Statins and Blood Pressure

Do Statins Reduce Blood Pressure?
A Meta-Analysis of Randomized, Controlled Trials

Pasquale Strazzullo, Sally M. Kerry, Antonio Barbato, Marco Versiero, Lanfranco D’Elia, Francesco P. Cappuccio

Abstract—A meta-analysis was performed of the effect of 3-hydroxy-3-methylglutaryl-coenzyme A reductase inhibitors (statins) on blood pressure in humans including the randomized, controlled trials of statin therapy (20 trials and 828 patients) in which concomitant antihypertensive treatment (if any) remained unchanged throughout the study. A total of 291 and 272 patients were given a statin or placebo, respectively, in parallel group trials, whereas 265 took part in crossover trials receiving a statin and placebo (or probucol, in 1 trial). Systolic blood pressure was significantly lower in patients on statin than in those on placebo or control hypolipidemic drug (mean difference: −1.9 mm Hg; 95% CI: −3.8 to −0.1). The effect was greater when the analysis was restricted to studies with a baseline systolic blood pressure >130 mm Hg (Δ systolic blood pressure: −4.0; 95% CI: −5.8 to −2.2 mm Hg). There was a trend for lower diastolic blood pressure in patients receiving statin therapy compared with control: −0.9 mm Hg (95% CI: −2.0 to 0.2) overall and −1.2 mm Hg (95% CI: −2.6 to 0.1) in studies with a baseline diastolic blood pressure >80 mm Hg. In general, the higher the baseline blood pressure, the greater the effect of statins on blood pressure (P = 0.066 for systolic blood pressure and P = 0.023 for diastolic blood pressure). The blood pressure response to statins was unrelated to age, changes in serum cholesterol, or length of the trial. In conclusion, statin therapy has a relatively small but statistically significant and clinically meaningful effect on blood pressure. (Hypertension. 2007;49:792-798.)

Key Words: blood pressure ■ hypertension, arterial ■ hypercholesterolemia ■ drug therapy ■ statins ■ meta-analysis

High blood pressure (BP) is common in hypercholesterolemic and in diabetic patients and powerfully contributes to the increase in cardiovascular risk.1 The prescription of both antihypertensive and cholesterol-lowering drugs is generally required for these patients. Inhibitors of 3-hydroxy-3-methylglutaryl-coenzyme A reductase (statins) are the most effective and widely used cholesterol-lowering drugs in industrialized countries.2 They significantly reduce the risk of cardiovascular events and death in both primary and secondary prevention of cardiovascular disease.3,4 Although the long-term benefit by statin treatment is largely attributed to their cholesterol-lowering action, increasing attention focuses on additional actions of these substances, which are independent from 3-hydroxy-3-methylglutaryl-coenzyme A reductase inhibition5 and might help explain why part of the benefit in terms of cardiovascular protection is already seen shortly after the initiation of therapy.6,7 Very few relatively small studies have investigated the antihypertensive effect of statins in patients with hypertension associated with hypercholesterolemia.8–10 The results of 2 recently published large statin studies, albeit not designed to answer this question, have attracted the interest on this subject.11,12 Many other studies, also not specifically aimed at the evaluation of the statins’ antihypertensive effect, have provided information concerning changes in BP during treatment with statins. Present knowledge is hampered by severe limitations, such as inadequate study design, small or very small sample size, too short treatment period, and modification of concomitant antihypertensive therapy during the trial. Nevertheless, an effect of statins on BP is potentially important and not implausible bearing in mind the reported effects of statins on endothelial function,13 their interaction with the renin–angiotensin system,14 and their ability to affect large artery compliance.15,16

We systematically reviewed the existing literature of randomized trials of statin therapy. We carried out a meta-analysis of the effect of statins on systolic and diastolic BP including only those trials in which concomitant antihypertensive therapy, if any, was kept constant during the trial.
Methods

Identification and Selection of Trials
We searched online databases (PUBMED, HTA, and EMBASE) up to October 2005 for randomized, controlled trials of statins, using a search strategy based on the words blood pressure and/or hypertension (as either text words or Medical Subjects Heading terms) and statin (or individuals' statin names) and randomized, controlled trial (Table S1, available in an online supplement at http://www.hypertensionaha.org). We also searched the Cochrane Database of Systematic Reviews, the Database of Abstracts of Clinical Effectiveness, the Health Technology Assessment Database, the National Health Service Economic Evaluation Database and the Web sites of the Centre for Reviews and Dissemination and of the Agency for Healthcare Research and Quality, for reviews regarding BP/hypertension and statins. Finally we examined the reference lists of relevant reviews and of all of the identified studies and reviewed cited literature. We identified 175 original reports (Table S2) and 63 reviews.

Inclusion and Exclusion Criteria
We included only randomized, controlled trials published as original articles in peer-reviewed scientific journals in English provided that they used either an identical placebo or a different hypolipidemic drug. We excluded trials where we could not extract or calculate the difference between baseline and end-of-treatment systolic and diastolic BP in intervention and control groups and those that did not report any of the following variables: number of patients in both the statin and control group, length of study, description of the main relevant features of the study population, including gender, age, hypertensive status, and description of concomitant therapy, if any. If an antihypertensive treatment was given during the trial period, the study was included only if a statement that antihypertensive drug therapy (in terms of number, type, and dosage of drugs) was kept unchanged during the trial was clearly made.

Eighteen randomized, controlled trials met the inclusion criteria and were included in the meta-analysis (Figure 1). Because 2 of them,25,26 however, were characterized by having 2 different pairs of control and treatment groups, we considered them as being split in 2 independent studies; thus, the final number of studies analyzed was actually 20.

Data Extraction
Two reviewers (A.B. and M.V.) independently extracted data from text and tables. Discrepancies about inclusion of studies and interpretation of data were resolved on arbitration (P.S.), and consensus was reached after discussion.

Statistical Methods
We used a random effect model (Stata Corp). For parallel groups trials, the intervention effect was the between-group difference in the extent of BP change from baseline. In 4 studies, the confidence intervals of the change in BP were estimated from the P value,9,16,26 and for 11 studies15,17,19–22,24,27–30 SDs of the BP change were estimated by assuming a correlation coefficient between baseline and follow-up BP of 0.5.31 For crossover trials, the outcome measure was given by the difference between the poststatin and the postplacebo BP. Also in this case, if the SD of the difference was not reported, we applied the same principle as for parallel group trials to the postplacebo and poststatin SD to estimate the SD of the difference. All of the trials, whether parallel groups or crossover, were analyzed together using the intervention effect and its SE for each study.

Results

Characteristics of Trials and Patients Included in the Meta-Analysis
A total of 828 patients from 20 studies was included in the analysis, 291 being allocated to statin treatment groups and 272 to control groups; 265 patients took part in crossover trials. In 18 studies, placebo was the treatment adopted for the control group. One study9 used probucol, a lipid-lowering drug as control, whereas in another one26 fluvastatin plus orlistat (an inhibitor of intestinal lipid digestion) were compared with orlistat alone. Pravastatin was the statin used in 8 studies,8,10,17,21–23,25 simvastatin was used in 5,15,19,20,24,28 fluvastatin in 2,26 cerivastatin in 2 studies,27,30 atorvastatin in 2 studies,16,29 and lovastatin in 1 study.18 The duration of treatment varied from 4 weeks15 to 1 year.24,26

Some studies included only hypertensive patients,10,16,17,23,28,29 others recruited either normotensive or treated hypertensive patients in reasonably good control,22,30 and a few studies included only normotensive individuals.22,23,28,30 Four studies included only type 1 or only type 2 diabetic patients,19,24,27,30 whereas 9 studies excluded patients affected by diabetes.9,10,15,17,18,20,21,23,29 (Table S3).

In 7 studies, none of the participants received drugs different from statins or control medications.15,21,23,25,26 In all of the others, the patients had a variety of concomitant medication regimes (Table) and, in particular, antihypertensive treatment: in 2 such studies,28,29 antihypertensive therapy was started at the same time as statin treatment. In all of the cases, however, antihypertensive therapy was kept unchanged throughout the trial. Ten studies gave instructions for patients’ diet,10,17,19,20,23–26 In 1 study, the patients’ previous
Type of Intervention Provided in Individual Studies

<table>
<thead>
<tr>
<th>First Author, Year</th>
<th>Active Therapy</th>
<th>Average Dose, mg/day</th>
<th>Additional Drug Therapy</th>
<th>Duration of Treatment, mo</th>
<th>Dietary Treatment</th>
<th>Crossover Design</th>
<th>Statin/Control</th>
<th>Mean Age, Statin/Control</th>
<th>% Male, Statin/Control</th>
</tr>
</thead>
<tbody>
<tr>
<td>McDowell, 1991</td>
<td>S</td>
<td>20</td>
<td>NR</td>
<td>3</td>
<td>Dietary supervision</td>
<td>No</td>
<td>15/12</td>
<td>NR/NR</td>
<td>NR/NR</td>
</tr>
<tr>
<td>Hommel, 1992</td>
<td>S</td>
<td>13</td>
<td>Yes</td>
<td>3</td>
<td>Dietary advice</td>
<td>No</td>
<td>12/9</td>
<td>41/35</td>
<td>50/67</td>
</tr>
<tr>
<td>O’Callaghan, 1994</td>
<td>P</td>
<td>23</td>
<td>Yes</td>
<td>3</td>
<td>None</td>
<td>No</td>
<td>12/12</td>
<td>56/62</td>
<td>50/50</td>
</tr>
<tr>
<td>Bak (1), 1998</td>
<td>P</td>
<td>20</td>
<td>None</td>
<td>6</td>
<td>STEP 1</td>
<td>No</td>
<td>49/51</td>
<td>55/55</td>
<td>100/100</td>
</tr>
<tr>
<td>Bak (2), 1998</td>
<td>P</td>
<td>20</td>
<td>None</td>
<td>6</td>
<td>STEP 2</td>
<td>No</td>
<td>46/51</td>
<td>56/55</td>
<td>100/100</td>
</tr>
<tr>
<td>Nakamura, 2001</td>
<td>C</td>
<td>0.15</td>
<td>Yes</td>
<td>6</td>
<td>None</td>
<td>No</td>
<td>30/30</td>
<td>58/55</td>
<td>60/66</td>
</tr>
<tr>
<td>Lee, 2002</td>
<td>P</td>
<td>12</td>
<td>None</td>
<td>6</td>
<td>None</td>
<td>No</td>
<td>25/25</td>
<td>52/50</td>
<td>60/64</td>
</tr>
<tr>
<td>De Rosa (1), 2003</td>
<td>F</td>
<td>80</td>
<td>None</td>
<td>12</td>
<td>Controlled energy intake/exercise</td>
<td>No</td>
<td>24/23</td>
<td>51/52</td>
<td>46/48</td>
</tr>
<tr>
<td>De Rosa (2), 2003</td>
<td>F</td>
<td>80</td>
<td>None</td>
<td>12</td>
<td>Controlled energy intake/exercise</td>
<td>No</td>
<td>24/25</td>
<td>51/52</td>
<td>46/48</td>
</tr>
<tr>
<td>Jenkins, 2003</td>
<td>L</td>
<td>20</td>
<td>Yes</td>
<td>1</td>
<td>Low fat</td>
<td>No</td>
<td>14/16</td>
<td>57/56</td>
<td>50/69</td>
</tr>
<tr>
<td>Ballethofer, 2005</td>
<td>C</td>
<td>0.2/0.8</td>
<td>Yes</td>
<td>3</td>
<td>None</td>
<td>No</td>
<td>40/18</td>
<td>60</td>
<td>67/50</td>
</tr>
<tr>
<td>Kool, 1995</td>
<td>P</td>
<td>40</td>
<td>Yes</td>
<td>2</td>
<td>Lipid lowering</td>
<td>Yes</td>
<td>19</td>
<td>52</td>
<td>58</td>
</tr>
<tr>
<td>Straznicky, 1995</td>
<td>P</td>
<td>40</td>
<td>None</td>
<td>2</td>
<td>Usual patient’s diet</td>
<td>Yes</td>
<td>14</td>
<td>56</td>
<td>50</td>
</tr>
<tr>
<td>Tonolo, 1997</td>
<td>S</td>
<td>20</td>
<td>Yes</td>
<td>12</td>
<td>250 mg chol/day</td>
<td>Yes</td>
<td>20</td>
<td>60</td>
<td>80</td>
</tr>
<tr>
<td>Glorioso, 1999</td>
<td>P</td>
<td>20</td>
<td>NR</td>
<td>8</td>
<td>Constant sodium and calorie diet</td>
<td>Yes</td>
<td>30</td>
<td>53</td>
<td>43</td>
</tr>
<tr>
<td>Shige, 2001</td>
<td>S</td>
<td>30</td>
<td>None</td>
<td>1</td>
<td>Dietary review</td>
<td>Yes</td>
<td>20</td>
<td>54</td>
<td>55</td>
</tr>
<tr>
<td>Ferrer, 2002</td>
<td>A</td>
<td>80</td>
<td>NR</td>
<td>3</td>
<td>None</td>
<td>Yes</td>
<td>22</td>
<td>60</td>
<td>82</td>
</tr>
<tr>
<td>Fogari, 2004</td>
<td>A</td>
<td>20</td>
<td>Yes</td>
<td>3</td>
<td>None</td>
<td>Yes</td>
<td>41</td>
<td>41 to 70</td>
<td>48</td>
</tr>
<tr>
<td>Ikeda, 2004</td>
<td>P</td>
<td>10</td>
<td>Yes</td>
<td>6</td>
<td>None</td>
<td>Yes</td>
<td>52</td>
<td>63</td>
<td>42</td>
</tr>
<tr>
<td>Koh, 2004</td>
<td>S</td>
<td>20</td>
<td>Yes</td>
<td>2</td>
<td>None</td>
<td>Yes</td>
<td>47</td>
<td>57</td>
<td>42</td>
</tr>
</tbody>
</table>

NR indicates not reported; S, simvastatin; P, pravastatin; C, cerivastatin; F, fluvastatin; L, lovastatin; A, atorvastatin.

Additional Lipid Levels, Inclusion Criteria, and Nonpharmacological Treatments Adopted (Diet and Lifestyle Suggestions) in the Single Trials are Reported in the Table.

Estimate of the BP Effect of Statins in the Trials Included in the Meta-Analysis

**Systolic BP**

The overall intervention effect for statin therapy on systolic BP (SBP) was a 1.9-mm Hg reduction (95% CI: -3.8 to -0.1), with significant heterogeneity between studies (P<0.01; Figure 2). The funnel plot did not show asymmetry consistent with publication bias, and Egger’s test was not significant (P=0.58).

**Diastolic BP**

For diastolic BP (DBP), the effect of statin therapy in all of the studies was in the same direction as for SBP but less marked: -0.9 mm Hg (95% CI: -2.0 to 0.2 mm Hg; Figure 2), with significant heterogeneity between studies (P<0.01). There was no evidence of publication bias (Egger’s test P=0.48).

**Meta-Regression and Subgroup Analysis**

The effect of statin therapy on BP was greater in studies that recruited patients with higher baseline BPs (P=0.023 for diastolic and P=0.066 for systolic BP; Figure 3). When the analysis was restricted to studies where baseline SBP was >130 mm Hg, the effect of statin therapy was -4.0 mm Hg (95% CI: -5.8 to -2.2 mm Hg), and heterogeneity was not statistically significant (P=0.26). In studies with average baseline DBP >80 mm Hg, the effect of statin therapy on DBP was -1.2 mm Hg (95% CI: -2.6 to 0.1 mm Hg; heterogeneity P=0.069; Figure 2). In those trials where SBP at baseline was ≤130 mm Hg and/or DBP ≤80 mm Hg, the average net effect of statin on systolic and diastolic BP, respectively, was negligible. In 4 trials that enrolled diabetic hypercholesterolemic patients, the weighted combined effect of statins on BP was -3.7 mm Hg (95% CI: -8 to 1.5 mm Hg)/-0.8 mm Hg (95% CI: -1.9 to 0.4 mm Hg).

Using meta-regression analysis, no evidence was obtained that any of the following factors were significantly related to the response to statin therapy: age (P=0.86 for SBP and 0.79 for DBP), length of the trial (P=0.79 and 0.66, respectively), baseline serum cholesterol (P=0.58 and 0.91), change in serum total cholesterol (P=0.51 and 0.86), or low-density lipoprotein cholesterol (P=0.40 and 0.69), whether patients were diabetic or not (P=0.50 and 0.51) and whether antihypertensive drugs were being used by at least some patients (P=0.53 and 0.98).
Strazzullo et al  Effects of Statins on Blood Pressure 795

Results From Other Trials Not Included in the Meta-Analysis

Two studies, composed of a total number of 64 patients, could not be included in the meta-analysis, because they provided only mean BP values at the start and end of treatment.34,35 The net effect of statin therapy on BP in these 2 studies was a mean BP reduction of 4.0 mm Hg (95% CI: −19.6 to 11.6) and of 2.0 mm Hg (95% CI: −19.9 to 15.9), respectively. The estimated combined effect in the 2 studies was a 3.1-mm Hg fall in mean BP (95% CI: −14.9 to 8.6).

Discussion

Main Findings

This meta-analysis of 20 randomized, controlled trials showed a small but statistically significant reduction of systolic BP and a trend to reduction of diastolic BP with statin therapy. These effects would have been slightly larger if 2 studies that provided only mean BP values and showed a combined net effect of statin of 3.1 mm Hg could have been included in the meta-analysis.34,35 Meta-regression analysis showed that statins were more effective on BP in subjects
who had higher baseline BP levels. A subanalysis of the studies that enrolled patients with SBP >130 or DBP >80 mm Hg indicated that, in fact, the BP-lowering effect of statins was restricted to these patients.

None of the large trials that highlighted the value of statin treatment in primary and secondary prevention of cardiovascular disease could be included in our meta-analysis, because BP values were not reported and/or concomitant antihypertensive treatment in participants with high BP was not kept constant during the study (Table S4). A recent communication (published as abstract) from the Anglo-Scandinavian Cardiac Outcomes Trial showed that between the week-6 visit and 2.5-year visit, BP was significantly lower in patients on atorvastatin than in those on placebo, with a maximum difference of 1.1/0.7 mm Hg.12 Similarly, in the University of California at San Diego Statin Study,11 both during and at the end of the trial, the patients’ groups treated with simvastatin or pravastatin had a significantly lower SBP and DBP compared with the placebo groups, with a maximum difference of 2.8/2.7 mm Hg. In both of these studies, the participants were prescribed antihypertensive medications that could be titrated at any time during the trial. Although both trials were, thus, not eligible for our meta-analysis, their results appear to be consistent with those of our study.

The BP effect of statins detected by our analysis was definitely lower than the average effect of regular antihypertensive drugs and reached statistical significance only for systolic BP; yet, it was clinically relevant, also considering that in most of the studies included in our meta-analysis the average BP at entry was lower than that observed in most trials of antihypertensive therapy and that, in addition, in several studies, the patients were already placed on regular treatment for high BP. In the Antihypertensive and Lipid-Lowering Treatment to Prevent Heart Attack Trial, a 2 mm Hg lower on-trial systolic BP in the chlorthalidone compared with the lisinopril arm was associated with a 15% lower rate of stroke and a 19% lower rate of congestive heart failure.36 Likewise, in the Hypertension Optimal Treatment Study, a 4/4 mm Hg difference in BP was associated with a 50% reduction in the rate of cardiovascular events in diabetic participants.37

**Limitations**

The patients’ population in whom the analysis was carried out was not very large, because large-scale studies of statin therapy did not provide BP values at the start and end of the trial or did not conform to our necessarily strict inclusion criteria with respect to concomitant use of antihypertensive medications or both. Also, the studies included in this quantitative review were rather heterogeneous, because they were carried out in a variety of settings, with different methods, using various criteria and different comparative groups. Although we selected only randomized, controlled trials, few of the studies had been specifically designed to test the hypothesis evaluated by our meta-analysis. The major parts of the studies were conducted on hypercholesterolemic patients. We were unable to examine a possible dose–effect relationship or possible differences in the BP effects of different statins given the relatively small number of trials and the limited sample size available. Many studies required an estimation of the SD of the effect size; in 4 studies, the P value was used, and this may have resulted in a slight overestimate of the SD, possibly reducing the significance of the effect size. For 1 study that provided both intention-to-treat and on-treatment analysis, the intention-to-treat analysis was used; also, this choice may have led to a conservative estimate of the effect.

**Possible Mechanisms of the BP Effect of Statins**

There are several mechanisms whereby statins may affect BP. In experimental studies, statins increase the endothelial production of NO, an effect correlated with upregulation of endothelial NO synthase expression.38–41 This effect may be reinforced by simultaneous inhibition of G proteins with reduced endothelial NO synthase mRNA degradation and, thus, increased NO bioavailability.42 Moreover, it may also be reinforced by a decrease in the release and circulating levels of the vasoconstrictor endothelin-1.43 These effects are translated in substantial improvements of endothelial function, assessed by vasodilator response to acetylcholine or as flow-mediated vasodilation, in various pathological conditions characterized by marked endothelial dysfunction.44–50 These various effects manifest themselves early after statin administration and, thus, appear substantially unrelated to their cholesterol-lowering action.12,51 This notion is in keeping...
with the result of our meta-regression analysis indicating no significant association with the cholesterol response and no relationship with length of treatment.

Statins inhibit the production of reactive oxygen species, such as superoxide anion, and hydroxyl radicals in animal vessel models, and also this action can contribute to vasodilation.52 Statins have been shown to reduce large artery stiffness and improve systemic arterial compliance,15,16 an effect ascribed to alterations in the relative content of vascular smooth muscle cells in large arteries and to restoration of endothelial function.13 This mechanism could be expected to affect, in particular, SBP, which is in line with our results.

A further possible mechanism of the BP-lowering effect of statins is downregulation of the angiotensin II–type 1 receptor. The angiotensin II–type 1 receptor is overexpressed in hypercholesterolemic patients, and this alteration was corrected by administration of statins,14 which also markedly reduced the vasoconstrictor response to angiotensin II infusion.14

Conclusions
Whatever the mechanism(s), our meta-analysis provided evidence of a favorable effect of statins on BP, particularly SBP, and indicated that the effect was larger in individuals with elevated BP. No statistically significant relationship could be demonstrated between the BP effect of statin therapy and baseline serum cholesterol or change in serum total or low-density lipoprotein cholesterol during the treatment period.

Perspectives
This study provided the first demonstration of a statistically significant effect of statin therapy on BP. Its main feature was the inclusion in the meta-analysis of only randomized, controlled trials in which concomitant antihypertensive treatment (if any) was kept constant throughout the study. Its most important limitation, on the other hand, was the relatively small patients’ population enrolled. Also, the study results derived mainly, although not exclusively, from the analysis of trials carried out in hypercholesterolemic patients. It remains to be clarified whether the BP effect of statins is a class effect or is a property of 1 or few substances in the class.

Although the effect on BP was moderate and statistically significant only for systolic pressure, it may be, nevertheless, relevant from the point of view of cardiovascular prevention. It can be speculated that, in hypertensive patients in whom the prescription of a statin is indicated (eg, because of concomitant hypercholesterolemia, diabetes, and/or previous myocardial infarction), this might reduce, to some extent, the dose and number of drugs required to achieve satisfactory BP control. Further studies to test the extent and the mechanism(s) of the BP effect of statins in these and other selected categories of very high-risk patients are warranted.

Disclosures
None.

References


Do Statins Reduce Blood Pressure?: A Meta-Analysis of Randomized, Controlled Trials
Pasquale Strazzullo, Sally M. Kerry, Antonio Barbato, Marco Versiero, Lanfranco D’Elia and Francesco P. Cappuccio

Hypertension. 2007;49:792-798; originally published online February 19, 2007;
doi: 10.1161/01.HYP.0000259737.43916.42
Hypertension is published by the American Heart Association, 7272 Greenville Avenue, Dallas, TX 75231
Copyright © 2007 American Heart Association, Inc. All rights reserved.
Print ISSN: 0194-911X. Online ISSN: 1524-4563

The online version of this article, along with updated information and services, is located on the World Wide Web at:
http://hyper.ahajournals.org/content/49/4/792

Data Supplement (unedited) at:
http://hyper.ahajournals.org/content/suppl/2007/02/12/01.HYP.0000259737.43916.42.DC1

Permissions: Requests for permissions to reproduce figures, tables, or portions of articles originally published in Hypertension can be obtained via RightsLink, a service of the Copyright Clearance Center, not the Editorial Office. Once the online version of the published article for which permission is being requested is located, click Request Permissions in the middle column of the Web page under Services. Further information about this process is available in the Permissions and Rights Question and Answer document.

Reprints: Information about reprints can be found online at:
http://www.lww.com/reprints

Subscriptions: Information about subscribing to Hypertension is online at:
http://hyper.ahajournals.org//subscriptions/