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Prediction of in-hospital mortality after ruptured abdominal aortic aneurysm repair using an artificial neural network

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Objective: **Ruptured abdominal aortic aneurysm (rAAA) carries a high mortality rate, even with prompt transfer to a medical center. An artificial neural network (ANN) is a computational model that improves predictive ability through pattern recognition while continually adapting to new input data. The goal of this study was to effectively use ANN modeling to provide vascular surgeons a discriminant adjunct to assess the likelihood of in-hospital mortality on a pending rAAA admission using easily obtainable patient information from the field.**

Methods: **Of 332 total patients from a single institution from 1998 to 2013 who had attempted rAAA repair, 125 were reviewed for preoperative factors associated with in-hospital mortality; 108 patients received an open operation, and 17 patients received endovascular repair. Five variables were found significant on multivariate analysis ($P < .05$), and four of these five (preoperative shock, loss of consciousness, cardiac arrest, and age) were modeled by multiple logistic regression and an ANN. These predictive models were compared against the Glasgow Aneurysm Score. All models were assessed by generation of receiver operating characteristic curves and actual vs predicted outcomes plots, with area under the curve and Pearson r^2 value as the primary measures of discriminant ability.**

Results: **Of the 125 patients, 53 (42%) did not survive to discharge. Five preoperative factors were significant ($P < .05$) independent predictors of in-hospital mortality in multivariate analysis: advanced age, renal disease, loss of consciousness, cardiac arrest, and shock, although renal disease was excluded from the models. The sequential accumulation of zero to four of these risk factors progressively increased overall mortality rate, from 11% to 16% to 44% to 76% to 89% (age ≥ 70 years considered a risk factor). Algorithms derived from multiple logistic regression, ANN, and Glasgow Aneurysm Score models generated area under the curve values of 0.85 ± 0.04, 0.88 ± 0.04 (training set), and 0.77 ± 0.06 and Pearson r^2 values of .36, .52 and .17, respectively. The ANN model represented the most discriminant of the three.**

Conclusions: **An ANN-based predictive model may represent a simple, useful, and highly discriminant adjunct to the vascular surgeon in accurately identifying those patients who may carry a high mortality risk from attempted repair of rAAA, using only easily definable preoperative variables. Although still requiring external validation, our model is available for demonstration at https://redcap.vanderbilt.edu/surveys/?s=NN97NM7DTK. (J Vasc Surg 2015;62:8-15.)**

Ruptured abdominal aortic aneurysm (rAAA) is a vascular surgical emergency; 50% of patients die before reaching the hospital, and it may carry an overall mortality rate of 80% to 90%.[1] Whereas predictive models have been developed using multiple logistic regression analysis, their clinical use has been hindered by lack of availability of all variables necessary to calculate a score, difficulty in interpretation, development in an age before endovascular aneurysm repair (EVAR), and lack of consistent validation.[1-4]

The first reported predictive scoring system for survival after repair of rAAA is the Glasgow Aneurysm Score (GAS), first described in 1994.[3] This model retrospectively examined 500 patients who underwent open repair for rAAA from 1980 to 1990 for risk factors associated with postoperative death and found that age, preoperative shock, myocardial disease (MCD), cerebrovascular disease (CVD), and renal disease (RD) were independent predictors of mortality on multivariate analysis.[3,5] Using variable weights suggested by multiple logistic regression coefficients, the GAS algorithm was reported as GAS = age (years) + 17 (if shock) + 7 (if MCD) + 10 (if CVD) + 14 (if RD).[1,3] Scores >95 corresponded to mortality >80%. In 1996, the Hardman Index was reported after a retrospective analysis of 154 patients who underwent open rAAA repair from 1985 to 1993 in Australia.[1,2,5-8] One point was awarded for each of five factors:

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age > 76 years, loss of consciousness (LOC) after presentation, creatinine level > 2.1 mg/dL, hemoglobin level < 9 g/dL, and indicators of ischemia on electrocardiogram.[8] Although it is simple to calculate and to interpret, Tambyraja et al,[5] in 2008, showed that the Hardman Index was not specific in predicting death in patients with three or more variables, the initially reported score cutoff for uniform mortality.

Through the 2000s, additional predictive models emerged that represented U.S. cohorts. The Vascular Study Group of New England recently reported and internally validated a risk score for in-hospital mortality after open rAAA repair using age, preoperative cardiac arrest (cardiopulmonary resuscitation [CPR]), LOC, and suprarenal aortic clamping as significant predictors of postoperative in-hospital mortality by analysis of 242 patients at 10 U.S. centers from 2003 to 2009.[1] The development of a risk score that incorporates patients who underwent either EVAR or open AAA repair remains elusive. The endovascular approach may lead to improved survival in tertiary care centers where it is readily accessible,[9] although prospective data currently do not support this in the case of emergent rAAA repair.[10]

The artificial neural network (ANN) is an emerging tool for outcomes modeling in which a series of interconnecting parallel nonlinear processing elements (nodes) is "taught" to model a data set, accounting for the complex relationships among the variables. The ANN is trained with selected patient data and provides an output layer with a prediction of end points based on factors that were input.[11-14] As with any model, the input variables can be categorical or continuous and can be rationally selected or determined by significance or trend in statistical analysis.

Because current prognostic models are rarely used for preoperative guidance, the purpose of this study was to use an ANN to develop a model applicable to surgeons at a tertiary care center with open and endovascular capability, in which readily available preoperative factors can provide accurate prognostic guidance and help determine appropriate candidates for rAAA repair. Furthermore, we aim to propose methods to conveniently facilitate the use of an ANN-derived model in the clinical setting such that a complex algorithm may provide easily interpretable data for the surgeon. To assess our algorithm's discriminant ability, our four-variable ANN model was compared with its analog derived by multiple logistic regression and with GAS, as a representative current scoring system.

METHODS

Patients who underwent repair for rAAA were determined using the Vanderbilt University Synthetic Derivative, a de-identified mirror of the institutional electronic medical record, StarPanel.[15] As no identifying information was available, this study was approved by the Vanderbilt University Institutional Review Board, and patient consent was waived. In Synthetic Derivative, a search for the International Classification of Diseases, Ninth Revision, code of either 441.3 (abdominal aortic aneurysm, ruptured) or 441.5 (aortic aneurysm of unspecified site, ruptured) was performed, yielding 332 patients with the diagnosis between 1998 and 2013. Patients were included if they underwent emergent operation for rAAA; operation was defined as the administration of anesthetic with the intent to operate.[5] Exclusion criteria included patients who had thoracic disease, isolated iliac disease, ruptured viscus (nonaorta), aortoenteric fistula, aortic dissection, or pseudoaneurysm and those with nonoperative management, death before operation, or lack of sufficient information in the medical record. Ultimately, 125 patients were included for analysis.

Prognostic variables were initially examined to determine those preoperative factors associated with postoperative in-hospital mortality. The screened variables were chosen on the basis of inclusion in at least one of five previously validated rAAA models for prediction of postoperative mortality, with sufficient reliable information retrospectively available in the Synthetic Derivative.[1,3,5,8,16] The initial set of rationally selected variables included the following: gender; age at rupture; LOC after presentation (defined as LOC, GCS < 15, or altered mental status necessitating protective intubation)[2,8]; signs of shock (systolic blood pressure < 90 mm Hg, heart rate > 120, pallor, diaphoresis)[3]; preoperative cardiac arrest/CPR; and history of MCD (myocardial infarction or angina),[3] CVD (stroke or transient ischemic attack),[3] and RD (any of chronic renal failure, acute kidney injury, urea level > 20 mmol/L, or creatinine level > 1.7 mg/dL on presentation).[3,5,8] Documentation in the medical record was sufficient for attribution of a variable. Electrocardiograms and laboratory values were not sufficiently available to surgeons before operation and were falsely altered because of blood transfusions; thus, they were not considered. Measures necessitating preoperative imaging or pertaining to intraoperative decision-making (such as need for suprarenal clamp) were excluded. Open or endovascular operation was noted, as 13.6% of patients received EVAR; there was no distinguishing between the two in the subsequent analysis. The primary outcome of this study was in-hospital mortality.

Bivariate analysis of the eight initial variables was performed on all 125 patients to screen for those risk factors associated with in-hospital mortality. Variables with $P < .05$ by Fisher exact test were considered for standard least squares multivariate analysis.[17] The five variables with $P < .05$ on multivariate analysis were age, LOC, shock, CPR, and RD. Although significant, RD was not thought to help the clinician preoperatively, as ascertaining its presence may be difficult; thus, it was not included in the two subsequent models.

For the four-variable ANN, 107 patients with all variables known were considered for analysis. The data were converted into comma-delimited files suitable for interfacing with JMP software (SAS Institute, Cary, NC) and input in the ANN. A back-propagation ANN with *k*-fold validation, with four nodes each assigned a learning value