

Survival Advantage Associated with Treatment of Injury at Designated Trauma Centers: A Bivariate Probit Model with Instrumental Variables

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This article analyzes the effectiveness of designated trauma centers in Florida concerning reduction in the mortality risk of severely injured trauma victims. A bivariate probit model is used to compute the differential impact of two alternative acute care treatment sites. The alternative sites are defined as (1) a nontrauma center (NC) or (2) a designated trauma center (DTC). An instrumental-variables method was used to adjust for prehospital selection bias in addition to the influence of age, gender, race, risk of mortality, and type of injury. Treatment at a DTC was associated with a reduction of 0.13 in the probability of mortality.

Keywords: *trauma; trauma systems; effectiveness; instrumental variables*

The International Classification of Diseases, Ninth Revision, Clinical Modification (ICD9-CM) classifies 17 broad categories of diseases and injuries. Considering only the primary diagnosis, the category injury and poisoning: ICD9-CM codes 800–999 accounted for more than 8 percent of all hospital episodes in Florida, making it the fifth most common reason for hospitalization in 2003.¹ In terms of nonadjusted mortality associated with the top five reasons for hospitalization, the injury and poisoning category had the third highest mortality rate,² driven primarily by the subset

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of trauma, which is defined more specifically below. Therefore, trauma, and perhaps more importantly, the state trauma system warrants special attention.

Florida has an inclusive trauma system consisting of multiple interrelated and coordinated elements: prevention, prehospital care, acute care, and posthospital care. The system matured since it was established in 1982 and currently includes 21 level I and level II DTC hospitals. The primary distinction between the levels is that the former must also meet pediatric trauma center standards, must provide education, research, and leadership, and must serve as resources to level II centers. The research question of this article concerns the value added of the Florida Trauma System in terms of its influence on reducing the probability of mortality resulting from serious injuries in a population of nonelderly adult patients.

New Contribution

While several empirical studies have found a reduction in mortality risk following the implementation of a trauma system (Mullins and Mann 1999), this finding is not universal (Sampalis et al. 1995; Rogers et al. 2001; Mann et al. 2001; Reilly et al. 2004). The lack of consensus in the literature suggests a gap. This article attempts to address that gap by accounting for the nonrandom nature of the triage decisions made before hospitalization using an instrumental-variables method. The nonrandomness of triage decisions, heretofore referred to as selection bias, is associated with unobserved factors that are assumed to influence the mortality risk of trauma victims differently depending on whether they were triaged to either a designated trauma center (DTC) or nontrauma center (NC). The methods used in this study take great care to correct this problem to obtain insight into the causal relationship as opposed to the mere correlation between treatment of trauma victims at DTCs and mortality. The analysis should assist state legislators and executive branches in understanding the benefit associated with public access to a DTC.

The Data

The Florida Agency for Health Care Administration (AHCA) collects data on all admissions to Florida hospitals. Patient data include demographic and case-mix-related characteristics such as age, sex, race, up to nine diagnoses and procedures, source and type of admission, and discharge status of all patients discharged from the state's community hospitals. This study uses the 2001–2003 AHCA inpatient hospital discharge data sets. Trauma victims were identified using ICD-9CM codes. The study population can be categorized according to five broad groups of trauma victims based on ICD-9CM codes: fractures other than those related to the skull, neck, and trunk (ICD-9CM codes 810–829); fractures of the skull, neck, and

trunk, intracranial injury, and spinal cord injuries (ICD9-CM codes 800–809, 850–854, and 952); internal injury of the thorax, abdomen, or pelvis (ICD-9CM codes 860–869); injury of blood vessels (ICD-9CM codes 900–904); and burns (ICD-9CM codes 940–949).

The overwhelming majority of patients (98.3 percent) in the study were admitted through hospital emergency rooms. The data do not indicate whether admissions were associated with a “trauma alert.” To ensure that the results are not unduly influenced by admissions that are not associated with life-threatening injuries, two criteria were implemented to identify true trauma victims. First, patients are classified by the medical staff as emergency, urgent, or elective following a preliminary examination. Since the outcome of interest is mortality in true trauma, urgent and elective admissions are excluded from the study population since all trauma alerts should be categorized as emergency admissions. In addition, the primary ICD-9CM code was used to identify trauma-related admissions that were historically associated with zero risk of mortality based on the 1998–2000 hospital discharge data sets. For example, none of the 285 hospitalizations for ICD-9CM code 800.00 (fracture of the clavicle—unspecified part) during the study period resulted in death. Indeed, there are no recorded deaths in the Florida hospital discharge data sets associated with this diagnosis going back to at least 1991. In summary, the study population includes only severely injured trauma victims who were admitted with a primary diagnosis that is associated with a historically nonzero risk of mortality.

Approximately 4 percent of trauma victims were transferred from the hospital where they initially presented to another short-term acute care institution. Unfortunately, the data set does not allow tracking of these individuals to assess their final discharge status. This introduces another potential source of bias; if a transferred patient dies in the second hospital, the admission will unfairly reduce or increase the mortality rate in, respectively, the initial and second hospital. To avoid this source of bias, only initial admissions are included in the final data set. The final data set included 23,076 nonelderly adult trauma victims. The sensitivity of the model (discussed below) to these exclusions was tested by executing it with and without the effected observations. The results of the sensitivity tests are discussed briefly in the results section.

The elderly (aged 65 and older) are not included in this analysis. This group of patients tends to suffer from greater comorbidities because of a higher probability of chronic illness and generally more fragile physiologic condition. The systematic difference was verified using a Chow test (Chow 1960). This test is used to determine whether the coefficients in a regression model are the same in different subsamples. The result of the empirical test for structural differences is supported by the literature. Elderly trauma patients are systematically different in terms of the risk of mortality and should be investigated separately to assure reliability of findings (Scheetz 2003; Demetriades et al. 2001; McMahon, Schwab, and Kauder 1996; Philips et al. 1996).

Conceptual Model

The dependent variable in the analysis is defined as dichotomous, with values of 1 or 0 for, respectively, nonsurviving or surviving patients. The goal of this study is to evaluate the survival advantage of trauma victims treated at DTC as compared to NC hospitals; the treatment variable is defined as dichotomous with a value of 1 if a patient presented at a DTC and 0 otherwise. Of the 23,076 severely injured trauma victims in the study population, 16,153 (70 percent) and 6,922 (30 percent) were treated in, respectively, DTC and NC settings. The current study is designed as a concurrent trauma versus nontrauma hospital comparison as opposed to a pretrauma or post-trauma system implementation analysis. Based on existing trauma care literature examining differential mortality rates using a similar design (Sampalis et al. 1995; Mullins et al. 1996; Rogers et al. 2001; Mann et al. 2001; Abernathy et al. 2002; Melton et al. 2003; Reilly et al. 2004), additional statistical controls are divided into (1) sociodemographic characteristics such as age, gender, and race; (2) the type of injury for which the patient is being treated—for example, vascular versus fracture; (3) one or more measures of the severity of the injury or injuries; and (4) other factors such as geographic region and an indicator for interhospital transfers. In the remainder of this section, the statistical controls are described briefly, followed by a discussion of the main variable of interest, particularly whether a trauma victim was treated at a DTC.

Explanatory Variables

Previous literature showed that injury severity scores and physiologic measures, and perhaps the mechanism of injury, are predictive of survival from trauma. To account for injury severity and physiologic condition, the model includes three measures: an ICISS (ICD-9 Injury Severity Score), the number of severe injuries, and the type of injury. An ICISS is calculated for each patient from survival risk ratios (SRRs) derived from the inpatient abstracts from the 3 years before the study period (1998–2000) to minimize colinearity concerns. An SRR indicates the proportion of victims that survived after being admitted for the associated diagnosis. Higher ICISS values indicate a lower level of severity; thus, a negative relationship is hypothesized between the odds of mortality and the ICISS (Boyd, Tolson, and Copes 1987; Osler et al. 1996; Rutledge and Osler 1998). In addition to the ICISS, the model also includes a simple count of injuries with an SRR of less than unity, indicating a positive risk of mortality associated with each individual injury diagnosis. A positive relationship is hypothesized between mortality and the number of such injuries. To further distinguish patients based on risk, the model includes dummy variables for the categories of trauma: fracture other than those related to the skull or spinal cord;

Table 1
Means and Standard Deviations of Model Variables

Variables	All	NC	DTC
<i>N</i>	23,076	6,922	16,153
Nonsurviving patients	0.10	0.06	0.12
Treated in DTC	0.71	0.00	1.00
Age	32.54	35.88	31.17
Female	0.28	0.33	0.26
White	0.62	0.68	0.60
Black	0.18	0.14	0.20
Hispanic	0.14	0.14	0.14
Other nonwhite	0.06	0.04	0.06
ICISS	0.87	0.94	0.85
Number of serious trauma injuries	1.75	1.36	1.92
Fractures other than those related to the skull, neck, and trunk	0.24	0.35	0.20
Internal injuries of the thorax, abdomen, and pelvis	0.22	0.20	0.23
Injuries associated with blood vessels	0.01	0.01	0.02
Fractures of the skull, neck, and trunk; intracranial and spinal cord injuries	0.47	0.43	0.48
Burns	0.05	0.01	0.07

Note: NC = nontrauma center; DTC = designated trauma center; ICISS = ICD-9 Injury Severity Score.

fractures related to the skull or spinal cord; injuries of the thorax, abdomen, and pelvis; injuries of blood vessels; and burns. In addition to severity and injury type, the model includes age, gender, and race to account for physiologic differences related to these patient demographic characteristics.

Table 1 contains the means and proportions of the model variables for all observations and patients treated at either DTCs or NCs. Nonsurviving patients make up 10 percent of the sample. The majority of nonelderly trauma victims in the sample (71 percent) were treated in DTCs. The average age of patients in the sample is 33 years, and the majority (72 percent) is male. The race composition of individuals in the sample is 62 percent non-Hispanic white, 18 percent black, 14 percent Hispanic, and 6 percent other nonwhite. The average ICISS for nonelderly trauma victims in the sample was 0.87. The most common type of trauma in the sample, according to the primary diagnosis, consists of fractures of the skull, neck, and trunk, intracranial injury, and spinal cord injuries (46 percent). Other fractures claimed 24 percent of injuries. Internal injuries of the thorax, abdomen, and pelvis accounted for 22 percent of admissions in the sample, while burns and injuries associated with blood vessels made up 5 and 1 percent, respectively.

Treatment at a DTC and Selection Bias

Selection bias represents an important problem in health outcomes research, particularly when observational data sets are used. Outcomes are affected by both observable—and therefore recordable—and unobservable characteristics. Standard statistical methods can be used to account for the influences of the observable characteristics but cannot adjust for the effects of the unobservable factors (McClellan, McNeil, and Newhouse 1994; McConnell et al. 2005). For example, certain hospitals may be associated with higher rates of mortality, not because they provide lower quality or less intensive care but because they treat a more severely ill patient population. Severity measures such as injury severity scores provide some measure of control but cannot fully capture the effect of patients' health status. Randomized trials provide an ideal experimental method for managing this problem but are extremely costly and not always possible. McClellan, McNeil, and Newhouse (1994) show that instrumental-variables (IV) estimation methods may be a useful alternative in such cases. IV estimation methods are well established in the econometrics literature and have recently become increasingly popular in health services research (Ettner 1996; Foster 2000; Frances et al. 2000; Howard 2000; Malkin, Broder, and Keeler 2000; Cawley 2000; Goldman et al. 2001; Ressler et al. 2005; McConnell et al. 2005).

Within the context of this research, a likely source of selection bias is the increased propensity to select more severely injured patients for transport to a DTC as opposed to an NC, holding all other variables constant. To the extent that selection bias exists, standard statistical methods will attribute two separate influences to a single variable indicating treatment at a DTC: the first effect represents the bias and is associated with the upward pressure on mortality that is related to the nonrandom selection of more severely injured patients into a DTC; the second is the effect that treatment in a DTC has on mortality. If the first type of effect exists, it will either cause an underestimate of the impact of trauma hospital services or, if it is large enough, produce a spurious positive correlation between mortality and treatment in a DTC. In such a case, IV estimation methods are well suited to deal with the bias problem and produce estimates of the independent marginal influence of treatment of trauma victims at a DTC. The results from the IV estimation method are unbiased and consistent (McClellan, McNeil, and Newhouse 1994; Card and McCall 1996).

An instrument is proposed here that is based, in part, on the time-related cost of transporting victims. Following McClellan, McNeil, and Newhouse (1994), the differential distance to alternative treatment sites is calculated in straight-line fashion from the geographic center of the victim's residence zip code and the nearest DTC minus the distance to the closest NC with an emergency department (ED). Distance is expected to influence a victim's destination since Florida's Emergency Medical Services' (EMS) protocol dictates that patients be transported to the nearest ED or DTC in case of a trauma alert (Florida DOH 2004).

The validity of differential distance as an instrument depends on two crucial assumptions: (1) that it is sufficiently correlated with the DTC variable after the effects of other exogenous variables have been accounted for and (2) that it is uncorrelated with the outcome variable, in this case, mortality. In other words, it must not be a significant omitted variable from the above equation. These criteria are discussed further below.

Estimation

A Hausman test (Hausman 1978) was used to examine whether selection bias is present or if a standard single-equation approach would suffice. The result of this test ($p < .01$) indicates that the single-equation approach would not produce consistent or efficient estimates of the parameters. Selection of a trauma victim for treatment at a DTC is nonrandom and must either be modeled before or simultaneously with the outcomes equation. Because both the variable of interest (treatment at a DTC) and the outcome (mortality) are dichotomous, a full-information maximum likelihood bivariate probit estimation is considered the more appropriate and efficient choice (Greene 2003). In this model, the endogenous binary DTC variable is included in the outcome equation as simply another regressor.

Let DTC_i be a binary endogenous dummy variable with a value of 1 if the patient presented at a DTC and 0 otherwise; then the outcome equation is given by

$$\text{mortality}_i^* = x_i\beta + DTC_i\gamma = e_i, \quad (1)$$

Mortality_{*i*} = 1 is observed when mortality_{*i*}^{*} in equation 1 exceeds a certain threshold; x_i is a vector of statistical controls (discussed above) that affect the probability of mortality; β is the associated vector of coefficients; γ is the DTC dummy coefficient; and e_i is a stochastic error term. The DTC equation is given by

$$DTC_i^* = x_i\alpha + d_i\delta + u_i, \quad (2)$$

where DTC_i^* is the unobserved probability that individual i will be treated at a DTC (i.e., $DTC = 1$), d_i is the instrumental variable differential distance, δ is the associated coefficient, and u_i is a stochastic error term. In equations 1 and 2, the stochastic error terms e_i and u_i are not independent. Estimating the equations jointly using a bivariate probit approach incorporates this nonindependence and produces consistent estimates (Greene 2003).

In addition to the bivariate probit model, a standard one-equation probit equation is also executed to assess and illustrate the extent to which selection bias plays a roll. Finally, a two-stage linear model is also estimated. While the linear probability specification suffers from some serious weaknesses, including probabilities that are not

bounded by 0 and 1, it provides useful estimates of the marginal effects of the model variables evaluated at the means.

Results

The regression results are shown in Table 2. Two criteria had to be met to verify the validity of differential distance as an instrument. The first criteria, whether differential distance is correlated with transport to a DTC, was easily verified using a single equation (equation 2) and subsequently using the full bivariate probit model (Table 2, column 3) and a Wald test. The selected instrument is highly statistically significant, therefore, satisfying the first condition (Staiger and Stock 1997; Greene 2003).

The second condition is more difficult to test and cannot be definitively proven. The selection is based on both theoretical grounds and statistical tests. The distance variable is based solely on geographic location and is, therefore, a plausible choice. It represents not only the time cost related to transport to a DTC but also the tendency of trauma hospitals to locate in regions associated with high levels of trauma and, therefore, strongly influences the selection. To examine the potential correlation between the distance variable and mortality, two tests were performed. For the first test, the data were divided into five groups based on distance (within 10, 20, 30, 40, or 50 miles from a DTC). A standard chi-square test was used to compare the observed and expected mortality rates under the null hypothesis that distance did not influence the outcome. The p value (.89) suggests that the null hypothesis cannot be rejected using the data at hand. A second, more formal chi-square test (see Greene 2003) was used to verify whether the distance variable is a legitimate instrument. This test is used to assess whether the instrument, in this case, differential distance, is a significant omitted variable from the primary equation. The results (chi-square = 1.35) indicate that it does not influence the error term significantly. Based on these tests, differential distance is considered to be not invalid as an instrument. In other words, it is not simply an omitted variable from the structural equation as argued above on theoretical grounds.

The focus of this article is on the influence of the DTC variable; therefore, the following provides only a brief summary of the findings related to the remaining factors. According to expectations, age has a highly significant and direct impact on the odds of mortality. Holding all other variables fixed, women face a lower risk of mortality. Blacks have a higher risk of mortality, while Hispanics face a significantly lower risk compared to non-Hispanic whites. The two severity measures, ICISS and the number of serious injuries, both had the expected signs. However, the ICISS variable is not statistically significant. This is likely the result of severe colinearity with the second severity measure, which had a highly significant influence on mortality. After controlling for confounding factors, injuries to blood vessels, burns, fractures of the skull, neck, and trunk, intracranial injury, and spinal cord injuries as well as

Table 2
Regression Results

	Bivariate Probit Equations for Primary Model			DTC	Two-stage Linear Probability for Mortality	Single Equation Probit for Mortality	Sensitivity Analysis Including Transfers
	Mortality	DTC	Bivariate Probit for Mortality				
N	(23,076)	(23,076)	(23,076)	(23,076)	(23,076)	(23,076)	(24,042)
Intercept	-0.624** (<.01)	2.112** (<.01)	2.112** (<.01)	0.286** (<.01)	-1.410** (<.01)	-0.664** (<.01)	
Differential distance							
DTC	-0.386** (0.01)	-0.010** (<.01)	-0.132** (<.01)	0.001** (<.01)	0.321** (<.01)	-0.334* (0.02)	
Age	0.009** (<.01)	-0.010** (<.01)	0.001** (<.01)	0.001** (<.01)	0.012** (<.01)	0.009** (<.01)	
Female	-0.100** (<.01)	-0.197** (<.01)	-0.197** (<.01)	-0.020** (<.01)	-0.062** (0.02)	-0.097** (<.01)	
Black	0.117** (<.01)	0.176** (<.01)	0.176** (<.01)	0.023** (<.01)	0.077** (0.02)	0.123** (<.01)	
Hispanic	-0.181** (<.01)	-0.056* (0.04)	-0.056* (0.04)	-0.026** (<.01)	-0.192** (<.01)	-0.1166** (<.01)	
Other nonwhite race	0.173** (<.01)	0.379** (<.01)	0.379** (<.01)	0.040** (<.01)	0.110* (0.03)	0.168** (<.01)	
ICISS	-0.528 (0.63)	90.272 (0.98)	90.272 (0.98)	-0.081 (0.59)	-0.463 (0.53)	-0.160 (0.79)	
Trauma diagnoses	0.145** (<.01)	0.195** (<.01)	0.195** (<.01)	0.034** (<.01)	0.119** (<.01)	0.129** (<.01)	
Internal injuries of the thorax, abdomen, pelvis	-0.082** (0.01)	-0.062** (0.01)	-0.062** (0.01)	-0.014** (0.01)	-0.069* (0.02)	-0.095** (<.01)	
Injuries associated with blood vessels							
Fractures of the skull, neck, and trunk;	-0.518** (<.01)	-0.555** (<.01)	-0.555** (<.01)	-0.114** (<.01)	-0.449** (<.01)	-0.502** (<.01)	
intracranial injury; and spinal cord injuries	-0.388** (<.01)	-0.156** (<.01)	-0.156** (<.01)	-0.058** (<.01)	-0.369** (<.01)	-0.388** (<.01)	
Burn	-0.317** (<.01)	-0.829** (<.01)	-0.829** (<.01)	-0.067** (<.01)	-0.195** (<.01)	-0.313** (<.01)	

Note: DTC = designated trauma center; ICISS = ICD-9 Injury Severity Score.

*Significant at the alpha = .05 level.

**Significant at the alpha = .01 level.

internal injuries to the thorax, abdomen, or pelvis are associated with lower mortality compared to fractures.

The estimated coefficient associated with the trauma center variable (-0.386) indicates a significantly lower risk of mortality for trauma victims treated in a DTC after controlling for the confounding influence of age, gender, race, severity, injury type, and selection bias. To simplify interpretation of this result, the estimated marginal effect, $f(\hat{\beta}'x) \times \hat{\beta}$, was calculated. In this equation, $f(\hat{\beta}'x)$ is the probability density function for the bivariate probit model evaluated at the means of the explanatory variables, and $\hat{\beta}$ is the estimated coefficient. The marginal effect, or mean mortality benefit of treatment at a DTC, was calculated to be .129 percent, almost replicating the value indicated by the linear probability model (.132) shown in Table 2 (column 4). The marginal effect represents the gain, defined as a decrease in the probability of mortality, to trauma victims who receive treatment in a DTC. Stated differently, this decline in the probability of death constitutes the value created by DTC on average.

Model Sensitivity

To test the sensitivity of the model's results to the exclusions (see methods section), it was executed separately including the affected observations. Thus, the model was estimated without excluding patients who had been transferred from the initial admitting hospital. The estimated coefficient associated with the variable of primary interest (treatment at a DTC) decreased slightly in absolute terms compared to the primary model but did not change significantly. Therefore, our final conclusions were not sensitive to the exclusion, which was maintained in our primary model for the reasons discussed above.

Next, the sensitivity of the results to the model specification was examined by executing a single-equation probit regression (Table 2, column 5). The estimated coefficient associated with the DTC variable illustrates the significant extent of the selection bias problem. The estimated effect in the noninstrumented model suggests a higher mortality rate for trauma victims presenting at a DTC after controlling for the influence of patient demographics, injury severity, and injury type (the observable factors).

Discussion

Trauma patients are typically severely injured and face a relatively high risk of mortality. The special needs of trauma patients led to the growth of emergency medicine as a specialty and the development of organized trauma systems to create access to clinical specialists and coordinate both the prehospital and inpatient processes. The establishment of trauma systems was anticipated to improve the survival prospects

of the severely injured. This study investigated whether nonelderly trauma victims treated in a DTC experienced improved probability of mortality compared to their counterparts who were treated in an NC.

Previous studies have compared patient outcomes, in terms of mortality rates, to evaluate the effectiveness of trauma systems. A search of the literature pertaining to population-based studies of trauma systems, using MEDLINE, PUBMED, and CINAHL, yielded 14 studies that met the following criteria: the studies involved the North American population and were published in the English language, multivariate statistical techniques were used to control for the influence of confounding factors, and the studies were not based on expert panels or national injury registries. The studies may be categorized into pretrauma- to posttrauma-center designation (Kane et al. 1992; Hedges et al. 1994; Mullins et al. 1994; Barquist et al. 2000), concurrent trauma center to nontrauma hospital (Mullins et al. 1996; Sampalis et al. 1995; Rogers et al. 2001; Mann et al. 2001; Abernathy et al. 2002; Melton et al. 2003; Reilly et al. 2004), comparisons of regional or state trauma to a nontrauma system (Mullins et al. 1998; Nathens et al. 2000), and time trend analysis (O'Keefe et al. 1999).

The most common statistical estimation method was logistic regression, controlling for some or all of the following variables: demographic characteristics (age, sex, and race), injury type, and severity. Overall, trauma systems were found to be associated with improved odds of survival in 8 of the 14 studies. On the other hand, 3 comparative studies showed worse odds of mortality for trauma centers, while the remaining 3 did not demonstrate any significant difference.

The present study falls in the concurrent trauma-center-to-nontrauma-hospital comparison category. Five of seven of these studies conclude that trauma centers are associated with the same or higher odds of mortality compared to nontrauma hospitals.

This study distinguishes itself from previous research in that it specifically controls for the selection bias inherent to the DTC patient population. Only one study was found to date (McConnell et al. 2005) that specifically addressed this problem. McConnell et al. (2005, 435) use an instrumental-variables approach similar to the one used in the present study to analyze the mortality outcome of "542 patients with head injury who initially presented to 1 of 31 rural trauma centers in Oregon and Washington, and were transferred from the emergency department to 1 of 15 level I or level II trauma centers, between 1991 and 1994." The authors find an improvement in the probability of survival for patients who were transported to level I trauma centers.

The results of this study suggest that a 10 percent increase in the proportion of trauma victims transported to a DTC would reduce absolute mortality by 1.3 percent for severely injured nonelderly patients. While other population-based studies have demonstrated the benefits of a trauma system in terms of improved patient outcomes, to our knowledge, this is the first that controlled for the prehospitalization selection bias. Failure to account for this problem may explain the relatively large number of studies that produced evidence contradicting the mission of trauma systems, which is to improve the odds of survival for the severely injured.

Instrumental-variables methods produce estimates that indicate the effect on the marginal-average (as opposed to the population-average) patient and are therefore easily applied to effectiveness analyses, increasing their value from a policy perspective. On the other hand, the instrumental-variables estimates may apply only to the marginal patients, meaning those patients whose selection (in this case, for transport to a DTC or NC) is influenced by the instrument, particularly differential distance. The distribution of the differential-distance variable suggests that more than 75 percent of trauma victims studied lived closer to an NC hospital with ED compared to a DTC, making them marginal and implying that the instrumental variable likely played an important role in the hospital selection for the majority of patients. Therefore, it is likely that the results apply to the greater part of patients in the study population.

Before concluding the discussion, however, it should be reiterated that the 21 DTCs on which this article has focused encompass but one of several integrated components in a multifaceted system; the other elements are prevention, prehospital care, and postdischarge longitudinal follow up. A systemwide perspective may be useful, whether for economic, legislative, or population health reasons. This study focused on the effectiveness of DTCs in caring for severely injured trauma victims in an acute care setting. However, it was unable to assess the cost-effectiveness of the acute-care component in terms of lives saved relative to other alternatives within the system, perhaps most importantly, prevention of injury. In a related study, Pracht et al. (2006) illustrate a clear seasonal pattern in trauma-related hospital admissions in Florida with spikes during the first and last quarters of the year. These time periods are associated with the holidays and an annual influx of out-of-state residents, dramatically increasing travel, and consequently, traffic accidents. Thus, preventive measures, perhaps related to traffic safety, would likely contribute significantly to reducing mortality from injury.

Finally, the influential role of triage of trauma victims to either a DTC or NC deserves mention. The severity level of injuries ranges from trivial to extreme. While DTCs care for the majority of severely injured patients, they also manage a substantial number of mild or non-life-threatening injuries. When a system functions at capacity, efficiency in prehospital triage of trauma victims to either a DTC or NC based on injury severity is essential and may avoid the need for expensive expansion of DTC capabilities.

Nonetheless, the results presented here may prove useful to policy makers who continue to debate the merit and effectiveness of trauma systems. Trauma centers maintain a wide range of highly specialized personnel and technologies and therefore have relatively high operations costs (Goldfarb et al. 1996). Increased economic pressures have resulted in greater urgency in the pursuit of cost containment, making evidence of enhanced patient outcomes at trauma centers essential. The results of this study show that the increased cost of operating trauma centers is associated with significantly improved patient mortality. Stated differently, the Florida popula-

tion would benefit from increased access to specialized trauma care in case of severe injuries. The Florida trauma system is inclusive in that participation as a DTC is voluntary on the parts of hospitals. This implies that increased access to trauma care may be achieved without expensive construction of new centers. However, while likely not as costly an undertaking as constructing new DTCs, some financial incentives may be necessary to increase participation by current NC hospitals. A recent related study (Flint et al. 2005) disclosed that financial pressures related to maintenance of up-to-date trauma care and the provision of medical specialist coverage are an important deterrent for increased hospital participation.

The limitations of the administrative data set available for this analysis have some important implications for general inferences. First, the heterogeneity of state trauma systems implies that the results likely are not applicable to systems outside Florida. Second, the study population was limited to nonelderly patients. Therefore, the results do not apply to the elderly, who, our tests indicate, are systematically different in their response to injury. The elderly are more likely to present with comorbidities and tend to require more care given a particular type of injury. Nonetheless, the IV estimation methods used here provide a useful starting point for analyzing other trauma-victim populations.

Notes

1. Diseases of the circulatory system (390–459), respiratory system (460–519), and digestive system (520–579) and complications of pregnancy, childbirth, and the puerperium (630–677) made up 20.66, 10.56, 10.33, and 9.54 percent, respectively, of hospital episodes in 2003.

2. The nonadjusted mortality rates in 2003 were 5.67, 3.64, and 2.41 percent, respectively, for diseases of the respiratory system, diseases of the circulatory system, and injury and poison.

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