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External validation of models predicting survival after ruptured abdominal aortic aneurysm repair

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Submitted
Abstract

Background
Prediction of survival after intervention for ruptured abdominal aortic aneurysms (RAAA) may support case mix comparison and tailor the prognosis for patients and relatives. The objective of this study was to assess the performance of four prediction models; the updated Glasgow Aneurysm Score (GAS), the Vancouver scoring system, the Edinburgh Ruptured Aneurysm Score (ERAS) and the Hardman index.

Methods
Retrospective study in 449 patients in ten hospitals with an RAAA (intervention between 2004 and 2011). Primary endpoint was combined 30-day or in-hospital death. The accuracy of the prediction models was assessed for discrimination (area under the curve (AUC)). An AUC > 0.70 was considered sufficiently accurate. In studies with sufficiently accurate discrimination, correspondence between the predicted and observed outcomes (i.e. calibration) was recalculated.

Results
The AUC of the updated GAS was 0.71 (95% confidence interval (CI) 0.66 to 0.76), of the Vancouver score was 0.72 (95% CI 0.67 to 0.77), and of the ERAS was 0.58 (95% CI 0.52 to 0.65). After recalibration predictions of the updated GAS slightly overestimated the death rate; e.g. predicted death rate 60% vs. observed death rate 54% (95% CI 44 to 64%). After recalibration, predictions of the Vancouver score considerably overestimated the death rate, e.g. predicted death rate 82% vs. observed death rate 62% (95% CI 52 to 71%). Performance of the Hardman index could not be assessed on discrimination and calibration. In 57% of patients electrocardiograms were missing. Where the Hardman index could be applied and where a death rate of 100% was predicted the observed death rate was 50% (95% CI 27 to 73%).

Conclusion
Concerning discrimination and calibration, only the updated GAS predicted death after intervention for an RAAA sufficiently accurately. Performances of the Vancouver score and the ERAS were insufficiently accurate. Because of the large number of missing electrocardiograms, no definite conclusions could be drawn for the Hardman index.
**Introduction**

The overall death rate in patients with a ruptured aneurysm of the abdominal aorta (RAAA) is approximately 74% (95% confidence interval (CI) 72 to 77%). In patients reaching the hospital and undergoing intervention, the death rate ranges between 24% and 49%. Surgeons have proposed distinguishing between those who would potentially benefit from surgery and those in whom it might be better to withhold intervention, after cardiopulmonary resuscitation for example. In current clinical practice, the decision to start surgical or conservative treatment is based on a fast evaluation of the patients' clinical condition, the surgeon’s experience and the wishes of the patient. It is a subjective interpretation of a harsh reality by the doctor, the patient and the relatives. A prediction model is a more standardized and objective way to evaluate the chances of successful intervention and might be helpful at these moments of vital choices. Further benefits of prediction models lie in case mix comparison between hospitals and a tailored prognosis for patients and relatives.

Several models have been developed to predict death after intervention in patients with an RAAA; the Glasgow Aneurysm Score (GAS), the Vancouver scoring system, the Edinburgh Ruptured Aneurysm Score (ERAS) and the Hardman index. These scoring systems were initially designed before the introduction of endovascular aneurysm repair (EVAR). Nowadays, EVAR is being carried out increasingly. Only the GAS has been updated to the era of EVAR by the addition of a variable for type of intervention.

The primary objective of our study was to assess the accuracy of the updated GAS (the model including differentiation between EVAR and OR), the Vancouver score, the ERAS and the Hardman index in predicting death. Only extremely reliable models, those predicting death accurately in more than 95% of cases, may be useful in clinical decision-making. A secondary objective was the assessment of accuracy in patients with a predicted death rate of ≥95% in whom withholding intervention might be considered.

**Methods**

We conducted a retrospective study in all consecutive surgically treated patients with an RAAA in the Amsterdam ambulance region between May 2004 and
February 2011. The present study was carried out as a sequel of the previously published Amsterdam Acute Aneurysm Trial. Other details and analyses of this cohort have been published previously. None of these previous studies aimed to validate prediction models for patients with an RAAA. The Amsterdam ambulance region covers an area of 1025 km² with 1.38 million inhabitants. During the inclusion period, care for patients with an RAAA was centralized in two university hospitals and one teaching hospital in cooperation with seven regional hospitals. All patients with an RAAA in all ten hospitals of the region were registered prospectively and included in the present study. Patients with a previous aortic reconstruction, an RAAA with associated trauma or aortoenteric fistula were excluded. Primary end point was the combined 30-day or in-hospital death rate. Compared to some previous validation studies of the prediction models, we added in-hospital death to the definition; from a patients’ perspective the ultimate goal is survival and being discharged. Approval from a medical ethics committee was not needed because of the observational design.

Updated GAS
The updated GAS score was calculated with the formula: age (years) + 7 for cardiac comorbidity (defined as previous history of myocardial infarction, cardiac surgery, angina pectoris or arrhythmia) + 10 for cerebrovascular comorbidity (defined as previous history of stroke or transient ischemic attack) + 17 for shock (defined as an in-hospital systolic blood pressure <80 mmHg) + 14 for renal insufficiency (defined as a pre-operative serum creatinine > 160 µmol/L) + 7 for OR (Figure 1).

\[
1 - \frac{1}{1 + (\exp (-5.3 + 0.052 \times \text{updated GAS score}))}
\]

Figure 1. The formula to calculate the predicted death rate using the updated GAS.

Vancouver score
The Vancouver score was calculated with the formula: age (years) * 0.062 + loss of consciousness (yes = 1 / no = -1) * 1.14 + cardiac arrest (yes = 1 / no = -1) * 0.6 (Figure 2).
Predictions of short-term survival after an RAAA

\[
\frac{1}{1 + (\exp(-3.44 + \text{Vancouver score}))}
\]

**Figure 2.** The formula to calculate the predicted death rate using the Vancouver score.

**ERAS**

The ERAS score was calculated with the formula: + 1 for best recorded in-hospital Glasgow coma scale (GCS) <15, + 1 for in-hospital systolic blood pressure <90 mmHg, + 1 for pre-operative hemoglobin level <5.6 mmol/L. A score of 0 or 1 corresponded with a predicted death rate of 30%, a score of 2 with a predicted death rate of 50% and a score of 3 with a predicted death rate of 80%.

**Hardman index**

The Hardman index was calculated with the formula: + 1 for age >76 years, + 1 for in-hospital loss of consciousness, + 1 for a pre-operative serum creatinine > 190 µmol/L, + 1 for pre-operative serum hemoglobin level <5.6 mmol/L, + 1 for electrocardiographic (ECG) ischemia (defined as ST-segment depression greater than 1 millimeter or an associated T-wave change determined by a senior cardiologist (RJGP)). A score of 3 or more corresponded with a predicted death rate of 100%.

**Data collection and statistical analysis**

Data were collected from the medical records by the first and second authors. Data entry was done using Microsoft Access 2003 (Microsoft Corporation, Redmond, Washington, USA) using field limits, univariate and multivariate checks. A valid way of coping with missing values is by imputation. Missing data was imputed for the variables blood pressure, hemoglobin, creatinine, cardiac comorbidity, cerebrovascular comorbidity, resuscitation, loss of consciousness and GCS. Multiple imputation was done creating ten datasets. Age, sex, renal and pulmonary comorbidity, death and the above mentioned imputed variables were used as predictors in the imputation model. We decided to not impute data for missing ECGs in this way, because of the large number of missing ECGs (>50%). Baseline characteristics and prediction model scores are reported in both the original dataset and in the imputed datasets (Tables 2 and 3).

The statistical analysis and the imputation procedure were done using IBM SPSS Statistics 19.0 (SPSS Inc., Armonk, New York, USA) and R (The R Foundation
for Statistical Computing, Boston, USA). Continuous data were described by the mean with corresponding standard deviation (SD) for data normally distributed, and by the median with corresponding inter-quartile range (IQR) for data with skewed distribution. The statistical analysis comprised four steps. First, the accuracy of the updated GAS, the Vancouver score and the ERAS was determined with regard to the overall performance and the discrimination. Overall performance represents the distance between the predicted outcome and actual outcome statistically and was assessed using the Brier Score. The Brier Score should be as close to 0 as possible and the threshold for a noninformative model was calculated to be at 0.23. Discrimination is the ability of a model to distinguish between dying and surviving patients and was assessed using the area under the receiver operating characteristics curve (AUC). An AUC >0.70 was considered sufficiently accurate. Second, in the models with an AUC >0.70 the calibration of the predictions was determined. Calibration refers to the agreement between the predicted and observed death rate. Calibration was assessed by dividing all patients into five comparable quintiles ranging between 0-20%, >20-40%, >40-60%, >60-80% and >80-100%. Because patients with equal predictions were categorized in the same quintile, the sizes of the quintiles differed slightly between the several prediction models. Subsequently, the mean predicted death rate per quintile was plotted with the corresponding mean observed death rate. In addition, the Hosmer and Lemeshow (HL) chi-square test was done to compare the observed and predicted death rates. The HL test P<.05 reflects a significant difference between the predicted and observed death rate which is a poor calibration. Third, the models with an AUC >0.70 and an HL test P<.05 were recalibrated using the ‘calibration intercept method’. Fourth, a subgroup analysis was done in patients with a predicted death rate of ≥95% in order to assess the accuracy in high-risk patients in whom withholding intervention might be considered.

As mentioned above, the Hardman index does not provide a specific predicted death rate for a score <3. For this reason, the accuracy of the Hardman index on overall performance, discrimination and calibration could not be assessed. The accuracy of the Hardman index was assessed by comparing the predicted death rate of 100% (a score of ≥3) with the observed death rate in these patients. Because of the large number of missing ECGs (>50%), a sensitivity analysis was done in which the data for missing ECGs were imputed in accordance with the outcome (death or no death). In this way, a ‘best case scenario’ for the accuracy of the Hardman index was created.
Results

Of 539 patients with an RAAA in the greater Amsterdam region, 66 did not have an intervention and 24 had to be excluded because of other reasons (Figure 3). The reasons to refrain from intervention were predominantly shock or resuscitation with an expected low chance of survival (n = 20), patient or patient’s family decision (n = 17) or unknown (n = 17). The updated GAS, the Vancouver score and the ERAS of these patients without intervention is shown in Table 1. Of 449 patients included in the analysis, the baseline characteristics are shown in Table 2. Sixty-nine patients were treated with EVAR and 380 patients were treated with OR. The death rate was 36% (160/449, CI 31 to 40%).

Figure 3. Flowchart of inclusion and exclusion in the analysis.
RAAA = ruptured abdominal aortic aneurysm, CI = confidence interval
CHAPTER 4

Table 1. The updated GAS, the Vancouver score and the ERAS in 66 patients without intervention.

GAS = Glasgow Aneurysm Score, ERAS = Edinburgh Ruptured Aneurysm Score

<table>
<thead>
<tr>
<th>Prediction model</th>
<th>Original data</th>
<th>Missing data</th>
</tr>
</thead>
<tbody>
<tr>
<td>Updated GAS</td>
<td>99 (90-106)</td>
<td>44% (29/66)</td>
</tr>
<tr>
<td>Vancouver</td>
<td>3.90 (3.59-6.20)</td>
<td>17% (11/66)</td>
</tr>
<tr>
<td>ERAS score ≤1</td>
<td>94% (15/16)</td>
<td>76% (50/66)</td>
</tr>
<tr>
<td>2</td>
<td>0</td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>6% (1/16)</td>
<td></td>
</tr>
</tbody>
</table>

Continuous data are presented as median (inter-quartile range) and categorical data as percentage (number).

Table 2. Baseline pre-operative characteristics.

SBP = systolic blood pressure, CPR = cardiopulmonary resuscitation, GCS = Glasgow coma scale, ER = emergency room, ECG = electrocardiogram, EVAR = endovascular aneurysm repair, OR = open repair

<table>
<thead>
<tr>
<th>Pre-operative variable</th>
<th>Original data</th>
<th>Imputed data</th>
</tr>
</thead>
<tbody>
<tr>
<td>Available data</td>
<td>Missing data</td>
<td></td>
</tr>
<tr>
<td>Age (years)</td>
<td>76 (69-80)</td>
<td>o</td>
</tr>
<tr>
<td>Male : Female</td>
<td>80% : 20% (360 : 89)</td>
<td>o</td>
</tr>
<tr>
<td>Cardiac co-morbidity</td>
<td>42% (184/435)</td>
<td>3% (14/449)</td>
</tr>
<tr>
<td>Cerebrovascular co-morbidity</td>
<td>15% (67/433)</td>
<td>4% (16/449)</td>
</tr>
<tr>
<td>Lowest in-hospital SBP (mmHg)</td>
<td>90 (70-125)</td>
<td>90 (70-125)</td>
</tr>
<tr>
<td>In-hospital CPR</td>
<td>11% (46/429)</td>
<td>4% (20/449)</td>
</tr>
<tr>
<td>In-hospital loss of consciousness</td>
<td>21% (81/388)</td>
<td>14% (61/449)</td>
</tr>
<tr>
<td>Best recorded GCS ≤15</td>
<td>17% (63/372)</td>
<td>17% (77/449)</td>
</tr>
<tr>
<td>Hemoglobin at ER (mmol/L)</td>
<td>7.0 (5.9-8.0)</td>
<td>7.0 (5.9-8.0)</td>
</tr>
<tr>
<td>Creatinine at ER (µmol/L)</td>
<td>106 (86-133)</td>
<td>107 (87-134)</td>
</tr>
<tr>
<td>ECG ischemia</td>
<td>21% (40/192)</td>
<td>57% (257/449)</td>
</tr>
<tr>
<td>EVAR : OR</td>
<td>15% : 85% (69 : 380)</td>
<td>o</td>
</tr>
</tbody>
</table>

Continuous data are presented as median (inter-quartile range) and categorical data as percentage (number).

Updated GAS

The mean updated GAS score was 93 (standard deviation (SD) ±15, Table 3). The Brier Score was 0.21 and the AUC was 0.71 (95% CI 0.66 to 0.76). The calibration plot showed an overestimation of the death rate in patients with a predicted death rate >50% (HL test P=.01, Figure 4). In the quintile of patients with a mean predicted death rate of 66%, the observed death rate was 55% (95% CI 44 to 65%). After recalibration, the plot slightly improved although there was still a
statistically significant deviation between the predicted and observed risks (HL test P=.04, Figure 5). In the quintile of patients with a mean predicted death rate of 60%, the observed death rate was 54% (95% CI 44 to 64%) after recalibration. Subgroup analysis to assess the accuracy in high-risk patients showed that no patients had a predicted death rate ≥95%.

Table 3. The outcomes and distribution in the original dataset and the imputed dataset of the updated GAS, the Vancouver score, the ERAS and the Hardman index.

<table>
<thead>
<tr>
<th>Prediction model</th>
<th>Original data</th>
<th>Imputed data</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Available data</td>
<td>Missing data</td>
</tr>
<tr>
<td>Updated GAS</td>
<td>93 (±15)</td>
<td>93 (±15)</td>
</tr>
<tr>
<td>Vancouver</td>
<td>3.10 (2.66-3.72)</td>
<td>3.10 (2.66-3.74)</td>
</tr>
<tr>
<td>ERAS score ≤1</td>
<td>79% (274/349)</td>
<td>77% (345/449)</td>
</tr>
<tr>
<td></td>
<td>22% (100/449)</td>
<td>19% (85/449)</td>
</tr>
<tr>
<td>ERAS score 2</td>
<td>17% (61/349)</td>
<td>19% (85/449)</td>
</tr>
<tr>
<td>ERAS score 3</td>
<td>4% (14/349)</td>
<td>4% (19/449)</td>
</tr>
<tr>
<td>Hardman index score 0</td>
<td>33% (60/180)</td>
<td>32% (62/192)</td>
</tr>
<tr>
<td>Hardman index score 1</td>
<td>37% (67/180)</td>
<td>38% (72/192)</td>
</tr>
<tr>
<td>Hardman index score ≥2</td>
<td>23% (42/180)</td>
<td>23% (45/192)</td>
</tr>
<tr>
<td>Hardman index score ≥3</td>
<td>6% (11/180)</td>
<td>7% (14/192)</td>
</tr>
</tbody>
</table>

Continuous data are presented as mean ±standard deviation or median (inter-quartile range) and categorical data as percentage (number).

Vancouver score

The median Vancouver score was 3.10 (inter-quartile range 2.66 to 3.72, Table 3). The Brier Score was 0.22 and the AUC was 0.72 (95% CI 0.67 to 0.77). With regard to calibration, in the quintile of patients with a mean predicted death rate of 33%, the observed death rate was 21% (95% CI 14 to 31%), and in the quintile of patients with a mean predicted death rate of 89%, the observed death rate was 62% (95% CI 52 to 71%). Hence, the calibration plot showed an overestimation of death (HL test P<0.01, Figure 6). After recalibration, this overestimation decreased minimally (HL test P<0.01, Figure 7). In high-risk patients there was a significant overestimation of the observed risk by the recalibrated model. In the quintile of patients with a mean predicted death rate of 82%, the observed death rate was 62% (95% CI 52 to 71%).

Subgroup analysis to assess the accuracy in high-risk patients showed that of 21 patients with a predicted death rate ≥95%, 18 patients died.
Figure 4. The calibration plots of the updated GAS before and after recalibration. The predicted death rate is plotted with the corresponding death rate and surrounding 95% confidence interval. The interrupted black line indicates ideal calibration. The P corresponds to the Hosmer and Lemeshow test.

GAS = Glasgow Aneurysm Score

\[
1 - \frac{1}{1 + \exp(-5.486 + 0.052 \times \text{updated GAS score})}
\]

Figure 5. The formula to calculate the predicted death rate using the updated GAS after recalibration.

ERAS

The distribution of patients per ERAS outcome is shown in Table 3. The Brier Score was 0.23 and the AUC was 0.58 (95% CI 0.52 to 0.64). Calibration was not assessed because of an AUC <0.70.

Subgroup analysis to assess the accuracy in high-risk patients showed that no patients had a predicted death rate ≥95%.
Figure 6. The calibration plots of the Vancouver score before and after recalibration. The predicted death rate is plotted with the corresponding death rate and surrounding 95% confidence interval. The interrupted black line indicates ideal calibration. The P corresponds to the Hosmer and Lemeshow test.

\[
1 - \frac{1}{1 + \exp(-3.973 + \text{Vancouver score})}
\]

Figure 7. The formula to calculate the predicted death rate using the Vancouver score after recalibration.

Hardman index
The distribution of patients per Hardman index outcome is shown in Table 3. In 57% (257/449), the preoperative ECGs was missing. Where the Hardman index could be applied and where a death rate of 100% was predicted the observed death rate was 50% (7/14, 95% CI 27 to 73%, Table 4). In the sensitivity analysis, in patients with a predicted death rate of 100%, the observed death rate was 84% (47/56, 95% CI 72 to 91%).
Table 4. The Hardman index score and corresponding observed 30-day and in-hospital death rate in patients without missing ECGs and in the sensitivity analysis. In the sensitivity analysis, data for missing ECGs were imputed in accordance with the outcome (death or no death).
CI = confidence interval

<table>
<thead>
<tr>
<th>Hardman index score in patients without missing ECGs</th>
<th>Observed death rate (number, 95% CI)</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>10% (6/62, 5 to 20%)</td>
</tr>
<tr>
<td>1</td>
<td>32% (23/72, 22 to 43%)</td>
</tr>
<tr>
<td>2</td>
<td>42% (19/45, 29 to 57%)</td>
</tr>
<tr>
<td>≥3</td>
<td>50% (7/14, 27 to 73%)</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Hardman index score in the sensitivity analysis</th>
<th>Observed death rate (number, 95% CI)</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>5% (6/127, 2 to 10%)</td>
</tr>
<tr>
<td>1</td>
<td>27% (41/152, 21 to 35%)</td>
</tr>
<tr>
<td>2</td>
<td>58% (66/114, 49 to 67%)</td>
</tr>
<tr>
<td>≥3</td>
<td>84% (47/56, 72 to 91%)</td>
</tr>
</tbody>
</table>

Discussion

Our study shows that following intervention for an RAAA the updated GAS predicted death most accurately for both discrimination and calibration. The present study expands on previous studies externally validating the updated GAS, the Vancouver score, the ERAS and the Hardman index in three ways. First, we set a cut-off value of patients in whom withholding intervention might be considered. In this way, we aimed to assess the additional value of the prediction models in clinical practice. Second, the number of patients included (n = 449) was higher than the previous largest study (n = 201).13 Finally, we recalibrated the updated GAS and Vancouver score to improve accuracy in the era of EVAR.

Decision making

The decision to withhold intervention in patients with an RAAA can be very difficult. Only extremely reliable models can be useful in clinical decision-making and in identifying patients in whom withholding intervention might be considered. For this purpose, we set a cut-off value for the predicted death rate at ≥95%. If the death rate were to be predicted accurately at 95%, the number needed to treat (NNT) would be 20. This cut-off value is arbitrary and could also have been 90% (NNT of 10) or 99% (NNT of 100). Different cut-off values can be used depending on the clinical situation. None of the prediction models met our criterion of identifying patients in whom to withhold intervention.
This disappointing conclusion is in agreement with previous validation studies.\textsuperscript{21-23} Currently, the prediction models have insufficient accuracy to evaluate the chances of successful intervention and future studies should focus on improvement towards this aim. The usefulness of current prediction models lies in case mix comparisons between hospitals, and in a tailored prognosis for patients and relatives.

Updated GAS
The updated GAS predicted death most accurately for both discrimination and calibration. Several other studies have validated the GAS.\textsuperscript{13, 23-27} In the only previous study including patients treated with EVAR, the AUC was 0.70 (95% CI 0.62 to 0.77).\textsuperscript{13} The calibration of the updated GAS was not assessed in this previous study. The strength of the previous validation (201 patients included, multicenter, prospective, including EVAR and OR)\textsuperscript{13} confirms our conclusion that the updated GAS is the most accurate in predicting death after intervention for an RAAA. If clinicians consider their patients to be comparable to the ones included in the present study, the model as shown in Figure 5 can be used to predict the risk of dying after intervention.

Vancouver score
The Vancouver score discriminated sufficiently accurately but even after recalibration its predictions still overestimated the death rate considerably. These results are in accordance with previous disappointing results on discrimination\textsuperscript{28}, but in conflict with previous fairly accurate results on calibration\textsuperscript{23}. Therefore, the accuracy of the Vancouver score has not yet been proven and we prefer the updated GAS.

ERAS
The prediction of death by the ERAS were insufficiently accurate. These results are in conflict with one validation study with sufficiently accurate discrimination\textsuperscript{25}, but in accordance with another validation study with insufficiently accurate discrimination.\textsuperscript{23} Concerning calibration, one previous validation reported an observed death rate of 50% in patients with a predicted death rate of 80% (estimated from figure).\textsuperscript{23} Because results regarding the ERAS are conflicting, we question its precision.
Hardman index
The accuracy of the Hardman index of the present study is in accordance with previously reported disappointing results.\textsuperscript{21, 25, 28} Even after imputation of >50% of the ECGs in accordance with the outcome in the sensitivity analysis, the predicted death rate of 100% corresponded to an observed death rate of only 84% (Table 4). Our statistical analysis of the Hardman index was hampered in two ways. First, overall performance, discrimination and calibration could not be assessed because a score of <3 did not correspond to a specific predicted death rate. Second, 57% of preoperative ECGs missing. Rightfully, one might question our imputation of missing ECGs in the sensitivity analysis. Probably, most ECGs were missing in hemodynamically unstable patients who were operated on as soon as possible. To illustrate, the death rate in patients with and without Hardman index was 29% (95% CI 23 to 35%) and 41% (95% CI 35 to 47%), respectively. Based on these results we are reluctant to draw definite conclusions regarding the accuracy of the Hardman index. The missing ECGs are a drawback of the present study, and also of the scoring system. Most surgical trainees and vascular surgeons do not know how to interpret an ECG with sufficient precision to use it as a variable in a prediction model. From a cardiac perspective, acute ischemia defined by ST segment depression greater than 1 millimeter or an associated T wave change is an oversimplification of the great diagnostic value of an ECG. Based on these considerations we are convinced that in our clinical practice the contribution of a preoperative ECG is limited and, consequently, that the Hardman index is not a useful prediction model.

Limitations
A limitation of the present study was the retrospective data collection. Probably, the variables ‘best recorded in-hospital Glasgow coma scale’ for the ERAS and ‘loss of consciousness’ for the Vancouver score contains imprecise data. Another limitation was the amount of missing data (Tables 2 and 3). This is a consequence of the acute character of the disease. Except for the missing ECGs, we coped with this problem by multiple imputation. Death was included as a predictor in the imputation model to correct for the bias that the most missing data was in patients who died. Two other prediction models have been described in the literature, the RAAA-physiological and operative severity score for enumeration of mortality and morbidity (RAAA-POSSUM)\textsuperscript{29} and the Vascular Study Group of New England (VSGNE) RAAA score\textsuperscript{23}. The RAAA-POSSUM was not included in
the present study because of its complexity including chest X-ray examination, and hence low clinical applicability. The VSGNE RAAA score was not included in the present study because of the use of an intra-operative variable, thereby making predictions prior to the intervention impossible. A final limitation was that a separate analysis in patients treated with EVAR and OR could not be done. Because of a low event rate in patients treated with EVAR (19/69), we were reluctant to draw conclusions regarding the accuracy in patients treated with EVAR and OR separately. Recently published randomized clinical trials reported a comparable death rate after EVAR and OR. This indicates that the risk-profiles are based on the same pre-operative variables and that the accuracy of the prediction models probably do not differ substantially between both interventions.

Conclusions
The updated GAS most accurately predicted death after intervention for an RAAA. However, the updated GAS did not identify patients with a predicted death rate ≥95% and therefore cannot reliably support the decision to withhold intervention.
Reference List


