



Universiteit
Leiden
The Netherlands

Alirocumab after acute coronary syndrome in patients with a history of heart failure

White, H.D.; Schwartz, G.G.; Szarek, M.; Bhatt, D.L.; Bittner, V.A.; Chiang, C.E.; ... ;
ODYSSEY OUTCOMES Investigators

Citation

White, H. D., Schwartz, G. G., Szarek, M., Bhatt, D. L., Bittner, V. A., Chiang, C. E., ... Steg, P. G. (2021). Alirocumab after acute coronary syndrome in patients with a history of heart failure. *European Heart Journal*, 43(16), 1554-1565. doi:10.1093/eurheartj/ehab804

Version: Publisher's Version

License: [Creative Commons CC BY-NC 4.0 license](https://creativecommons.org/licenses/by-nc/4.0/)

Downloaded from: <https://hdl.handle.net/1887/3590620>

Note: To cite this publication please use the final published version (if applicable).

Alirocumab after acute coronary syndrome in patients with a history of heart failure

Harvey D. White ^{1*}, Gregory G. Schwartz², Michael Szarek ^{3,4,5},
Deepak L. Bhatt ⁶, Vera A. Bittner ⁷, Chern-En Chiang ⁸, Rafael Diaz ⁹,
Shaun G. Goodman ^{10,11}, Johan Wouter Jukema ^{12,13}, Megan Loy¹⁴,
Neha Pagidipati¹⁵, Robert Pordy ¹⁶, Arsen D. Ristić¹⁷, Andreas M. Zeiher ¹⁸,
Daniel M. Wojdyla¹⁵, and Philippe Gabriel Steg ^{19,20}; for the ODYSSEY
OUTCOMES Investigators[†]

¹Green Lane Cardiovascular Services, Auckland City Hospital, 5 Park Road, Grafton, Auckland, New Zealand; ²Division of Cardiology, University of Colorado School of Medicine, B130, Aurora, CO 80045, USA; ³Department of Epidemiology and Biostatistics, State University of New York, Downstate School of Public Health, 450 Clarkson Avenue, MS 43, Brooklyn, NY 11203, USA; ⁴CPC Clinical Research, 13199 E Montview Blvd Suite 200, Aurora, CO 80045, USA; ⁵Division of Cardiology, University of Colorado School of Medicine, Fitzsimons Building - 13001 E. 17th Place, Campus Box C290, Aurora, CO 80045, USA; ⁶Department of Medicine, Brigham and Women's Hospital Heart and Vascular Center, Harvard Medical School, 75 Francis Street, Boston, MA 02115, USA; ⁷Division of Cardiovascular Disease, University of Alabama at Birmingham, 701 19th Street South—LHRB 310, Birmingham, AL 35294, USA; ⁸General Clinical Research Center, Taipei Veterans General Hospital and Taiwan School of Medicine, National Yang-Ming University, 201, Sec. 2, Shih-Pai road, Taipei, Taiwan; ⁹Estudios Clinicos Latino America, Instituto Cardiovascular de Rosario, Paraguay 160, Santa Fe, Rosario 2000, Argentina; ¹⁰Canadian VIGOUR Centre, University of Alberta, 87 Ave NW, Edmonton, Alberta T6G 2E1, Canada; ¹¹Division of Cardiology, St. Michael's Hospital, Room 6-034 Donnelly Wing, Toronto, Ontario M5B 1W8, Canada; ¹²Department of Cardiology, Leiden University Medical Center, Albinusdreef 2, Leiden 2333 ZA, the Netherlands; ¹³Netherlands Heart Institute, Moreelsepark 1, Utrecht 3511 EP, the Netherlands; ¹⁴Sanofi, 55 Corporate Dr, Bridgewater, NJ 08807, USA; ¹⁵Duke Clinical Research Institute, Duke University, School of Medicine, 300 W. Morgan St., NC 27701, USA; ¹⁶Regeneron Pharmaceuticals, 777 Old Saw Mill River Rd, Tarrytown, NY 10591, USA; ¹⁷Department of Cardiology, University Clinical Center of Serbia, Belgrade University School of Medicine, 8 Dr Subotića Street, Belgrade; ¹⁸Department of Medicine III, Goethe University, Theodor-Stern-Kai 7, Frankfurt am Main 60590, Germany; ¹⁹Assistance Publique-Hôpitaux de Paris, Hôpital Bichat, Université de Paris, FACT (French Alliance for Cardiovascular Trials), INSERM U1148, 46 Rue Henri Huchard, Paris, 75018 France; and ²⁰National Heart and Lung Institute, Imperial College, Royal Brompton Hospital, Sydney St, Chelsea, London SW3 6NP, UK



Received 20 August 2021; revised 16 September 2021; editorial decision 9 November 2021; accepted 9 November 2021; online publish-ahead-of-print 18 December 2021

Listen to the audio abstract of this contribution

See the editorial comment for this article 'PCSK9 inhibition in patients with heart failure: neutral or harmful intervention?', by Alexander Niessner and Heinz Drexel, <https://doi.org/10.1093/eurheartj/ehab913>.

Aims

Patients with heart failure (HF) have not been shown to benefit from statins. In a *post hoc* analysis, we evaluated outcomes in ODYSSEY OUTCOMES in patients with vs. without a history of HF randomized to the proprotein convertase subtilisin/kexin type 9 (PCSK9) inhibitor alirocumab or placebo.

Methods and results

Among 18 924 patients with recent acute coronary syndrome (ACS) receiving intensive or maximum-tolerated statin treatment, the primary outcome of major adverse cardiovascular events (MACE) was compared in patients with or without a history of HF. The pre-specified secondary outcome of hospitalization for HF was also analysed. Overall, 2815 (14.9%) patients had a history of HF. Alirocumab reduced low-density lipoprotein cholesterol and lipoprotein(a) similarly in patients with or without HF. Overall, alirocumab reduced MACE compared with placebo [hazard ratio (HR): 0.85; 95% confidence interval (CI): 0.78–0.93; $P=0.0001$]. This effect was observed among patients without a history of HF (HR: 0.78; 95% CI: 0.70–0.86; $P<0.0001$), but not in those with a history of HF (HR: 1.17; 95% CI: 0.97–1.40; $P=0.10$) ($P_{\text{interaction}} = 0.0001$). Alirocumab did not reduce hospitalization for HF, overall or in patients with or without prior HF.

Conclusion

Alirocumab reduced MACE in patients without a history of HF but not in patients with a history of HF. Alirocumab did not reduce hospitalizations for HF in either group. Patients with a history of HF are a high-risk group that does not appear to benefit from PCSK9 inhibition after ACS.

* Corresponding author. Tel: +64 9 6309992. Email: harveyw@adhb.govt.nz

[†] A complete list of the ODYSSEY OUTCOMES committee members, investigators, and contributors is provided in [Supplementary material online, Text S1](#).

© The Author(s) 2021. Published by Oxford University Press on behalf of the European Society of Cardiology.

This is an Open Access article distributed under the terms of the Creative Commons Attribution-NonCommercial License (<https://creativecommons.org/licenses/by-nc/4.0/>), which permits non-commercial re-use, distribution, and reproduction in any medium, provided the original work is properly cited. For commercial re-use, please contact journals.permissions@oup.com

Key Question

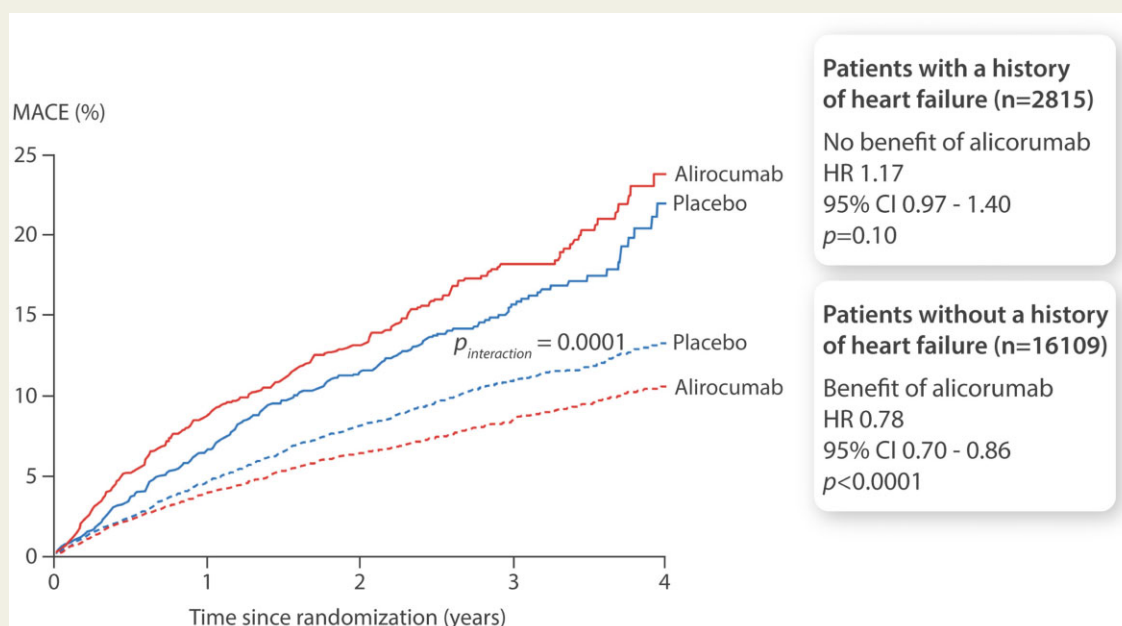
Patients with heart failure (HF) have not been shown to benefit from statins. In a *post hoc* analysis of the ODYSSEY OUTCOMES trial in patients with recent acute coronary syndrome (ACS), we evaluated major adverse cardiovascular events (MACE) in patients with or without a history of HF assigned to treatment with the proprotein convertase subtilisin/kexin type 9 (PCSK9) inhibitor alirocumab or placebo.

Key Finding

Alirocumab reduced low-density lipoprotein cholesterol similarly in patients with or without HF. However, alirocumab reduced MACE among patients without a history of HF, but not in those with a history of HF.

Take Home Message

The current hypothesis-generating analysis does not provide a basis to recommend PCSK9 inhibitors to patients with recent ACS and a history of HF. A prospective placebo-controlled evaluation of PCSK9 inhibition in this setting is warranted.



Structured Graphical Abstract There was a reduction in MACE in patients without a history of heart failure but not in patients with a history of heart failure.

Keywords

Acute coronary syndromes • Alirocumab • Heart failure • ODYSSEY OUTCOMES • MACE

Introduction

Statins have been shown to reduce cardiovascular events in most patients in primary or secondary prevention¹ but failed to show benefit in two large clinical trials in patients with a history of heart failure (HF).^{2,3} These findings were surprising considering the high cardiovascular event rate in patients with HF and substantial representation of patients with ischaemic HF in the two trials: 40% of patients in the GISSI-HF (Gruppo Italiano per lo Studio della Sopravvivenza nell'Insufficienza Cardiaca-Heart Failure) trial² and 100% in CORONA (Controlled ROsuvastatin multiNAtional Trial in Heart Failure).³

Two large, placebo-controlled trials have demonstrated that inhibition of proprotein convertase subtilisin/kexin type 9 (PCSK9) reduces the risk of cardiovascular events in patients with stable or

acute atherosclerotic cardiovascular disease.⁴⁻⁶ The ODYSSEY OUTCOMES (Evaluation of Cardiovascular Outcomes After an Acute Coronary Syndrome During Treatment With Alirocumab) trial included patients with a recent acute coronary syndrome (ACS),^{4,5} while the FOURIER (Further Cardiovascular Outcomes Research with PCSK9 Inhibition in Subjects with Elevated Risk) trial included patients with clinically evident stable atherosclerosis.⁶ However, neither trial demonstrated an effect of PCSK9 inhibitors on hospitalizations for HF.

Whether PCSK9 inhibitors reduce major adverse cardiovascular events (MACE) or reduce hospitalizations for HF in patients with a history of HF is unknown. We therefore addressed these questions using data from the ODYSSEY OUTCOMES trial that compared the PCSK9 inhibitor alirocumab with placebo in patients with a recent ACS.

Methods

Study design

The design⁷ and primary results⁴ of the ODYSSEY OUTCOMES trial (ClinicalTrials.gov: NCT01663402) have been published. Briefly, patients were aged ≥ 40 years, had provided written informed consent, had been hospitalized with an ACS 1–12 months before randomization, and had low-density lipoprotein cholesterol (LDL-C) ≥ 1.81 mmol/L (70 mg/dL), or non-high-density lipoprotein cholesterol ≥ 2.59 mmol/L (100 mg/dL), or apolipoprotein B ≥ 80 mg/dL after ≥ 2 weeks of stable treatment with atorvastatin 40–80 mg daily, rosuvastatin 20–40 mg daily, or the maximum-tolerated dose of one of these statins.

Exclusions included New York Heart Association (NYHA) class III or IV for HF and/or known left ventricular ejection fraction $< 25\%$. After a pre-randomization run-in phase and completion of all planned coronary revascularizations for the qualifying ACS, patients were randomly assigned to receive blinded treatment with alirocumab 75 mg or matching placebo given by subcutaneous injection every 2 weeks. For patients assigned to alirocumab, blinded protocol-specified dose-adjustment algorithms were used to target achieved LDL-C levels between 0.65 and 1.29 mmol/L (25–50 mg/dL) and to avoid sustained levels < 0.39 mmol/L (15 mg/dL).^{4,7} The primary outcome was MACE, defined as the composite of death from coronary heart disease (CHD), non-fatal myocardial infarction (MI), non-fatal or fatal ischaemic stroke, or hospitalization for unstable angina. Hospitalization for HF was a pre-specified secondary outcome. Total mortality and a composite of all-cause death, non-fatal MI, and non-fatal ischaemic stroke were also pre-specified secondary outcomes.

In the current analysis, the effects of alirocumab on MACE, components of MACE including types of MI, hospitalization for HF, and death were compared between patients with a history of HF and those without a history of HF. Change in high-sensitivity C-reactive protein (hs-CRP) was also analysed in the two groups.

History of HF was defined from case report forms and reasons for hospitalization⁸ as shown in [Supplementary material online, Text S2](#). Data on timing of diagnosis, ejection fraction, or classification as HF with reduced ejection fraction or preserved ejection fraction were not collected. MACE, hospitalization for HF, and causes of death were adjudicated by a blinded clinical events committee. In a *post hoc* classification, patients were considered to have a probable ischaemic basis for HF if there was documentation of coronary artery stenosis $\geq 70\%$ by coronary angiography, a history of MI, or percutaneous coronary intervention (PCI) or coronary artery bypass graft (CABG) antedating the qualifying ACS. Patients without such medical history were considered to have a non-ischaemic or undetermined basis for HF.

Statistical analyses

Baseline characteristics, including patient demographics, medical history before index ACS, type of index ACS, renal function, and concomitant medications are presented by history of HF at randomization. Categorical variables are presented as counts and percentages and were compared with χ^2 tests. Continuous variables are presented as medians and quartiles (Q1, Q3) and were compared with Wilcoxon tests. Event rates were estimated per 100 patient-years of follow-up. A Cox proportional hazards model was used to compare the treatment effect (alirocumab vs. placebo) in the subgroups of patients with and without a previous history of HF. The heterogeneity of treatment effect between patients with and without a previous history of HF was analysed with a test for treatment-by-history of HF interaction. We also used a Fine–Gray model for MACE to account for competing risks.⁹ Recurrent hospitalizations for HF were analysed with the Cox proportional hazards model with robust sandwich

variance estimates. All models were stratified by region. The cumulative incidence of MACE and HF hospitalization by treatment and history of HF was estimated by the Kaplan–Meier method. The distribution of causes of death by history of HF and by history of HF and treatment were compared using χ^2 tests. All analyses were performed separately from the sponsor by an independent academic statistician using SAS System version 9.4 (TS1M6).

Results

Overall, 18 924 patients were randomized at 1315 sites in 57 countries, at a median (Q1, Q3) of 2.6 (1.7, 4.3) months after the qualifying ACS. There were 2815 patients (14.9%) with a history of HF and 16 109 patients (85.1%) without a history of HF. Median (Q1, Q3) follow-up in patients with or without a history of HF was the same, 2.8 (2.3, 3.4) years. [Table 1](#) shows the baseline demographics of the two groups.

Compared with patients without a history of HF, those with a history of HF were older (median 61 vs. 58 years) and more likely to be women (30.0% vs. 24.3%), white (86.7% vs. 78.1%), and enrolled in Eastern Europe (61.0% vs. 23.1%). Patients with a history of HF were more likely to have characteristics associated with cardiovascular risk including diabetes, hypertension, atrial fibrillation, prior MI or stroke, and impaired renal function ([Table 1](#)). They were more likely to have had coronary revascularization before the qualifying ACS, but less likely to have had coronary revascularization for the qualifying ACS. Compared with those without a history of HF, patients with a history of HF had higher median baseline concentrations of LDL-C [2.3 (1.9, 2.8) vs. 2.2 (1.9, 2.7) mmol/L; $P < 0.0001$] and hs-CRP [2.0 (0.9, 4.5) vs. 1.6 (0.8, 3.7) mg/L; $P < 0.0001$] and lower levels of lipoprotein(a) [18.5 (5.9, 56.6) vs. 21.6 (6.8, 59.9) mg/dL, respectively; $P = 0.0008$].

The proportions of patients randomized to alirocumab or placebo were approximately equal in both HF subgroups. The utilization of evidence-based medical therapy for HF in the patients with a history of HF included beta-blockers in 87.8%, angiotensin-converting enzyme inhibitors or angiotensin receptor blockers in 82.9%, and aldosterone antagonists in 25.1% ([Table 1](#)).

Persistence and intensity of study treatment

Patient-reported adherence with study medication (i.e. self-administered from diaries) (data not shown) and premature discontinuation of treatment ([Supplementary material online, Table S1](#)) did not differ according to HF category. There were also no differences in the distribution of alirocumab doses, treatment duration, or number of injections received by HF category ([Supplementary material online, Tables S2 and S3](#)).

Effects on lipids and high-sensitivity C-reactive protein

At month 4, alirocumab produced similar relative median (Q1, Q3) decreases in LDL-C in patients with vs. without a history of HF: -1.4 ($-1.9, -0.9$) vs. -1.4 ($-1.8, -0.9$) mmol/L ($P = 0.62$). [Figure 1](#) shows the effect of alirocumab and placebo on median LDL-C levels over 36 months.

Table 1 Baseline characteristics by history of heart failure

Variables	History of HF (n = 2815)	No history of HF (n = 16 109)	P-value
Age (years), median (Q1, Q3)	61 (54, 67)	58 (51, 65)	<0.0001
Women, n (%)	845 (30.0)	3917 (24.3)	<0.0001
Race, n (%)			<0.0001
White	2441 (86.7)	12 583 (78.1)	
Asian	179 (6.4)	2319 (14.4)	
Black	79 (2.8)	394 (2.4)	
Other	116 (4.1)	813 (5.0)	
Geographic region, n (%)			<0.0001
Eastern Europe	1717 (61.0)	3720 (23.1)	
Western Europe	240 (8.5)	3935 (24.4)	
North America	281 (10.0)	2590 (16.1)	
South America	310 (11.0)	2278 (14.1)	
Asia	167 (5.9)	2126 (13.2)	
Rest of world	100 (3.6)	1460 (9.1)	
Risk factors/medical history			
Body mass index (kg/m ²), median (Q1, Q3)	28.6 (25.9, 31.8)	27.8 (25.1, 30.9)	<0.0001
Systolic blood pressure (mmHg), median (Q1, Q3)	126 (119, 136)	127 (117, 138)	0.27
NYHA class, n (%)			—
I	923 (32.9)	—	
II	1879 (67.0)	—	
III	3 (0.1)	—	
Diabetes, n (%)	974 (34.6)	4470 (27.7)	<0.0001
Current smoking, n (%)	566 (20.1)	3994 (24.8)	<0.0001
Hypertension, n (%)	2327 (82.7)	9922 (61.6)	<0.0001
History of MI, n (%)	973 (34.6)	2666 (16.5)	<0.0001
History of stroke, n (%)	167 (5.9)	444 (2.8)	<0.0001
History of atrial fibrillation, n (%)	131 (4.7)	280 (1.7)	<0.0001
History of PAD, n (%)	185 (6.6)	574 (3.6)	<0.0001
History of VTE, n (%)	37 (1.3)	162 (1.0)	0.14
History of COPD, n (%)	188 (6.7)	558 (3.5)	<0.0001
History of cerebrovascular disease, n (%)	232 (8.2)	712 (4.4)	<0.0001
History of malignant disease, n (%)	76 (2.7)	456 (2.8)	0.70
History of revascularization, n (%)	746 (26.5)	2989 (18.6)	<0.0001
PCI	614 (21.8)	2627 (16.3)	<0.0001
CABG	271 (9.6)	776 (4.8)	<0.0001
Coronary artery stenosis on angiography ≥70%, n (%)	482 (17.2)	3363 (20.9)	<0.0001
Prior coronary events, procedures, or CAD, ^a n (%)	1406 (49.9)	6186 (38.4)	<0.001
GFR <60 mL/min/1.73 m ² , n (%)	629 (22.3)	1910 (11.9)	<0.0001
Index event			
Time from ACS to randomization (months), median (Q1, Q3)	2.5 (1.7, 3.9)	2.6 (1.7, 4.4)	0.0006
ACS type, n (%)			<0.0001
NSTEMI	1373 (48.8)	7802 (48.5)	
STEMI	896 (31.9)	5640 (35.1)	
Unstable angina	543 (19.3)	2639 (16.4)	
Revascularization for index event, n (%)	1682 (59.8)	11 995 (74.5)	<0.0001
Medications, n (%)			
Aspirin	2625 (93.3)	15 461 (96.0)	<0.0001
High-intensity statin	2528 (89.8)	14 283 (88.7)	0.08
Oral ADP receptor antagonist	2753 (97.8)	15 951 (99.0)	<0.0001
ACE inhibitor or ARB	2335 (82.9)	12 381 (76.9)	<0.0001
Beta-blocker	2471 (87.8)	13 524 (84.0)	<0.0001

Continued

Table 1 Continued

Variables	History of HF (n = 2815)	No history of HF (n = 16 109)	P-value
Loop diuretics, n (%)			
Furosemide	478 (17.0)	925 (5.7)	<0.0001
Bumetanide	13 (0.5)	21 (0.1)	0.0001
Torsemide, n (%)	225 (8.0)	213 (1.3)	<0.0001
Thiazides, n (%)	121 (4.3)	722 (4.5)	0.6632
Aldosterone antagonists	707 (25.1)	1146 (7.1)	<0.0001
Specific oral anticoagulant	223 (7.9)	558 (3.5)	<0.0001
Lipoproteins, median (Q1, Q3)			
LDL-C (mmol/L)	2.3 (1.9, 2.8)	2.2 (1.9, 2.7)	<0.0001
Non-HDL-C (mmol/L)	3.1 (2.6, 3.7)	3.0 (2.6, 3.5)	<0.0001
Apolipoprotein B (g/L)	0.81 (0.69, 0.96)	0.79 (0.69, 0.92)	0.0002
Lipoprotein(a) (mg/dL)	18.5 (5.9, 56.6)	21.6 (6.8, 59.9)	0.0008
HDL-C (mmol/L)	1.1 (0.9, 1.3)	1.1 (0.9, 1.3)	0.31
Triglycerides (mmol/L)	1.5 (1.1, 2.1)	1.5 (1.1, 2.1)	0.19
hs-CRP (mg/L), median (Q1, Q3)	2.0 (0.9, 4.5)	1.6 (0.8, 3.7)	<0.0001
HbA1c (%), median (Q1, Q3)	5.9 (5.6, 6.4)	5.8 (5.5, 6.3)	<0.0001
Switched to blinded placebo after randomization, n (%)	88 (6.4)	642 (7.9)	0.056

ACE, angiotensin-converting enzyme; ACS, acute coronary syndrome; ADP, adenosine diphosphate; ARB, angiotensin receptor blocker; CABG, coronary artery bypass graft; CAD, coronary artery disease; COPD, chronic obstructive pulmonary disease; GFR, glomerular filtration rate; HbA1c, glycated haemoglobin; HDL-C, high-density lipoprotein cholesterol; HF, heart failure; hs-CRP, high-sensitivity C reactive protein; LDL-C, low-density lipoprotein cholesterol; MI, myocardial infarction; NSTEMI, non-ST-elevation myocardial infarction; NYHA, New York Heart Association; PAD, peripheral artery disease; PCI, percutaneous coronary intervention; Q, quartile; STEMI, ST-elevation myocardial infarction; VTE, venous thrombo-embolism.

^aMI/PCI/CABG/coronary artery stenosis $\geq 70\%$.

At month 4, in patients with vs. without a history of HF, alirocumab also produced similar relative median (Q1, Q3) decreases in lipoprotein(a): -4.7 ($-12.9, 0$) vs. -5.1 ($-13.6, 0$) mmol/dL ($P = 0.052$) and hs-CRP: -0.12 ($-0.98, 0.63$) vs. -0.07 ($-0.83, 0.51$) mg/L ($P = 0.35$).

Effects on major adverse cardiovascular events

The rates of MACE was higher in patients with vs. without a history of HF (6.34 vs. 3.43 events per 100 patient-years). As shown in Figures 2 and 3, there were reductions in MACE with alirocumab vs. placebo in the overall trial cohort [3.53 vs. 4.16 events per 100 patient-years; hazard ratio (HR), 0.85; 95% confidence interval (CI): 0.78–0.93; $P = 0.0001$] and in the subgroup of patients with no history of HF (3.00 vs. 3.87 events per 100 patient-years; HR: 0.78; 95% CI: 0.70–0.86; $P < 0.0001$). Conversely, in patients with a history of HF, there was no reduction in MACE with alirocumab vs. placebo (6.87 vs. 5.84; HR: 1.17; 95% CI: 0.97–1.40; $P = 0.10$) (Graphical abstract). The interaction between randomized treatment and history of HF on MACE was significant ($P_{\text{interaction}} = 0.0001$).

Based on the Fine–Gray model, in the subgroup of patients with a history of HF vs. those with no history of HF, the effects on MACE were the same as the analysis using the Cox model (HR: 1.17; 95% CI: 0.97–1.40 and 0.78; 95% CI: 0.70–0.86, respectively; $P_{\text{interaction}} < 0.0001$).

Effects on components of major adverse cardiovascular events

Figure 2 shows the randomized treatment effects on components of MACE in patients with and without HF. In the overall trial cohort,

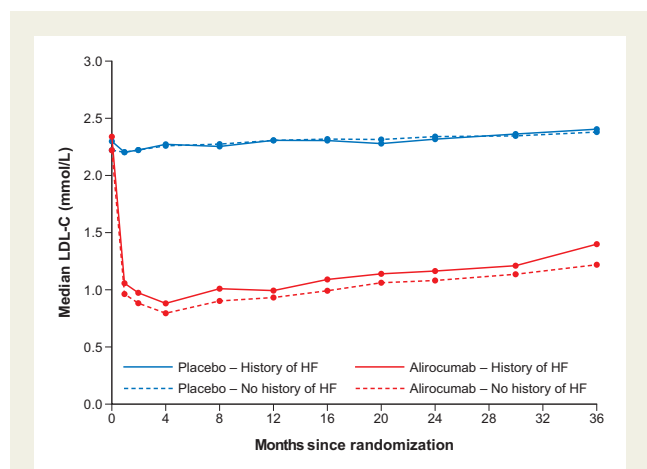


Figure 1 Mean low-density lipoprotein cholesterol levels on alirocumab and placebo according to history of heart failure. For patients on alirocumab, the shape of the curve is similar for patients with and without heart failure ($P = 0.53$). For patients on placebo, the shape of the curve is similar for patients with and without heart failure ($P = 0.15$). There was a significant difference in mean low-density lipoprotein cholesterol between patients with and without heart failure ($P < 0.0001$). HF, heart failure; LDL-C, low-density lipoprotein cholesterol.

alirocumab reduced non-fatal MIs (2.43 vs. 2.83 per 100 patient-years; HR: 0.86; 95% CI: 0.77–0.96; $P = 0.006$). This was the result of a reduction in non-fatal MIs with alirocumab in patients without a history of HF (2.13 vs. 2.75 per 100 patient-years; HR: 0.78; 95% CI:

0.69–0.88; $P < 0.0001$), with an excess of non-fatal MIs with alirocumab compared with placebo in those with a history of HF (4.32 vs. 3.28 per 100 patient-years; HR: 1.30; 95% CI: 1.02–1.64; $P = 0.032$) ($P_{\text{interaction}} = 0.0002$).

The distribution of types of MI differed in patients with vs. without a history of HF (Supplementary material online, Table S4). Type 2 MIs comprised a greater proportion of MI endpoints in patients with vs. without a history of HF (28.1% vs. 15.2%). Periprocedural MIs (Types 4 and 5) comprised a smaller proportion of MI endpoints in patients with vs. without HF (6.5% vs. 16.4%). Type 1 MIs comprised a similar proportion of MI endpoints in patients with vs. without a history of HF (65.5% vs. 68.3%).

There was no significant interaction of treatment and HF history on the other components of MACE (CHD death, ischaemic stroke, or hospitalization for unstable angina).

Effects on hospitalization for heart failure

There were more HF hospitalizations in patients with vs. without a history of HF (2.20 vs. 0.42 per 100 patient-years, $P < 0.0001$) (Figure 4). Alirocumab did not reduce HF hospitalizations compared with placebo, either overall (0.66 vs. 0.68 per 100 patient-years; HR: 0.98; 95% CI: 0.79–1.20; $P = 0.84$) or in patients with HF (2.43 vs. 1.98 per 100 patient-years; HR: 1.22; 95% CI: 0.90–1.66; $P = 0.20$; Figure 2). There was also no effect of treatment on HF hospitalization in patients without a history of HF (0.38 vs. 0.45 per 100 patient-years; HR: 0.84; 95% CI: 0.63–1.12; $P = 0.24$) ($P_{\text{interaction}} = 0.08$).

Effects of alirocumab on total HF hospitalizations (first and recurrent) in patients with vs. without a history of HF were similar to effects of alirocumab on first hospitalization for HF, as shown in Supplementary material online, Table S5.

Effects on death

The rate of all-cause death was higher among patients with vs. without a history of HF (3.07 vs. 1.05 per 100 patient-years; $P < 0.0001$). Cause-specific mortality rates were generally higher among patients with a history of HF (see Supplementary material online, Table S6).

In the overall trial population, alirocumab reduced all-cause death vs. placebo (1.24 vs. 1.46 per 100 patient-years; HR: 0.85; 95% CI: 0.73–0.98; $P = 0.026$) and in patients with no history of HF (0.94 vs. 1.17 per 100 patient-years; HR: 0.80; 95% CI: 0.67–0.95; $P = 0.0135$) (Figure 2). However, there was no effect of alirocumab on death among patients with a history of HF (3.06 vs. 3.08 per 100 patient-years; HR: 0.99; 95% CI: 0.77–1.28; $P = 0.95$). Treatment HRs for cardiovascular death and non-cardiovascular death were numerically more favourable in patients without a history of HF than in those with a history of HF and were significantly different for non-cardiovascular death in patients without HF, but there was no significant interaction of treatment and HF history (Supplementary material online, Table S6).

Effects on cardiovascular death or hospitalization for heart failure

Effects of treatment on this *post hoc* composite endpoint are shown for the overall trial population in Figure 2. There was no significant reduction with alirocumab, but a significant heterogeneity of effects

was observed with a non-significant decrease in patients with no history of HF (0.95 vs. 1.13 per 100 patient-years; HR: 0.84; 95% CI: 0.70–1.01; $P = 0.06$) and a non-significant increase in patients with a history of HF (alirocumab vs. placebo: 4.48 vs. 3.94 per 100 patient-years; HR: 1.14; 95% CI: 0.91–1.42; $P = 0.25$) ($P_{\text{interaction}} = 0.038$).

Effects on death, non-fatal myocardial infarction, or non-fatal ischaemic stroke

In the overall trial cohort, there was a significant reduction in the composite endpoint of death, non-fatal MI or non-fatal ischaemic stroke with alirocumab (3.80 vs. 4.44 per 100 patient-years; HR: 0.86; 95% CI: 0.79–0.93; $P = 0.0003$). In patients with a history of HF, there was a non-significant increase in this endpoint (7.25 vs. 6.35 per 100 patient-years; HR: 1.13; 95% CI: 0.95–1.35; $P = 0.1656$). In patients with no history of HF, there was a significant decrease in this endpoint (3.25 vs. 4.10 per 100 patient-years; HR: 0.79; 95% CI: 0.72–0.88; $P < 0.0001$). The interaction of history of HF and treatment on this composite endpoint was significant ($P_{\text{interaction}} = 0.0001$).

Effects in patients with previous coronary events, procedures, or angiographic evidence of coronary artery disease

We evaluated the effect of alirocumab in patients with a probable ischaemic basis for HF, based on a prior history of MI, PCI or CABG, or coronary artery stenosis $\geq 70\%$ documented on angiography. Overall, 49.9% of patients with a history of HF fulfilled at least one of these criteria, compared with 38.4% of those without a history of HF (Table 1). Supplementary material online, Table S7 shows the effects of alirocumab on MACE, its components, hospitalization for HF, and other secondary endpoints in these patients. Alirocumab reduced MACE vs. placebo in the patients with prior coronary events, procedures, or angiographic documentation of disease without a history of HF (3.91 vs. 5.22 per 100 patient-years; HR: 0.75; 95% CI: 0.65–0.86; $P < 0.0001$). However, alirocumab had no significant effect in patients with prior coronary events, procedures, or angiographic documentation of disease and a history of HF (9.03 vs. 7.83 per 100 patient-years; HR: 1.13; 95% CI: 0.90–1.41; $P = 0.28$) ($P_{\text{interaction}} = 0.002$). There were parallel, significant interactions for HF hospitalizations and non-fatal MI.

Adverse events

Overall rates of adverse events were similar in patients with or without a history of HF, but serious adverse events were more frequent among patients with a history of HF. The incidence of total and serious adverse events was similar with alirocumab vs. placebo within each HF category. These data, as well as data on specific types of adverse events and laboratory abnormalities, are shown in Supplementary material online, Table S8.

Discussion

In the ODYSSEY OUTCOMES trial, 14.9% of patients had a history of HF. Alirocumab reduced atherogenic lipoproteins to a similar extent in patients with or without a history of HF. However, despite a

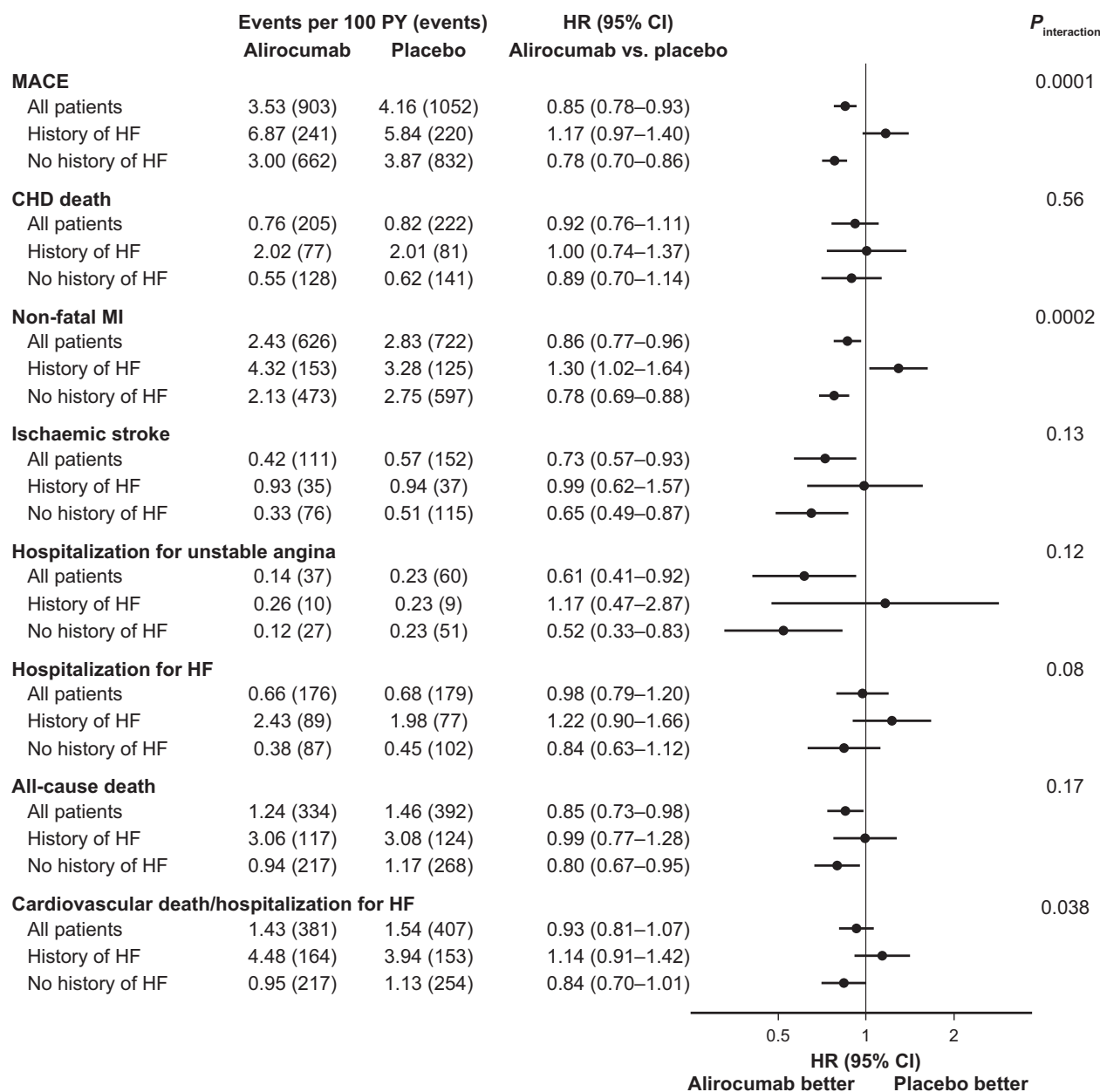


Figure 2 Forest plot of major adverse cardiovascular events, components of major adverse cardiovascular events, hospitalization for heart failure, all-cause death, and the composite of cardiovascular death and hospitalization for heart failure according to history of heart failure. CHD, coronary heart disease; CI, confidence interval; HF, heart failure; HR, hazard ratio; MACE, major adverse cardiovascular events; MI, myocardial infarction; PY, patient-years.

significant effect of alirocumab at reducing MACE in the overall trial cohort and in those without a history of HF, there was no reduction in MACE in patients with a history of HF, with a significant increase in non-fatal MIs. Alirocumab had no effect on hospitalizations for HF, overall or in patients with or without prior HF. Similarly, alirocumab reduced all-cause death in the overall population and patients without a history of HF, but not in patients with a history of HF. Alirocumab was not associated with an excess of adverse events in patients with or without a history of HF.

The absence of benefit of alirocumab on MACE, hospitalizations for HF, or death in patients with recent ACS and a history of HF is unexpected given the large reduction in LDL-C. There are several explanations for these findings. First, patients with a history of HF may have had competing risks from mechanisms such as cardiac pump failure or arrhythmias that were not modified by PCSK9 inhibition. Second, there were differences in the baseline characteristics of patients with vs. without a history of HF, suggesting that the former may have had disease processes that were more advanced or less

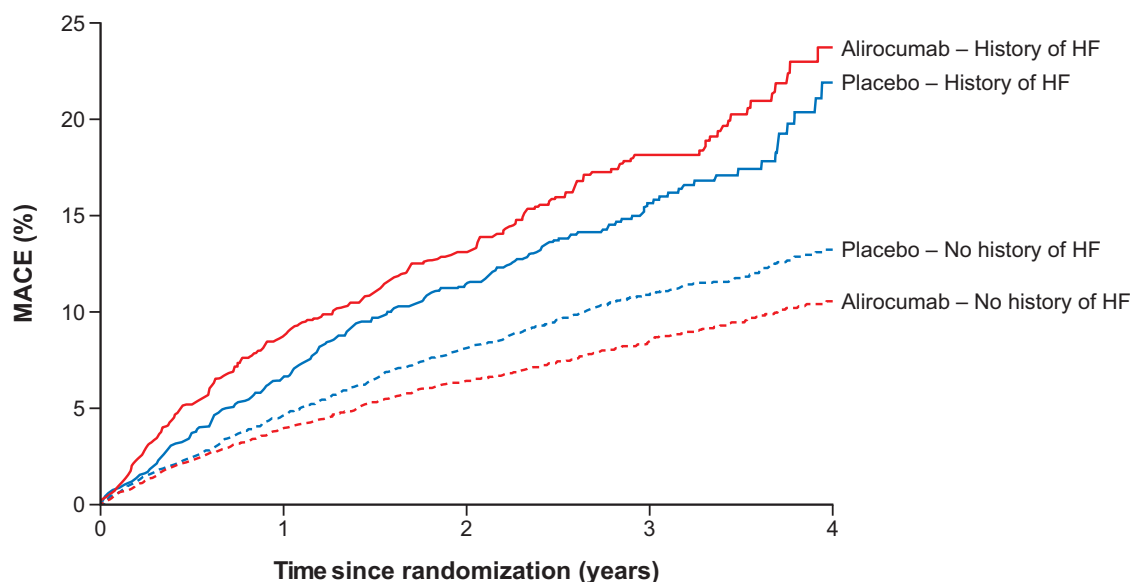


Figure 3 Effects of alirocumab vs. placebo on cumulative incidence of major adverse cardiovascular events by history of heart failure. HF, heart failure; MACE, major adverse cardiovascular events.

modifiable with lipid-lowering therapy. Third, an association of lower lipoprotein concentrations with impaired survival in patients with chronic HF has been reported,^{10–12} but may reflect reverse causality and confounding by unadjusted or unknown factors.

The absence of a favourable effect of alirocumab on MACE in patients with a history of HF is consistent with previous large, randomized trials with statins in patients with HF.^{2,3} The GISSI-HF trial² randomized 4631 patients with chronic HF of NYHA class II–IV irrespective of cause or ejection fraction. ACS <1 month ago was an exclusion criterion, and follow-up was 3.9 years. There was no effect of rosuvastatin 10 mg/day vs. placebo on the primary endpoints of death or death/admission to hospital for cardiovascular reasons. There was also no effect in the 40% of patients where the aetiology of a history of HF was ischaemic in nature.

In CORONA, 5011 patients with NYHA class II–IV ischaemic HF were randomly assigned to receive rosuvastatin 10 mg/day or placebo.³ Rosuvastatin did not reduce the primary outcome of death from cardiovascular causes, non-fatal MI, or non-fatal stroke.

In the CORONA³ and GISSI-HF² studies, the intensity of randomized statin therapy was moderate (10 mg rosuvastatin), which lowered LDL-C by 45.0% at 3 months³ and 32.0% at 1 year² from an untreated baseline. In the current study, patients were randomized to alirocumab or placebo on a background of intensive statin therapy, and alirocumab produced a further reduction of LDL-C by a mean of 63.4%. As in CORONA³ and GISSI-HF,² the effects of the lipid-lowering intervention in patients with a history of HF were neutral.

In an analysis from the CORONA trial and Heart Protection Study, patients had a decrease in the benefit of rosuvastatin and simvastatin, respectively, with higher N-terminal pro-B-type natriuretic peptide levels^{13,14} suggesting that there may be a transition point of less severe HF where patients with HF may benefit from statins.

In BIOSTAT-CHF (BIOlogy Study to TAIlored Treatment in Chronic Heart Failure), which included 2174 patients with worsening HF, multivariable analysis revealed a positive linear association between PCSK9 levels and the risk of mortality, and also with the composite of mortality and unplanned HF hospitalization.¹⁵ This led to the hypothesis that higher PCSK9 levels may contribute to worsening HF.¹⁶ A corollary would be that PCSK9 inhibitors would be beneficial in patients with a history of HF and reduce MACE and hospitalizations for HF. However, the current findings do not support this hypothesis.

Effects on non-fatal myocardial infarction

Pooled individual-patient data re-analysis of CORONA and GISSI-HF¹⁷ reported a significant reduction in MI (HR: 0.81; 95% CI: 0.66–0.99; $P < 0.05$). In the current study, findings for MACE were mirrored by findings for non-fatal MI. Alirocumab decreased the risk of MI in patients without a history of HF and increased non-fatal MI in patients with a history of HF. The distribution of MI type differed according to HF category, with a greater proportion of Type 2 MIs and a smaller proportion of Types 4 and 5 MIs in those with a history of HF. However, these are small numbers of events when considered according to combinations of MI type, HF category, and treatment group, and inference regarding triple interaction of these factors cannot be reliably drawn. Although the treatment HR for non-fatal MI was unfavourable in patients with a history of HF, there is no plausible mechanism for provocation of MI by PCSK9 inhibition in this subgroup, and this may be a chance finding.

No effect of alirocumab on hospitalizations for heart failure

Alirocumab did not significantly reduce hospitalizations for HF, overall or in the subgroups of patients with or without a history of HF.

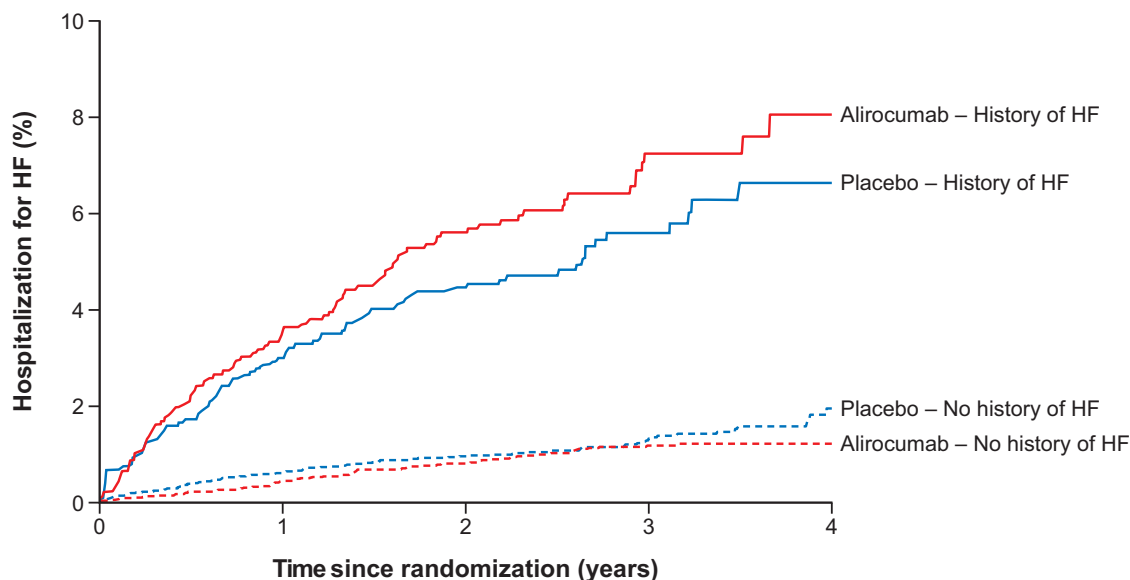


Figure 4 Cumulative incidence of hospitalization for heart failure by history of heart failure. HF, heart failure.

The results for total hospitalizations for HF were consistent with the rates for first hospitalizations for HF favouring placebo in patients with HF and favouring alirocumab in patients without HF.

As alirocumab treatment was associated with a numerical excess of non-fatal MI in patients with a history of HF, a lack of effect on downstream hospitalization for HF may not be surprising in this subgroup. However, alirocumab reduced non-fatal MIs by 14% overall and 22% in patients without a history of HF. The incidences of both Type 1 and 2 MIs were reduced overall and in patients without a history of HF.^{18,19} Therefore, it is unexpected that there was no effect of treatment on hospitalization for HF overall or in patients without prior HF. Longer follow-up may be required to see a reduction in hospitalization for HF in the wake of a reduction in non-fatal MIs.

A recent study showed that 28% of patients presenting with HF from the community have HF with preserved ejection fraction.²⁰ In the current analysis, it is also likely that a proportion of those with a history of HF had HF with preserved ejection fraction. Interestingly, a recent study in mice showed that PCSK9 deficiency contributes to the development of HF with preserved ejection fraction.²¹

Effects on death

Alirocumab reduced all-cause death,⁵ overall and in patients without HF, but not in patients with a history of HF. The latter finding is not surprising given the lack of benefit of treatment on MACE or hospitalization for HF in this subgroup. Sudden cardiac death (presumed arrhythmic) was the most common cause of death, followed by deaths due to fatal MI and to HF with cardiogenic shock. Alirocumab did not affect the risk of these or any other subcategory of death, either overall or in patients with or without prior HF. However, small numbers of events in individual subcategories of death may have limited the power to detect potential treatment effects.

Effects on cardiovascular death or hospitalization for heart failure, and death, non-fatal myocardial infarction, and non-fatal ischaemic stroke

In HF trials, the composite of cardiovascular death or hospitalizations for HF is often the primary efficacy measure. We examined this composite as a *post hoc* outcome in ODYSSEY OUTCOMES according to history of HF. The outcome was not modified by alirocumab in the overall trial population or in patients with or without prior HF. Similarly, the PCSK9 inhibitor evolocumab did not modify this outcome in the FOURIER trial, despite a 27% reduction in non-fatal MIs.⁶ However, in ODYSSEY OUTCOMES, we observed a significant interaction of treatment and HF history on the composite of cardiovascular death or hospitalization for HF, resulting from a non-significant reduction in patients without HF and a non-significant increase in patients with HF.

For the pre-specified composite of death, non-fatal MI, or non-fatal ischaemic stroke, the results were similar to the MACE endpoints.

Effects in patients with previous coronary events, procedures, or angiographic evidence of coronary artery disease

We defined a subgroup of patients with HF who had a probable ischaemic aetiology for HF based on a history of coronary events, procedures, or angiographic evidence of CAD. We hypothesized that intensive lipid lowering with alirocumab would be more likely to reduce MACE in patients with a probable ischaemic basis for HF than in patients with a non-ischaemic or undetermined basis for HF. However, similar to the entire trial population, among these patients, the treatment HRs for MACE, death, HF hospitalization, and other

cardiovascular events were generally more favourable in patients without a history of HF than in patients with a history of HF.

Studies with statins and hospitalization for heart failure

In CORONA, there was a reduction in hospitalizations for HF with rosuvastatin vs. placebo (44.1% vs. 52.0%; $P = 0.01$) and a *post hoc* analysis revealed a significant reduction in total HF hospitalizations.²²

In the PROVE IT-TIMI 22 (Pravastatin or Atorvastatin Evaluation and Infection Trial–Thrombolysis In Myocardial Infarction-22) study, intensive statin therapy with atorvastatin 80 mg vs. moderate statin therapy with pravastatin 40 mg reduced the risk of hospitalization for HF after ACS.²³ There was a significant 45% reduction in hospitalizations for HF (1.6% vs. 3.1%; HR: 0.55; 95% CI: 0.35–0.85, $P = 0.008$). This reduction was not attenuated when controlling for the occurrence of MI (HR: 0.58; 95% CI: 0.37–0.90; $P = 0.016$) or a history of prior HF (HR: 0.55; 95% CI: 0.35–0.86; $P = 0.008$). The benefit of atorvastatin in reducing hospitalizations for HF achieved significance at 2 years.

A meta-analysis has been performed of four trials^{23–27} in patients with a history of HF with intensive vs. moderate lipid lowering or early intensive vs. a delayed simvastatin strategy. The trials included 27 546 patients and the meta-analysis showed a 27% reduction in hospitalization for HF with intensive-statin therapy ($P < 0.001$).

It is unclear why there was no similar benefit on hospitalization for HF when alirocumab was added to high-intensity statin treatment. In the aforementioned intensive statin trials, levels of baseline LDL-C were high: TNT (Treating to New Targets),²⁷ mean 3.15 mmol/L; A to Z trial,²⁵ median 2.87 mmol/L; PROVE IT-TIMI 22,²³ median 2.74 mmol/L; IDEAL (Incremental Decrease in End Points Through Aggressive Lipid Lowering),²⁶ mean 3.15 mmol/L. These were lowered to moderate levels on intensive statin treatment: TNT: 2.07, A to Z: 1.63, PROVE IT-TIMI 22: 1.60, and IDEAL: 2.07 mmol/L. In contrast, median baseline LDL-C in ODYSSEY OUTCOMES was 2.34 mmol/L among those with a history of HF in the alirocumab arm and was lowered to a mean of 0.88 mmol/L at 4 months. It is possible that a benefit of lipid lowering on hospitalization for HF is achieved when LDL-C is reduced from high to moderate levels, but no further benefit is achieved when LDL-C is lowered from moderate to very low levels when a PCSK9 inhibitor is added to background statin treatment.

Guidelines

The 2019 European Society of Cardiology/European Atherosclerosis Society guidelines for the management of dyslipidaemias¹ state that 'initiation of lipid-lowering therapy is not recommended in patients with HF in the absence of other indications for their use' and 'routine administration of statins in patients with HF without other indications for their use (e.g. CAD) is not recommended'. Regarding PCSK9 inhibition in patients with chronic HF, the guidelines state 'there is no evidence regarding the effect of PCSK9 inhibition in patients with chronic HF. In the recent PCSK9 clinical outcomes trials, FOURIER and ODYSSEY OUTCOMES, PCSK9 inhibition in patients with atherosclerotic cardiovascular disease or after an ACS did not reduce the risk of HF hospitalization'.

The current *post hoc* analysis does not provide a basis to recommend PCSK9 inhibitors to patients with recent ACS and a history of

HF but should be viewed as hypothesis generating. A prospective placebo-controlled evaluation of the efficacy of PCSK9 inhibition in this setting is warranted.

Limitations and strengths

There are a number of limitations to this study. Patients with known ejection fraction <25% or NYHA class III–IV were exclusion factors of the trial. Information on admission for HF before randomization was not collected. Information on ejection fraction was not collected and there was no documentation of the basis for the history of HF. Therefore, a history of HF with reduced ejection fraction could not be distinguished from a history of HF with preserved ejection fraction.

Most patients randomized with a recent ACS in ODYSSEY OUTCOMES would be expected to have CAD, although ~ 5% could have had MI with non-obstructive coronary arteries²⁸ due to epicardial coronary artery spasm or microvascular disease. It is possible that some of the patients with a history of HF may have had a qualifying ACS event with troponin elevations being due to HF and not due to a Type 1 MI with acute plaque rupture or a supply demand imbalance Type 2 MI. We did not collect information to classify the qualifying ACS events into Type 1 or 2 MI and angiographic data were not systematically collected.

Levels of B-type natriuretic peptide were not available for this analysis and PCSK9 levels are not reported. Median (Q1, Q3) follow-up was 2.8 (2.3, 3.4) years and longer follow-up would have provided more events and more time to observe effects of alirocumab on cardiovascular risk in patients with a history of HF. Milder episodes of HF not requiring hospitalization were not reported.

Strengths of the current study include the large number of patients with a history of HF with a large number of events in those patients, and the blinded adjudication of MACE and HF hospitalizations.

Conclusion

In ODYSSEY OUTCOMES, a substantial proportion of patients had a history of HF. These patients had a rate of MACE almost twice as high as patients without a history of HF. Although alirocumab lowered LDL-C and lipoprotein(a) by similar amounts in patients with or without a history of HF, it reduced MACE only in patients without prior HF and not in patients with a history of HF. Moreover, alirocumab had no effect on hospitalizations for HF either overall or in patients with or without HF.

Patients with ACS and a history of HF on optimized statin therapy do not appear to benefit from treatment with the PCSK9 inhibitor alirocumab.

Supplementary material

Supplementary material is available at *European Heart Journal* online.

Acknowledgements

Editorial support was provided by Jenny Lloyd (MedLink Healthcare Communications, London) and was funded by Sanofi. Michelle

D'Souza provided secretarial assistance in the preparation of the manuscript and was funded by The Green Lane Research and Educational Fund (GLREF), Auckland City Hospital, Auckland, New Zealand. H.D.W. gratefully thanks the GLREF for support as the John Neutze Fellow.

Funding

This work was supported by Sanofi and Regeneron Pharmaceuticals.

Conflict of interest: H.D.W. reports receiving grant support paid to the institution and fees for serving on a steering committee for the ODYSSEY OUTCOMES trial (Evaluation of Cardiovascular Outcomes After an Acute Coronary Syndrome During Treatment With Alirocumab) from Sanofi-Aventis and Regeneron Pharmaceuticals, for the ACCELERATE study (A Study of Evacetrapib in High-Risk Vascular Disease) from Eli Lilly, for the STRENGTH trial (Outcomes Study to Assess Statin Residual Risk Reduction With EpaNova in High CV Risk Patients With Hypertriglyceridaemia) from Omthera Pharmaceuticals, for the SPIRE trial [The Evaluation of Bococizumab (PF-04950615; RN 316) in Reducing the Occurrence of Major Cardiovascular Events in High Risk Subjects] from Pfizer USA, for the HEART-FID study (Randomized Placebo-Controlled Trial of FCM as Treatment for Heart Failure With Iron Deficiency) from American Regent, for the CAMELLIA-TIMI study [A Study to Evaluate the Effect of Long-term Treatment With BELVIQ (Lorcaserin HC) on the Incidence of Major Adverse Cardiovascular Events and Conversion to Type 2 Diabetes Mellitus in Obese and Overweight Subjects With Cardiovascular Disease or Multiple Cardiovascular Risk Factors] from Eisai, Inc., for the dal-GenE study (Effect of Dalcetrapib vs. Placebo on CV Risk in a Genetically Defined Population With a Recent ACS) from DalCor Pharma UK, Inc., for the AEGIS-II study from CSL Behring, for the SCORED trial (Effect of Sotagliflozin on Cardiovascular and Renal Events in Patients With Type 2 Diabetes and Moderate Renal Impairment Who Are at Cardiovascular Risk) and the SOLOIST-WHF trial (Effect of Sotagliflozin on Cardiovascular Events in Patients With Type 2 Diabetes Post Worsening Heart Failure) from Sanofi-Aventis Australia Pty Ltd, and for the CLEAR Outcomes Study [Evaluation of Major Cardiovascular Events in Patients with, or at High Risk for, Cardiovascular Disease Who Are Statin Intolerant Treated with Bempedoic Acid (ETC-1002) or Placebo] from Esperion Therapeutics, Inc., was on the Advisory Boards for Genentech, Inc. (an affiliate of F. Hoffmann-La Roche Ltd, 'Roche'; Lytics Post-PCI Advisory Board at European Society of Cardiology), and received lecture fees from AstraZeneca. G.G.S. reports research grants to the University of Colorado from Resverlogix, Sanofi, The Medicines Company, and Roche and is a co-inventor of pending US patent 62/806 313 (Methods for Reducing Cardiovascular Risk) assigned in full to the University of Colorado. M.S. reports serving as a consultant or on advisory boards (or both) for CiVi, Resverlogix, Baxter, Esperion, Sanofi, and Regeneron Pharmaceuticals, Inc. D.L.B. discloses the following relationships—Advisory Board: Cardax, CellProthera, Cereno Scientific, Elsevier Practice Update Cardiology, Janssen, Level Ex, Medscape Cardiology, MyoKardia, NirvaMed, Novo Nordisk, PhaseBio, PLx Pharma, Regado Biosciences; Board of Directors: Boston VA Research Institute, Society of Cardiovascular Patient Care, TobeSoft; Chair: Inaugural Chair, American Heart Association Quality Oversight Committee; Data Monitoring Committees: Baim Institute for Clinical Research (formerly Harvard Clinical Research Institute, for the PORTICO trial, funded by St. Jude Medical, now Abbott), Cleveland Clinic (including for the ExCEED trial, funded by Edwards), Contego Medical (Chair, PERFORMANCE 2), Duke Clinical Research Institute, Mayo Clinic, Mount Sinai School of Medicine (for the ENVISAGE trial, funded by Daiichi Sankyo), Population Health Research Institute; Honoraria: American College of Cardiology (Senior

Associate Editor, Clinical Trials and News, ACC.org; Chair, ACC Accreditation Oversight Committee), Baim Institute for Clinical Research (formerly Harvard Clinical Research Institute; RE-DUAL PCI clinical trial steering committee funded by Boehringer Ingelheim; AEGIS-II executive committee funded by CSL Behring), Belvoir Publications (Editor in Chief, Harvard Heart Letter), Canadian Medical and Surgical Knowledge Translation Research Group (clinical trial steering committees), Duke Clinical Research Institute (clinical trial steering committees, including for the PRONOUNCE trial, funded by Ferring Pharmaceuticals), HMP Global (Editor in Chief, Journal of Invasive Cardiology), Journal of the American College of Cardiology (Guest Editor; Associate Editor), K2P (Co-Chair, interdisciplinary curriculum), Level Ex, Medtelligence/ReachMD (CME steering committees), MJH Life Sciences, Population Health Research Institute (for the COMPASS operations committee, publications committee, steering committee, and USA national co-leader, funded by Bayer), Slack Publications (Chief Medical Editor, Cardiology Today's Intervention), Society of Cardiovascular Patient Care (Secretary/Treasurer), WebMD (CME steering committees); Other: Clinical Cardiology (Deputy Editor), NCDR-ACTION Registry Steering Committee (Chair), VA CART Research and Publications Committee (Chair); Research Funding: Abbott, Afimmune, Amarin, Amgen, AstraZeneca, Bayer, Boehringer Ingelheim, Bristol-Myers Squibb, Cardax, CellProthera, Cereno Scientific, Chiesi, CSL Behring, Eisai, Ethicon, Ferring Pharmaceuticals, Forest Laboratories, Fractyl, Garmin, HLS Therapeutics, Idorsia, Ironwood, Ischemix, Janssen, Lexicon, Lilly, Medtronic, MyoKardia, NirvaMed, Novartis, Novo Nordisk, Owkin, Pfizer, PhaseBio, PLx Pharma, Regeneron, Roche, Sanofi, Synaptic, The Medicines Company, 89Bio; Royalties: Elsevier (Editor, Cardiovascular Intervention: A Companion to Braunwald's Heart Disease); Site Co-Investigator: Abbott, Biotronik, Boston Scientific, CSI, St. Jude Medical (now Abbott), Philips, Svelte; Trustee: American College of Cardiology; Unfunded Research: FlowCo, Merck, Takeda. V.A.B. reports grant support from Sanofi, Astra Zeneca, DalCor, Esperion, Bayer, The Medicines Company, and Amgen, all paid directly to her institution, and personal fees from Sanofi and Pfizer. C.-E.C. reports personal fees (honoraria) from Sanofi, Pfizer, Novartis, Merck Sharp Dohme, AstraZeneca, Daiichi Sankyo, Bayer, and Boehringer Ingelheim. R.D. reports research grants from Sanofi, DalCor Pharmaceuticals, Population Health Research Institute, Duke Clinical Research Institute, the TIMI group, Amgen, Cirus, Montreal Health Innovations Coordinating Center, and Lepetit and personal fees, as a member of the Executive Steering Committee, from Amgen and Cirus. S.G.G. reports research grants paid to the institution from Resverlogix, Sanofi, The Medicines Company, and Roche; and a co-inventor of pending US patent 62/806,313 ('Methods of Reducing Cardiovascular Risk') assigned in full to the University of Colorado. J.W.J. reports research grants from the Netherlands Heart Foundation, the Interuniversity Cardiology Institute of the Netherlands, and the European Commission Seventh Framework Programme and research support from Amgen, Astellas, AstraZeneca, Daiichi-Sankyo, Lilly, Merck-Schering-Plough, Pfizer, Roche, and Sanofi. M.L. is an employee of Sanofi. N.P. reports research grants from: Amgen, Inc.; AstraZeneca; Baseline Study LLC; Boehringer Ingelheim; Duke Clinical Research Institute; Eli Lilly & Company; Novartis Pharmaceuticals, Novo Nordisk Pharmaceutical Company; Regeneron Pharmaceuticals, Inc.; Sanofi-S.A.; Verily Sciences Research Company. She reports consulting fees from AstraZeneca; Boehringer Ingelheim; Esperion Therapeutics, Eli Lilly & Company, Novo Nordisk Pharmaceutical Company. R.P. is an employee of Regeneron Pharmaceuticals, Inc. A.D.R. reports research grants and personal fees from Actavis, Alvogen, Astra Zeneca, Arena, CSL Behring, Berlin Chemie Menarini, Boehringer Ingelheim, GSK, Hemofarm Stada, Janssens, Merck, Ministry of Education and Science, Republic of Serbia, MSD, Novartis, Novonordisk, European Union H2020 Program, Pfizer, Resverlogix,

Sanofi, Sandoz, and United Therapeutics outside of the scope of this publication. A.M.Z. reports receiving fees for serving on a steering committee for the ODYSSEY OUTCOMES trial from Sanofi and advisory board and speaker fees from Sanofi, Amgen, Boehringer Ingelheim, Bayer, Novartis, Pfizer, AstraZeneca, and Vifor. D.M.W. has nothing to report. P.G.S. reports grants and non-financial support paid to his institution and as co-chair of the ODYSSEY OUTCOMES trial from Sanofi; research grants and personal fees from Bayer (Steering Committee of MARINER, grant for epidemiological study), Merck (speaker fees, grant for epidemiological studies), Sanofi (co-chair of the ODYSSEY OUTCOMES and of the SCORED trials; consulting, speaking), Servier (chair of the CLARIFY registry; grant for epidemiological research), and Amarin (Executive Steering Committee of the REDUCE-IT trial; consulting); has received personal fees from Amgen, Bristol-Myers Squibb, Boehringer Ingelheim, Pfizer, Novartis, Regeneron Pharmaceuticals, Lilly, and AstraZeneca; and has a European application number/patent number, issued 26 October 2016 (number 15712241.7), for a method for reducing cardiovascular risk.

Data availability

Requests from qualified investigators for data from the ODYSSEY OUTCOMES study will be considered by its Executive Steering Committee at odysseyoutcomesESC@gmail.com.

Declaration of Helsinki

This study complies with the Declaration of Helsinki and the locally appointed ethics committee has approved the research protocol and informed consent has been obtained from the subjects (or their legally authorized representative).

References

- Mach F, Baigent C, Catapano AL *et al*; The Task Force for the Management of Dyslipidaemias of the European Society of Cardiology (ESC) and European Atherosclerosis Society (EAS). 2019 ESC/EAS Guidelines for the management of dyslipidaemias: lipid modification to reduce cardiovascular risk. *Eur Heart J* 2020; **41**:111–188.
- Tavazzi L, Maggioni AP, Marchioli R *et al*; GISSI-HF Investigators. Effect of rosuvastatin in patients with chronic heart failure (the GISSI-HF trial): a randomised, double-blind, placebo-controlled trial. *Lancet* 2008; **372**: 1231–1239.
- Kjekshus J, Apetrei E, Barrios V *et al*; CORONA Group. Rosuvastatin in older patients with systolic heart failure. *N Engl J Med* 2007; **357**:2248–2261.
- Schwartz GG, Steg PG, Szarek M *et al*; ODYSSEY OUTCOMES Committees and Investigators. Alirocumab and cardiovascular outcomes after acute coronary syndrome. *N Engl J Med* 2018; **379**:2097–2107.
- Steg PG, Szarek M, Bhatt DL *et al*; For the ODYSSEY OUTCOMES Committees and Investigators. Effect of alirocumab on mortality after acute coronary syndromes. *Circulation* 2019; **140**:103–112.
- Sabatine MS, Giugliano RP, Keech AC *et al*; FOURIER Steering Committee and Investigators. Evolocumab and clinical outcomes in patients with cardiovascular disease. *N Engl J Med* 2017; **376**:1713–1722.
- Schwartz GG, Bessac L, Berdan LG *et al*. Effect of alirocumab, a monoclonal antibody to PCSK9, on long-term cardiovascular outcomes following acute coronary syndromes: rationale and design of the ODYSSEY outcomes trial. *Am Heart J* 2014; **168**:682–689.
- Robinson JG, Farnier M, Krempf M *et al*; ODYSSEY LONG TERM Investigators. Efficacy and safety of alirocumab in reducing lipids and cardiovascular events. *N Engl J Med* 2015; **372**:1489–1499.
- Austin PC, Lee DS, Fine JP. Introduction to the analysis of survival data in the presence of competing risks. *Circulation* 2016; **133**:601–609.
- Rauchhaus M, Clark AL, Doehner W *et al*. The relationship between cholesterol and survival in patients with chronic heart failure. *J Am Coll Cardiol* 2003; **42**: 1933–1940.
- Horwich TB, Hamilton MA, MacLellan WR, Fonarow GC. Low serum total cholesterol is associated with marked increase in mortality in advanced heart failure. *J Card Fail* 2002; **8**:216–224.
- Rauchhaus M, Kolczek V, Volk H *et al*. Inflammatory cytokines and the possible immunological role for lipoproteins in chronic heart failure. *Int J Cardiol* 2000; **76**: 125–133.
- Cleland JG, Squire I, Ng L. Interpretation of amino-terminal pro-brain natriuretic peptide levels in the HPS and the CORONA study. *J Am Coll Cardiol* 2008; **52**: 1104–1105.
- Cleland JGF, McMurray JJV, Kjekshus J *et al*; CORONA Study Group. Plasma concentration of amino-terminal pro-brain natriuretic peptide in chronic heart failure: prediction of cardiovascular events and interaction with the effects of rosuvastatin: a report from CORONA. *J Am Coll Cardiol* 2009; **54**:1850–1859.
- Bayes-Genis A, Nunez J, Zannad F *et al*. The PCSK9-LDL receptor axis and outcomes in heart failure: BIOSTAT-CHF subanalysis. *J Am Coll Cardiol* 2017; **70**: 2128–2136.
- Francis GS. Cholesterol and heart failure: is there an important connection? *J Am Coll Cardiol* 2017; **70**:2137–2138.
- Feinstein MJ, Jhund P, Kang J *et al*. Do statins reduce the risk of myocardial infarction in patients with heart failure? A pooled individual-level reanalysis of CORONA and GISSI-HF. *Eur J Heart Fail* 2015; **17**:434–441.
- White HD, Steg PG, Szarek M *et al*; ODYSSEY OUTCOMES Investigators. Effects of alirocumab on types of myocardial infarction: insights from the ODYSSEY OUTCOMES trial. *Eur Heart J* 2019; **40**:2801–2809.
- White HD, Steg PG, Schwartz GG. Myocardial infarction and evolocumab. *JAMA Cardiol* 2021; **6**:1220.
- Lam CSP, Gamble GD, Ling LH *et al*. Mortality associated with heart failure with preserved vs. reduced ejection fraction in a prospective international multi-ethnic cohort study. *Eur Heart J* 2018; **39**:1770–1780.
- Da Dalt L, Castiglioni L, Baragetti A *et al*. PCSK9 deficiency rewires heart metabolism and drives heart failure with preserved ejection fraction. *Eur Heart J* 2021; **42**:3078–3090.
- Rogers JK, Jhund PS, Perez AC *et al*. Effect of rosuvastatin on repeat heart failure hospitalizations: the CORONA trial (Controlled Rosuvastatin Multinational Trial in Heart Failure). *JACC Heart Fail* 2014; **2**:289–297.
- Scirica BM, Morrow DA, Cannon CP *et al*; PROVE IT-TIMI 22 Investigators. Intensive statin therapy and the risk of hospitalization for heart failure after an acute coronary syndrome in the PROVE IT-TIMI 22 study. *J Am Coll Cardiol* 2006; **47**:2326–2331.
- Cannon CP, Braunwald E, McCabe CH *et al*; Pravastatin or Atorvastatin Evaluation and Infection Therapy-Thrombolysis in Myocardial Infarction 22 Investigators. Intensive versus moderate lipid lowering with statins after acute coronary syndromes. *N Engl J Med* 2004; **350**:1495–1504.
- de Lemos JA, Blazing MA, Wiviott SD *et al*; A to Z Investigators. Early intensive vs a delayed conservative simvastatin strategy in patients with acute coronary syndromes: phase Z of the A to Z trial. *JAMA* 2004; **292**:1307–1316.
- Pedersen TR, Faergeman O, Kastelein JJ *et al*; Incremental Decrease in End Points Through Aggressive Lipid Lowering (IDEAL) Study Group. High-dose atorvastatin vs usual-dose simvastatin for secondary prevention after myocardial infarction: the IDEAL study: a randomized controlled trial. *JAMA* 2005; **294**: 2437–2445.
- LaRosa JC, Grundy SM, Waters DD *et al*; Treating to New Targets Investigators. Intensive lipid lowering with atorvastatin in patients with stable coronary disease. *N Engl J Med* 2005; **352**:1425–1435.
- Tamis-Holland JE, Jneid H, Reynolds HR *et al*; American Heart Association Interventional Cardiovascular Care Committee of the Council on Clinical Cardiology; Council on Cardiovascular and Stroke Nursing; Council on Epidemiology and Prevention; and Council on Quality of Care and Outcomes Research. Contemporary diagnosis and management of patients with myocardial infarction in the absence of obstructive coronary artery disease: scientific statement from the American Heart Association. *Circulation* 2019; **139**:e891–e908.