High-Dose Statin Therapy in Patients With Stable Coronary Artery Disease
Treating the Right Patients Based on Individualized Prediction of Treatment Effect

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Background—Clinicians need to identify coronary artery disease patients for whom the benefits of high-dose versus usual-dose statin therapy outweigh potential harm. We therefore aimed to develop and validate a model for prediction of the incremental treatment effect of high-dose statins for individual patients in terms of reduction of 5-year absolute risk for myocardial infarction, stroke, coronary death, or cardiac resuscitation.

Methods and Results—Based on data from the Treating to New Targets trial (TNT; n=10,001), a Cox proportional hazards model was developed comprising 13 easy-to-measure clinical predictors: age, sex, smoking, diabetes mellitus, total cholesterol, high-density lipoprotein cholesterol, systolic blood pressure, history of myocardial infarction, coronary artery bypass grafting, congestive heart failure or abdominal aortic aneurysm, glomerular filtration rate, and treatment status (ie, atorvastatin 80 mg or 10 mg). External validation in the Incremental Decrease in End Points Through Aggressive Lipid Lowering trial (IDEAL; n=8888) confirmed adequate goodness-of-fit and calibration, but moderate discrimination (C-statistic, 0.63; 95% confidence interval, 0.62–0.65). Still, among participants of both trials combined, the model identified a group of 11.7% whose predicted 5-year number needed to treat was ≤25 and a group of 41.9% whose predicted number to treat was ≥50. A decision curve shows that making treatment decisions on the basis of predictions using our model may improve net benefit.

Conclusions—Estimation of the incremental treatment effect of high-dose versus usual-dose statin therapy in individual coronary artery disease patients enables selection of high-risk patients that benefit most from more aggressive therapy.

Clinical Trial Registration—URL: http://www.clinicaltrials.gov. Unique identifiers: NCT00327691 and NCT00159835.

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Key words: coronary disease ■ forecasting ■ prevention & control ■ statins, HMG-CoA ■ treatment outcome

Lipid-lowering is the cornerstone of secondary prevention for vascular events in patients with coronary artery disease (CAD). Randomized clinical trials evaluating high-dose versus usual-dose statin therapy have shown that intensive lipid lowering results in additional reduction of vascular events.1-6 Despite this high-quality evidence of superior effectiveness, high-dose statin therapy is not unequivocally recommended for all patients with stable CAD.7,8 This reluctance may be explained by concern about high-dose statins causing higher rates of side-effects, such as myalgia and transaminits.1-3 Moreover, intensive treatment is more costly and requires closer follow-up of patients, because high-dose versus usual-dose statin therapy is associated with a somewhat higher risk of developing diabetes mellitus.9 Therefore, clinicians need to identify patients who will benefit most from high-dose versus usual-dose statin therapy. Guidelines recommend titration of statin-dose, but only in patients whose low-density lipoprotein (LDL) cholesterol level is not at target.7,8 Although...
this approach seems sensible from a pharmacodynamic perspective, meta-analyses show that the effectiveness of statin therapy in terms of reduction of vascular events does not depend on pretreatment LDL-cholesterol level. Instead, the absolute cardiovascular risk reduction achieved by high-dose statin therapy is only proportional to the absolute baseline risk. Previously, Deedwania et al[9] have indicated that selecting patients with the metabolic syndrome or diabetes mellitus is a simple and effective method for identifying high-risk patients who significantly benefit from high-dose statin therapy. Such risk stratification, however, may be further improved by taking into account additional patient characteristics.

Clinical Perspective on p 2493

In the present study we aimed to develop and validate a model, based on multiple clinical patient characteristics, for prediction of treatment effect (ie, 5-year absolute risk reduction of major cardiovascular events [MCVEs]) of high-dose statin therapy versus usual-dose statin therapy in individual patients with stable CAD. For this purpose we use data from the Treating to New Targets (TNT) trial and the Incremental Decrease in End Points Through Aggressive Lipid Lowering (IDEAL) trial. Because such a predicted treatment effect may be used for guiding individual treatment decisions, we also compare the net benefit of a number of strategies to select high-risk patients with stable CAD to qualify for high-dose statin therapy (ie, [1] all patients, [2] no patients, [3] patients with the metabolic syndrome or diabetes mellitus, and [4] patients whose predicted treatment effect exceeds a certain threshold). Here we present our results.

Methods

The design, rationale, and outcomes of the TNT and IDEAL trials have been described in detail elsewhere. In brief, both trials evaluated the efficacy and safety of high-dose statin therapy (ie, atorvastatin 80 mg) versus usual-dose statin therapy (ie, atorvastatin 10 mg in TNT and simvastatin 20 or 40 mg in IDEAL) for the prevention of new vascular events in patients with stable CAD. The TNT trial enrolled 10,001 patients in the United States, Europe, and Australia with a history of myocardial infarction, angina with objective evidence of atherosclerotic CAD, or a history of coronary revascularization. After a median follow-up period of 4.9 years, the hazard ratio for the occurrence of MCVE (ie, fatal or nonfatal myocardial infarction, fatal or nonfatal stroke, fatal coronary heart disease, or resuscitation after cardiac arrest) was 0.78 (95% confidence interval [CI], 0.69–0.89) favoring atorvastatin 80 mg. The IDEAL trial enrolled 8888 patients in Northern Europe with a history of myocardial infarction. After a median follow-up of 4.8 years, the hazard ratio for the occurrence of MCVE was 0.87 (95% CI, 0.78–0.98), favoring atorvastatin 80 mg.

Model Derivation

Based on data from the TNT trial a Cox proportional hazards model was developed for prediction of 5-year treatment effect (ie, absolute reduction of MCVE risk) of high-dose statin therapy versus usual-dose statin therapy in individual patients with stable CAD using previously described methods. Data from the IDEAL trial were reserved as a validation data set. MCVE was defined by the above described primary end point definition of the TNT trial. Candidate predictors were based on the Framingham risk score for general cardiovascular disease, with the addition of a few readily available clinical characteristics of particular importance in secondary prevention. As a result, the following candidate predictors were considered: age, sex, current smoking, diabetes mellitus, total cholesterol, high-density lipoprotein cholesterol, systolic blood pressure, a history of myocardial infarction, percutaneous coronary intervention, coronary artery bypass grafting, congestive heart failure (New York Heart Association [NYHA] class 1–IIIa) or abdominal aortic aneurysm, glomerular filtration rate (estimated using the Modification of Diet in Renal Disease [MDRD] formula), and treatment status (ie, atorvastatin 80 mg or usual-dose statin). In accordance with the Framingham risk score, an interaction variable between systolic blood pressure and blood pressure treatment (yes/no) was considered. Finally, because separate Framingham risk scores exist for men and women, any sex-based interactions were evaluated to allow the effect of risk factors to differ between men and women. Interaction terms with treatment were not evaluated because modification of relative treatment effect by clinical patient characteristics was not anticipated based on previous studies.

One or more covariate data were missing in 43 (0.4%) TNT trial participants, and these were single imputed by weighted probability matching on the basis of multivariable regression using covariate and outcome data, because complete case analysis leads to loss of statistical power and possibly to bias. Continuous predictors were truncated at the 1st and 99th percentile to limit the effect of outliers. If the association between a continuous predictor and the outcome was not linear, the predictor was transformed to improve model fit. As a result, a quadratic term was added for age and glomerular filtration rate to obtain optimal model fit.

First, sex-based interactions with probability values ≥0.05 were removed from the starting model. Next, the model was further simplified by stepwise backward selection on the basis of the Akaike’s Information Criterion (AIC). Although all candidate predictors are well-known risk factors for vascular events and, thus, little optimism was expected, the coefficients of the remaining predictors were penalized by uniform shrinkage. The percentage optimism and appropriate shrinkage factor were determined by bootstrap resampling. Models were fitted for prediction of 5-year MCVE risk. This duration of follow-up was achieved by 4755 TNT participants (47.5%). The proportional hazard assumption was assessed by testing the correlations between scaled Schoenfeld residuals for the various predictors and time.

Model Validation

One or more covariate data were missing in 248 (2.8%) IDEAL participants, and these were single imputed using the same methods described above. Likewise, continuous variables were truncated at the 1st and 99th percentile. The discriminatory ability of the model (ie, the extent to which the model can separate those with and without a MCVE) was expressed by the C statistic. Model calibration, reflecting the precision of how close the predicted survival probabilities are to the actual (observed) survival, was demonstrated by calibration plots. In addition, overall goodness-of-fit of both models was assessed in the validation cohort with the Gronnesby and Borgan test.

Risk Stratification and Net Benefit

Data of the TNT and IDEAL trials were combined to determine the ability of the derived model to stratify risk and treatment effect. Predictions of 5-year MCVE risk while on usual-dose statin treatment were made for all trial participants and displayed in a histogram. Similarly, the distribution of predictions of 5-year effect of high-dose versus usual-dose statin treatment was presented in a histogram. Moreover, we determined the incremental value of treatment decision-making on the basis of predicted treatment effect. Such incremental value is conditional on the estimated harm of unnecessary high-dose statin treatment (ie, adverse events, inconvenience, and costs) and can be expressed in terms of net benefit. By unnecessary treatment we mean high-dose statin treatment of patients who will not have a MCVE even on usual-dose statin treatment. When unnecessary treatment is assumed to be relatively harmless, there is no need for selection and, thus, no rationale for using a prediction model. However, when unnecessary treatment is considered detrimental, the treatment effect needs to be adjusted for treatment harm (ie, net benefit). To enable adjustment of treatment effect for treatment harm, a quantitative estimate of the latter is needed. For this purpose,
treatment harm can be quantified by estimating at which level of MCVE risk the benefits of high-dose statin treatment start to outweigh treatment harm (ie, the cut-off value for determining high risk). For example, when ≥15% MCVE risk is thought to outweigh treatment harm, the threshold is 15%. This threshold reflects the relative weight of unnecessary treatment of low-risk patients versus correct treatment of high-risk patients and is incorporated in the net benefit calculation. In this study, we compared the net benefit of selecting patients for high-dose statin therapy based on our prediction model versus the net benefit of treating all patients, no patients or just the patients with the metabolic syndrome or diabetes mellitus with high-dose statin therapy. Metabolic syndrome was defined by the same criteria used by Deedwania et al as the presence of ≥3 of the following risk factors: body mass index of ≥28 kg/m², triglycerides ≥150 mg/dL (1.7 mmol/L), high-density lipoprotein cholesterol ≤40 mg/dL (1.0 mmol/L) in men or ≤50 mg/dL (1.3 mmol/L) in women, blood pressure ≥130/85 mm Hg, or fasting glucose ≥100 mg/dL (5.6 mmol/L). We did not evaluate the net benefit of selective administration of high-dose statin treatment to patients whose LDL-cholesterol is not on target (<70 mg/dL or <180 mg/dL) during usual-dose statin therapy, as is currently recommended by guidelines. Because the LDL-cholesterol was <70 mg/dL (<180 mg/dL) in only 4% of trial patients, the net benefit of that strategy is approximately equal to the net benefit of high-dose statin treatment for all patients. Calculations were based on pooled data of control group patients (treated with usual-dose statin) of the TNT and the IDEAL trials. We refrained from making subjective assumptions about the appropriate decision threshold level and present the net benefit for a range of thresholds in a decision curve. Analyses were conducted with R statistical software version 2.11.1. (http://www.R-project.org) using add-on packages Design, Hmisc, Survival, Survcomp, stdc (http://www.decisioncurveanalysis.org).

Results

Table 1 shows baseline characteristics of participants of the TNT and IDEAL trials. Patients had a median age of 62 years and were 81% men in both trials. Almost half of patients fulfilled the criteria of the metabolic syndrome. In TNT, baseline lipids were recorded during the run-in phase on atorvastatin 10 mg, whereas in IDEAL baseline lipids were measured with the majority of patients still using lipid-lowering medication (doses not exceeding the equivalent of simvastatin 20 mg) that was prescribed before enrollment. Almost all participants received aspirin or anticoagulants, and the majority were using antihypertensive medication. In TNT, 982 MCVEs occurred during 47,369 person-years follow-up (yearly event rate: 2.1%). In IDEAL 1141 MCVEs occurred during 39,099 person-years follow-up (yearly event rate: 2.9%).

Model Derivation

Interaction terms for sex-based differences and terms for history of abdominal aortic aneurysm and history of percutaneous coronary intervention were removed from the starting model during backward selection. Next, coefficients were penalized by a uniform shrinkage factor of 0.965, and the proportional hazards assumption was confirmed. The 16 coefficients of the final model, accompanying likelihood ratio statistics, probability values, and (unpenalized) hazard ratios with corresponding 95% confidence intervals are presented in Table 2. The computational formulas for 5-year treatment effect of high-dose versus usual-dose statin treatment are presented in Table I in the online-only Data Supplement. Moreover, a calculation sheet is available in the online-only Data Supplement, and an example of treatment effect prediction for an individual patient with this calculation sheet is demonstrated in Figure 1.

Model Validation

The model C statistic was 0.67 (95% CI, 0.65–0.68) in its derivation sample (ie, TNT), and 0.63 (95% CI, 0.62–0.65) in the validation sample (ie, IDEAL). The calibration plots of 5-year predicted versus observed event-free survival (ie, 1 risk) in the derivation and validation sample (Figure 2A and 2B) show that model calibration was excellent. The probability values of the Gronnesby and Borgan tests were 0.65 in the derivation sample and 0.30 in the validation sample, thus confirming satisfactory goodness-of-fit.

### Table 1. Characteristics of TNT and IDEAL Participants

<table>
<thead>
<tr>
<th>Characteristic</th>
<th>TNT (n=10001)</th>
<th>IDEAL (n=8888)</th>
<th>Total (n=18889)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Male sex</td>
<td>8099 (81%)</td>
<td>7187 (81%)</td>
<td>15286 (81%)</td>
</tr>
<tr>
<td>Current smoking</td>
<td>1341 (13%)</td>
<td>1838 (21%)</td>
<td>3179 (17%)</td>
</tr>
<tr>
<td>Past smoking</td>
<td>6322 (63%)</td>
<td>5191 (58%)</td>
<td>11513 (61%)</td>
</tr>
<tr>
<td>Systolic blood pressure, mmHg</td>
<td>130 [120–140]</td>
<td>135 [120–150]</td>
<td>130 [120–145]</td>
</tr>
<tr>
<td>Diastolic blood pressure, mmHg</td>
<td>80 [70–84]</td>
<td>80 [74–87]</td>
<td>80 [70–85]</td>
</tr>
<tr>
<td>Body mass index, kg/m²</td>
<td>27.9 [25.5–30.7]</td>
<td>26.9 [24.7–29.4]</td>
<td>27.4 [25.1–30.1]</td>
</tr>
</tbody>
</table>
The decision curve in Figure 4 presents the net benefit of decision-making on the basis of model predictions at a range of thresholds of clinical relevance. The appropriate decision-threshold level is subjective and conditional on the estimated harm (ie, adverse events, inconvenience, and costs) of unnecessary high-dose statin treatment. A low threshold is appropriate when estimated harms are low and vice versa. For threshold levels between ≥6% and ≥23% 5-year MCVE-risk, prediction-based treatment is associated with higher net benefit than making the same decisions for all patients (ie, atorvastatin 80 mg for all or usual-dose statin treatment for all).

In other words, Figure 4 shows that if treatment of patients with <6% 5-year MCVE-risk with atorvastatin 80 mg instead of usual-dose statin is acceptable, the strategy that leads to optimal net benefit is to simply prescribe atorvastatin 80 mg to all. The median treatment effect will then be 2.0% reduction of absolute MCVE risk (effective NNT=49; Table 3). If a threshold between ≥6% and ≥23% is considered appropriate, more selective prediction-based treatment can reduce the treatment rate and average NNT. For example, if treatment is reserved for patients with ≥15% 5-year MCVE risk, the treatment rate is only 26% of CAD patients and the effective NNT decreases to 26 (Table 3). If a 5-year NNT of ≥21 is still considered unacceptably high, our prediction model is not able to identify patients whose MCVE risk is high enough for the benefits of treatment to outweigh treatment harm. In that situation, maximum net benefit is achieved by treating all patients with usual-dose statins. Selective high-dose treatment of patients with the metabolic syndrome or diabetes mellitus is not associated with the highest net benefit at any decision-threshold level. If this were the strategy of choice, however, the treatment rate would be 49% and the average treatment effect 2.8% (NNT=36).

Table 2. Coefficients of the Treatment Effect Prediction Model

<table>
<thead>
<tr>
<th>Model</th>
<th>Coefficient*</th>
<th>LRT Statistic</th>
<th>P Value</th>
<th>Hazard Ratio (95% CI)*</th>
</tr>
</thead>
<tbody>
<tr>
<td>Age, y</td>
<td>-0.0478</td>
<td>12.8†</td>
<td>&lt;0.01†</td>
<td>1.24 [1.10–1.40]†</td>
</tr>
<tr>
<td>Age squared, y</td>
<td>0.0005</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Male sex</td>
<td>0.3147</td>
<td>12.8</td>
<td>&lt;0.01</td>
<td>1.39 [1.15–1.66]</td>
</tr>
<tr>
<td>History of myocardial infarction</td>
<td>0.4097</td>
<td>38.2</td>
<td>&lt;0.01</td>
<td>1.53 [1.33–1.75]</td>
</tr>
<tr>
<td>History of CAGB</td>
<td>0.2263</td>
<td>12.1</td>
<td>&lt;0.01</td>
<td>1.26 [1.11–1.44]</td>
</tr>
<tr>
<td>History of congestive heart failure</td>
<td>0.4694</td>
<td>25.3</td>
<td>&lt;0.01</td>
<td>1.62 [1.36–1.95]</td>
</tr>
<tr>
<td>History of cerebrovascular disease</td>
<td>0.6172</td>
<td>32.4</td>
<td>&lt;0.01</td>
<td>1.89 [1.54–2.32]</td>
</tr>
<tr>
<td>Diabetes mellitus</td>
<td>0.4318</td>
<td>30.8</td>
<td>&lt;0.01</td>
<td>1.56 [1.34–1.82]</td>
</tr>
<tr>
<td>Current smoking</td>
<td>0.5379</td>
<td>38.2</td>
<td>&lt;0.01</td>
<td>1.75 [1.48–2.07]</td>
</tr>
<tr>
<td>Total cholesterol, per 10 mg/dL</td>
<td>0.0042</td>
<td>9.5</td>
<td>&lt;0.01</td>
<td>1.04 [1.02–1.07]</td>
</tr>
<tr>
<td>HDL-cholesterol, per 10 mg/dL</td>
<td>-0.0130</td>
<td>15.0</td>
<td>&lt;0.01</td>
<td>0.87 [0.82–0.94]</td>
</tr>
<tr>
<td>eGFR, mL/min/1.73m²</td>
<td>-0.0605</td>
<td>11.7*</td>
<td>&lt;0.01*</td>
<td>0.92 [0.84–1.00]*</td>
</tr>
<tr>
<td>eGFR squared, mL/min/1.73m²</td>
<td>0.0004</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Systolic blood pressure (treated or not), per 10 mmHg</td>
<td>0.0371</td>
<td>3.3</td>
<td>0.07</td>
<td>1.04 [1.00–1.08]</td>
</tr>
<tr>
<td>Systolic blood pressure (if on treatment), per 10 mmHg</td>
<td>0.0254</td>
<td>14.5</td>
<td>&lt;0.01</td>
<td>1.03 [1.01–1.04]</td>
</tr>
<tr>
<td>High-dose statin, vs usual dose statin</td>
<td>-0.2411</td>
<td>15.2</td>
<td>&lt;0.01</td>
<td>0.78 [0.69–0.88]</td>
</tr>
</tbody>
</table>

CABG indicates coronary artery bypass grafting; CI, confidence interval; eGFR, glomerular filtration rate (estimated by the Modification of Diet in Renal Disease [MDRD] equation; LRT, Likelihood Ratio Test; and HDL, high-density lipoprotein.

*Uniform shrinkage was applied to the coefficients but not the hazard ratios, because penalization increases external validity of the model overall, yet leads to underestimation of the importance of the individual risk factors.

†The risk model contains linear and squared terms for age and eGFR. Therefore, the $\chi^2$ and P value of age and eGFR are computed for both terms together. Furthermore, hazard ratios were computed for the difference between the study population’s 75th and the 25th percentile of age (ie, 69 versus 55 yr) and eGFR (ie, 72 versus 58 mL/min/1.73 m²).

Risk Stratification

The median 5-year MCVE risk of patients on usual-dose statin therapy was 11% (interquartile range, 8% to 15%). Figure 3A shows that 44% of patients had ≤10% predicted baseline MCVE risk, 43% had intermediate (10 to <20%) predicted MCVE risk, and 13% had ≥20% predicted 5-year MCVE risk. As a consequence, predicted treatment effect of high-dose versus usual-dose statin therapy also varied widely (Figure 3B). The median absolute reduction of 5-year MCVE risk was 2.2% (interquartile range, 1.6–3.1% ; 5-year number needed to treat [NNT] 45). However, 41.9% of patients had <2% predicted treatment effect (5-year NNT>50) and 46.4% of patients had 2 to 4% predicted treatment effect (5-year NNT between 25 and 50). A total of 11.7% of patients had >4% predicted reduction of absolute 5-year MCVE risk (5-year NNT <25).
harm that is associated with high-dose statin treatment. The estimated harm of treatment needs to be quantified in terms of a decision-threshold. If the threshold ranges between $\approx 6\%$ and $\approx 23\%$, selective treatment with high-dose statins of high-risk patients (ie, whose predicted treatment effect is higher than average) results in higher net benefit than using the same statin dose (high or low) for everyone. Moreover, prediction-based treatment led to higher net benefit than selective treatment based on the presence of the metabolic syndrome or diabetes mellitus, meaning that the present risk score provides a superior estimate of absolute risk and treatment effect. Individual treatment-effect prediction can thus be used to reduce the treatment rate, reduce the effective NNT, and increase the average treatment effect of patients who receive high-dose statins such as atorvastatin 80 mg.

This post hoc analysis of the TNT and IDEAL trials addresses an ongoing discussion about appropriate indications for high-dose statin treatment in patients with stable CAD. Historically, results of randomized controlled trials are implemented in clinical practice by either applying the intervention to all patients (in the case of a positive trial result) or to no one (in the case of a negative result). The situation of high-dose statin treatment in patients with stable CAD, however, is different. TNT, IDEAL, and a wealth of other studies have provided consistent high-quality evidence of superior effectiveness of high-dose statin over usual-dose statin therapy. Moreover, there are no indications that effectiveness is lacking in subgroups of CAD patients, except perhaps those with severe congestive heart failure (NYHA class II–IV), aortic stenosis, or those undergoing hemodialysis. Still, clinicians

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**Figure 1.** Example of high-dose statin treatment effect prediction for an individual patient with the calculation sheet available online. This 65-year-old nonsmoking male with a medical history of coronary artery bypass grafting (CABG) after myocardial infarction who has on-target blood pressure while on medication, stage 3 kidney disease, and whose cholesterol is not on-target despite low-dose statin therapy, has 18% 5-year major cardiovascular event (MCVE) risk. High-dose statin treatment could reduce his MCVE risk by 4%, meaning that the number of similar patients that need to be treated during 5 years to prevent one MCVE (NNT) is 25. This patient, however, will still have 14% residual MCVE risk. eGFR indicates glomerular filtration rate; HDL, high-density lipoprotein; and Tx, treatment.

**Figure 2.** Calibration plots. Predicted and observed event-free survival (ie, 1 minus risk) within deciles of predicted survival at 5-years in the derivation sample (ie, the Treating to New Targets trial [TNT] cohort; A) and the validation sample (ie, the Incremental Decrease in End Points Through Aggressive Lipid Lowering trial [IDEAL] cohort; B).
are reluctant to use high-dose statin treatment and only do it in a selective subset of CAD-patients, most often those not reaching treatment targets with usual-dose statins. Reasons include a higher frequency of side effects, although the magnitude of this association is not exactly known. Higher rates of myopathy were observed during simvastatin 80 mg compared with simvastatin 20 mg in the Study of the Effectiveness of Additional Reductions in Cholesterol and Homocysteine (SEARCH) trial, but it is often argued that this problem could be specific to simvastatin. Moreover, higher rates of myalgia, diarrhea, abdominal pain, and nausea were observed during atorvastatin 80 mg in the IDEAL trial, but this was an open-label trial which could have influenced adverse event reporting. Still, higher rates of adverse reactions were also observed during double-blind treatment with atorvastatin 80 mg versus atorvastatin 10 mg in the TNT trial (8.1% versus 5.8%, \( P < 0.001 \)), and this led to a higher discontinuation rate. In addition, high-dose statins are associated with a 12% increased relative risk of new-onset diabetes mellitus. A meta-analysis, however, demonstrates that this translates to only a small absolute risk increase: the average 1-year number needed to harm was 498.

Nevertheless, treatment guidelines endorse the clinicians’ reluctance and recommend reserving high-dose statin treatment for patients whose LDL-cholesterol is not on target during usual-dose statin treatment. Yet, because cholesterol treatment is aimed at reducing MCVEs, not just lowering cholesterol, this apparently obvious recommendation may not be entirely logical. In fact, meta-analyses demonstrate that the relative treatment effect of statin therapy for reducing MCVEs is not dependent on baseline LDL-cholesterol level. Importantly, in the absence of such modification of relative treatment effect, absolute treatment effect of high-dose statin therapy (ie, reduction of absolute MCVE risk) is proportional to the patient’s absolute MCVE risk. Of course, LDL-cholesterol level can be considered as one of the indicators of risk in this respect. However, other patient characteristics or multiple characteristics combined may be superior predictors of MCVE risk.

Barriers toward widespread implementation of prediction models in clinical practice include the complexity of computing treatment effect for individual patients and the fact that it is time-consuming. Simple decision-algorithms are, therefore, preferred, whereas 13 patient-specific variables were required for treatment effect estimation using the model.
The calculation sheet’s interactive bar graph demonstrates the disease and the need for preventive treatment. Second, it enables patients to be involved in treatment decision-making. The calculation sheet’s interactive bar graph demonstrates potential treatment effect in an insightful manner. Because patients’ disagreement with the need for treatment is one of the main reasons for nonadherence, shared decision-making may increase patient compliance. This is important because the adherence-rate to self-administered treatments is typically only 50%, thereby seriously compromising the effect of preventive therapy. Experience with a similar health decision aid shows that implementation in routine clinical practice is feasible, increases patients’ perception of shared decision-making, and reduces patients’ anxiety.

Limitations of the present study include the fact that our prediction model is derived from a trial population that was selected on the basis of strict eligibility criteria. Participants of the TNT trial were, for example, aged ≤75 years, were not allowed to have a left ventricular ejection fraction <30%, and did not have any survival-limiting diseases other than CAD. It is, therefore, uncertain whether our prediction model can be generalized to patients who do not fit the TNT trial eligibility profile. Furthermore, because atherosclerosis is a systemic progressive condition, many CAD patients have multiple manifestations of disease. Although concomitant cerebrovascular disease, aortic aneurysmal disease, and peripheral artery disease were allowed, the prevalence of these conditions in the TNT and IDEAL populations was low. For example, an abdominal aortic aneurysm was present in only 101 TNT participants (1%). Although we know from previous research that having multiple disease manifestations is a strong risk factor for recurrent vascular events, the low prevalence of abdominal aortic aneurysm in this population explains why its regression coefficient did not reach statistical significance and was removed from the model. Participants of the IDEAL trial were even more homogeneous, because all had a history of a definite myocardial infarction. This explains why the C statistic of our prediction model was considerably lower in the IDEAL dataset than in the derivation set. In fact, the C statistics that we found in this study may be considered low for a risk score in an asymptomatic population. Yet, the distribution of predicted treatment effect (Figure 3B) shows that the model can still discriminate patients whose expected gain from high-dose statin treatment is considerably higher than average. Furthermore, the decision curve (Figure 4) demonstrates that using model predictions for treatment assignment can improve net benefit at clinically relevant threshold levels. We recognize that the model’s discrimination could be further improved by including additional information on biomarkers, such as C-reactive protein (hs-CRP), imaging, such as carotid intima-media thickness or coronary CT-angiography. Yet, because such information is not readily available for most patients, this would come at the expense of more limited applicability in clinical practice. Also, because of the limited duration of follow-up in trials, models like these can only predict treatment effect for a certain duration of follow-up (in this case 5 years), whereas statins are usually prescribed lifelong in practice. It may be argued that patients with low predicted 5-year treatment effect still benefit from high-dose statins after a longer time period. Finally, although the treatment arms of the trial were pooled for derivation of the prediction model, this does not violate the randomized distribution of the study interventions. Therefore, we stress that treatment effect predictions on the basis of this model are not vulnerable to confounding bias.

### Conclusions

The incremental treatment effect of high-dose statin therapy over usual-dose statin therapy in individual CAD patients can be estimated by a prediction model, containing 13 easy-to-measure clinical predictors that are readily available in clinical practice. Predicted treatment effect can be used to guide treatment decisions in clinical practice, and this may improve net benefit of therapy.

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### Disclosures

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References

Evidence from large clinical trials supports the use of high-dose statins in patients with stable coronary artery disease. Still, because of concern about high-dose statins causing higher rates of side effects, such as myalgia, elevated transaminases, and diabetes mellitus, high-dose statins are not unequivocally recommended for all coronary artery disease patients. This study describes the development and validation of a prediction model for the incremental treatment effect of high-dose statins for individual patients in terms of 5-year absolute risk reduction for myocardial infarction, stroke, coronary death, or cardiac resuscitation. Model derivation was based on data from the Treating to New Targets trial (TNT; n=10,001), and the model was validated in the Incremental Decrease in End Points Through Aggressive Lipid Lowering trial (IDEAL; n=8888). The model is easy to use in clinical practice because it contains only readily available predictors, such as age, sex, smoking status, blood pressure, medical history, and routine laboratory tests. Moreover, it is made available as an interactive calculation sheet. The model can thus be used in the consulting room. A decision curve shows that making treatment decisions on the basis of the model’s predictions may improve the net benefit of treatment, meaning that prediction-based treatment reduces treatment rate and the effective number needed to treat. Estimation of the incremental treatment effect of high-dose versus usual-dose statin therapy in individual coronary artery disease patients thus enables selection of high-risk patients that benefit most from more aggressive lipid-lowering therapy.
High-Dose Statin Therapy in Patients With Stable Coronary Artery Disease: Treating the Right Patients Based on Individualized Prediction of Treatment Effect
Johannes A.N. Dorresteijn, S. Matthijs Boekholdt, Yolanda van der Graaf, John J.P. Kastelein, John C. LaRosa, Terje R. Pedersen, David A. DeMicco, Paul M. Ridker, Nancy R. Cook and Frank L.J. Visseren

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SUPPLEMENTAL MATERIAL

TO

High-dose statin therapy in patients with stable coronary artery disease: treating the right patients based on individualized prediction of treatment effect.

N.R. Cook, F.L.J. Visseren
Supplemental table 1

Computational formula for 5-year absolute treatment effect of high-dose versus usual-dose statin treatment in patients with stable coronary artery disease.

<table>
<thead>
<tr>
<th>Predicted 5-year treatment effect of high-dose statin</th>
</tr>
</thead>
<tbody>
<tr>
<td>= (1 - 0.78) x 5-year MCVE risk on usual-dose statin</td>
</tr>
</tbody>
</table>

5-year MCVE risk on usual-dose statin (%) = (1 - 0.914 \( \exp[^A + 1.5106] \)) x 100%, where

\[
A = -0.0478 \text{ age in years} + 0.000515 \text{ x (age in years)}^2 + 0.315 \text{ [if male]} + 0.410 \text{ [if history of myocardial infarction]} + 0.226 \text{ [if history of CABG]} + 0.469 \text{ [if history of congestive heart failure]} + 0.617 \text{ [if history of cerebrovascular disease]} + 0.432 \text{ [if diabetic]} + 0.538 \text{ [if current smoker]} + 0.00419 \text{ x total cholesterol in mg/dL} - 0.0130 \text{ x HDL-cholesterol in mg/dL} - 0.0605 \text{ x eGFR in mL/min/1.73m}^2 + 0.000419 \text{ x (eGFR in mL/min/1.73m}^2)\^2 + 0.00371 \text{ x systolic blood pressure in mmHg} + 0.00254 \text{ x systolic blood pressure in mmHg [if on antihypertensive treatment]}
\]