Statin Therapy and Risk of Developing Type 2 Diabetes: A Meta-Analysis

Swapan N. Rajpathak, MD, DrPH
Dharam J. Kumbhani, MD, SM
Jill Crandall, MD
Nir Barzilai, MD
Michael Alderman, MD
Paul M. Ridker, MD

OBJECTIVE — Although statin therapy reduces cardiovascular risk, its relationship with the development of diabetes is controversial. The first study (West of Scotland Coronary Prevention Study [WOSCOPS]) that evaluated this association reported a small protective effect but used nonstandardized criteria for diabetes diagnosis. However, results from subsequent hypothesis-testing trials have been inconsistent. The aim of this meta-analysis is to evaluate the possible effect of statin therapy on incident diabetes.

RESEARCH DESIGN AND METHODS — A systematic literature search for randomized statin trials that reported data on diabetes through February 2009 was conducted using specific search terms. In addition to the hypothesis-generating data from WOSCOPS, hypothesis-testing data were available from the Heart Protection Study (HPS), the Long-Term Intervention with Pravastatin in Ischemic Disease (LIPID) Study, the Anglo-Scandinavian Cardiac Outcomes Trial (ASCOT), the Justification for the Use of Statins in Prevention: an Intervention Trial Evaluating Rosuvastatin (JUPITER), and the Controlled Rosuvastatin Multinational Study in Heart Failure (CORONA), together including 57,993 patients with mean follow-up of 3.9 years during which 2,082 incident diabetes cases accrued. Weighted averages were reported as risk ratios (RRs) with 95% CIs using a random-effects model. Statistical heterogeneity scores were assessed with the Q and I² statistic.

RESULTS — In the meta-analysis of the hypothesis-testing trials, we observed a small increase in diabetes risk (RR 1.13 [95% CI 1.03–1.23]) with no evidence of heterogeneity across trials. However, this estimate was attenuated and no longer significant when the hypothesis-generating trial WOSCOPS was included (1.06 [0.93–1.25]) and also resulted in significant heterogeneity (Q 118.5 [5 d.f.], P = 0.03, I² = 57.7%).

CONCLUSIONS — Although statin therapy greatly lowers vascular risk, including among those with and at risk for diabetes, the relationship of statin therapy to incident diabetes remains uncertain. Future statin trials should be designed to formally address this issue.

Diabetes Care 32:1924–1929, 2009
summary statistics, we included both primary and secondary cardiovascular prevention trials but excluded registries and other nonrandomized analyses as well as studies where patients had preexisting diabetes or where one statin was compared with another. In addition, we excluded studies where other lipid-lowering medications were used either in lieu of or in addition to atorvastatin. Studies examining the role of statins on nonclinical outcomes where no data on diabetes was available were excluded, as were studies limited to specialized noncardiovascular populations.

The primary clinical outcome of interest was the incidence of new-onset diabetes. Because this was not uniformly diagnosed, the different definitions in each trial were separately recorded. Physician- or patient-reported new-onset diabetes was permissible.

Two independent reviewers (S.N.R. and D.J.K.) abstracted the following variables in each study: 1) patient demographics, 2) number of patients who experienced and who were at risk for the outcome of diabetes, 3) type and dose of statin used, 4) criteria used for diagnosis of diabetes, and 5) duration of follow-up. Discrepancies were resolved through a third reviewer (J.C.). The methodological quality of the included randomized clinical trials was assessed using criteria suggested by Jadad et al. (7). Because all studies met at least three of the five criteria, they were judged to be of high quality. No formal scoring method was therefore used.

Statistical analyses

On an a priori basis, we elected to perform a hypothesis-testing meta-analysis that excluded the initial observations from WOSCOPS as well as an analysis of all available data including the hypothesis-generating WOSCOPS data. Summary RRs with 95% CIs were computed for each outcome. RRs were defined as the risk of cumulative incidence of diabetes among those who received statins compared with that among those who received placebo. The summary RR and its 95% CI were estimated using the DerSimonian and Laird method for random effects (8). The random-effects model is reported in the text and figures. To assess heterogeneity across studies, we used the Cochran Q statistic based on the pooled RR by Mantel-Haenszel and measured inconsistency ($I^2$; the percentage of total variance across studies attributable to heterogeneity rather than chance) of treatment effects across trials (9). We used Begg and Mazumdar’s funnel plot to assess for publication bias (10). All $P$ values were two tailed, and $P < 0.05$ was considered statistically significant. All analyses were performed using STATA software version 10.0 (STATA, College Station, TX) and Comprehensive Meta-Analysis software version 2 (Biostat, Englewood, NJ).

RESULTS — Six trials met inclusion criteria (Figure 1 and Table 1) and included 57,593 randomized patients ($n$ for statin intervention = 28,842; $n$ for placebo = 28,751). Three studies (WOSCOPS, the Anglo-Scandinavian Cardiac Outcomes Trial [ASCOT], and the JUPITER) were primary cardiovascular prevention trials, whereas three were secondary prevention trials (the Heart Protection Study [HPS], the Long-Term Intervention with Pravastatin in Ischemic Disease [LIPID] Study, and the Controlled Rosuvastatin Multinational Study in Heart Failure [CORONA]). Two of the trials used 40 mg/day pravastatin (WOSCOPS and LIPID), two rosuvastatin (CORONA 10 mg/day and JUPITER 20 mg/day), one 40 mg/day simvastatin (HPS), and one 10 mg/day atorvastatin (ASCOT). Clinical follow-up ranged from a median 1.9 years (JUPITER) to over 5 years (LIPID), with a weighted mean duration of follow-up of 3.9 years. The primary analysis of data from these trials suggested an 8–44% risk reduction in CVD incidence comparing statin group with placebo group. Because the study populations for each trial differed considerably, we have provided the baseline characteristics of individual trials in Table 2.

Together, the six studies reported a total of 2,082 incident cases of diabetes during follow-up. The criteria for ascertainment of type 2 diabetes varied in these studies (Table 1). Three studies (HPS, CORONA, and JUPITER) relied on physician-reported diagnosis and treatment for diabetes, whereas the other three (WOSCOPS, ASCOT, and LIPID) also incorporated standardized diagnostic criteria based on plasma glucose levels or oral glucose tolerance test. In addition to the standardized fasting glucose criteria ($\geq 126$ mg/dl plasma glucose on two occasions), the WOSCOPS trial also required a $\geq 2$ mmol/l (or 36 mg/dl) increase in fasting glucose level from baseline for diabetes diagnosis.

Among the individual studies, four of the studies reported a null association between statin use and diabetes risk. One study (WOSCOPS) reported a statistically
| Study population, follow-up time | Median follow-up | Intervention (sample size) | Diagnosis of incident diabetes | Results for primary outcome, RR (95% CI) | Incident diabetes cases (n in statin group/n in placebo group) | RR (95% CI) for diabetes comparing statin treatment with placebo |
|---------------------------------|-----------------|----------------------------|--------------------------------|------------------------------------------|-------------------------------------------------------------|---------------------------------------------------------------|
| WOSCOPS (2001)¹                | 4.9 years       | Pravastatin 40 mg (n = 2,999) vs. placebo (n = 2,975) | Fasting glucose ≥126 mg/dl on two occasions, one of which must be ≥36 mg/dl above baseline or use of hypoglycemic agents | Nonfatal MI and cardiovascular death, 0.69 (0.57–0.83) | 57/82 | 0.7 (0.50–0.99) |
| Adults (78% men) aged 40–80 years (mean 62.1 years) with occlusive arterial disease | 4.6 years | Simvastatin 40 mg (n = 7,291) vs. placebo (n = 7,282) | Initiation of pharmacotherapy for diabetes or a specific report of diabetes during follow-up | All-cause mortality, 0.87 (0.81–0.94) | 335/293 | 1.14 (0.98–1.33) |
| ASCOT (2003)²                   | 3.3 years       | Atorvastatin 10 mg (n = 3,910) vs. placebo (n = 3,863) | Fasting glucose ≥126 mg/dl or 2-h OGTT glucose level ≥200 mg/dl | Nonfatal MI, cardiovascular death, 0.64 (0.50–0.83) | 154/134 | 1.15 (0.91–1.44) |
| Adults aged 40–79 years (mean 63.2 years) with hypertension and at high-risk for CVD | 5 years | Pravastatin 40 mg (n = 3,970) vs. placebo (n = 3,967) | Fasting glucose ≥126 mg/dl or reported use of diabetes medication (oral agents or insulin) | Cardiovascular death, 0.76 (0.65–0.88) | 172/181 | 0.95 (0.77–1.16) |
| LIPID (2003)⁴                  |                 | | Physician-diagnosed diabetes | | | |
| Adults aged 31–75 years (mean 62 years) with CVD | | | | | | |
| CORONA (2007)⁵                 | 2.7 years       | Rosuvastatin 10 mg (n = 1,771) vs. placebo (n = 1,763) | | | | |
| Elderly adults (mean age 73 years) with heart failure | | | | | | |
| JUPITER (2008)⁶                | 1.9 years       | Rosuvastatin, 20 mg (n = 8,901) vs. placebo (n = 8,901) | Physician-diagnosed diabetes | Nonfatal MI and stroke, unstable angina, arterial revascularization, and cardiovascular death, 0.56 (0.46–0.69) | 270/216 | |
| Multicenter trial with a median follow-up of 1.9 years. Apparently healthy men and women (median age 66 years) with LDL cholesterol <130 mg/dl and hsCRP ≥2.0 mg/l | | | | | | |

hsCRP, high-sensitivity C-reactive protein; MI, myocardial infarction; OGTT, oral glucose tolerance test.
significant protective effect of statin use on diabetes incidence (RR 0.70 [95% CI 0.50–0.99]; P = 0.042), whereas one (JUPITER) reported a significant positive association (1.25 [1.05–1.49]; P = 0.01).

In a meta-analysis of the five hypothesis-testing trials, the summary RR for incident diabetes was 1.13 (95% CI 1.03–1.24; P = 0.007) (Fig. 2). This corresponded to a risk difference of 0.5% (2–0.8). No significant heterogeneity was observed in this latter analysis (Q statistic = 4.06 [4 d.f.], P = 0.40, I^2 = 1.6%), and we observed no evidence in these hypothesis-testing analyses of any interaction by specific drug. However, when the hypothesis-generating WOSCOPS was included in the analyses, the summary RR from the random-effects model was 1.06 (95% CI 0.93–1.23; P = 0.38) (Fig. 2). This analysis also revealed significant heterogeneity (Q statistic = 11.8 [5 d.f.], P = 0.03, I^2 = 57.7%) driven largely by the WOSCOPS data. Further, there was no evidence of publication bias (P = 0.15).

**CONCLUSIONS** — In the first study that evaluated the statin-diabetes association, Freeman et al. (1) reported an inverse association between pravastatin use and diabetes incidence in the WOSCOPS (RR 0.7 [95% CI 0.55–0.99]) but used additional nonstandardized criteria for diabetes diagnosis. Subsequent statin trials did not confirm this protective effect, and in the recent JUPITER a small but significant increase in physician-reported diabetes was reported among statin users compared with those taking placebo, although in the absence of any effect on glucose levels (6). As suggested here, and contrary to the hypothesis-generating data from WOSCOPS, in this meta-analysis of five hypothesis-testing trials a small but statistically significant increase in diabetes incidence may be associated with statin use, which does not appear to be drug or dose specific. This potential effect was attenuated and no longer significant in meta-analysis of all available data including WOSCOPS.

Our data suggest that continued efforts to understand relationships between statin therapy and diabetes are needed, both in future clinical trials and in terms of laboratory exploration. Understanding the potential mechanisms that may explain this effect will require direct experimental effort. One possible explanation is that in addition to CVD protective effects, statin therapy may interfere with normal glucose metabolism (11). In this regard, both in vitro and in vivo data suggest that atorvastatin decreases adipocyte maturation and results in a decline in expression of GLUT4 and upregulation of GLUT1 in cultured preadipocytes and in mice (12). This results in a marked reduction in insulin-mediated cellular glucose uptake caused by decreased insulin sensitivity, which may possibly result in exacerbation of glucose intolerance (13). It is also possible that statin-induced insulin resistance may result from inhibition of isoprenoid biosynthesis, an intermedi-
Statins and diabetes

associated with an increase in A1C levels (12,18).

Certain limitations of our meta-analysis warrant consideration. First, our analysis was restricted to the few clinical trials that reported data on diabetes incidence in statin trials; other statin trials may have data on diabetes available that can augment these analyses. Second, none of these clinical trials were conducted with diabetes as the primary outcome and therefore were not statistically powered to evaluate this outcome. Our data are also limited in that the diagnostic criterion for diabetes varied among the trials and often was based on physician report rather than systematic surveillance. Finally, we cannot rule out the possibility that the increased risk of diabetes among statin users may be due to survival bias related to better survival in the intervention group. We conducted meta-analysis both with and without the initial hypothesis-generating WOSCOPS for two important reasons. First, as indicated earlier, WOSCOPS used additional non-standardized criteria for diabetes diagnosis. Second, the practice of conducting summary analysis after excluding the chronologically first (hypothesis-generating) study is commonly used in meta-analysis. In fact, Fleming et al. (20) recently suggested that this approach is important to avoid any regression-to-the-mean effect and to provide the most unbiased estimates of effect. Furthermore, when we additionally conducted a meta-regression analysis of the included trials, both age (P = 0.029) and female sex (P = 0.002) were significantly associated with an increased risk of statin-induced diabetes. When both age and sex were included together, only sex (elevated risk among women) remained significant (P = 0.044). WOSCOPS was the only trial that included only men and hence may be considered as an outlier for this additional reason. Finally, unlike the analysis that excluded WOSCOPS, there was significant heterogeneity between trials when WOSCOPS was included in the analysis.

Figure 2—Meta-analysis of clinical trials evaluating the effects of statins on diabetes risk.
Nonetheless, we believe the fully inclusive meta-analysis is also meaningful, underscoring the need for future statin trials to formally investigate this issue.

In conclusion, in the hypothesis-testing component of this meta-analysis, we found no evidence for a protective role of statin treatment on incident diabetes but rather observed a small but significant increase in risk. By contrast, this effect was attenuated and no longer significant in a meta-analysis that included all available evidence, including the original hypothesis-generating data. Given this uncertainty, ongoing efforts in clinical and experimental settings should continue to investigate these relationships. In the meantime, the clear benefits of statins on CVD likely outweigh any potential detrimental effects on glucose metabolism and diabetes risk.

Acknowledgments—This study was supported by a Pilot and Feasibility Grant from the National Institutes of Health–funded Diabetes Research and Training Center (3P50DK20541) at the Albert Einstein College of Medicine, New York, New York. P.R. has also received research support and/or served as a consultant to the National Heart, Lung, and Blood Institute, the National Cancer Institute, the Donald W. Reynolds Foundation, and the Foundation Leducq. P.R. served as the trial chairman and principal investigator of the JUPITER, which was funded by AstraZeneca. He is listed as a co-inventor on patents that relate to the use of inflammatory biomarkers in CVD and diabetes that are held by the Brigham and Women’s Hospital and has also received research support and/or served as a consultant to Merck, Sanofi-aventis, Abbott, Vascular Biogenics, and Seimens. None of these entities contributed to the current analyses. No other potential conflicts of interest relevant to this article were reported.

We thank Charlene Surace, Department of Graphics, Cleveland Clinic, Cleveland, Ohio, for assistance with the figure.

References
1. Freeman DJ, Norrie J, Sattar N, Neely RD, Cobbe SM, Ford I, Isles C, Lorimer AR, Macfarlane PW, McKillop JH, Packard CJ, Shepherd J, Gaw A. Pravastatin and the development of diabetes mellitus: evidence for a protective treatment effect in the West of Scotland Coronary Prevention Study. Circulation 2001;103:357–362
2. Collins R, Armitage J, Parish S, Sleijgh P, Peto R. MRC/BHF Heart Protection Study of cholesterol-lowering with simvastatin in 5963 people with diabetes: a randomised placebo-controlled trial. Lancet 2003;361:2005–2016
3. Sever PS, Dahlöf B, Poulter NR, Wedel H, Beevers G, Caulfield M, Collins R, Kjeldsen SE, Kristinsson A, McNees GT, Mehlsen J, Nieminen M, O’Brien E, Östergren J. Prevention of coronary and stroke events with atorvastatin in hypertensive patients who have average or lower-than-average cholesterol concentrations, in the Anglo-Scandinavian Cardiac Outcomes Trial–Lipid Lowering Arm (ASCOT-LLA): a multicentre randomised controlled trial. Drugs 2004;64(Suppl. 2): 43–60
4. Kech A, Colquhoun D, Best J, Kirby A, Simes RJ, Hunt D, Hague W, Beller E, Arulchelvam M, Baker J, Tonkin A. Secondary prevention of cardiovascular events with long-term pravastatin in patients with diabetes or impaired fasting glucose: results from the LIPID trial. Diabetes Care 2003;26:2713–2721
5. Kjekshus J, Apetrei E, Barrios V, Bohm M, Cleland JG, Cornel JH, Dumselmen P, Fonseca C, Goudev A, Grande P, Gullestad L, Hjalmarson A, Hradasc J, Janosi A, Kamensky G, Komajda M, Korewicki J, Kuusi T, Mach F, Mareev V, McMurray JJ, Ranjith N, Schaufelberger M, Vanhaecke J, van Veldhuisen DJ, Waagstein F, Wedel H, Wikstrand J. Rosuvastatin in older patients with systolic heart failure. N Engl J Med 2007;357:2248–2261
6. Ridker PM, Danielson E, Fonseca FA, Genest J, Gotto AM, Jr, Kastelein JJ, Koennig W, Libby P, Lorenzatti AJ, MacFadyen JG, Nordestgaard BG, Shepherd J, Willerson JT, Glynn RJ. Rosuvastatin to prevent vascular events in men and women with elevated C-reactive protein. N Engl J Med 2008;359:2193–2207
7. Jadad AR, Moore RA, Carroll D, Jenkinson C, Reynolds DJ, Gavaghan DJ, McQuay HJ. Assessing the quality of reports of randomized clinical trials: is blinding necessary? Control Clin Trials 1996;17:1–12
8. DerSimonian R, Laird N. Meta-analysis in clinical trials. Control Clin Trials 1986;7:177–188
9. Higgins JP, Thompson SG, Deeks JJ, Altman DG. Measuring inconsistency in meta-analyses. BMJ 2003;327:557–560
10. Begg CB, Mazumdar M. Operating characteristics of a rank correlation test for publication bias. Biometrics 1994;50:1088–1101
11. Sasaki J, Iwashita M, Kono S. Statins: beneficial or adverse for glucose metabolism. J Atheroscler Thromb 2006;13:123–129
12. Nakata M, Nagasaka S, Kusaka I, Matsumoto H, Ishibashi S, Yada T. Effects of statins on the adipocyte maturation and expression of glucose transporter 4 (SLC2A4): implications in glycemic control. Diabetologia 2006;49:1881–1892
13. Kanda M, Satoh K, Ichihara K. Effects of atorvastatin and pravastatin on glucose tolerance in diabetic rats mildly induced by streptozotocin. Biol Pharm Bull 2003;26:1681–1684
14. Chamberlain LH. Inhibition of isoprenoid biosynthesis causes insulin resistance in 3T3-L1 adipocytes. FEBS Lett 2001;507:357–361
15. Yada T, Nakata M, Shiraiishi T, Kakej Memory loss. Pravastatin and simvastatin on glucose in diabetes is blockage of L-type Ca2+ channels in rat islet beta-cells. Br J Pharmacol 1999;126:1205–1213
16. Ishikawa M, Okajima F, Inoue N, Motomura K, Kato T, Takahashi A, Oikawa S, Yamada N, Shimano H. Distinct effects of pravastatin, atorvastatin, and simvastatin on insulin secretion from a beta-cell line, MIN6 cells. J Atheroscler Thromb 2006;13:329–335
17. Ridker PM. C-reactive protein and the prediction of cardiovascular events among those at intermediate risk: moving an inflammatory hypothesis toward consensus. J Am Coll Cardiol 2007;49:2129–2138
18. Ishikawa M, Namiki A, Kubota T, Yajima S, Fukazawa M, Moroi M, Sugi K. Effect of pravastatin and atorvastatin on glucose metabolism in non-diabetic patients with hypercholesterolemia. Intern Med 2006;45:51–55
19. Sabatine MS, Wiviott SD, Morrow DA, McCabe CH, Canon CP. High-dose atorvastatin associated with worse glycemic control: A PROVE-IT TIMI 22 substudy (Abstract). Circulation 2004;110:S834
20. Fleming TR. Identifying and addressing safety signals in clinical trials. N Engl J Med 2008;359:1400–1402