Fifteen-Year Trauma System Performance Analysis Demonstrates Optimal Coverage for Most Severely Injured Patients and Identifies a Vulnerable Population

David J Ciesla, MD, FACS, Joseph J Tepas III, MD, FACS, Etienne E Pracht, PhD, Barbara Langland-Orban, MD, John Y Cha, MD, FACS, Lewis M Flint, MD, FACS

BACKGROUND: Trauma systems are designed to deliver timely and appropriate care. Prehospital triage regulations and interfacility transfer guidelines are the primary determinants of system efficacy. We analyzed the effectiveness of the Florida trauma system in delivering trauma patients to trauma centers over time.

STUDY DESIGN: Injured patients were identified by ICD-9 codes from a statewide discharge dataset, and they were categorized as children (less than 16 years old), adult (16 to 65 years old), or elderly (over 65 years old). Severe injury was defined by International Classification Injury Severity Scores (ICISS) < 0.85. Residence ZIP codes were used as a surrogate for injury location.

RESULTS: Severe injury discharges increased at designated trauma centers (DTCs) and decreased at non-trauma centers (NTCs). The proportion of patients with severe injuries discharged from DTCs increased for all age groups, capturing nearly all severely injured children and adults. Access to DTCs was dependent on proximity for severely injured elderly but not for severely injured children and adults.

CONCLUSIONS: Triage improved over time, enabling near complete capture of at-risk children and adults independent of DTC proximity. Because distance from a DTC does not limit access for children and adults, existing trauma system resources are sufficient to meet the current demands. Efforts are needed to determine the trauma resource and triage needs of the severely injured elderly. (J Am Coll Surg 2013;216:687–698. © 2013 by the American College of Surgeons)

Trauma systems are designed to assure that injured patients receive timely and appropriate care. In 1982, the Florida legislature established a statewide trauma system within the Department of Health to designate trauma facilities, establish prehospital trauma triage practices to ensure the transport of the severely injured to the nearest appropriate trauma center, and create interfacility transfer guidelines for those in need of a higher level of care. By 2010, there were 22 designated trauma centers (DTCs) distributed throughout the state serving a population of almost 19 million people.

Access to trauma centers is dependent on proximity (geographic and practical) and availability of existing centers. Areas remote from trauma centers depend on local hospitals for initial stabilization and transfer of severely injured patients to a regional trauma center. So the primary determinants of triage efficacy are the proximity and availability of trauma centers and compliance with prehospital triage regulations and interfacility transfer guidelines. The proportion of severely injured patients discharged from trauma centers within a system reflects the accuracy of both field triage and interfacility transfer to trauma centers and is a measure of system performance.

A 2006 study demonstrated that treatment in a Florida trauma center was associated with a substantial reduction...
in mortality and cost of care. The same study found that only 38% of all injured patients received care at a trauma center despite the fact that 95% of Florida citizens reside within 85 minutes of a trauma center. This suggested that a large portion of the population was not being served by the current system. It can be argued that many of the less severely injured in this cohort could receive definitive care in community hospitals and that the trauma center confers its greatest benefit on the severely injured. In a more focused study, we reported that although 93% of Floridians reside within an area routinely served by at least 1 trauma center, only 52% of severely injured patients reached a trauma center, again suggesting a significant need for improved trauma system access for the severely injured.

Because of its maturity, its statewide coverage, and because there is little overlap between neighboring state trauma systems, the Florida trauma system can serve as a model for the study of trauma system implementation and performance. The purpose of this study was to assess the effectiveness of trauma system triage as the system matured and determine the completeness of coverage for the severely injured patient. Hypothesizing that triage accuracy improves with system maturity, we analyzed the effectiveness of the Florida trauma system in delivering trauma patients to trauma centers over time.

**METHODS**

Data were obtained from the Florida Agency for Health Care Administration (AHCA) database over 15 years ending in 2010. The database includes information on patient residence, discharging hospital, and up to 30 ICD-9 diagnosis codes. Acute care facilities listed as general or teaching hospitals were considered capable of receiving injured patients. Discharging hospitals were categorized as designated trauma centers (DTCs) and nontrauma centers (NTCs) during each reporting year. Patients discharged from DTCs were considered to have accessed the state trauma system. Because the analysis included NTCs that are not required to maintain a trauma registry, the International Classification Injury Severity Scores (ICISS) methodology was used to estimate the severity of injury and the risk of mortality for patients admitted to Florida hospitals. Injured patients were defined as those with ICD-9 codes between 800 and 959, excluding patients with a single injury that had no potential for mortality, as determined by an ICISS survival risk ratio of 1; admissions not classified as emergencies; patients with diagnoses relating to the insertion of foreign objects into body orifices; patients admitted for complications occurring from a previous trauma; and patients with a length of stay less than 24 hours who had no ICU charges.

The study group consisted of: patients with fractures of the skull, neck, trunk, intracranial injury, and spinal cord injuries (ICD-9 codes 800–809, 850–854, 952); other fractures (810–819, 821–829); internal injury of the thorax, abdomen, or pelvis (860–869); injury of blood vessels (900–904); and burns (940–949). Patients were categorized as children (less than 16 years old), adults (16 to 65 years old), or elderly (greater than 65 years old). Survival risk ratios for specific injuries were calculated for each age group from the Florida Agency for Health Care Administration database using the 5 years preceding the reported year. The 5-year rolling calculations were used to adjust for changes in care over the 15-year study period. The ICISS for patients with multiple injuries were calculated as the product of the individual survival risk ratios. Severe injury was defined by ICISS < 0.85, indicating a probability of fatality greater than 15%. Overall incidence of injury and proportion of severe injury treated at DTCs were evaluated for each age group.

To assess geographic trauma system coverage, the home ZIP code was used as a surrogate for injury location for each trauma victim. For mapping purposes, each patient was assigned a random geographic coordinate within his or her home ZIP code and mapped using ESRI ARCGIS software. Individual patient residence distributions were assessed for each year within the study period.

The annual volumes of injured and severely injured patients were reported as actual numbers rather than population adjusted rates because our objective was to measure the effectiveness of the existing trauma system in meeting the state’s actual need. Data are reported as actual numbers or mean ± standard deviation unless otherwise noted, and p < 0.05 was considered significant. Analyses were performed using SAS for Windows. Least squares regression was used to determine significance of the change in the proportion over time.

**RESULTS**

The number of hospitals designated as capable of receiving injured patients decreased from 211 in 1996 to 185 in 2010. The total number of pediatric and adult
DTCs increased from 7 and 16, respectively, in 1996 to 9 and 20, respectively, in 2010. During the 15-year study period, 1,552,048 injured patients accessed the Florida state trauma system. Of these, 211,246 (13.6%) were classified as severely injured. The injured population included 79,945 (5%) children, 616,910 (40%) adults, and 855,193 (55%) elderly. Within this population, those with severe injury included 4,449 children (2%), 100,894 adults (48%), and 105,853 elderly (50%).

The incidence of both injury and severe injury increased during the study period (Fig. 1). In both the elderly and adult populations, the annual injury incidence significantly increased, but it did not in children (Table 1). Similarly, the annual severe injury incidence increased in the elderly and adults but decreased in children.

In 1996, 28% of all patients with injuries and 44% of those with severe injuries accessed the trauma system. Although the number of injured patients increased for both NTC and DTC hospitals, the flow of severe injury reversed with the number of severely injured increasing for DTC and dropping for NTCs (Fig. 2). By the conclusion of this study period, 35% of all injured patients and 64% of severely injured patients accessed the trauma system. Because DTCs accounted for 10% ± 1% of Florida hospitals across the study time period, the number of all injuries treated per hospital increased slightly for NTC and substantially for DTC (Fig. 3A). This was especially true for severe injuries, which increased substantially for DTC and decreased slightly for NTC (Fig. 3B). These trends did not differ among age groups. By 2010, there were substantially more injured and severely injured patients discharged per DTC compared with discharges per NTC (Table 2). Moreover, severely injured children and adults were concentrated relative to all injured patients at DTCs to a much greater degree than the concentration of the severely injured elderly relative to all injured elderly at DTCs.

As stated earlier, triage accuracy determines the proportion of injured patients who access trauma centers, and thereby reflects a trauma system’s ability to capture the

<table>
<thead>
<tr>
<th>Patients</th>
<th>1996 Value</th>
<th>2010 Value</th>
<th>Intercept</th>
<th>SE</th>
<th>Slope</th>
<th>SE</th>
<th>R²</th>
<th>p Value</th>
</tr>
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<tr>
<td>Children</td>
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<td>5,067</td>
<td>5,400.4</td>
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Intercept is the model estimate for 1996 value; slope is the annual increase/decrease in injury discharge. R², model least squares value; SE, standard error of parameter.

Figure 1. Annual discharges for (A) all injured patients and (B) severely injured patients. Annual injury discharges increased in the elderly and adults but decreased for children. Severe injury discharges increased for the elderly and adults but decreased in children. Light gray, elderly; dark gray, adult; black, children.
target population (Fig. 4). In 1996, 47% of injured children, 44% of injured adults, and 15% of injured elderly were discharged from DTCs. When assessed from the perspective of severe injury, which is the system’s primary target population, 66% of severely injured children and 66% of severely injured adults, but only 27% of severely injured elderly accessed DTCs. By 2010, these proportions increased to 73% of injured children, 52% of injured adults, and 21% of injured elderly. More importantly, this population of patients treated in DTCs in 2010 included 93% of severely injured children and 85% of severely injured adults, but still only 41% of severely injured elderly.

The 2010 geographic distribution of all severely injured patients based on home ZIP code is shown in Figure 5 along with the distributions stratified by age group. During the study period there was progressive statewide coverage of severely injured children and nearly complete coverage of severely injured adults. The majority of severely injured adults discharged from NTCs were clustered around Bay County in the Florida panhandle. The distribution of severely injured elderly...
differed in that those who accessed the trauma system resided near DTCs; those discharged from NTCs resided far from DTCs.

DISCUSSION

The Florida trauma system was established in 1982, when the legislature authorized the Florida Department of Health (DOH) to designate trauma centers. Subsequent system improvements included legislation to designate a statewide system of trauma centers and a prehospital triage plan to ensure triage of severely injured patients to the nearest appropriate trauma center. In 2005, the Florida Legislature commissioned a study to evaluate the efficacy, efficiency, and equity of the Florida trauma system as a basis for continuing its funding. This study demonstrated that treatment in a trauma center was associated with a substantial reduction in mortality and cost of care. Although 95% of Florida citizens resided within 85 minutes of a trauma center, only 38% of all injured
patients actually reached a trauma center. In a more recent study of severely injured patients, we found that although 98% of patients lived within a trauma center catchment area, only 52% of severely injured patients reached a trauma center. The purpose of this study was to evaluate access to the trauma system during implementation of the statewide trauma plan and further identify factors that limit effective triage.

As in previous studies, injury severity was stratified using the discharge diagnosis ICD-9—based ICISS scoring system, which has been shown to outperform other scoring systems in predicting injury mortality and is particularly suited for the study of administrative databases. The definition of severely injured patients was chosen to match that in several preceding studies that focused on the survival advantage of severely injured patients treated at DTCs in Florida. Because this was a longitudinal study over 15 years, we used a rolling 5-year sample to estimate the mortality risk of the year reported to account for advances in care and changes in mortality risk over time. The age categories were chosen based on the state definition of pediatric trauma and previous studies defining the elderly as older than age 65. Survival risk ratios were calculated separately for each age group to adjust for the influence of age on mortality risk. One limitation of this methodology is that injury severity is determined retrospectively by the risk of death, which is subject to influence by noninjury factors, particularly age. So the term severely injured may not be accurate in this population, in which the major risk of death is due to the influence of age and related comorbidities and not necessarily as a result of anatomic injury. Conversely, there may be a number of patients who clinically would be considered severely injured, or at least require services available only at DTCs, who are not recognized by the ICISS methodology.

Although trauma is often considered a disease of the young, we found that the majority of injury discharges were elderly patients. In 2010, children and the elderly each accounted for 17% of the state's population, but where children accounted for only 5% of all injuries and 2% of severe injuries, the elderly accounted for 55% of all injuries and 50% of severe injuries. The incidence of all injury among children demonstrated a clinically but not statistically significant decrease. The incidence of all injury among adults and the elderly each increased significantly. Although the incidence of severe injuries decreased in children and increased in adults and the elderly, the proportion of all injuries that were severe decreased for children and the elderly and remained constant for adults. Together these observations describe an injury population that is increasing in size, becoming older, and is less severely injured.

A critical function of a regional trauma system is triage of the severely injured to DTCs. Although injury discharges increased at both NTCs and DTCs, severe injury discharges decreased at NTCs and increased at DTCs. The increased proportion of hospitals designated as trauma centers alone does not explain the increased triage of patients to DTCs because the number of injured and severely injured patients per DTC increased during the study period. The progressive increase in accuracy of severely injured triage trauma centers is more apparent when the relative number of DTCs and NTCs is considered. Substantially more injured and severely injured patients per center were treated in DTCs compared with NTCs in all age groups. By 2010, an individual NTC averaged less than 3 injured adults per week and less than 7 severely injured adults per year. Although more elderly and severely injured elderly were discharged from NTCs than DTCs statewide, an individual NTC saw very few of these at-risk patients compared with DTCs, on average. Conversely, by 2010, nearly all severely injured children and adults were triaged to trauma centers.

Concomitant with the improved triage of severely injured was an increase in triage of all patients to trauma centers, which may be attributed to a halo effect surrounding the triage of the severely injured. The geographic distribution of severely injured patients demonstrates statewide coverage of children and near statewide coverage of adults. The exception is the region surrounding Bay County in the northwest part of the state. Although triage of the severely injured elderly to DTCs increased during the study period, the proportion

<table>
<thead>
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<th>Patients</th>
<th>DC/DTC 2010</th>
<th>DC/NTC</th>
<th>DTC/NTC</th>
</tr>
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<tbody>
<tr>
<td>Children</td>
<td>413.1</td>
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<td>53.9</td>
</tr>
<tr>
<td>Severe</td>
<td>23.3</td>
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<tr>
<td>Adult</td>
<td>1,207.7</td>
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<td>8.9</td>
</tr>
<tr>
<td>Severe</td>
<td>318.3</td>
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</tr>
<tr>
<td>Elderly</td>
<td>2,758.8</td>
<td>334.4</td>
<td>8.3</td>
</tr>
<tr>
<td>Severe</td>
<td>160.4</td>
<td>28.0</td>
<td>5.7</td>
</tr>
<tr>
<td>All</td>
<td>3,189.9</td>
<td>621.1</td>
<td>5.1</td>
</tr>
<tr>
<td>Severe</td>
<td>444.7</td>
<td>34.8</td>
<td>12.8</td>
</tr>
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</table>

Pediatric DTCs included dedicated pediatric trauma centers and adult trauma centers with pediatric capabilities. Adult DTCs excluded pediatric-specific trauma centers. Pediatric NTCs included nontrauma centers and DTCs without pediatric capabilities. DTC/NTC reflects the relative concentration of injured patients in DTC compared with NTC. DC, discharge; DTC, designated trauma center; NTC, nontrauma center.
was consistently below that of severely injured adults and children.

Against this background of consistently improved trauma triage, the plight of the elderly seems atypical. In 2010, only 41% of severely injured elderly accessed the trauma system. In contrast to children and adults, triage of the severely injured elderly did appear to be dependent on proximity to DTC. As discussed previously, this may not necessarily reflect a systematic defect in the trauma system’s ability to identify elderly patients with severe injuries, but rather, an effect of age-related factors on overall mortality. With the exception of a single
region of the state, we concluded that the distance from a DTC does not limit triage of the severely injured to the trauma centers in the current system.

Along with the capture of the target population, a trauma system’s mission is predicated on the concentration of severely injured patients transported to trauma centers. This not only minimizes the duplication of services, but also ensures sufficient patient volume to maintain clinical competency (Table 2). Severely injured children were substantially more concentrated in DTCs than all injured children, which suggests that triage of children to DTCs was not based on age alone. Although children were concentrated in trauma centers to a greater degree than adults and the elderly, on average, each of the 9 pediatric-capable DTCs discharged just 413 injured children and only 23 severely injured children in 2010, despite near complete capture of this population. It was remarkable that only 15 severely injured children were discharged from NTCs in 2010. Nonetheless, the annual pediatric DTC volume is small compared with adult DTCs, which may have significant implications for the clinical experience and financial viability of pediatric trauma programs.

Adults were also concentrated in DTCs, but to a lesser degree than children. On average, each of the 20 adult DTCs discharged 1,208 injured and 318 severely injured adults. Similar to children, the severely injured adults were concentrated in DTCs to a greater degree than the overall population of injured adults, suggesting appropriately accurate triage according to injury severity for adults as well as children. The number of injured and severely injured adult discharges per DTC was higher than that observed in children, which suggests a more favorable volume for maintenance of clinical competency and recovery of costs in adult trauma programs. We did not review the annual volume of severely injured patients at each DTC in this analysis, but our previous work identified significant variability in the volume of severely injured patients among centers. The finding that a high proportion of at-risk adults access the trauma system even in areas served by high volume centers suggests that the current capacity is sufficient to meet current needs. A more focused study is necessary to determine if the volume of severely injured patients in areas served by several low volume centers is sufficient to allow meaningful patient volumes at each center.

Although the majority of elderly trauma patients were not treated in trauma centers, the injured and severely injured elderly were still concentrated in DTCs relative to NTCs. On average, a DTC discharged substantially more injured and severely injured elderly than children and adults. Unlike children and adults, there was no identifiable concentration of severely injured elderly at DTCs. In effect, the severely injured elderly were actually less concentrated at DTCs than injured elderly overall. In previous reports, fewer elderly patients accessing the trauma system has been attributed to reluctance of the elderly to accept transfer, a better ability to pay as an incentive for initial receiving hospitals to defer transfer, and/or the inability of clinical staff to recognize the severity of injury related threat to life in the elderly. Alternatively, it is possible that the methods used in this study misclassify a portion of the injured elderly as severely injured, not because of the injury pattern itself, but because of the increased mortality risk conferred by advanced age. The observation that severely injured children and adults accessed DTCs independent of proximity suggests that the same access is available to the elderly. That it is not realized in practice is consistent with the hypothesis the severely injured elderly may be more elderly than injured.

It is tempting to propose designation of additional trauma centers to increase access the injured elderly have to the trauma system. However, although the elderly do realize a small survival advantage by accessing the trauma system, this advantage decreases with age. So, it is unclear whether improved access in this group alone would translate to improved outcomes overall. Furthermore, without improved primary and secondary triage criteria that accurately identify at-risk elderly, it is unlikely that additional trauma centers will increase access for any elderly patients except those in immediate proximity to these new centers. On the contrary, additional trauma centers would be expected to redirect severely
injured adults and children away from the existing centers. The net effect would be redistribution of at-risk children and adults among a larger pool of trauma centers and a reduced volume of at-risk children and adults at each center. A concerted epidemiologic investigation of the injured elderly is needed to better define how this vulnerable population’s needs could be better met by the trauma system. It is important to determine if these patents are at risk of because of their injuries or if they are at risk with their injuries.

CONCLUSIONS
In conclusion, from the public health perspective of injury management, the Florida trauma system has achieved extensive coverage for nearly all of the state’s population. Coverage for severely injured children and adults, for which the resources of the trauma system are so important, is comprehensive and continues to expand. With the exception of 1 region, additional trauma centers are not likely to improve access to trauma care and have the potential to reduce system performance by diluting the volumes of the existing trauma centers. The injured elderly remains a population of concern and continues to have a significant impact on public health resources. Although almost half of these fragile patients do not access the trauma system, and as a group, account for a disproportionate cost of injury care, more comprehensive study is needed to determine how the trauma system can meet the needs of this vulnerable population.

Author Contributions
Study conception and design: Ciesla, Tepas, Pracht
Acquisition of data: Pracht
Analysis and interpretation of data: Ciesla, Pracht, Flint
Drafting of manuscript: Ciesla, Cha
Critical revision: Ciesla, Tepas, Pracht, Langland-Orban, Cha, Flint

REFERENCES

Discussion
DR DONALD TRUNKEY (Portland, OR): I think that was a very nice paper. It gives us a lot of the demographics, particularly in the elderly. Falls are now the number 1 cause of injury in the elderly. And these are low falls, certainly not high velocity injuries. You state in your manuscript, in discussing the availability of access, “that it is not realized, and practice is consistent with the hypothesis, the severely injured elderly may be more elderly than injured.”

This points out, I think, a very critical issue: you don’t have any data on comorbid factors. And many of these patients are on platelet inhibitors, warfarin, etc, which compounds injury in the elderly.