronk is a consultant for Bayer and has a research grant from Bayer. H. ten Cate is a consultant for Bayer and Stago and has a research grant from Bayer. The other author reports no conflicts.

References

- Ross R. Atherosclerosis—an inflammatory disease. *N Engl J Med*. 1999;340:115–126. doi: 10.1056/NEJM199901143400207.
- Mackman N. Triggers, targets and treatments for thrombosis. *Nature*. 2008;451:914–918. doi: 10.1038/nature06797.
- Coughlin SR. Thrombin signalling and protease-activated receptors. *Nature*. 2000;407:258–264. doi: 10.1038/35025229.
- Posma JJ, Posthuma JJ, Spronk HM. Coagulation and non-coagulation effects of thrombin. *J Thromb Haemost*. 2016;14:1908–1916. doi: 10.1111/jth.13441.
- Patrono C, Morais J, Baigent C, Collet JP, Fitzgerald D, Halvorsen S, Rocca B, Siegbahn A, Storey RF, Vilahur G. Antiplatelet agents for the treatment and prevention of coronary atherothrombosis. *J Am Coll Cardiol*. 2017;70:1760–1776. doi: 10.1016/j.jacc.2017.08.037.
- Chan NC, Eikelboom JW, Weitz JI. Evolving treatments for arterial and venous thrombosis: role of the direct oral anticoagulants. *Circ Res*. 2016;118:1409–1424. doi: 10.1161/CIRCRESAHA.116.306925.
- Patrono CP, Morais J, Baigent C, et al; Antiplatelet agents for the treatment and prevention of coronary atherothrombosis. *J Am Coll Cardiol*. 2017;70:1760–1776. doi: 10.1016/j.jacc.2017.08.037.
- Levine GN, Bates ER, Blankenship JC, et al. 2015 ACC/AHA/SCAI Focused Update on Primary Percutaneous Coronary Intervention for Patients With ST-Elevation Myocardial Infarction: an Update of the 2011 ACCF/AHA/SCAI Guideline for Percutaneous Coronary Intervention and the 2013 ACCF/AHA Guideline for the Management of ST-Elevation Myocardial Infarction: a Report of the American College of Cardiology/American Heart Association Task Force on Clinical Practice Guidelines and the Society for Cardiovascular Angiography and Interventions. *Circulation*. 2016;133:1135–1147. doi: 10.1161/CIR.0000000000000336.
- Montalescot G, Sechtem U, Achenbach S, et al; Task Force Members; ESC Committee for Practice Guidelines; Document Reviewers. 2013 ESC guidelines on the management of stable coronary artery disease: the Task Force on the management of stable coronary artery disease of the European Society of Cardiology. *Eur Heart J*. 2013;34:2949–3003. doi: 10.1093/eurheartj/ehd296.
- Tendera M, Aboyans V, Bartelink ML, et al; European Stroke Organisation; ESC Committee for Practice Guidelines. ESC Guidelines on the diagnosis and treatment of peripheral artery diseases: document covering atherosclerotic disease of extracranial carotid and vertebral, mesenteric, renal, upper and lower extremity arteries: the Task Force on the Diagnosis and Treatment of Peripheral Artery Diseases of the European Society of Cardiology (ESC). *Eur Heart J*. 2011;32:2851–2906. doi: 10.1093/eurheartj/ehr211.

11. Bhatt DL. Identification of and management approaches for the high-risk patient. *Am J Cardiol.* 2006;98:22Q–29Q. doi: 10.1016/j.amjcard.2006.09.021.
12. Bonaca MP, Bhatt DL, Steg PG, et al. Ischaemic risk and efficacy of ticagrelor in relation to time from P2Y12 inhibitor withdrawal in patients with prior myocardial infarction: insights from PEGASUS-TIMI 54. *Eur Heart J.* 2016;37:1133–1142. doi: 10.1093/eurheartj/ehv531.
13. Hiatt WR, Fowkes FG, Heizer G, Berger JS, Baumgartner I, Held P, Katona BG, Mahaffey KW, Norgren L, Jones WS, Blomster J, Millegård M, Reist C, Patel MR; EUCLID Trial Steering Committee and Investigators. Ticagrelor versus clopidogrel in symptomatic peripheral artery disease. *N Engl J Med.* 2017;376:32–40. doi: 10.1056/NEJMoa1611688.
14. Scirica BM, Bonaca MP, Braunwald E, De Ferrari GM, Isaza D, Lewis BS, Mehrhof F, Merlini PA, Murphy SA, Sabatine MS, Tendera M, Van de Werf F, Wilcox R, Morrow DA; TRA 2°P-TIMI 50 Steering Committee Investigators. Vorapaxar for secondary prevention of thrombotic events for patients with previous myocardial infarction: a prespecified subgroup analysis of the TRA 2°P-TIMI 50 trial. *Lancet.* 2012;380:1317–1324. doi: 10.1016/S0140-6736(12)61269-0.
15. Bonaca MP, Scirica BM, Creager MA, Olin J, Bounameaux H, Dellborg M, Lamp JM, Murphy SA, Braunwald E, Morrow DA. Vorapaxar in patients with peripheral artery disease: results from TRA2{degrees} P-TIMI 50. *Circulation.* 2013;127:1522, 1529e1–1529, 1529e1. doi: 10.1161/CIRCULATIONAHA.112.000679.
16. Olie RH, ten Cate H, van der Meijden PEJ. The coagulation system in atherothrombosis; implications for new therapeutic strategies. *Res Pract Thromb Hemost.* 2018. In press.
17. Wallentin L, Becker RC, Budaj A, et al Ticagrelor versus clopidogrel in patients with acute coronary syndromes. *N Engl J Med.* 2009;361:1045–1057.
18. Wiviott SD, Braunwald E, McCabe CH, Montalescot G, Ruzyllo W, Gottlieb S, Neumann FJ, Ardissino D, De Servi S, Murphy SA, Riesmeyer J, Weerakkody G, Gibson CM, Antman EM; TRITON-TIMI 38 Investigators. Prasugrel versus clopidogrel in patients with acute coronary syndromes. *N Engl J Med.* 2007;357:2001–2015. doi: 10.1056/NEJMoa0706482.
19. Roe MT, Armstrong PW, Fox KA, et al; TRILOGY ACS Investigators. Prasugrel versus clopidogrel for acute coronary syndromes without revascularization. *N Engl J Med.* 2012;367:1297–1309. doi: 10.1056/NEJMoa1205512.
20. Cavallari LH, Lee CR, Beitelshes AL, et al; IGNITE Network. Multisite investigation of outcomes with implementation of CYP2C19 genotype-guided antiplatelet therapy after percutaneous coronary intervention. *JACC Cardiovasc Interv.* 2018;11:181–191. doi: 10.1016/j.jcin.2017.07.022.
21. Bhatt DL, Fox KA, Hacke W, et al; CHARISMA Investigators. Clopidogrel and aspirin versus aspirin alone for the prevention of atherothrombotic events. *N Engl J Med.* 2006;354:1706–1717. doi: 10.1056/NEJMoa060989.
22. Bhatt DL, Flather MD, Hacke W, et al; CHARISMA Investigators. Patients with prior myocardial infarction, stroke, or symptomatic peripheral arterial disease in the CHARISMA trial. *J Am Coll Cardiol.* 2007;49:1982–1988. doi: 10.1016/j.jacc.2007.03.025.
23. Bonaca MP, Bhatt DL, Cohen M, et al; PEGASUS-TIMI 54 Steering Committee and Investigators. Long-term use of ticagrelor in patients with prior myocardial infarction. *N Engl J Med.* 2015;372:1791–1800. doi: 10.1056/NEJMoa1500857.
24. Chackalamannil S, Wang Y, Greenlee WJ, Hu Z, Xia Y, Ahn HS, Boykow G, Hsieh Y, Palamanda J, Agans-Fantuzzi J, Kurowski S, Graziano M, Chintala M. Discovery of a novel, orally active himbacine-based thrombin receptor antagonist (SCH 530348) with potent antiplatelet activity. *J Med Chem.* 2008;51:3061–3064. doi: 10.1021/jm800180e.
25. Tricoci P, Huang Z, Held C, et al; TRACER Investigators. Thrombin-receptor antagonist vorapaxar in acute coronary syndromes. *N Engl J Med.* 2012;366:20–33. doi: 10.1056/NEJMoa1109719.
26. Morrow DA, Braunwald E, Bonaca MP, et al; TRA 2P-TIMI 50 Steering Committee and Investigators. Vorapaxar in the secondary prevention of atherothrombotic events. *N Engl J Med.* 2012;366:1404–1413. doi: 10.1056/NEJMoa1200933.
27. Rothberg MB, Celestin C, Fiore LD, Lawler E, Cook JR. Warfarin plus aspirin after myocardial infarction or the acute coronary syndrome: meta-analysis with estimates of risk and benefit. *Ann Intern Med.* 2005;143:241–250.
28. Weitz JI, Harenberg J. New developments in anticoagulants: past, present and future. *Thromb Haemost.* 2017;117:1283–1288. doi: 10.1160/TH16-10-0807.
29. Weitz JI, Jaffer IH, Fredenburgh JC. Recent advances in the treatment of venous thromboembolism in the era of the direct oral anticoagulants. *F1000Res.* 2017;6:985. doi: 10.12688/f1000research.11174.1.
30. Alexander JH, Lopes RD, James S, et al; APPRAISE-2 Investigators. Apixaban with antiplatelet therapy after acute coronary syndrome. *N Engl J Med.* 2011;365:699–708. doi: 10.1056/NEJMoa1105819.
31. Mega JL, Braunwald E, Wiviott SD, et al; ATLAS ACS 2-TIMI 51 Investigators. Rivaroxaban in patients with a recent acute coronary syndrome. *N Engl J Med.* 2012;366:9–19. doi: 10.1056/NEJMoa1112277.
32. Hanson SR, Griffin JH, Harker LA, Kelly AB, Esmon CT, Gruber A. Antithrombotic effects of thrombin-induced activation of endogenous protein C in primates. *J Clin Invest.* 1993;92:2003–2012. doi: 10.1172/JCI116795.
33. Esmon CT. Protein C anticoagulant system—anti-inflammatory effects. *Semin Immunopathol.* 2012;34:127–132. doi: 10.1007/s00281-011-0284-6.
34. Griffin JH, Zlokovic BV, Mosnier LO. Protein C anticoagulant and cytoprotective pathways. *Int J Hematol.* 2012;95:333–345. doi: 10.1007/s12185-012-1059-0.
35. Eikelboom JW, Connolly SJ, Bosch J, et al; COMPASS Investigators. Rivaroxaban with or without aspirin in stable cardiovascular disease. *N Engl J Med.* 2017;377:1319–1330. doi: 10.1056/NEJMoa1709118.
36. Connolly SJ, Eikelboom JW, Bosch J, et al; COMPASS Investigators. Rivaroxaban with or without aspirin in patients with stable coronary artery disease: an international, randomised, double-blind, placebo-controlled trial [published online ahead of print November 10, 2017]. *Lancet.* doi: 10.1016/S0140-6736(17)32458-3.
37. Anand SS, Bosch J, Eikelboom JW, et al; COMPASS Investigators. Rivaroxaban with or without aspirin in patients with stable peripheral or carotid artery disease: an international, randomised, double-blind, placebo-controlled trial [published online ahead of print November 10, 2017]. *Lancet.* doi: 10.1016/S0140-6736(17)32409-1.
38. Burger PC, Wagner DD. Platelet P-selectin facilitates atherosclerotic lesion development. *Blood.* 2003;101:2661–2666. doi: 10.1182/blood-2002-07-2209.
39. Li D, Wang Y, Zhang L, Luo X, Li J, Chen X, Niu H, Wang K, Sun Y, Wang X, Yan Y, Chai W, Gartner TK, Liu J. Roles of purinergic receptor P2Y₆ protein-coupled 12 in the development of atherosclerosis in apolipoprotein E-deficient mice. *Arterioscler Thromb Vasc Biol.* 2012;32:e81–e89. doi: 10.1161/ATVBAHA.111.239095.
40. Boulaftali Y, Owens AP III, Beale A, Piatt R, Casari C, Lee RH, Conley PB, Paul DS, Mackman N, Bergmeier W. CalDAG-GEFI deficiency reduces atherosclerotic lesion development in mice. *Arterioscler Thromb Vasc Biol.* 2016;36:792–799. doi: 10.1161/ATVBAHA.115.306347.
41. Loeffen R, Spronk HM, ten Cate H. The impact of blood coagulability on atherosclerosis and cardiovascular disease. *J Thromb Haemost.* 2012;10:1207–1216. doi: 10.1111/j.1538-7836.2012.04782.x.
42. Bea F, Kreuzer J, Preusch M, Schaab S, Isermann B, Rosenfeld ME, Katus H, Blessing E. Melagatran reduces advanced atherosclerotic lesion size and may promote plaque stability in apolipoprotein E-deficient mice. *Arterioscler Thromb Vasc Biol.* 2006;26:2787–2792. doi: 10.1161/01.ATV.0000246797.05781.ad.
43. Lee IO, Kratz MT, Schirmer SH, Baumhäkel M, Böhm M. The effects of direct thrombin inhibition with dabigatran on plaque formation and endothelial function in apolipoprotein E-deficient mice. *J Pharmacol Exp Ther.* 2012;343:253–257. doi: 10.1124/jpet.112.194837.
44. Pingel S, Tiyerili V, Mueller J, Werner N, Nickenig G, Mueller C. Thrombin inhibition by dabigatran attenuates atherosclerosis in ApoE deficient mice. *Arch Med Sci.* 2014;10:154–160. doi: 10.5114/aoms.2014.40742.
45. Borissoff JJ, Otten JJ, Heeneman S, et al. Genetic and pharmacological modifications of thrombin formation in apolipoprotein e-deficient mice determine atherosclerosis severity and atherothrombosis onset in a neutrophil-dependent manner. *PLoS One.* 2013;8:e55784. doi: 10.1371/journal.pone.0055784.
46. Hara T, Fukuda D, Tanaka K, Higashikuni Y, Hirata Y, Nishimoto S, Yagi S, Yamada H, Soeki T, Wakatsuki T, Shimabukuro M, Sata M. Rivaroxaban, a novel oral anticoagulant, attenuates atherosclerotic plaque progression and destabilization in ApoE-deficient mice. *Atherosclerosis.* 2015;242:639–646. doi: 10.1016/j.atherosclerosis.2015.03.023.
47. Zhou Q, Bea F, Preusch M, Wang H, Isermann B, Shahzad K, Katus HA, Blessing E. Evaluation of plaque stability of advanced atherosclerotic lesions in apo E-deficient mice after treatment with the oral factor Xa inhibitor rivaroxaban. *Mediators Inflamm.* 2011;2011:432080. doi: 10.1155/2011/432080.
48. Sparkenbaugh EM, Chantrathammachart P, Mickelson J, van Ryn J, Heibel RP, Monroe DM, Mackman N, Key NS, Pawlinski R. Differential contribution

- of FXa and thrombin to vascular inflammation in a mouse model of sickle cell disease. *Blood*. 2014;123:1747–1756. doi: 10.1182/blood-2013-08-523936.
49. Zuo P, Zuo Z, Zheng Y, Wang X, Zhou Q, Chen L, Ma G. Protease-activated receptor-2 deficiency attenuates atherosclerotic lesion progression and instability in apolipoprotein E-deficient mice. *Front Pharmacol*. 2017;8:647. doi: 10.3389/fphar.2017.00647.
 50. Cui J, O'Shea KS, Purkayastha A, Saunders TL, Ginsburg D. Fatal haemorrhage and incomplete block to embryogenesis in mice lacking coagulation factor V. *Nature*. 1996;384:66–68. doi: 10.1038/384066a0.
 51. Dewerchin M, Liang Z, Moons L, Carmeliet P, Castellino FJ, Collen D, Rosen ED. Blood coagulation factor X deficiency causes partial embryonic lethality and fatal neonatal bleeding in mice. *Thromb Haemost*. 2000;83:185–190.
 52. Sun WY, Witte DP, Degen JL, Colbert MC, Burkart MC, Holmbäck K, Xiao Q, Bugge TH, Degen SJ. Prothrombin deficiency results in embryonic and neonatal lethality in mice. *Proc Natl Acad Sci USA*. 1998;95:7597–7602.
 53. Xue J, Wu Q, Westfield LA, Tuley EA, Lu D, Zhang Q, Shim K, Zheng X, Sadler JE. Incomplete embryonic lethality and fatal neonatal hemorrhage caused by prothrombin deficiency in mice. *Proc Natl Acad Sci USA*. 1998;95:7603–7607.
 54. Büller HR, Bethune C, Bhanot S, Gailani D, Monia BP, Raskob GE, Segers A, Verhamme P, Weitz JI; FXI-ASO TKA Investigators. Factor XI antisense oligonucleotide for prevention of venous thrombosis. *N Engl J Med*. 2015;372:232–240. doi: 10.1056/NEJMoa1405760.
 55. Weitz JI, Fredenburgh JC. 2017 Scientific Sessions Sol Sherry Distinguished Lecture in Thrombosis: Factor XI as a target for new anticoagulants. *Arterioscler Thromb Vasc Biol*. 2018;38:304–310. doi: 10.1161/ATVBAHA.117.309664.

KEY WORDS: anticoagulants ■ apolipoprotein ■ coronary artery disease ■ myocardial infarction ■ patients

Arteriosclerosis, Thrombosis, and Vascular Biology



JOURNAL OF THE AMERICAN HEART ASSOCIATION

Dual Anticoagulant and Antiplatelet Therapy for Coronary Artery Disease and Peripheral Artery Disease Patients

Nigel Mackman, Henri M.H. Spronk, George A. Stouffer and Hugo ten Cate

Arterioscler Thromb Vasc Biol. 2018;38:726-732; originally published online February 15, 2018;

doi: 10.1161/ATVBAHA.117.310048

Arteriosclerosis, Thrombosis, and Vascular Biology is published by the American Heart Association, 7272 Greenville Avenue, Dallas, TX 75231

Copyright © 2018 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/38/4/726>

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/>