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Do pediatric patients with trauma in Florida have reduced mortality rates when treated in designated trauma centers?

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Abstract

Objective: The purposes of the study were to compare the survival associated with treatment of seriously injured patients with pediatric trauma in Florida at designated trauma centers (DTCs) with nontrauma center (NCs) acute care hospitals and to evaluate differences in mortality between designated pediatric and nonpediatric trauma centers.

Methods: Trauma-related inpatient hospital discharge records from 1995 to 2004 were analyzed for children aged from 0 to 19 years. Age, sex, ethnicity, injury mechanism, discharge diagnoses, and severity as defined by the International Classification Injury Severity Score were analyzed, using mortality during hospitalization as the outcome measure. Children with central nervous system, spine, torso, and vascular injuries and burns were evaluated. Instrumental variable analysis was used to control for triage bias, and mortality was compared by probabilistic regression and bivariate probit modeling. Children treated at a DTC were compared with those treated at a nontrauma center. Within the population treated at a DTC, those treated at a DTC with pediatric capability were compared with those treated at a DTC without additional pediatric capability. Models were analyzed for children aged 0 to 19 years and 0 to 15 years.

Results: For the 27,313 patients between ages 0 and 19 years, treatment in DTCs was associated with a 3.15% reduction in the probability of mortality ($P < .0001$, bivariate probit). The survival advantage for children aged 0 to 15 years was 1.6%, which is not statistically significant. Treatment of 16,607 children in a designated pediatric DTC, as opposed to a nonpediatric DTC, was associated with an additional 4.84% reduction in mortality in the 0- to 19-year age group and 4.5% in the 0 to 15 years group ($P < .001$, bivariate probit).

Conclusions: Optimal care of the seriously injured child requires both the extensive and immediate resources of a DTC as well as pediatric-specific specialty support.

The effectiveness of designated trauma centers (DTCs) and trauma systems in improving the probability of survival (Ps) for patients with injury has been widely investigated in the published peer-reviewed literature [1-4]. The efficacy of

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these systems in reducing the toll from childhood injury is less well defined, especially as related to the concept of *pediatric competence* [5-7]. This analysis is a component of the recently completed comprehensive assessment of the Florida Trauma System and focuses specifically on the effectiveness of Florida's trauma system in caring for the injured child [8,9].

In Florida, approximately 40% of severely injured patients with pediatric trauma are treated in nontrauma hospitals. Therefore, it is important from a policy perspective to understand the effectiveness of DTCs and the potential benefits that may be realized by the pediatric population through increased access to DTCs. Understanding these benefits to this young population group is particularly important because limitations of outcome and quality of life accrue over a much longer period relative to adults.

The Florida Agency for Health Care Administration (AHCA) inpatient discharge data define injury and poisoning (*International Classification of Diseases, Ninth Revision, Clinical Modification* [*ICD-9-CM*] codes 800-999) as the second most common reason for hospitalization of children. Within the top 5 reasons for hospitalization, injury and poisoning is associated with the highest per admission mortality rate. This is true in Florida, nationally, and in other industrialized nations [10,11].

Florida's per-admission pediatric mortality rate in 2003 was 0.45% for hospitalizations overall and 1.21% for injury and poisoning. Within the context of injuries, this mortality rate exhibited significant variation (Table 1). The objective of this study is to examine 2 specific hypotheses.

1. The first hypothesis states that there is a survival advantage associated with treatment in a DTC, as opposed to a nontrauma center (NC), for seriously injured children.
2. The second is conditional on transport to a DTC after injury and states that there is an additional survival advantage associated with treatment in a DTC that is specially equipped to handle pediatric patients as opposed to one that does not have that capability.

1. The Florida Trauma System

The first legislation concerning the Florida Trauma System was enacted in 1982 and required the Department of Health and Rehabilitative Services to verify that DTCs met established guidelines. Florida's trauma laws and regulations were further developed and expanded in 1987 and 1990. By 2004, the Florida Department of Health designated 20 hospitals as DTCs. These included 6 Level I, 12 Level II, and 2 pediatric trauma centers (PDTCs). All 6 Level I and 4 Level II trauma centers also met medical specialty staffing requirements for PDTC designation. Eight Level II trauma centers are not certified for pediatric trauma. In both 1998 and 2000, an NC-designated hospital converted to a DTC with a Level II designation. Thus, including the 2 pediatric-only trauma centers in freestanding children's hospitals, 12 Florida trauma centers have been designated for pediatrics, whereas 8 are not. The term *nonpediatric trauma center* (*NPDTC*) will be used hereafter to refer to the Level II DTCs that are not specifically designated as having pediatric trauma handling capability.

Table 1 Florida 2003 pediatric injury mortality

Injury	*ICD-9-CM*	Mortality (%)
Skull fractures	800-804	3.2
Intracranial injury	850-854	4.6
Injury to blood vessels	900-904	3.6
Open wounds	870-897	0.0

2. Methods

Florida AHCA inpatient discharge data sets from 1995 to 2004 were analyzed. These data sets contain information concerning patient demographic and case-mix–related characteristics, such as age, sex, race, type of diagnosis, source of admission, and discharge status. *International Classification of Diseases, Ninth Revision, Clinical Modification* codes were used to identify a study population consisting of 5 groups of patients with trauma who sustained (*a*) fractures (of the skull, neck, and trunk), intracranial injury, and spinal cord injuries (800-809, 850-854, and 952); (*b*) other fractures (810-829); (*c*) internal injury of the thorax, abdomen, or pelvis (860-869); (*d*) injury of blood vessels (900-904); and (*e*) and burns (940-949).

Because the data do not specify whether a particular patient presented as a trauma alert, 2 criteria were implemented to identify such patients. First, because each record contains a classification indicating whether the patient was admitted as emergency, urgent, or elective, and because all patients presented as a trauma alert are emergency cases, patients categorized as either urgent or elective were excluded. Second, the International Classification Injury Severity Score (ICISS) survival risk ratio (SRR) injury diagnosis stratification methodology was used to exclude all admissions with a primary diagnosis code not associated with risk of mortality. The SRR measures the proportion of patients who survive after admission with a specific *ICD-9-CM* code [12,13]. The product of the worst 3 yields a Ps, which has been validated as predictive of mortality, morbidity, and resource use [14,15]. After these exclusions, the data set contained 27,313 pediatric patients, categorized as seriously injured.

The study was designed as a concurrent comparison between DTC and NC hospitals, or between PDTC and NPDTC hospitals, to test the second hypothesis. The first hypothesis addressed the broader transport destination choice of either a DTC (including both nonpediatric and pediatric) or an NC. All arguments also apply to the second comparison of

PDTC vs NPDTC. Triage of patients with trauma to a DTC is expected to be nonrandom [16,17]. Florida's emergency medical services protocol dictates that patients should be transported to the nearest emergency department or DTC in case of a trauma alert. Therefore, more severely injured patients with trauma have a higher propensity to be transported to a DTC, creating selection bias.

Outcome, which in this study is mortality, is influenced by both observable and unobservable factors. Measures of injury severity or patient physiologic condition included in the analysis are, by definition, based on observable characteristics and cannot adjust for the presence of the more problematic unobserved qualities. Because selection bias is significant, and patients with trauma who are transported to DTCs are systematically more seriously injured, a single regressor that indicated treatment at a DTC was used to adjust for the greater risk of mortality because of the systematically higher level of injury severity and the independent influence of more specialized and aggressive treatment at a DTC. This selection bias and its associated difference in immediately available resources were controlled using instrumental variable (IV) methods. Details regarding the application and validity of IV are described in the appendix (Appendix Table A).

Four models were analyzed. The first (model A1) uses the all children aged between 0 and 19 years to examine the hypothesis that a survival difference exists for seriously injured children treated at DTC compared with NC hospitals. The second (model A2) eliminates the effect of motor vehicle driving by focusing on children between 0 and 15 years to examine the same hypothesis as in A1. The third (model B1) uses the larger data set to examine the hypothesis that an additional survival advantage exists for patients treated in PDTCs as compared with DTCs. The fourth (model B2) uses the reduced data set to test the same hypothesis as in B1.

International Classification Injury Severity Score methodology was used to control for injury severity. To minimize bias concerns, the SRRs used to compute Ps in the present study were calculated from the 2003 nationwide inpatient sample excluding Florida hospitalizations. Higher ICISS Ps values indicate a lower level of severity, underscoring the negative relationship between the probability of mortality and the ICISS. To further distinguish patients based on risk, the population was classified as those presenting with (*a*) fractures other than those related to the skull or spinal cord; (*b*) skull or spinal cord fractures; (*c*) internal injuries of the thorax, abdomen, and pelvis; (*d*) injuries associated with blood vessels; and (*e*) burns. In addition, the model contains an indicator for the presence of comorbidities. Approximately 4.7% of the study population had at least 1 comorbidity.

The data include 10 years of patient records covering 1995 to 2004. To account for contemporaneous changes that affect all patients, for example, technological advancements, time fixed effects for all years with the exception of 1995, the comparison period, are included in the model. When a hospital became a trauma center during the study period, the hospital was identified as a NC in the years before becoming a trauma center and a trauma center in the year the designation occurred. Finally, in addition to severity, hospital designation, and injury type, the model controlled for patient age, sex, and race.

3. Results

Table 2 lists the demographic and mortality distributions of patients. The number of pediatric patients with trauma, aged 0 to 19 years, included in the overall analysis was 27,313. Approximately 60% of these children were treated in a DTC. A little more than 46% were transported to a PDTC. The overall mortality rate of pediatric patients with

Table 2 Summary statistics pertaining to model variables

Year	Total	PDTC	DTC	NC
No. including ages 0 to 19 y	27,313	12,663	16,384	10,929
% Including ages 0 to 19 y	100	46.36	59.98	40.02
Mortality				
Ages 0 to 19 y	3.22	4.39	4.23	1.71
Ages 0 to 15 y	2.52	3.54	3.36	1.47
Ages 16 to 19 y	4.31	5.77	5.35	2.21
Age <1 y (%)	4.14	4.72	3.94	4.44
Age 1 to 5 y (%)	16.57	17.71	15.24	18.57
Age 6 to 10 y (%)	15.63	16.16	14.42	17.43
Age 11 to 15 y (%)	24.46	23.33	22.85	26.87
Age 16 to 19 y (%)	39.20	38.08	43.55	32.68
Mean age (y)	11.87	11.59	12.30	11.24
Male (%)	67.41	66.46	66.66	68.52
American Indian	0.11	0.08	0.09	0.14
Asian	0.57	0.43	0.46	0.72
Black	22.35	27.24	24.62	18.95
White	59.40	50.29	54.99	66.02
Hispanic white	13.18	16.88	14.51	11.19
Hispanic black	0.53	0.46	0.62	0.39
Non-white/black/Hispanic	4.53	5.13	5.26	3.45
Fractures, other than skull or spinal cord	30.67	26.88	26.99	36.19
Skull or spinal cord fracture	37.13	39.95	41.14	31.1
Internal injury of thorax, abdomen, or pelvis	16.82	17.43	17.6	15.66
Injuries of blood vessels	0.55	0.69	0.7	0.33
Burns	4.21	5.46	4.38	3.95
Mortality rate from				
Fractures, other than skull or spinal cord	1.11	1.82	1.7	0.46
Skull or spinal cord fracture	5.24	6.4	6.16	3.41
Internal injury of thorax, abdomen, or pelvis	3.09	4.3	4.16	1.29
Injuries of blood vessels	10.60	11.49	11.3	8.33
Burns	1.39	1.88	1.81	0.69

All summary measures were generated from the Florida AHCA hospital discharge data (1995-2004).

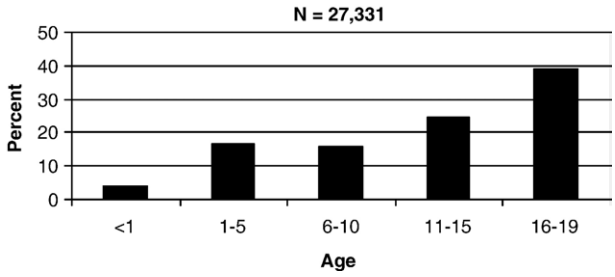

Fig. 1 Age distribution.

trauma was 3.22% but increased to 4.23% when only DTC-treated pediatric patients were included. The rate increased slightly to 4.39% when the population was restricted to PDTC patients.

Approximately 60% of the study population was aged 15 years or younger. A more detailed breakdown is illustrated in Fig. 1. Slightly less than 40% of the study population was 16 years or older but younger than 19 years. From the perspectives of race and sex, the study population was overwhelmingly male (67.4%) or white (59.4%). Blacks account for 22.4% of patients, whereas Hispanics patients make up approximately 15% of the study population. The remaining race categories, including American Indian, Asian, and others, account for less than 6% of patients with trauma in the final data set.

Most pediatric patients with trauma, counting only primary trauma diagnoses, were admitted for a fracture. Thirty-seven percent were admitted for a fracture of the skull or spinal cord, whereas 30.67% were admitted for a different fracture. The next-largest category is internal injury of the thorax, abdomen, or pelvis, accounting for 16.82% of patients. Vascular and burn patients accounted for, respectively, 0.55% and 4.21% of the study population. The nonadjusted mortality rate associated with these injury categories displayed substantial variation and are listed in Table 3. The most frequently occurring comorbidity in the data set was chronic pulmonary disease (3.57%). At least 1 comorbidity was reported for 1285 (4.7%) patients.

3.1. Bivariate probit

The results associated with the treatment variables in the full information maximum likelihood (FIML) bivariate probit regressions are shown in Table 4. The full model results and a brief discussion of the remaining independent variables are included in the appendix. Also included in the appendix is a discussion of the results of tests that were performed concerning the validity of the instrument. The first column of the table shows the age groups included in the estimation, and in parentheses, the number of observations used. The percentage of "yes" responses represents the raw mortality rate. The second column contains the coefficient estimates and associated *P* values in parentheses. The third column contains the estimated marginal effects evaluated at the mean values of the explanatory variables in the model.

Models A1 and A2 were designed to test the survival advantage associated with treatment of seriously injured children in DTCs as opposed to NCs. In these models, the DTC variable encompassed both NPDTC and PDTCs. Model A1 was estimated using the overall pediatric trauma population, covering ages 0 to 19 years. Model A2 was estimated for the reduced population, covering only ages 0 to 15 years to reflect the Florida trauma score card methodology used by emergency personnel in the pre-hospitalization phase and to eliminate vehicular driving as a factor. The estimated coefficients provide evidence of a statistically significant survival advantage associated with treatment in a DTC in the overall (A1) data set. However, the estimated coefficient loses its significance in the reduced (A2) data set. To facilitate interpretation of these coefficients, the marginal effects were estimated. In the overall population, the estimate indicates a 3.15% reduction in the probability of mortality associated with treatment in a DTC vs NC. When the age group of 16 to 19 years is excluded, the estimate declines by approximately 50% to 1.64% and is not statistically significant.

Models B1 and B2 were limited to the proportion of the pediatric trauma population that was treated in a DTC. These models were estimated to test whether a survival differential exists between PDTC hospitals that are specially equipped to treat pediatric patients with trauma and their NPDTC

Table 3 Mortality by primary injury group

Injury type	Mortality (%)
Fractures other than skull and spinal cord	1.1
Skull and spinal cord fractures	5.2
Injuries of thorax, abdomen, and pelvis	3.1
Blood vessels	10.6
Burns	1.4

Table 4 Condensed FIML bivariate probit results

Study population (n; % mortality)	Estimate (*P*)	Marginal effect	Survival improvement
Dependent variable, DTC vs NC			
Model A1, DTC vs NC			
Ages 0 to 19 y (27,313; 3.22)	−0.446 (<.001)	0.0315	+3.1%
Model A2, DTC vs NC			
Ages 0 to 15 y (16,607; 2.52)	−0.223 (.211)	0.0164	+1.6%
Dependent variable, PDTC vs non-PDTC			
Model B1, PDTC vs DTC			
Ages 0 to 19 y (16,384; 4.23)	−0.455 (<.001)	0.0484	+7.94%
Model B2, PDTC vs DTC)			
Ages 0 to 15 y (9250; 3.36)	−0.717 (.012)	0.0450	+6.14%

counterparts. The results indicate a significant reduction in the probability of mortality in both the overall and the reduced study populations. The estimated marginal effect is similar in both, 4.84% and 4.5%, respectively, in the overall (0-19 years) and reduced (0-15 years) cohorts. The net reduction in mortality probability for all children treated at a DTC with pediatric capability was therefore 7.94%. For those younger than 16 years, it was 6.14%.

4. Discussion

The efficacy of systems of trauma care in saving lives and preserving quality of life is now well established and validated [1-7]. How these advances in systems of care apply to children is still not completely defined, especially with regard to the concept of institutional qualifications. Children's hospitals exist for the sole purpose of providing a full range of child-specific resources for every patient. Trauma centers, which often are not collocated with children's hospitals, have evolved from the realization that continuous availability of the extensive and intensive resources necessary to save a dying patient are the critical component of both survival and quality of life. The objective of this study was to determine whether seriously injured pediatric patients with trauma were better off when treated in a DTC as compared with an NC. Secondarily, within the subpopulation of these children treated at a DTC, the study also investigated whether a survival advantage exists when treatment is administered in a certified PDTC as compared with an NPDTC. An FIML bivariate probit model was used to predict the probability that a patient with trauma is transported to a DTC (or PDTC) and, subsequently, the probability of mortality. Because the epidemiological characteristics of adolescent injury differ somewhat from that encountered in younger children, 2 age groups were used to define a pediatric patient with trauma. The reason for these age cutoffs has been discussed.

The disproportionate skew toward minor injury in the pediatric trauma population undermines to some degree the true mortality reduction benefit associated with triage to a DTC with or without pediatric capability. In model A2, pertaining to the DTC-vs-NC comparison using the reduced data set, the proportion of yes responses (patient died) falls to a mere 2.52%. Although this is desirable from a population health standpoint, it makes detection of small marginal effects. Not surprisingly, the estimated marginal effect in this case was not statistically significant. In the larger model (A1) including the population aged 16 to 19 years, the proportion of yes responses climbs to 3.22%. In this case, the model A1 provides strong statistical evidence of a survival advantage associated with treatment in a DTC vs an NC. The estimated marginal effect in this model (A1) is 0.0315, indicating that a 10% increase in the triage of seriously injured pediatric patients with trauma to DTCs would, on average, reduce mortality rates by 0.315%.

The second set of models (B1 and B2) focused on the subset of patients treated in a DTC to examine the existence of a survival advantage associated with treatment in a PDTC. Because the populations transported to these specialty hospitals tends to be more seriously injured, as hypothesized earlier, the proportion of yes responses in the outcome equations are substantially higher (by more than 30%). Therefore, detection of marginal effects is more plausible in these models. The estimations provided strong statistical evidence for a survival advantage associated with treatment in a PDTC in both the larger and reduced populations. The marginal effects in the larger and reduced data sets were, respectively, 0.0484 and 0.0450. Thus, within the population of patients treated in a DTC, a 10% increase in triage to a PDTC would reduce mortality by 0.48% in the age group of 0 to 19 years and 0.45% in the age group of 0 to 15 years.

The marginal effects found by this study for the pediatric population are relatively small compared with that found by some studies focusing on adults. For example, in a study of the Florida nonelderly adult population, also using the state's hospital discharge data, Pracht et al [17] report a survival advantage of 0.132 associated with treatment in a DTC vs an NC hospital. This is more than 4 times the marginal effect found here in model A1 that also focused on the DTC-vs-NC hypothesis. The primary reason for this difference relates to the overwhelming preponderance of inconsequential injury seen in the pediatric population. Differences in population mortality rates of less than 5% become very difficult to define. When this population is winnowed to include only significant injury as defined, the marginal effect of the benefit of treatment at a DTC becomes more apparent. For obvious reasons, comparable studies for adults do not exist in the case of the PDTC–vs–non-PDTC comparison. It is important to point out that this relative difference does not in any way trivialize the marginal effect reported here for the pediatric population. The mean age for the population in the study of Pracht et al was 33, compared with 12 in the current study. Therefore, any benefit associated with the pediatric population would, on average, accrue over a much longer period. Moreover, there is no reason to believe that the benefits associated with treatment in a DTC are limited to survival. The skills and resources necessary to preserve life also focus on quality of life, further adding to the long-term benefits of treatment in a DTC vs an NC.

The current analysis focused entirely on the role of acute care facilities by examining probabilities of survival at NC, DTC, and PDTC hospitals. Although these hospitals represent an important component of Florida's inclusive trauma system, it is important to point out that they comprise but one of several interrelated components. Certainly not the least important of these components is prevention. A simple count of e-codes indicated that motor vehicle accidents accounted for 44% of the mechanisms for injury concerning the patients with trauma in the larger sample. Moreover, the percentage increased from 40% to 49% between 1995 and 2004.

This analysis of 10 years of trauma system experience in a state with more than 18 million citizens clearly demonstrates the crucial role of trauma center designation in improving outcome from severe injury. The added survival advantage for children transferred to hospitals that possessed the additional qualifications required for pediatric care even more clearly demonstrates that both resource availability and specialty capability are the critical ingredients necessary for optimal outcome of injured children. Should children's hospitals that are not designated as trauma centers invest in the extensive resources necessary for continuous comprehensive preparedness? Should trauma centers without pediatric capability invest in the personnel and resources necessary for comprehensive care of children? In these times of limited resources, the answer most likely lies in collaboration. Communities with both of these resources must develop synergistic affiliations that integrate both of these components into a seamless system of care that guarantees every injured child optimal care. As specialists with the deepest and most intense commitment to care of the injured child, pediatric surgeons must be the both the leaders and catalysts of this synergy.

Appendix A

Instrumental variables provide a useful alternative for estimation of unobservable triage bias factors [18]. Instrumental variable estimation methods have been widely used in econometrics and health services research and have recently been applied to investigate the effectiveness of trauma systems [16,17]. These 2 studies used a similar concurrent DTC-vs-NC study design as the present study. Instrumental variable estimation involves the introduction of an "instrument" for the biased regressor, which, for this investigation, was the DTC treatment variable. To be valid, the instrument must not be contemporaneously correlated with the outcome variable, and it must be correlated (preferably highly so) with the regressor for which it serves as an instrument. This analysis used a similar instrument to those used by McClellan et al [18], McConnell et al [16], and Pracht et al [17]. The instrument was based on the straight-line differential distance from the patient's residence zip code to the nearest DTC as compared with an NC with an emergency department. Tests concerning the validity of the instrument are discussed as follows.

A.1. The estimator

To determine whether the treatment variable should be considered endogenous (ie, selection bias is present in the model) a Hausman test was executed [19]. The outcome of the test ($P < .01$) indicates that a single equation would not produce consistent results and that the selection of either a DTC or an NC should be considered endogenous. The same result applied to the selection of a PDTC over an NPDTC. Therefore a model consisting of 2 simultaneously estimated equations is more appropriate.

Focusing first on the choice of DTC (including both pediatric and nonpediatric) vs NC hospitals, the outcome equation is specified as

$$\text{mortality}_i^* = x_i'\beta + \text{DTC}_i\gamma + e_i \quad \text{(i)}$$

In this equation, mortality_i has a value of 1 when mortality_i^* exceeds a certain threshold; x_i is a vector of statistical controls (discussed later) 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. Second, the DTC equation is given by

$$\text{DTC}_i^* = x_i'\alpha + d_i'\delta + u_i \quad \text{(ii)}$$

where DTC_i^* is the unobserved probability that individual i will be treated at a DTC (ie, DTC = 1), d_i is the IV differential distance, δ is the associated coefficient, and u_i is a stochastic error term.

Next, the specification was changed to examine the influence of treatment at a PDTC on the mortality rate, conditional on transport to a DTC. The alternative in this case is defined as an NPDTC. More formally stated, the model consists of the 2 following equations:

$$\text{mortality}_i^* = x_i'\beta + \text{PDTC}_i\gamma + e_i \quad \text{(iii)}$$

$$\text{PDTC}_i^* = x_i'\alpha + d_i'\delta + u_i \quad \text{(iv)}$$

where the definition of all symbols is as indicated for equations (i) and (ii).

Two methods were considered to obtain estimates of the unknown parameters. The first was a 2-stage approach where the predicted value of a linear specification of (ii) or (iv) is substituted for DTC or PDTC in (i) or (iii), which is then estimated using a probabilistic regression. The second approach considered was to estimate the 2 equations simultaneously using a bivariate probit model. Because both the outcome (mortality) and the treatment variables (treatment in a DTC or PDTC) are dichotomous, the FIML bivariate estimator was deemed more efficient. However, the coefficients produced by this estimation method are not directly interpretable. To facilitate interpretation of the results, the marginal effects were calculated as $\hat{f}(\beta'\mathbf{x}) \times \beta$ and presented in the results section along with the bivariate probit results. In this last equation, $\hat{f}(\beta'\mathbf{x})$ 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.

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 (ii) and subsequently using the full bivariate probit model (Appendix Table 2) and a Wald test. The selected instrument is highly statistically significant, therefore

satisfying the first condition. 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, 2 tests were performed. For the first test, the data were divided into 5 groups based on distance (within 10, 20, 30, 40, or 50 miles from a DTC). A standard χ^2 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 (0.78) suggests that the null hypothesis cannot be rejected using the data at hand. A second, more formal χ^2 test 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 ($\chi^2 = 1.67$) 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 on theoretical grounds.

A.2. Explanatory variables

A.2.1. Model A1: comparing DTC vs NC (ages 0 to 19 years)

In this model, older children have an increased probability of mortality, perhaps reflecting differences in the types and severity of injuries. The sex variable is not statistically significant. Black and Hispanic patients do not have a statistically different probability of mortality. In contrast, the probability increases for other children who were not white, black, or Hispanic children. The ICISS variable, as expected, indicates significantly higher mortality for more severely injured patients. Patients admitted for internal injuries to the thorax (includes abdomen and pelvis), blood vessels, and spinal cord have a significantly higher probability of mortality compared with those admitted for non–spinal cord related fractures. Finally, patients with a recorded comorbidity have an increased probability of mortality in this model.

A.2.2. Model A2: comparing DTC vs NC (ages 0 to 15 years)

In contrast to the model that included 16- to 19-year-old children, the age variable has a negative sign, indicating increased mortality for younger children. The sex variable is not statistically significant, as is the race-equals-black variable. On the other hand, Hispanic patients have a reduced probability of mortality, whereas the other race variable is associated with increased mortality. The ICISS variable again behaves as expected, indicating increased mortality with higher injury severity. The injury type variables indicate relatively higher mortality risks associated with injuries to the thorax, blood vessels, and spinal cord. In this model, the variable indicating the presence of comorbidity is not significant.

A.2.3. Model B1: comparing PDTC vs NPDTC (ages 0 to 19 years)

The age variable in this model has a positive influence of mortality as was the case in model A1. The sex variable is again not statistically significant. Pertaining to race, blacks and Hispanic patients do not have a significantly different probability of mortality compared with whites, whereas the mortality risk increases in the case of the *other* race variable. The ICISS variable again has the expected influence on mortality. The injury type variables indicate relatively higher mortality risks associated with injuries to the thorax, blood vessels, and spinal cord. In this model, the variable indicating the presence of comorbidity is not significant.

A.2.4. Model B2: comparing PDTC vs NPDTC (ages 0 to 15 years)

As was the case in model A2, the age variable indicates higher risk of mortality for younger children. Sex is again not statistically significant. Pertaining to race, the *other* race variable indicates higher mortality, whereas the black and Hispanic variables are not significant. The ICISS variable again behaves as expected, indicating increased mortality for more serious injury. The injury type variables indicate relatively higher mortality risks associated with injuries to the thorax, blood vessels, and spinal cord. In this model, the variable indicating the presence of comorbidity is not significant.

Table A4 contains the estimates associated with an alternative hypothesis mentioned in the "Methods" section. This alternative model analyzes the differential in survival probability associated with treatment of serious injury at a PDTC vs an NC. The study population contains only patients treated at one of these types of hospitals, whereas the DTC patients were omitted. Because this, in theory, widens the gap between the treatment and control populations, the estimates may be more pronounced.

The results indicate the existence of a survival advantage in the age population of 0 to 19 years (marginal effect of 2.4%). However, when the population was reduced to include only the age group of 0 to 15 years, the difference was no longer significant at the .05 level of α.

The lack of significance is likely because of the same problem that plagued the results from the previous models, in particular, the low proportion of yes responses in the mortality equation. In the age population of 0 to 19 years, the proportion was 3.15 but fell to 2.54 in the age group of 0 to 15 years, again making it difficult to detect any marginal effects of alternative treatment sites.

Table A1 Single-equation probit estimates

Parameter	A1	A2	B1	B2
	Estimate (*P*)	Estimate (*P*)	Estimate (*P*)	Estimate (*P*)
Intercept	0.957 (.0011)	1.282 (.0010)	1.170 (.0010)	1.206 (.0091)
DTC	0.348 (<.0001)	0.319 (<.0001)	0.163 (.0004)	0.237 (.0043)
Year 1996	−0.105 (.1164)	−0.078 (.4000)	−0.078 (.3402)	−0.036 (.7511)
Year 1997	−0.158 (.0246)	−0.138 (.1630)	−0.075 (.3730)	−0.056 (.6371)
Year 1998	−0.058 (.3951)	−0.036 (.7100)	−0.012 (.8827)	0.040 (.7286)
Year 1999	−0.069 (.3171)	−0.003 (.9729)	0.013 (.8750)	0.026 (.8287)
Year 2000	−0.126 (.0587)	−0.095 (.3242)	−0.081 (.3103)	−0.095 (.4199)
Year 2001	−0.110 (.0951)	0.053 (.5663)	−0.072 (.3637)	0.092 (.3994)
Year 2002	−0.083 (.1989)	0.024 (.7920)	−0.082 (.2937)	−0.120 (.3060)
Year 2003	−0.292 (<.0001)	−0.235 (.0206)	−0.273 (.0016)	−0.284 (.0244)
Year 2004	−0.138 (.0317)	−0.167 (.0841)	−0.067 (.3684)	−0.146 (.1978)
Age	0.007 (.0134)	−0.014 (.0022)	0.012 (.0003)	−0.007 (.2112)
Female	−0.018 (.5932)	0.051 (.2670)	−0.019 (.6314)	0.064 (.2430)
Black	0.001 (.9772)	−0.064 (.2259)	−0.023 (.6041)	−0.092 (.1378)
Hispanic	−0.153 (.0027)	−0.233 (.0018)	−0.163 (.0046)	−0.337 (.0002)
Race NWHB	0.195 (.0026)	0.157 (.0802)	0.209 (.0036)	0.188 (.0605)
ICISS	−3.318 (<.0001)	−3.567 (<.0001)	−3.394 (<.0001)	−3.403 (<.0001)
Thorax	0.234 (<.0001)	0.130 (.0786)	0.250 (<.0001)	0.135 (.1214)
Vascular	0.800 (<.0001)	1.056 (<.0001)	0.744 (<.0001)	0.912 (.0001)
Spinal	0.467 (<.0001)	0.500 (<.0001)	0.435 (<.0001)	0.460 (<.0001)
Burns	−0.099 (.3459)	−0.152 (.2369)	−0.127 (.2891)	−0.161 (.2868)
Comorbidity	0.099 (.1545)	0.029 (.7755)	0.010 (.9089)	0.025 (.8320)

Models A1 and A2 contain the results for the DTC-vs-NC comparisons for, respectively, the populations of 0 to 19 and 0 to 15 years. Columns B1 and B2 contain the results for the PDTC–vs–non-PDTC comparisons for the same population groups. NWHB, patients who are not white, black or Hispanic.

Table A2 Full information maximum likelihood bivariate probit results for the equations modeling the choice of the type of hospital

Parameter	A1	A2	B1	B2
	Estimate (*P*)	Estimate (*P*)	Estimate (*P*)	Estimate (*P*)
Center	0.871 (.0010)	0.751 (.0174)	2.608 (<.0001)	2.511 (<.0001)
Differential distance	−0.021 (<.0001)	−0.021 (<.0001)	−0.022 (<.0001)	−0.022 (<.0001)
Year 1996	0.094 (.0076)	0.058 (.1847)	0.078 (.1441)	0.032 (.6460)
Year 1997	0.022 (.5431)	−0.140 (.0019)	0.313 (<.0001)	0.278 (.0005)
Year 1998	0.065 (.0715)	−0.038 (.4033)	0.209 (.0002)	0.279 (.0004)
Year 1999	0.024 (.5058)	−0.094 (.0428)	0.178 (.0017)	0.276 (.0006)
Year 2000	0.130 (.0002)	−0.021 (.6352)	0.095 (.0702)	0.187 (.0112)
Year 2001	0.203 (<.0001)	0.076 (.0890)	0.188 (.0003)	0.172 (.0174)
Year 2002	0.237 (<.0001)	0.116 (.0092)	0.218 (<.0001)	0.321 (<.0001)
Year 2003	0.168 (<.0001)	0.034 (.4403)	0.248 (<.0001)	0.352 (<.0001)
Year 2004	0.355 (<.0001)	0.219 (<.0001)	0.349 (<.0001)	0.576 (<.0001)
Age	0.022 (<.0001)	0.007 (.0016)	−0.055 (<.0001)	−0.045 (<.0001)
Female	0.081 (<.0001)	0.094 (<.0001)	0.033 (.1888)	0.007 (.8543)
Black	0.176 (<.0001)	0.211 (<.0001)	0.183 (<.0001)	0.132 (.0021)
Hispanic	0.155 (<.0001)	0.263 (<.0001)	0.465 (<.0001)	0.511 (<.0001)
Race NWHB	0.364 (<.0001)	0.340 (<.0001)	0.057 (.2838)	0.116 (.1326)
ICISS	−1.006 (.0001)	−0.734 (.0206)	−0.869 (.0203)	−0.911 (.1061)
Thorax	0.274 (<.0001)	0.318 (<.0001)	0.061 (.0738)	0.130 (.0117)
Vascular	0.674 (<.0001)	0.624 (.0001)	0.033 (.8161)	0.098 (.6743)
Spinal	0.385 (<.0001)	0.392 (<.0001)	0.006 (.8133)	0.083 (.0320)
Burns	0.323 (<.0001)	0.251 (<.0001)	0.985 (<.0001)	0.897 (<.0001)
Comorbidity	0.069 (.0709)	0.140 (.0036)	0.150 (.0108)	0.006 (.9387)

Models A1 and A2 contain the results for, respectively, the populations of 0 to 19 and 0 to 15 years, in the DTC-vs-NC comparisons. Columns B1 and B2 contain the results for the PDTC–vs–non-PDTC comparisons for the same population groups.

Table A3 Full information maximum likelihood bivariate probit results for outcome (mortality) equations

Parameter	A1	A2	B1	B2
	Estimate (*P*)	Estimate (*P*)	Estimate (*P*)	Estimate (*P*)
Intercept	1.440 (<.0001)	1.602 (<.0001)	1.838 (<.0001)	2.082 (<.0001)
DTC	−0.446 (.0003)	−0.223 (.2119)		
PDTC			−0.455 (.0007)	−0.717 (.0122)
Year 1996	−0.075 (.2376)	−0.063 (.4858)	−0.073 (.3614)	−0.024 (.8265)
Year 1997	−0.140 (.0366)	−0.154 (.1079)	−0.034 (.6764)	−0.003 (.9802)
Year 1998	−0.033 (.6049)	−0.038 (.6809)	0.018 (.8230)	0.096 (.3940)
Year 1999	−0.054 (.4062)	−0.016 (.8680)	0.033 (.6865)	0.075 (.5125)
Year 2000	−0.088 (.1686)	−0.100 (.2886)	−0.074 (.3454)	−0.054 (.6392)
Year 2001	−0.056 (.3794)	0.062 (.4883)	−0.056 (.4713)	0.112 (.2930)
Year 2002	−0.020 (.7472)	0.048 (.5972)	−0.062 (.4228)	−0.075 (.5126)
Year 2003	−0.231 (.0009)	−0.214 (.0312)	−0.239 (.0051)	−0.231 (.0609)
Year 2004	−0.053 (.3965)	−0.127 (.1823)	−0.031 (.6759)	−0.058 (.6073)
Age	0.011 (<.0001)	−0.012 (.0044)	0.005 (.1208)	−0.012 (.0212)
Female	0.001 (.9762)	0.063 (.1584)	−0.017 (.6615)	0.058 (.2697)
Black	0.077 (.0433)	0.003 (.9554)	0.037 (.4095)	−0.039 (.5212)
Hispanic	−0.078 (.1194)	−0.154 (.0460)	−0.079 (.1726)	−0.255 (.0049)
Race NWHB	0.271 (<.0001)	0.219 (.0138)	0.214 (.0025)	0.205 (.0355)
ICISS	−3.360 (<.0001)	−3.597 (<.0001)	−3.503 (<.0001)	−3.421 (<.0001)
Thorax	0.279 (<.0001)	0.176 (.0156)	0.249 (<.0001)	0.138 (.1037)
Vascular	0.884 (<.0001)	1.125 (<.0001)	0.729 (<.0001)	0.890 (<.0001)
Spinal	0.528 (<.0001)	0.550 (<.0001)	0.420 (<.0001)	0.453 (<.0001)
Burns	−0.018 (.8574)	−0.114 (.3678)	−0.074 (.5365)	−0.119 (.4281)
Comorbidity	0.126 (.0559)	0.056 (.5659)	0.023 (.7785)	0.017 (.8799)
ρ	0.476 (<.0001)	0.338 (.0008)	0.380 (<.0001)	0.517 (<.0001)

Models A1 and A2 contain the results for, respectively, the populations of 0 to 19 and 0 to 15 years. Columns B1 and B2 contain the results for the PDTC–vs–non-PDTC comparisons for the same population groups.

Table A4 Alternative hypothesis model testing PDTC vs NC

	Ages 0 to 19 y			Ages 0 to 15 y		
	Single-equation probit	Selection equation	Bivariate probit, FIML	Single-equation probit	Selection equation	Bivariate probit, FIML
	Estimate (*P*)	Estimate (*P*)	Estimate (*P*)	Estimate (*P*)	Estimate (*P*)	Estimate (*P*)
Intercept	0.8729 (.004)	1.0364 (<.001)	1.3195 (<.001)	1.4884 (.0005)	0.7816 (.017)	1.7983 (<.001)
Differential distance		−0.0189 (<.001)			−0.0170 (<.001)	
PDTC	0.3855 (<.001)		−0.3276 (.004)	0.3513 (<.001)		−0.2489 (.139)
Year 1996	−0.1495 (.038)	0.1205 (.001)	−0.1144 (.098)	−0.1056 (.285)	0.0787 (.093)	−0.0867 (.365)
Year 1997	−0.2064 (.006)	0.1054 (.006)	−0.1668 (.020)	−0.1584 (.123)	−0.0647 (.174)	−0.1650 (.097)
Year 1998	−0.1094 (.133)	0.1267 (.001)	−0.0692 (.322)	−0.0763 (.450)	0.0378 (.434)	−0.0619 (.526)
Year 1999	−0.1248 (.093)	0.0783 (.047)	−0.0976 (.170)	−0.0430 (.672)	−0.0258 (.599)	−0.0450 (.646)
Year 2000	−0.2101 (.004)	0.1610 (<.001)	−0.1642 (.021)	−0.1241 (.221)	0.0345 (.464)	−0.1180 (.229)
Year 2001	−0.1213 (.086)	0.2386 (<.001)	−0.0616 (.368)	0.0337 (.726)	0.1067 (.023)	0.0442 (.635)
Year 2002	−0.1245 (.076)	0.2862 (<.001)	−0.0508 (.457)	0.0330 (.729)	0.1801 (.001)	0.0693 (.455)
Year 2003	−0.3135 (<.001)	0.2314 (<.001)	−0.2420 (.001)	−0.2260 (.031)	0.1040 (.025)	−0.1973 (.052)
Year 2004	−0.1833 (.008)	0.4298 (<.001)	−0.0802 (.239)	−0.2167 (.033)	0.3151 (<.001)	−0.1523 (.129)
Age	0.0061 (.031)	0.0102 (<.001)	0.0077 (.004)	−0.0150 (.001)	−0.0014 (.517)	−0.0150 (<.001)
Female	−0.0155 (.667)	0.0849 (<.001)	0.0024 (.944)	0.0568 (.233)	0.0900 (<.001)	0.0705 (.126)
Black	−0.0128 (.755)	0.2045 (<.001)	0.0864 (.037)	−0.0678 (.214)	0.2251 (<.001)	0.0221 (.699)
Hispanic	−0.2062 (.000)	0.2178 (<.001)	−0.0979 (.076)	−0.2628 (<.001)	0.3148 (<.001)	−0.1502 (.061)
Race NWHB	0.2124 (.002)	0.3505 (<.001)	0.2966 (<.001)	0.1469 (.120)	0.3448 (<.001)	0.2263 (.015)
ICISS	−3.1731 (<.001)	−1.0790 (<.001)	−3.2813 (<.001)	−3.7368 (<.001)	−0.7357 (.026)	−3.7521 (<.001)

(*continued on next page*)

Table A4 (*continued*)

	Ages 0 to 19 y			Ages 0 to 15 y		
	Single-equation probit	Selection equation	Bivariate probit, FIML	Single-equation probit	Selection equation	Bivariate probit, FIML
	Estimate (*P*)	Estimate (*P*)	Estimate (*P*)	Estimate (*P*)	Estimate (*P*)	Estimate (*P*)
Thorax	0.2112 (<.001)	0.2844 (<.001)	0.2595 (<.001)	0.1391 (.068)	0.3352 (<.001)	0.1951 (.009)
Vascular	0.7923 (<.001)	0.6583 (<.001)	0.8820 (<.001)	0.9639 (<.001)	0.6129 (<.001)	1.0363 (<.000)
Spinal	0.4567 (<.001)	0.3810 (<.001)	0.5165 (<.001)	0.4862 (<.001)	0.4023 (<.001)	0.5428 (<.000)
Burns	−0.1236 (.241)	0.4297 (<.001)	−0.0350 (.732)	−0.1808 (.163)	0.3440 (<.001)	−0.1151 (.364)
Comorbidity	0.1031 (.161)	0.1052 (.009)	0.1279 (.070)	0.0423 (.683)	0.1402 (.005)	0.0748 (.456)
ρ			0.4481 (<.001)			0.3759 (<.001)

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