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Estimating the risk of bowel ischemia requiring surgery in patients with tomographic evidence of pneumatosis intestinalis

Bindu A. Umapathi, M.D., M.R.C.S., Charles M. Friel, M.D., F.A.C.S., George J. Stukenborg, Ph.D., M.A., Traci L. Hedrick, M.D., F.A.C.S.*

Department of Surgery, University of Virginia, Charlottesville, VA, USA

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Abstract

BACKGROUND: Pneumatosis intestinalis (PI) presents a challenging dilemma for surgeons given its association with both benign and life threatening conditions. As such, the need for surgical intervention is oftentimes difficult to discern. We hypothesize that a clinical nomogram can be used to predict the need for surgical intervention in patients with PI.

METHODS: We performed a retrospective review of 217 consecutive cases with PI on abdominal computed tomography over a 10-year period at a tertiary care hospital. Bivariable and multivariable analysis were conducted to assess the statistical significance of the association between patient factors and need for surgical intervention, defined as positive findings at surgery.

RESULTS: There were 217 patients with PI identified during the study, of which 178 were treated with curative intent. Of these, 82 patients underwent surgical exploration, and 96 patients were managed conservatively. Forty-four percent of patients who had radiographic evidence of PI were managed conservatively and did well, whereas an additional 6% underwent nontherapeutic laparotomies. Multivariable analysis demonstrated that patients with tenderness on examination, lactic acidosis, and tachycardia had significantly higher likelihood of the need for surgical intervention, whereas patients with diabetes had a lower likelihood of surgical intervention. These and other selected patient characteristics can be used to efficiently and reliably estimate the probability of ischemic bowel at laparotomy.

CONCLUSIONS: The presence of PI does not always warrant surgical intervention. We present a nomogram to assist with clinical decision-making based on the presence of clinical factors.

Pneumatosis intestinalis (PI) was 1st described as a postmortem finding during cadaveric dissections in the 17th century. It is characterized by the presence of gas in the subserosal or submucosal layers of the intestinal wall.[1] It can be associated with a wide spectrum of diseases ranging from intestinal ischemia to an incidental finding in an otherwise healthy patient. The pathogenesis of PI is poorly understood. Several theories have been proposed including (1) Bacterial translocation theory which describes bacterial invasion of the bowel wall without

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* Corresponding author. Tel.: 434-243-2670; fax: 434-924-5250.

E-mail address: Th8q@virginia.edu

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mucosal injury; (2) increased mucosal pressure theory which proposes that intraluminal air is driven into the bowel wall because of high luminal pressure; and (3) Mucosal break theory, which suggests that gas is driven into the bowel wall in cases of mucosal ischemia/inflammation.[1] Historically, when evident on a plain radiograph, pneumatosis was an ominous sign that mandated surgical intervention. The current true incidence of PI is unknown. However, with the widespread use of cross sectional imaging, it is now frequently identified and poses a challenge to the clinician. The finding often leads to a surgical consultation, extensive work up, repeat imaging, and in many cases exploration.

Given that the surgical indication in patients with PI is not well defined, the objective of this study was to determine factors that predict the risk of intestinal ischemia in a patient with PI. Furthermore, as an adjunct to existing literature,[2–5] our goal was to provide the clinician with an objective tool to quantify the risk of ischemia and aid with decision-making. We hypothesize that PI is not an absolute indication for surgery and that clinical factors can be used to quantify the risk of intestinal ischemia and the need for surgical intervention.

Methods

All consecutive patients with PI admitted to the University of Virginia Medical Center during the 10-year period from January 2001 to October 2011 were included in the study population. Patients with PI were identified by searching all cases in a prospectively maintained radiology database for occurrences of the terms “pneumatosis”, “PI”, and “pneumatosis coli”. Members of the study team reviewed medical records and imaging for all identified patients. Cases that were determined as inconclusive or as nonconfirmatory for pneumatosis were excluded from further consideration. The presence of PI was further characterized into isolated (confined to either the colon or the small bowel or the stomach) or extensive (involving multiple sites). Demographic and clinical data were abstracted from the medical records along with imaging data for all confirmed cases. The primary outcome, pathologic pneumatosis, was defined as a positive finding for ischemia at laparotomy. Ischemia was either full thickness requiring resection or partial ischemia that resolved with detorsion of the bowel or adhesiolysis. This study was reviewed and approved as exempt human subjects research by the University of Virginia Institutional Review Board.

Bivariable logistic regression analysis was used to estimate the probability of positive findings for ischemia at laparotomy in the study population associated with each measured patient characteristic listed in Table 1. Bivariable logistic regression measures the unadjusted association between an individual covariate and the occurrence of positive finding for ischemia. The statistical significance of the observed association was assessed using the Wald chi-square test statistic, with alpha = .05 as the threshold for significance. Multivariable logistic regression analysis was then used to estimate the probability of positive findings for ischemia at laparotomy in the study population as a function of all patient characteristics with statistically significant individual associations. The relative independent contribution of each statistically significant covariate toward the overall explanatory power of the multivariable model was assessed by measuring the Wald chi-square test statistic and assessing the proportion of the model’s total log-likelihood accounted for by the covariate.

An abbreviated model was also developed using a subset of covariates that were highly statistically significant predictors in the complete model. The abbreviated model was developed to serve as the basis for a nomogram plot useful for the efficient assessment of individual patient risk for pathologic pneumatosis. The number of covariates included in the abbreviated model was set to yield a level of discrimination (c statistic) within .01 points of that achieved by the full model. The nested model log-likelihood test, which compares the total log-likelihood obtained by the full model to that obtained by the reduced model, was used to assess the statistical significance of the difference in predictive information between the full and reduced models.[6]

The capacity of the multivariable models to discriminate between patients with and without ischemia was measured using the c statistic.[7,8] A c statistic value of .5 indicates that the model provides no predictive discrimination, whereas a value of 1.0 indicates perfect discrimination between cases with and without ischemia. The proportion of variance in the occurrence of ischemia explained by the models was assessed using the maximum adjusted R^2 statistic, which ranges from 0 for models that provide no predictive information to 1 for models that predict perfectly.[9–11]

The c statistic and Nagelkerke R^2 statistic obtained for the reduced model were validated using bootstrap simulation to address the potential for model overfitting.[12–15] The reduced model was fit to 1,000 samples of equivalent size drawn at random with replacement from the original study population. The measures of predictive performance obtained for each statistic in the bootstrap samples were used to estimate the “shrinkage factor” or amount of bias in the model statistics attributable to overfitting. Validated c statistics and Nagelkerke R^2 statistics were respectively derived by subtracting the estimated amount of bias from the originally estimated statistics.

Data management and multivariable logistic regression model estimation were conducted using SAS, version 9.3. The abbreviated model nomogram and model validation results using bootstrap simulation were developed using the Hmisc package and *R* statistical software, version 2.13 (*R* foundation for Statistical Computing, Vienna, Austria).[16]