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Trauma centre patient volume and inpatient mortality risk reconsidered

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ABSTRACT

Background: Several studies have examined the relationship between injury volumes and trauma centre outcomes, with varying results attributable to differences in the measurement of volume's effect on mortality and differences in how characteristics are addressed as potential confounders.
Methods: This analysis includes all trauma cases reported to the NTDB 2012. The effect of trauma centre volume on patient mortality risk was measured in three different contexts: as a linear function of trauma centre volume, as a dichotomous function comparing patients in trauma centres with and without 1200 or more cases, and as a non-linear function of trauma centre volume. Multivariable weighted Hierarchical Generalized Linear Models were used to account for the combined effects of facility level and patient level covariates. Patient level mortality risk was assessed using the ACS Trauma Quality Improvement Programme methodology.
Results: Trauma centre volume was not a statistically significant predictor (at the $\alpha = 0.01$ level) of patient mortality risk, in any of the three models. Comprehensive adjustments for patient level risk were obtained, with excellent discrimination between survivor and decedent cases. The addition of trauma volume to baseline patient mortality risk yielded no improvement in the accuracy of any model. These results were not sensitive to the inclusion of Level II trauma centres. Equivalent results were obtained by repeating the analysis for the Level I subpopulation only.
Conclusions: Case volume may be a reasonable standard for determining whether adequate numbers of injured patients are available to support training needs and experience requirements of a Level I trauma centre. However, case volume is not a useful predictor of patient mortality in individual facilities. Trauma centre volume has no independent effect, after accounting for the patient level characteristics that predominantly influence mortality.

Introduction

Minimum trauma centre case volumes are used as standards for anticipating centre performance. The American College of Surgeons (ACS) Committee on Trauma requirements for Level I trauma centre designation specify that centres have at least 1200 annual trauma patient admissions or 240 annual admissions of patients with an Injury Severity Score of more than 15 [1]. Evidence for this volume standard is drawn from several studies that have examined the relationship between volume and mortality outcomes for trauma patients [2–4].

However, a recent review of the evidence for the relationship between trauma centre volume and patient mortality indicates that prior studies present both heterogeneous methods and results [5]. These disparate results reflect differences in the statistical approaches used to measure volume's effect on mortality, differences in how characteristics (other than facility volume) are addressed as potential confounders of the relationship, and differences in the types of facilities and patients included across studies [5].

Recent declines in overall trauma patient mortality rates have also reduced the utility of evidence from older studies, some of which are based on collections of patient data reflecting events more than a decade ago. Research indicates that in-hospital mortality among adult trauma patients admitted to Level I or Level II trauma centres declined by 30% between 2000 and 2009

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[6]. Other studies indicate that total trauma-related mortality has decreased by 6% from 2002 to 2010 [7].

The present study reconsiders the statistical relationship between trauma centre mortality and patient volume using updated collections of data for trauma patient outcomes in the U.S. in 2012. The relationship is assessed using statistical methods that account for the hierarchical structure of the data, where both patient level and facility level predictors of mortality are included.

Methods

The ACS National Trauma Data Bank (NTDB) National Sample Programme Arrival Year 2012 is used in this study to measure trauma centre volume and patient level mortality risk. The ACS NTDB National Sample includes detailed clinical reports for all incidents of injured patients treated in a stratified sample of trauma centres. Cases not admitted to the hospital are not included in the NTDB. Hospitals included in the stratified sample are selected from the total series of Level I or II U.S. trauma centres. The sample includes data reported in the NTDB that was selected based on probability-proportional to size methodology, with weighted results that are generalizable to the broad U.S. population of injured patients treated in Level I and II trauma centres [8]. All available case reports were included in the study population.

Patient level mortality risk was assessed for each patient using patient level characteristics included in the ACS Trauma Quality Improvement Programme (TQIP) methodology [9,10]. The ACS TQIP methodology identifies a series of patient level characteristics demonstrated to significantly contribute to the probability of in-patient death among adult trauma patients. The TQIP mortality prediction model includes the following patient characteristics: age greater than 65 years of age, injury from firearms vs. other mechanism of injury, initial systolic blood pressure group in emergency department, initial pulse rate group, initial Glasgow motor score, injury severity score group, transfer from an outside centre, head injury severity group, and abdominal injury severity group [9].

Trauma centre volume was measured as the total number of cases reported for each facility in the data for all arrivals in 2012. The effect of trauma centre volume on patient mortality risk was measured in three different contexts: (1) as a linear function of trauma centre volume, (2) as a dichotomous function comparing patients in trauma centres with 1200 or more cases during 2012 to patients in centres with fewer cases, and (3) as a non-linear function of trauma centre volume fit using restricted cubic splines. While the truncation of continuous variables into categories allows non-linearity to be measured in a readily interpretable format, the categorization of continuous data eliminates much of the available information available [11]. Splines allow more accurate characterization of non-linearity in the relationship between volume and mortality, using piecewise polynomial functions fit to the shape of the relationship between volume and probability of mortality [12,13]. Restricted cubic splines limit the two distant ends of the polynomial function to be linear [14].

Weighted Hierarchical Generalised Linear Models (HGLMs) were used to appropriately account for the combined effects of facility level and patient level covariates [15]. Data that include both facility and patient level measures are hierarchically structured, with individual cases stratified within trauma centres. The typical general linear model formulation is not appropriate for measuring the combined effects of trauma centre volume and patient level risk factors on mortality risk, because the assumption that the error components of the model are independent is violated [16]. In hierarchically structured data the cases are correlated with facilities, since cases from the same facility have identical volume measures. When both facility and patient characteristics are included in the same model, the variance estimates have an additional component that is not addressed by the general linear model. However, the HGLM method accommodates this additional variance component and allows the combined variance components of the model error term to be correctly represented.

Models were developed using each of the three alternative measures of volume's effect (linear function, dichotomous function, and spline function) in additional to the patient level effects of risk factors assessed using the TQIP methodology. The relative contribution of each covariate to the model's overall predictive performance was assessed by calculating type III tests of fixed effects (F test statistics), which reflect the proportion of the total model log-likelihood independently explained by each model covariate. Weighted HGLM models were estimated for the total study population of cases for adults in Level I or Level II trauma centres and for the subset of cases in Level I trauma centres only. The capacity of each model to discriminate between cases discharged alive or discharged deceased was measured using the *C* statistic [17,18]. A *C* statistic value of 0.5 indicates that the model provides no predictive discrimination, while a value of 1.0 indicates perfect discrimination.

The independent contribution of trauma centre volume to the estimation of patient mortality risk was assessed using nested models. Results for each model including volume were compared to the results obtained using a baseline model with only the patient level risk factors assessed using the TQIP methodology. Each pair of nested models was assessed using the integrated discrimination improvement (IDI) statistic to assess the accuracy of model reclassification [19]. Reclassification addresses the extent to which the model supplemented by the volume measure correctly (or incorrectly) reclassifies cases as having died or survived compared with the baseline model's classification of the same case. The IDI obtains a value of −100% for the maximum possible decline in the overall sensitivity and specificity, 0% for no difference, and 100% for the maximum possible improvement. The precision of the IDI estimates was assessed with 95% confidence intervals calculated for each IDI.

All cases reported to the NTDB for the NSP Arrival Year 2012 were included in this study. Cases with unknown values for any measure in the ACS TQIP method were retained, with unknown values listed as a category for covariates where they occurred. Sensitivity analyses were conducted to assess the potential for bias on the estimation of type III tests of fixed effects (*F* test statistics), attributable to including cases with unknown values for covariates. First, the complete model estimation process was repeated, excluding all adults in Level I or Level II trauma centres with unknown values for any model covariate, for each of the three alternative measures of volume's effect, respectively. Second, a set of 100 datasets was created using multiple imputation to randomly replace unknown covariate values for adults in Level I or Level II trauma centres. Replacement values were estimated using ordinal monotone logistic regression models that included all covariates in the original weighted HGLM models (excluding the predicted response) [20]. Mean values for *F* test statistics were calculated for the series of models estimated using the multiply imputed data sets, for each of the three alternative measures of volume's effect, respectively. The results of the original analysis were then compared to the results of the sensitivity analyses to assess the potential for bias.

Statistical significance was assessed at the a priori threshold value of $p < 0.01$ for each comparison made – due to the large sample size. Data management, multivariable weighted logistic regression analysis, weighted HGLM analysis, and multiple imputation of missing data were conducted using SAS version 9.4. Graphics programming was conducted using R statistical software, version 2.13 (R foundation for Statistical Computing, Vienna, Austria).