

Effect of Alirocumab on Stroke in ODYSSEY OUTCOMES

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Effect of Alirocumab on Stroke in ODYSSEY OUTCOMES

Editorial, see p 2063

BACKGROUND: Lowering of atherogenic lipoproteins, including low-density lipoprotein cholesterol (LDL-C), reduces the risk of ischemic stroke. However, concerns have been raised about very low LDL-C levels and a potential increased risk of hemorrhagic stroke. ODYSSEY OUTCOMES compared the PCSK9 inhibitor alirocumab with placebo in 18 924 patients with recent acute coronary syndrome and elevated atherogenic lipoproteins, despite intensive statin therapy, targeting LDL-C levels of 25 to 50 mg/dL and avoiding sustained LDL-C <15 mg/dL. This prespecified analysis was designed to assess the effect of alirocumab on ischemic and hemorrhagic stroke. We hypothesized that for patients treated with alirocumab there would be a reduction in risk of ischemic stroke without increasing hemorrhagic stroke, irrespective of baseline LDL-C and of history of cerebrovascular disease.

METHODS: Patients were randomized to alirocumab or placebo 1 to 12 months after acute coronary syndrome. The risk of nonfatal or fatal ischemic or hemorrhagic stroke was evaluated, stratified by baseline LDL-C concentration and history of cerebrovascular disease. A potential association of very low achieved LDL-C with alirocumab treatment at month 4 and subsequent hemorrhagic stroke was assessed.

RESULTS: Median follow-up was 2.8 years. In total, 263 ischemic and 33 hemorrhagic strokes occurred. Alirocumab reduced the risk of any stroke (HR, 0.72 [95% CI, 0.57–0.91]) and ischemic stroke (HR, 0.73 [95% CI, 0.57–0.93]) without increasing hemorrhagic stroke (HR, 0.83 [95% CI, 0.42–1.65]). In total, 7164 (37.9%), 6128 (32.4%), and 5629 (29.7%) patients had a baseline LDL-C of <80, 80 to 100, and >100 mg/dL, respectively. The treatment effect on stroke appeared numerically greater for patients with higher baseline LDL-C, but there was no formal evidence of heterogeneity ($P_{\text{interaction}}=0.31$). The effect of alirocumab on stroke was similar among 944 patients (5.0%) with a history of previous cerebrovascular disease and among those without a history of cerebrovascular disease ($P_{\text{interaction}}=0.37$). There was no apparent adverse relation between lower achieved LDL-C and incidence of hemorrhagic stroke in the alirocumab group.

CONCLUSIONS: In patients with recent acute coronary syndrome and dyslipidemia despite intensive statin therapy, alirocumab decreased the risk of stroke, irrespective of baseline LDL-C and history of cerebrovascular disease, over a median follow-up of 2.8 years. Furthermore, risk of hemorrhagic stroke did not depend on achieved LDL-C levels within the alirocumab group.

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■ cerebrovascular disorders
■ lipoprotein, LDL ■ stroke

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Clinical Perspective

What Is New?

- In a randomized, double-blind trial in 18 924 patients with acute coronary syndrome and elevated atherogenic lipoproteins despite intensive statin treatment, PCSK9 (proprotein convertase subtilisin–kexin type 9) inhibition with alirocumab significantly decreased the risk of ischemic stroke, without increasing hemorrhagic stroke.
- This effect did not depend on baseline low-density lipoprotein cholesterol or history of cerebrovascular disease.
- Furthermore, the present findings indicate that risk of hemorrhagic stroke did not depend on achieved low-density lipoprotein cholesterol levels in the alirocumab group.

What Are the Clinical Implications?

- Alirocumab added to intensive statin therapy provides an opportunity to lower low-density lipoprotein cholesterol to levels not previously achievable in most patients with statins and/or ezetimibe.
- Lowering of low-density lipoprotein cholesterol to very low levels reduces the risk of ischemic stroke without increasing hemorrhagic stroke.

Lowering of atherogenic lipoproteins with statin treatment reduces the risk of first or recurrent stroke,^{1–3} and the benefit has been shown by the Cholesterol Treatment Trialist meta-analysis to be directly proportional to the degree of absolute lowering of low-density lipoprotein cholesterol (LDL-C).⁴ Accordingly, international guidelines recommend statin treatment for patients at high cardiovascular risk or with established cardiovascular disease with or without a history of cerebrovascular disease, to prevent major cardiovascular events, including ischemic stroke.^{5,6}

Although some data have raised a potential association of very low LDL-C levels and risk of hemorrhagic stroke,^{7,8} the decrease in ischemic stroke outweighed the potential increase in hemorrhagic stroke.^{4,9} The advent of inhibitors of PCSK9 (proprotein convertase subtilisin–kexin type 9) provided an opportunity to lower LDL-C to levels not previously achievable in most patients with statins and/or ezetimibe. Two large cardiovascular outcomes trials have compared the effect of a fully human PCSK9 inhibitor with placebo on the risk of stroke in patients with atherosclerotic cardiovascular disease and elevated atherogenic lipoproteins despite background statin treatment.^{10,11} In both trials, treatment with the PCSK9 inhibitor lowered LDL-C by more than 50% below the statin-treated baseline. The FOURIER trial (Further Cardiovascular Outcomes Research With PCSK9 Inhibition in Patients With Elevated

Risk)¹⁰ compared evolocumab with placebo in patients with established, stable, atherosclerotic cardiovascular disease. Evolocumab treatment reduced the risk of ischemic stroke without a significant effect on hemorrhagic stroke. The ODYSSEY OUTCOMES trial (Evaluation of Cardiovascular Outcomes After an Acute Coronary Syndrome During Treatment With Alirocumab)¹¹ compared alirocumab with placebo in 18 924 patients with recent acute coronary syndrome (ACS) and showed a reduction in major adverse cardiovascular events with alirocumab compared with placebo. This prespecified analysis was designed to assess the effect of alirocumab on ischemic and hemorrhagic stroke. We hypothesized that for patients treated with alirocumab, there would be a reduction in risk of ischemic stroke without increasing hemorrhagic stroke, irrespective of baseline LDL-C and of history of cerebrovascular disease.

METHODS

The data that support the findings of this study are available from the corresponding author upon reasonable request.

Details of the study design¹² and primary efficacy and safety results¹¹ have been published. In brief, ODYSSEY OUTCOMES was a multicenter, double-blind, placebo-controlled trial in 18 924 patients at least 40 years of age who provided written informed consent and had been hospitalized with an ACS (defined as myocardial infarction or unstable angina) 1 to 12 months before randomization. Qualifying patients had a level of LDL-C ≥ 70 mg/dL (1.81 mmol/L), or non-high-density lipoprotein cholesterol (non-HDL-C) ≥ 100 mg/dL (2.59 mmol/L), or apolipoprotein B ≥ 80 mg/dL (0.8 mmol/L), measured after a minimum of 2 weeks of stable treatment with atorvastatin 40 to 80 mg daily, rosuvastatin 20 to 40 mg daily, or the maximum tolerated dose of either statin (including no statin in case of documented intolerance). All sites obtained institutional review board approval as per local and national guidelines.

Patients were randomly assigned in a 1:1 ratio stratified by country to receive treatment with alirocumab 75 mg subcutaneously every 2 weeks or matching placebo. In case of a persistent LDL-C ≥ 50 mg/dL, the dose of alirocumab was up-titrated to 150 mg/dL. When 2 consecutive measurements of LDL-C < 25 mg/dL were identified, the alirocumab dose was reduced to 75 mg (if measurements were made on the 150-mg dose), and safety was monitored by an independent physician blinded to treatment allocation. In case of two consecutive measurements of LDL-C < 15 mg/dL on alirocumab 75 mg, alirocumab was discontinued with blinded substitution of placebo for the remainder of the trial. The protocol did not specify any change to the background statin dose.

Patients were compared based on three prespecified categories of baseline LDL-C (ie, < 80 mg/dL, 80 to 100 mg/dL, ≥ 100 mg/dL). We compared the effect of alirocumab on stroke among patients with or without a history of cerebrovascular disease, defined as a history of carotid endarterectomy, carotid stenting, previous stroke, or transient ischemic attack. A multivariable prediction model of stroke risk was performed. Last, a subgroup analysis was performed based on the treat-to-target design of the trial, where patients assigned

to alirocumab treatment were classified in the following categories on the basis of their achieved LDL-C value at month 4: below target range (<25 mg/dL), within target range (25 to <50 mg/dL), above target range (50 to <70 mg/dL), and very above target range (\geq 70 mg/dL). In this analysis, the incidence of hemorrhagic stroke after month 4 was summarized among patients in each of these achieved LDL-C categories.

End Points

End points were classified as fatal or nonfatal ischemic or hemorrhagic stroke, adjudicated by physicians who were unaware of the study treatment group assignments. As part of the original analysis conventions, an ischemic or unclassified stroke that was followed by a death within 30 days with a cause of ischemic or undetermined stroke was considered a fatal ischemic stroke, with an event date of the initial event. For the purposes of the current report, this convention was applied for hemorrhagic strokes (ie, a hemorrhagic stroke that was followed by a death within 30 days was considered a fatal hemorrhagic stroke, with an event date of the initial event). In addition, 9 nonfatal strokes with an unclassified cause were grouped with nonfatal ischemic strokes, as prespecified in the design of the study.

Statistical Considerations

Analyses of clinical outcomes and LDL-C levels were performed according to the intention-to-treat principle, including all patients, events, and measurements from randomization to the study end date (November 11, 2017). Hazard ratios (HR) and 95% CIs were estimated by Cox proportional hazards models, stratified by geographic region; *P* values were determined using stratified log-rank tests. End point rates were based on observed incidences. The treatment proportional hazards assumption for each type of stroke (any, ischemic, hemorrhagic) was assessed by a Kolmogorov-type supremum test. A multivariable model was performed to predict all-cause stroke with stepwise selection, using *P*=0.05 for entry or exit. Prespecified candidate variables were age category, sex, race, region, index event, lipid-lowering therapy at randomization, LDL-C, HDL-C, lipoprotein(a), body mass index, systolic blood pressure, glomerular filtration rate, diabetes, hypertension, myocardial infarction, cerebrovascular disease, malignant disease, percutaneous coronary intervention, chronic obstructive pulmonary disease, coronary artery bypass grafting, peripheral artery disease, chronic heart failure, venous thromboembolism, atrial fibrillation, current smoker, revascularization for index event, oral adenosine diphosphate receptor antagonist, oral anticoagulant, and alirocumab treatment. Relationships between categories of achieved month-4 LDL-C and subsequent hemorrhagic stroke in the alirocumab group were summarized by descriptive statistics. Analyses were performed in SAS 9.4 and S+ 8.2.

RESULTS

Of 18 924 randomized patients, 9462 were assigned to the alirocumab group and 9462 to the placebo group, with a median (quartile 1, quartile 3) follow-up of 2.8 (2.3, 3.4) years. There were no major differences in

baseline characteristics between the alirocumab group and the placebo group.¹¹ At baseline, there were 944 patients (5.0%) with a history of cerebrovascular disease and 17 980 (95.0%) without a history of cerebrovascular disease.

Table 1 summarizes the baseline characteristics of patients with or without a history of cerebrovascular disease. Compared with patients without a history of cerebrovascular disease, those with cerebrovascular disease were older (median age, 63 vs 58 years) and included more women (31.9% vs 24.8%). Of all patients with cerebrovascular disease, 611 (64.7%) had a history of stroke. Furthermore, compared with patients without a history of cerebrovascular disease, those with cerebrovascular disease had a higher systolic blood pressure and more often had comorbidities, including a history of diabetes, hypertension, myocardial infarction, atrial fibrillation, peripheral artery disease, venous thromboembolism, chronic obstructive pulmonary disease, heart failure, malignant disease, percutaneous coronary intervention, coronary artery bypass grafting, and a glomerular filtration rate <60 mL/min/1.73m²). Median (quartile 1, quartile 3) baseline LDL-C was 91 (76–110) mg/dL in patients with cerebrovascular disease versus 86 (73–104) mg/dL in those without cerebrovascular disease.

The Kaplan-Meier curves for any stroke, ischemic stroke, and hemorrhagic stroke are shown in Figure 1. In total, 263 ischemic strokes and 33 hemorrhagic strokes occurred. Of the 33 hemorrhagic strokes, 25 occurred in the safety population during the treatment-emergent adverse event reporting period,¹¹ and 8 were captured in the intention-to-treat analysis. Alirocumab reduced the risk of any stroke (HR, 0.72 [95% CI, 0.57–0.91]) and ischemic stroke (HR, 0.73 [95% CI, 0.57–0.93]) without increasing hemorrhagic stroke (HR, 0.83 [95% CI, 0.42–1.65]). There was no evidence of non-proportionality in the treatment effects (supremum test *P*=0.56, 0.35, and 0.47 for any, ischemic, and hemorrhagic, respectively).

Figure 2 shows the HRs for stroke by baseline LDL-C category and history of cerebrovascular disease. In total, 7164 (37.9%) patients had a baseline LDL-C <80 mg/dL, 6128 (32.4%) had a value of 80 to 100 mg/dL, and 5629 (29.7%) had a value >100 mg/dL. The treatment effect appeared numerically greater for patients with higher baseline LDL-C, but there was no formal evidence of treatment effect heterogeneity (*P*_{interaction}=0.31). An exploratory analysis was performed in which baseline LDL-C was categorized dichotomously (<100 mg/dL and \geq 100 mg/dL), which also found no formal evidence of treatment effect heterogeneity (*P*_{interaction}=0.18). Similarly, the effect of alirocumab on stroke appeared consistent regardless of the presence (*n*=944 patients [5.0%]) or absence of a history of cerebrovascular disease, (*P*_{interaction}=0.37).

Table 1. Baseline Characteristics, by History of Cerebrovascular Disease

Variable	History of Cerebrovascular Disease (n=944)	No History of Cerebrovascular Disease (n=17 980)	P Value
Demographics			
Age, y	63 (57, 70)	58 (52, 65)	<0.001
Women	301 (31.9)	4461 (24.8)	<0.001
Race			
White	754 (79.9)	14 270 (79.4)	0.004
Asian	107 (11.3)	2391 (13.3)	
Black	39 (4.1)	434 (2.4)	
Other	44 (4.7)	885 (4.9)	
Geographic region			
Western Europe	171 (18.1)	4004 (22.3)	<0.001
Eastern Europe	255 (27.0)	5182 (28.8)	
North America	224 (23.7)	2647 (14.7)	
South America	111 (11.8)	2477 (13.8)	
Asia	101 (10.7)	2192 (12.2)	
Rest of world	82 (8.7)	1478 (8.2)	
Risk factors/medical history			
Body mass index, kg/m ²	28.1 (25.2, 31.3)	27.9 (25.2, 31.1)	0.24
Systolic blood pressure, mmHg	130 (120, 141)	126 (117, 137)	<0.001
Diabetes	414 (43.9)	5030 (28.0)	<0.001
Current smoking	190 (20.1)	4370 (24.3)	0.003
Hypertension	830 (87.9)	11 419 (63.5)	<0.001
Myocardial infarction	288 (30.5)	3351 (18.6)	<0.001
Stroke	611 (64.7)	0	<0.001
Atrial fibrillation	54 (5.7)	357 (2.0)	<0.001
Peripheral artery disease	149 (15.8)	610 (3.4)	<0.001
Venous thromboembolism	17 (1.8)	182 (1.0)	0.021
Chronic obstructive pulmonary disease	69 (7.3)	677 (3.8)	<0.001
Heart failure	232 (24.6)	2583 (14.4)	<0.001
Malignant disease	46 (4.9)	486 (2.7)	<0.001
Percutaneous coronary intervention	277 (29.3)	2964 (16.5)	<0.001
Coronary artery bypass graft	139 (14.7)	908 (5.1)	<0.001
Glomerular filtration rate <60 mL/min/1.73 m ²)	265 (28.1)	2274 (12.7)	<0.001
Index event			
Time from acute coronary syndrome to randomization, months	2.8 (1.8, 4.7)	2.6 (1.7, 4.3)	0.04
Acute coronary syndrome type			
Non-ST-segment elevation myocardial infarction	533 (56.6)	8642 (48.1)	<0.001
ST-segment elevation myocardial infarction	261 (27.7)	6275 (35.0)	

(Continued)

Table 1. Continued

Variable	History of Cerebrovascular Disease (n=944)	No History of Cerebrovascular Disease (n=17 980)	P Value
Unstable angina	148 (15.7)	3034 (16.9)	
Revascularization	645 (68.3)	13 032 (72.5)	0.005
Medications			
Aspirin	875 (92.7)	17 211 (95.7)	<0.001
High-intensity statin	800 (84.7)	16 011 (89.0)	<0.001
Oral adenosine diphosphate receptor antagonist	922 (97.7)	17 782 (98.9)	0.001
Specific oral anticoagulant	101 (10.7)	680 (3.8)	<0.001
ACE inhibitor or ARB	778 (82.4)	13 938 (77.5)	<0.001
β-blocker	796 (84.3)	15 199 (84.5)	0.86
Lipoproteins, mg/dL			
Lipoprotein(a)	22.4 (7.6, 62.1)	21.2 (6.9, 57.5)	0.09
HDL-C	43 (36, 51)	42 (36, 50)	0.20
LDL-C	91 (76, 110)	86 (73, 104)	<0.001
Non-HDL-C	121 (104, 144)	115 (99, 137)	<0.001
Triglycerides	136 (97, 190)	129 (94, 182)	0.002
Total cholesterol	166 (148, 190)	159 (142, 182)	<0.001
Apolipoprotein B	83 (72, 96)	79 (69, 93)	<0.001
C-reactive protein, mg/dL	0.22 (0.10, 0.48)	0.16 (0.08, 0.38)	<0.001
Glycated hemoglobin A1c, %	6.1 (5.7, 7.0)	5.8 (5.5, 6.3)	<0.001
Switched to blinded placebo after randomization	27 (2.9)	703 (3.9)	0.10

Data presented as n (%), median (quartile 1, quartile 3). A Wilcoxon rank-sum test was used to compare means for continuous variables and chi-square tests for categorical variables. To convert the values for cholesterol to mmol/L, multiply by 0.02586. To convert the values for triglycerides to mmol/L, multiply by 0.01129. ACE indicates angiotensin-converting enzyme inhibitor; ARB, angiotensin receptor blocker; HDL-C, high-density lipoprotein cholesterol; and LDL-C, low-density lipoprotein cholesterol.

The multivariable baseline predictors of any stroke are shown in Table 2. History of cerebrovascular disease was the strongest predictor, with a HR of 2.469 (95% CI, 1.792–3.401; $P<0.0001$). In addition, glomerular filtration rate <60 mL/min/1.73 m²), diabetes, heart failure, myocardial infarction, oral anticoagulants, current smoking and peripheral artery disease, and increasing age, systolic blood pressure, and LDL-C were associated with an increased risk of all-cause stroke (all $P<0.05$). Alirocumab had the strongest negative association with stroke (HR, 0.712 [95% CI, 0.564–0.898]; $P=0.0041$). Per 1-mg/dL increment, HDL-C also had a negative association with stroke (HR, 0.989 [95% CI, 0.978–1.000]; $P=0.0476$).

Achieved LDL-C at month 4 by treatment group is shown in Figure 3. Among the 9462 alirocumab-assigned patients, 3397 (35.9%) achieved LDL-C concentrations

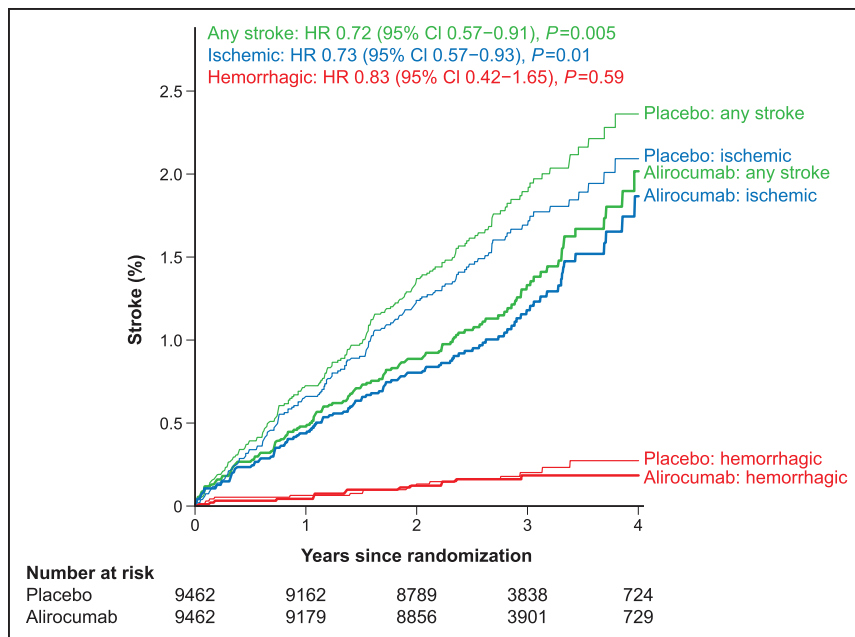


Figure 1. Kaplan-Meier curves for any stroke, ischemic stroke and hemorrhagic stroke. CI indicates confidence interval; and HR, hazard ratio.

at month 4 <25 mg/dL, 3749 (39.6%) achieved 25 to <50 mg/dL, 1087 (11.5%) achieved 50 to <70 mg/dL, and 1169 (12.4%) achieved ≥ 70 mg/dL. Table 3 shows the incidence of hemorrhagic stroke by ordered category of month 4 achieved LDL-C in the alirocumab group. There was no apparent adverse relation between lower achieved LDL-C and incidence of hemorrhagic stroke, with a numerically lower proportion of patients in the lowest categories of achieved LDL-C (ie, <50 mg/dL) experiencing this outcome.

DISCUSSION

In patients with recent ACS and dyslipidemia despite intensive statin therapy, alirocumab decreased the risk of

ischemic stroke without increasing hemorrhagic stroke. Furthermore, risk of hemorrhagic stroke did not depend on achieved LDL-C levels in the alirocumab group.

The treatment effect appeared numerically greater with lower HRs for patients with higher baseline LDL-C, suggesting that patients with a higher risk at baseline have a larger benefit of alirocumab. However, this linear trend was not statistically significant. Furthermore, because qualification for inclusion in the ODYSSEY OUTCOMES trial required an ACS, patients with a history of cerebrovascular disease all had polyvascular disease, which is associated with a high risk of major adverse cardiovascular events and large absolute benefit of alirocumab in reducing such events.¹³ Accordingly, stroke risk was markedly higher in patients with a history of

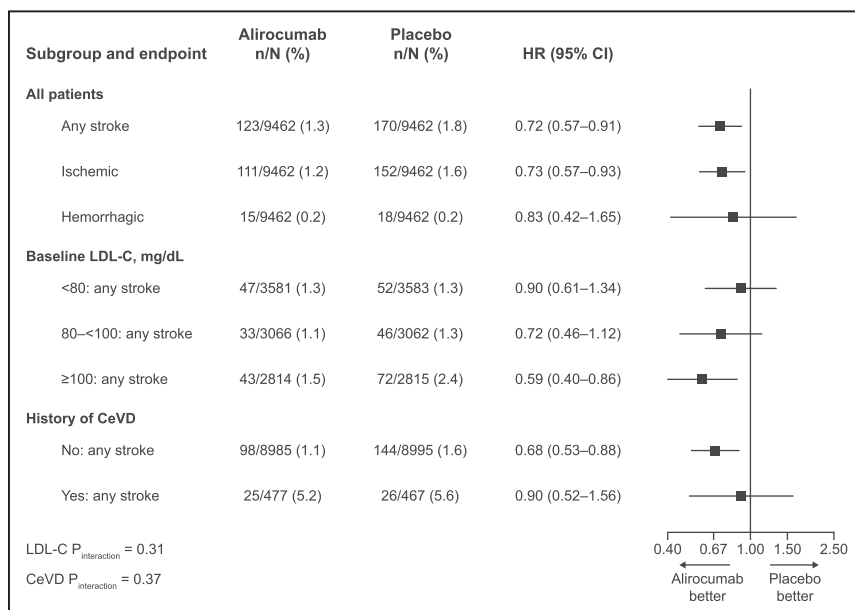


Figure 2. Stroke by history of cerebrovascular disease and baseline LDL-C category. LDL-C indicates low-density lipoprotein cholesterol; and HR, hazard ratio.

Table 2. Multivariable Model Predicting Stroke

Variable	Hazard Ratio (95% CI)	P Value
History of cerebrovascular disease	2.469 (1.792, 3.401)	<0.0001
Glomerular filtration rate <60 mL/min/1.73 m ²	1.751 (1.328, 2.309)	<0.0001
Age, per 1-year increment	1.027 (1.013, 1.042)	0.0001
History of diabetes	1.589 (1.251, 2.020)	0.0001
Systolic blood pressure, per 1-mmHg increment	1.012 (1.005, 1.019)	0.0008
LDL-C, per 1-mg/dL increment	1.005 (1.002, 1.008)	0.0009
Alirocumab treatment	0.712 (0.564, 0.898)	0.0041
History of heart failure	1.502 (1.124, 2.004)	0.0060
Geographic region		
Western Europe	Reference	0.0065
Eastern Europe	1.493 (1.010, 2.206)	
North America	1.569 (1.032, 2.386)	
South America	1.603 (1.013, 2.537)	
Asia	2.288 (1.434, 3.648)	
Rest of world	2.173 (1.371, 3.445)	
Myocardial infarction before index event	1.366 (1.056, 1.770)	0.0177
Specific oral anticoagulant	1.595 (1.054, 2.415)	0.0272
Current smoker	1.355 (1.024, 1.795)	0.0339
History of peripheral artery disease	1.497 (1.007, 2.223)	0.0461
HDL-C, per 1-mg/dL increment	0.989 (0.978, 1.000)	0.0476

Candidate predictors (stepwise selection), $P=0.05$ for entry or exit: age category, sex, race, geographic region, index event, lipid-lowering therapy at randomization, low-density lipoprotein cholesterol (LDL-C, HDL-C), lipoprotein(a), body mass index, systolic blood pressure, glomerular filtration rate, diabetes, hypertension, myocardial infarction, cerebrovascular disease, malignant disease, percutaneous coronary intervention, chronic obstructive pulmonary disease, coronary artery bypass graft, peripheral artery disease, congestive heart failure, venous thromboembolism, atrial fibrillation, current smoker, revascularization for index event, oral adenosine diphosphate receptor antagonist, oral anticoagulant, alirocumab treatment. HDL-C indicates high-density lipoprotein cholesterol; and LDL-C, low-density lipoprotein cholesterol.

cerebrovascular disease, with a HR of 2.469 (95% CI, 1.792–3.401) in multivariable analysis. However, the treatment effect of alirocumab on stroke was similar in both patients with or without a history of cerebrovascular disease. Therefore, alirocumab is a suitable therapy in patients with recent ACS, irrespective of baseline LDL-C and of history of cerebrovascular disease.

The potential association of very low LDL-C with hemorrhagic stroke risk has been investigated primarily in epidemiologic studies,¹⁴ but more recently 2 large prospective cohort studies tried to provide clarity on this matter in healthy participants and found increased risks of hemorrhagic stroke with LDL-C <70 mg/dL.^{7,15} The Women's Health Study in the United States found an adjusted relative risk of 2.17 (95% CI, 1.05–4.48).¹⁵ The Kailuan study in China reported adjusted HRs of 1.65 (95% CI, 1.32–2.05) for LDL-C 50 to 69 mg/dL and 2.69 (95% CI, 2.03–3.57) for LDL-C <50 mg/dL.⁷

Despite concerns regarding hemorrhagic stroke, our findings that intensive reduction of LDL-C did not cause harm in terms of hemorrhagic stroke reinforces and extends other previous data. The SPARCL trial (Stroke Prevention by Aggressive Reduction in Cholesterol Levels) showed a reduction in overall strokes with high-intensity atorvastatin therapy, despite a small increase in hemorrhagic stroke in 4731 patients with recent stroke or transient ischemic attack.¹⁶ SPARCL also demonstrated that achieving $\geq 50\%$ LDL-C lowering was associated with a greater reduction in the risk of ischemic stroke without increasing hemorrhagic stroke and that a higher risk of hemorrhagic stroke was largely in patients with a history of small vessel disease or nonatherothrombotic stroke.^{1,17}

Similar conclusions regarding stroke were drawn from the FOURIER trial, investigating the PCSK9 inhibitor evolocumab added to statin therapy in 27 564 patients with stable, established, atherosclerotic cardiovascular disease, including 19.4% with a history of nonhemorrhagic stroke. Evolocumab treatment significantly reduced the risk of ischemic stroke (HR, 0.75 [95% CI, 0.62–0.92]), without a significant effect on hemorrhagic stroke (HR, 1.16 [95% CI, 0.68–1.98]).¹⁰ Although PCSK9 inhibition may lower LDL-C to levels far below those achieved with statins alone, FOURIER found that lower achieved LDL-C did not increase the risk of hemorrhagic stroke, even when LDL-C levels were <0.5 mmol/L (20 mg/dL).¹⁸

As most lipid trials have few hemorrhagic stroke events, a meta-analysis was performed recently of randomized trials, including all lipid-lowering trials with statins, ezetimibe, and PCSK9 inhibition.⁹ The investigators found a net benefit of lipid-lowering, with a rate ratio of 0.80 (95% CI, 0.76–0.84) for ischemic stroke and 1.17 (95% CI, 1.03–1.32) for hemorrhagic stroke, for each 1 mmol/L lower LDL-C achieved at about 1 year of follow-up.⁹ Of note, in these studies different types and doses of lipid-lowering therapies were used in patients with or without proven vascular disease in various vascular beds, including coronary artery disease, peripheral artery disease, and cerebrovascular disease. Our results are in line with this meta-analysis in that we found a large benefit of alirocumab in multivariable analysis (HR, 0.712 [95% CI, 0.564–0.898]; $P=0.0041$) and no relationship between very low achieved LDL-C and incidence of hemorrhagic stroke. However, given that only 33 patients had a hemorrhagic stroke, the confidence intervals were large, with an HR in all patients of 0.83 (95% CI, 0.42–1.65). The ongoing Treat Stroke to Target trial of patients with stroke of atherothrombotic origin treated with statins, is testing whether targeting a lower LDL-C level with statins and ezetimibe reduces cardiovascular event rates further, and will also provide additional prospective testing of the safety of that strategy.¹⁹

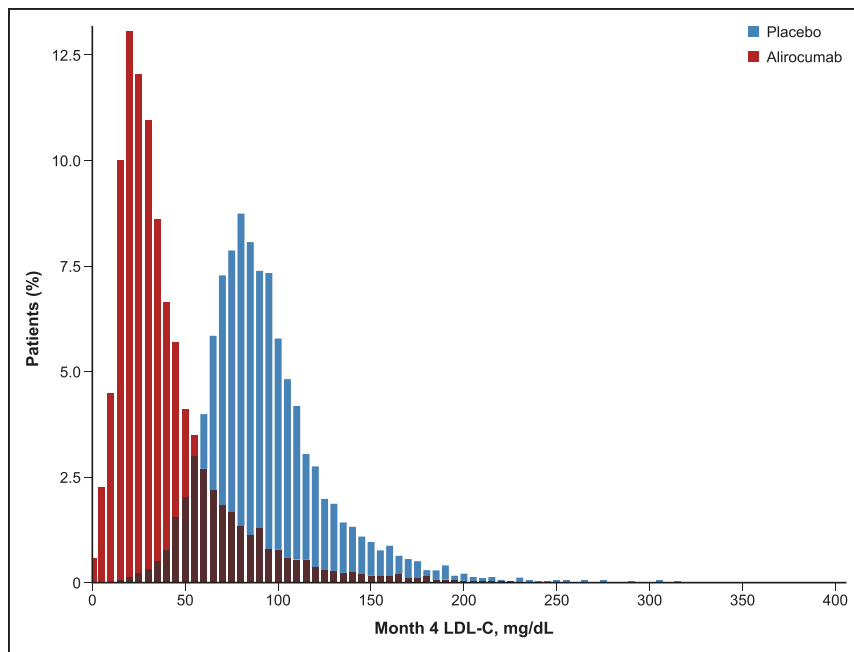


Figure 3. Month 4 LDL-C by treatment group.

LDL-C indicates low-density lipoprotein cholesterol.

Limitations

Median follow-up was relatively brief, at 2.8 years, and one cannot exclude that the effects of alirocumab on ischemic or particularly hemorrhagic stroke might differ with much longer-term follow-up. Therefore, a relationship of alirocumab treatment to long-term risk of stroke is as yet unknown. A relatively small number of patients had a history of cerebrovascular disease, and therefore the power to detect effects of alirocumab in this subgroup was limited. Only a dedicated randomized controlled trial among individuals with cerebrovascular disease could reliably establish the efficacy and safety in this subgroup. Because blood pressure was generally well controlled in the trial population, the present results may not necessarily apply in populations with uncontrolled blood pressure. In the analyses relating achieved LDL-C levels to subsequent risk of hemorrhagic stroke, patients who achieved lower LDL-C might have other prognostic characteristics placing them at lower risk for this outcome, on average, relative to patients with higher achieved LDL-C. This, in combination with few hemorrhagic strokes after month 4, might in part explain the lack of an observed adverse relationship.

Table 3. Hemorrhagic Stroke, by Achieved LDL-C Category at 4 Months in Patients Assigned to Alirocumab Treatment

Month 4 LDL-C, mg/dL	n/N (%)
<25	2/3399 (0.1)
25 to <50	3/3754 (0.1)
50 to <70	3/1090 (0.3)
≥70	4/1177 (0.3)

To convert the values for cholesterol to mmol/L, multiply by 0.02586. LDL-C indicates low-density lipoprotein cholesterol.

Conclusions

This analysis of the ODYSSEY OUTCOMES trial shows that in patients with recent ACS and dyslipidemia despite intensive statin therapy, the PCSK9 inhibitor alirocumab decreased the risk of stroke, irrespective of baseline LDL-C and of history of cerebrovascular disease, over a median follow-up of 2.8 years. Furthermore, the present findings indicate that the risk of hemorrhagic stroke did not depend on achieved LDL-C levels in the alirocumab group.

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REFERENCES

- Amarencu P, Goldstein LB, Szarek M, Sillesen H, Rudolph AE, Callahan A 3rd, Hennerici M, Simunovic L, Zivin JA, Welch KM; SPARCL Investigators. Effects of intense low-density lipoprotein cholesterol reduction in patients with stroke or transient ischemic attack: the Stroke Prevention by Aggressive Reduction in Cholesterol Levels (SPARCL) trial. *Stroke*. 2007;38:3198–3204. doi: 10.1161/STROKEAHA.107.493106
- Goldstein LB, Amarencu P, Zivin J, Messig M, Altafullah I, Callahan A, Hennerici M, MacLeod MJ, Sillesen H, Zweifler R, et al; Stroke Prevention by Aggressive Reduction in Cholesterol Levels Investigators. Statin treatment and stroke outcome in the Stroke Prevention by Aggressive Reduction in Cholesterol Levels (SPARCL) trial. *Stroke*. 2009;40:3526–3531. doi: 10.1161/STROKEAHA.109.557330
- White HD, Simes RJ, Anderson NE, Hankey GJ, Watson JD, Hunt D, Colquhoun DM, Glasziou P, MacMahon S, Kirby AC, et al. Pravastatin therapy and the risk of stroke. *N Engl J Med*. 2000;343:317–326. doi: 10.1056/NEJM200008033430502
- Baigent C, Blackwell L, Emberson J, Holland LE, Reith C, Bhalra N, Peto R, Barnes EH, Keech A, Simes J, et al. Efficacy and safety of more intensive lowering of LDL cholesterol: a meta-analysis of data from 170,000 participants in 26 randomised trials. *Lancet*. 2010;376:1670–1681.
- Kernan WN, Ovbiagele B, Black HR, Bravata DM, Chimowitz MI, Ezekowitz MD, Fang MC, Fisher M, Furie KL, Heck DV, et al; American Heart Association Stroke Council, Council on Cardiovascular and Stroke Nursing, Council on Clinical Cardiology, and Council on Peripheral Vascular Disease. Guidelines for the prevention of stroke in patients with stroke and transient ischemic attack: a guideline for healthcare professionals from the American Heart Association/American Stroke Association. *Stroke*. 2014;45:2160–2236. doi: 10.1161/STR.0000000000000024
- Mach F, Baigent C, Catapano AL, Koskinas KC, Casula M, Badimon L, Chapman MJ, De Backer GG, Delgado V, Ference BA, et al; ESC Scientific Document Group. 2019 ESC/EAS Guidelines for the management of dyslipidaemias: lipid modification to reduce cardiovascular risk [published online ahead of print August 31, 2019]. *Eur Heart J*. 2019;ehz455. doi: 10.1093/eurheartj/ehz455.
- Ma C, Gurol ME, Huang Z, Lichtenstein AH, Wang X, Wang Y, Neumann S, Wu S, Gao X. Low-density lipoprotein cholesterol and risk of intracerebral hemorrhage: a prospective study. *Neurology*. 2019;93:e445–e457. doi: 10.1212/WNL.00000000000007853
- Collins R, Reith C, Emberson J, Armitage J, Baigent C, Blackwell L, Blumenthal R, Danesh J, Smith GD, DeMets D, et al. Interpretation of the evidence for the efficacy and safety of statin therapy. *Lancet*. 2016;388:2532–2561. doi: 10.1016/S0140-6736(16)31357-5
- Sun L, Clarke R, Bennett D, Guo Y, Walters RG, Hill M, Parish S, Millwood IY, Bian X, Chen Y, et al; China Kadoorie Biobank Collaborative Group; International Steering Committee; International Co-ordinating Centre, Oxford; National Co-ordinating Centre, Beijing; Regional Co-ordinating Centres. Causal associations of blood lipids with risk of ischemic stroke and intracerebral hemorrhage in Chinese adults. *Nat Med*. 2019;25:569–574. doi: 10.1038/s41591-019-0366-x
- Sabatine MS, Giugliano RP, Keech AC, Honarpour N, Wiviott SD, Murphy SA, Kuder JF, Wang H, Liu T, Wasserman SM, et al; FOURIER Steering Committee and Investigators. Evolocumab and clinical outcomes in patients with cardiovascular disease. *N Engl J Med*. 2017;376:1713–1722. doi: 10.1056/NEJMoa1615664
- Schwartz GG, Steg PG, Szarek M, Bhatt DL, Bittner VA, Diaz R, Edelberg JM, Goodman SG, Hanotin C, Harrington RA, et al; ODYSSEY OUTCOMES Committees and Investigators. Alirocumab and cardiovascular outcomes after acute coronary syndrome. *N Engl J Med*. 2018;379:2097–2107. doi: 10.1056/NEJMoa1801174
- Schwartz GG, Bessac L, Berdan LG, Bhatt DL, Bittner V, Diaz R, Goodman SG, Hanotin C, Harrington RA, Jukema JW, 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. doi: 10.1016/j.ahj.2014.07.028
- Jukema JW, Szarek M, Zijlstra LE, de Silva HA, Bhatt DL, Bittner VA, Diaz R, Edelberg JM, Goodman SG, Hanotin C, et al; ODYSSEY OUTCOMES Committees and Investigators. Alirocumab in patients with polyvascular disease and recent acute coronary syndrome: ODYSSEY OUTCOMES trial. *J Am Coll Cardiol*. 2019;74:1167–1176. doi: 10.1016/j.jacc.2019.03.013
- Noda H, Iso H, Irie F, Sairenchi T, Ohtaka E, Doi M, Izumi Y, Ohta H. Low-density lipoprotein cholesterol concentrations and death due to intraparenchymal hemorrhage: the Ibaraki Prefectural Health Study. *Circulation*. 2009;119:2136–2145. doi: 10.1161/CIRCULATIONAHA.108.795666
- Rist PM, Buring JE, Ridker PM, Kase CS, Kurth T, Rexrode KM. Lipid levels and the risk of hemorrhagic stroke among women. *Neurology*. 2019;92:e2286–e2294. doi: 10.1212/WNL.00000000000007454
- Amarencu P, Bogousslavsky J, Callahan A 3rd, Goldstein LB, Hennerici M, Rudolph AE, Sillesen H, Simunovic L, Szarek M, Welch KM, et al; Stroke Prevention by Aggressive Reduction in Cholesterol Levels (SPARCL) Investigators. High-dose atorvastatin after stroke or transient ischemic attack. *N Engl J Med*. 2006;355:549–559. doi: 10.1056/NEJMoa061894
- Goldstein LB, Amarencu P, Szarek M, Callahan A 3rd, Hennerici M, Sillesen H, Zivin JA, Welch KM; SPARCL Investigators. Hemorrhagic stroke in the Stroke Prevention by Aggressive Reduction in Cholesterol Levels study. *Neurology*. 2008;70(24 Pt 2):2364–2370. doi: 10.1212/01.wnl.0000296277.63350.77
- Giugliano RP, Pedersen TR, Park JG, de Ferrari GM, Gaciong ZA, Ceska R, Toth K, Gouni-Berthold I, Lopez-Miranda J, Schiele F, et al; FOURIER Investigators. Clinical efficacy and safety of achieving very low LDL-cholesterol concentrations with the PCSK9 inhibitor evolocumab: a prespecified secondary analysis of the FOURIER trial. *Lancet*. 2017;390:1962–1971. doi: 10.1016/S0140-6736(17)32290-0
- Amarencu P, Kim JS, Labreuche J, Giroud M, Lee B-C, Mahagne M-H, Nighoghossian N, Simon T, Steg PG, Touboul P-J, et al. Treat stroke to target trial design: first trial comparing two LDL targets in patients with atherothrombotic strokes. *Eur Stroke J*. 2019;4:271–280.