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Original Contribution

Denver ED Trauma Organ Failure Score predicts healthcare resource utilization in adult trauma patients☆

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ABSTRACT

Background: Early identification of trauma patients who need specialized healthcare resources may facilitate goal-directed resuscitation and effective secondary triage.
Objective: To estimate associations between Denver Emergency Department (ED) Trauma Organ Failure (TOF) Score and healthcare resource utilization.
Methods: Retrospective study of adult trauma patients at Denver Health Medical Center. The outcome was resource utilization including: intensive care unit (ICU) length of stay (LOS), hospital LOS, procedures, and costs. Multivariable regression analyses were used to estimate associations between moderate- or high-risk patients, as determined by the Denver ED TOF Score, and healthcare resource utilization.
Results: We included 3000 patients with a median age of 42 (IQR 27–56) years, 71% male, median injury severity score 9 (IQR 5–16), and 83% blunt mechanism. Among the cohort, 1379 patients (46%) were admitted to the ICU and 122 (4%) died. The adjusted relative risk for high- and moderate-risk as compared to low risk for number of procedures performed was 2.31 (95% CI 2.07–2.57) and 1.80 (95% CI 1.59–2.03) respectively; ICU LOS was 2.87 (95% CI 2.70–3.05) and 1.71 (95% CI 1.60–1.83) respectively; hospital LOS was 3.33 (95% CI 3.21–3.45) and 1.97 (95% CI 1.90–2.05) respectively. The adjusted geometric mean for high-, moderate-, and low-risk for costs was $48,881 (95% CI $43,799–$54,552), $27,890 (95% CI $25,460–$30,551), and $12,983 (95% CI $12,493–$13,492), respectively.
Conclusions: The Denver ED TOF Score predicts healthcare resource utilization, and is a useful bedside tool to identify patients early after injury that are likely to require significant healthcare resources and specialized trauma care.

1. Introduction

Resource utilization in healthcare is becoming an increasingly important issue with the national focus on healthcare coverage and costs [1]. Improvements in trauma and critical care have led to an increasing rate of multiply-injured trauma patients surviving the early post-traumatic period [2,3]. During their convalescence, trauma patients often require expensive hospital-based healthcare services and resources [4,5]. Early recognition of trauma patients who will need specialized care and who are at risk for worse outcomes is especially important to improve healthcare resource allocation.

Several scoring systems currently exist to grade the severity of traumatic injuries and to stratify trauma patients into mortality risk groups [6]. However, the data necessary to compute many of these scores is not readily available early in the post-injury period; it may take several hours for all of the injuries to be identified and some scores necessitate data that are not available until hospital discharge. Identification of a prediction tool that uses information easily obtained at the bedside early in the post-injury course to identify patients in need of specialized intensive care would be beneficial to facilitate targeted resuscitation and triage of injured patients to higher levels of trauma care to improve resource allocation and outcomes.

We recently derived and validated the Denver Emergency Department (ED) Trauma Organ Failure (TOF) Score, which uses data obtained within 4 h of injury to predict multiple organ failure (MOF) within

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seven days of hospitalization in adult trauma patients (Fig. 1) [7,8]. The Denver ED TOF Score has not previously been evaluated to ascertain its ability to predict healthcare resource utilization. The objective of this study was to estimate the associations between different Denver TOF Score risk categories (i.e., low-, moderate- and high-risk) and healthcare resource utilization. We hypothesized that intensive care resource utilization (defined by mechanical ventilation, invasive procedures, length of intensive care unit and hospital stay, and total costs) would increase incrementally among adult trauma patients categorized into low- (Denver TOF Score 0–1), moderate- (Score 2–3), and high-risk (Score ≥ 4) groups, respectively.

2. Methods

2.1. Study design and setting

This was a cohort study from Denver Health Medical Center in Denver, Colorado. Denver Health Medical Center is a 477-bed, urban safety-net hospital and the Rocky Mountain Regional Level 1 Trauma Center, the only academic Level 1 trauma center in Colorado [9]. The ED is the primary receiving facility for all trauma patients, and has an approximate annual adult census of 60,000 visits, of which approximately 2000 are included in the trauma registry, and approximately 500 of which are classified as major trauma (defined by an Injury Severity Score [ISS] > 15). The study was approved by the Colorado Multiple Institutional Review Board.

2.2. Study population

Consecutive trauma patients (≥18 years of age) who presented to Denver Health Medical Center from June 23, 2010, through December 26, 2012, and who were entered in the trauma registry were included in this study. The trauma registry contains trauma patients who are admitted to the ED observation unit for at least 12 h, admitted to the hospital, die in the ED, or are transferred from outside hospitals for further trauma care. Patients were excluded from this study if they: (1) were < 18 years of age; (2) died in the ED; or (3) were transferred from another hospital.

2.3. Data collection

Patients included in the trauma registry are identified daily from the ED log by a team of personnel specifically trained in the oversight of the trauma registry and in the acquisition of data. Data are systematically abstracted from the patients' medical records and entered into an electronic database. To maintain quality assurance, an internal review of approximately 20% of the trauma registry records is conducted on a regular basis using a standardized protocol. Each review is completed by registry staff members who did not perform the initial chart abstraction. Any data discrepancies identified in this review are presented to the trauma registry committee and corrections are made through a consensus process.

Data recorded in the trauma registry and obtained for purposes of this study included: (1) Denver TOF Score variables (age, intubation, and initial systolic blood pressure, hematocrit, blood urea nitrogen, and white blood cell count); (2) gender; (3) clinical care characteristics (invasive procedures, operative interventions, and the duration of mechanical ventilation); (4) ICU admission and length of ICU stay; (5) length of hospital stay; (6) mortality during hospitalization; (7) patient's five-digit household zip code (to assess socioeconomic status using median household income); (8) payer source (commercial, Medicaid, Medicare, self); and (9) total hospital costs. Laboratory data obtained within 4 h of arrival were obtained from the hospital's computerized laboratory reporting system (MiSYS Healthcare Systems, Raleigh, NC) and linked to patient data obtained from the trauma registry. If more than one laboratory value was available within 4 h of hospital arrival, the most extreme value was utilized. Total hospital charges were obtained from the patient records and converted to hospital charges using the Denver Health Medical Center cost-to-charge ratio. Costs were adjusted for inflation to 2012 costs using the Consumer Price Index for all consumers for 2010 and 2011 at 0.053 and 0.021 respectively.

The medical records of all patients were systematically reviewed in a blinded fashion by trained physician abstractors to obtain specific measures of healthcare resource utilization not included in the trauma registry, including the following: (1) clinical care characteristics (arrival vital signs and the type and volume of blood products transfused during hospitalization); (2) specific procedures performed during hospitalization (arterial line and central venous line); and (3) comorbidities (asthma, coronary artery disease, congestive heart failure, peripheral vascular occlusive disease, cerebrovascular disease, dementia, chronic obstructive pulmonary disease, asthma, liver disease including cirrhosis, diabetes, renal disease [dialysis dependent or dialysis eligible], leukemia, lymphoma, solid tumor, metastatic cancer, and Acquired Immunodeficiency Syndrome).

The blinded physician abstractors were trained to use a closed-response data collection instrument to systematically abstract each endpoint using standardized medical record abstraction methodology [10]. Ten percent of the charts were re-abstracted to verify reliability of the abstraction process. Inter-rater reliability was assessed to determine the overall agreement and the median kappa was 0.98 (IQR 0.84–1.00).

Predictor	Score
Age ≥ 65 years	1
Emergent intubation§	3
Hematocrit < 20%	2
Hematocrit ≥ 20% and < 35%	1
ED systolic blood pressure < 90 mmHg	1
Blood Urea Nitrogen ≥ 30 mg/dL	1
White Blood Cell count ≥ 20,000 /μL	1

§Emergent intubation defined as intubation in the prehospital or emergency department settings.
Levels of risk as determined by the Denver ED TOF Score: low- (Score 0-1), moderate- (Score 2-3), and high-risk (Score ≥4).

Fig. 1. The Denver Emergency Department (ED) Trauma Organ Failure (TOF) Score for prediction of multiple organ failure in adult trauma patients [7,8].

2.4. Outcome measures

The outcomes for the study included several measures of intensive care and hospital resource utilization as follows: total hospital costs, tracheostomy tube, mechanical ventilation duration, central venous catheter placement, arterial line placement, parenteral nutrition, quantity of blood product transfusion, hospital and ICU length of stay, and operative intervention.

2.5. Data management and statistical analyses

Data were transferred electronically from the trauma registry and MiSYS into separate electronic spreadsheets (Microsoft Excel, Microsoft Corporation, Redmond, WA). Abstracted data were recorded in an electronic closed-response data collection instrument (REDCap). REDCap is a secure, web-based application designed to support data capture for research studies that provides online validated data entry, audit trails for tracking data manipulation, and export procedures for data downloads to statistical packages [11].

Each electronic file was then transferred into native SAS format. All analyses were performed using SAS Version 9.3 (SAS Institute, Inc., Cary, NC) or Stata Version 12.0 (Stata Corporation, College Station, TX). Continuous data are reported as medians with interquartile ranges (IQRs) and categorical data are reported as percentages with 95% confidence intervals (CIs).

Multivariable regression analyses were used to estimate the independent associations between patients categorized as moderate- or high-risk for MOF (with low-risk serving as the reference), as determined by the Denver ED TOF Score, and intensive care resource utilization using the following conceptual model:

$$\text{Outcome} = f\,[\text{moderate risk} + \text{high risk} + \text{age} + \text{comorbidities} + \text{SES status} + \text{payer source}]$$

Because no composite summary measure of intensive care resource utilization exists, we developed separate regression models a priori for the following outcomes: total hospital costs (linear regression); tracheostomy tube (logistic regression); mechanical ventilation duration (Poisson); central venous catheter placement (logistic); arterial line placement (logistic); parenteral nutrition (logistic); quantity (in mL) of blood product transfusion (linear); hospital and ICU length of stay (Poisson); and operative intervention defined as any operative intervention by any surgical specialty during hospitalization (logistic). In addition, we developed a model that incorporated all procedures (arterial line, central venous catheter, mechanical ventilation, gastrostomy tube, and tracheostomy) as a composite outcome. We included age, the number of comorbidities [12,13], SES status as median household income for the zip code, and payer source as multi-selection (self-pay, government-sponsored, Medicare, and other, with commercial as the reference) in each model.

Automated variable selection methods were not used to select variables for inclusion in any of the model. Instead we performed complete model analysis with variables being included based upon our a priori knowledge of known or hypothesized relationships between multiple organ failure and healthcare resource utilization.

2.6. Sample size estimation

We anticipated including nine independent variables in each model. Of all the dependent variables, we anticipated some of the procedures being assessed to have the lowest prevalence (approximately 3%) and therefore used this statistic to provide a conservative estimate of the total number of patients required for the study. As a general rule, multivariable logistic regression analyses require an event to predictor ratio of 10:1 to prevent over-fitting and to thus allow for valid inferences [14]. We therefore estimated requiring a minimum of 90 patients who had the procedure performed, and therefore a total minimum of 3000 patients for inclusion.

3. Results

During the study period, 3000 consecutive trauma patients met criteria for inclusion and therefore represent our study sample. The median age was 42 (IQR 27–56) years; 71% were male, 83% experienced a blunt injury mechanism, and the median ISS was 9 (IQR 5–16). A complete description of the demographics and characteristics of the study sample is presented in Table 1. Of the 3000 patients, the median hospital LOS was 4 (IQR 2–8) days, with 1379 (46%) admitted to the ICU with a median ICU length of stay (LOS) of 2 (IQR 1–5) days. Excluding patients with short ICU stays (e.g., those simply observed for 24 h then transferred to a ward), 651 (22%) had an ICU LOS > 48 h with a median ICU LOS of 5 days (IQR 3–10). Among the 3000 participants, 122 (4%) died. A complete description of the outcomes for the study sample is presented in Table 2.

Table 1
Demographics and characteristics of the study sample (n = 3000).

Variable	No.	(% or IQR)	Missing	
			No.	(%)
Total (n)	3000			
Median age, years	42	(27–56)	0	(0)
Male gender	2140	71	3	(0)
Race			27	(0)
White	2444	82		
Black	307	10		
American Indian	42	1		
Asian	50	2		
Pacific Islander	2	0		
Other	128	4		
Hispanic ethnicity	1002	33		
Mechanism				
Blunt	2499	83	1	(0)
Injury type			2	(0)
Motor vehicle crash	637	21		
Motorcycle crash	208	7		
Assault	346	12		
Auto-pedestrian crash	236	8		
Bicycle crash	119	4		
Gunshot	163	5		
Stabbing	229	8		
Fall	827	28		
Other	233	8		
Median injury severity score	9	(5–16)	0	(0)

Abbreviations: ED, emergency department; IQR, interquartile range; MOF, multiple organ failure.

Trauma patients identified as high risk using the Denver ED TOF Score had significantly increased total volume of blood products transfused and hospital costs (Table 3). As the level of risk as identified by the Denver ED TOF Score increased, total hospital costs increased (Fig. 2). Patients at high or moderate risk using the Denver ED TOF Score had increased total procedures, ICU LOS, and hospital LOS (Table 4). There was no significant difference in duration of mechanical ventilation among patients identified as high versus low risk using the Denver ED TOF Score (Table 4). Patients identified as high risk by the Denver ED TOF Score had increased interventions during hospitalization including arterial line, central venous catheter, parenteral nutrition, gastrostomy tube, tracheostomy, and operations (Table 5). The association between patients who were high-risk determined by the Denver ED TOF Score and outcomes for the study were statistically significant

Table 2
Outcomes of the study sample (n = 3000).

Variable	No.	% or (IQR)
Total (n)	3000	
Procedures		
Arterial line	474	16
Central venous catheter	351	12
Mechanical ventilation	562	19
Gastrostomy tube	81	3
Tracheostomy	193	6
Median number of procedures performed[a]	2	(1–4)
Parenteral nutrition	46	6
Renal replacement therapy	6	0
Received blood products	603	20
Median volume of blood products transfused, mL	1213	(500–3206)
Operative intervention[b]	1746	58
Intensive care unit		
Admission	1379	46
Median length of stay	2	(1–5)
Median hospital length of stay, days	4	(2–8)
In-hospital mortality	122	4

Abbreviations: ED, emergency department; IQR, interquartile range.
[a] Includes arterial line, central venous catheter, mechanical ventilation, percutaneous endoscopic gastrostomy tube, and tracheostomy.
[b] Defined as operative intervention by any surgeon during hospitalization.

Table 3
Adjusted associations between total healthcare costs and volume of blood products transfused and risk as determined by the Denver Emergency Department (ED) Trauma Organ Failure (TOF) Score.[a,b]

Variable	Geometric mean	95% CI
Total volume of blood products transfused[c]		
High versus low risk	2561	2189–2996
Moderate versus low risk	1345	1122–1611
Total hospital costs		
High risk	$48,881	$43,799–$54,551
Moderate risk	$27,890	$25,460–$30,551
Low risk	$12,983	$12,493–$13,492

Abbreviations: confidence interval, CI; emergency department, ED; Trauma Organ Failure, TOF.
[a] High risk is defined as a Denver ED TOF score of ≥4; moderate risk is defined as a Denver ED TOF score of 2–3; and low risk is defined as a Denver ED TOF score of 0–1.
[b] Each model was adjusted for age, number of comorbidities, median household income of home zip code as a measure of socioeconomic status, and payer source with commercial as the reference.
[c] Volume of total blood products transfused is reported in milliliters.

Table 4
Adjusted associations between healthcare resource utilization and risk as determined by the Denver Emergency Department (ED) Trauma Organ Failure (TOF) Score.[a,b]

Healthcare resource utilization measure	Relative risk	(95% CI)
Duration of mechanical ventilation		
High versus low risk	1.00	(0.92, 1.10)
Moderate versus low risk	0.68	(0.62, 0.97)
Total procedures during hospitalization[c]		
High versus low risk	2.31	(2.07, 2.57)
Moderate versus low risk	1.80	(1.59, 2.03)
Intensive care unit length of stay		
High versus low risk	2.87	(2.70, 3.05)
Moderate versus low risk	1.71	(1.60, 1.83)
Hospital length of stay		
High versus low risk	3.33	(3.21, 3.45)
Moderate versus low risk	1.97	(1.90, 2.05)

Abbreviations: confidence interval, CI; emergency department, ED; Trauma Organ Failure, TOF.
[a] High risk is defined as a Denver ED TOF score of ≥4; moderate risk is defined as a Denver ED TOF score of 2–3; and low risk is defined as a Denver ED TOF score of 0–1.
[b] Each model was adjusted for age, number of comorbidities, median household income of home zip code as a measure of socioeconomic status, and payer source with commercial as the reference.
[c] Procedures included arterial line, central venous catheter, mechanical ventilation, percutaneous endoscopic gastrostomy tube, and tracheostomy.

for all outcomes with the exception of duration of mechanical ventilation.

4. Discussion

This study was conducted to determine the associations between the Denver ED TOF Score risk categories, which use objective clinical data readily available within 4 h of injury, and healthcare resource utilization in trauma care. We demonstrated that the Denver ED TOF Score is associated with several measures of healthcare resource utilization including arterial line, central venous catheter, gastrostomy tube, hospital length of stay, intensive care unit length of stay, operative intervention, parenteral nutrition, total hospital costs, total procedures, tracheostomy, and volume of blood products transfused. The use of the Denver ED TOF Score early in the post-injury period may serve as a useful tool to identify patients in need of specialized healthcare resources and higher levels of trauma care. Early identification of these at-risk patients may subsequently facilitate improved healthcare outcomes.

Several trauma and intensive care unit scoring systems have been used to evaluate outcomes other than mortality risk [15-25]. The ISS has been used to evaluate hospital stay, ICU stay, time ventilated, complications, and emergency surgery [15,16]. The ICISS has outperformed the ISS and TRISS for prediction of hospital charges and hospital length of stay [17]. The ISS, TRISS, ICISS and ASCOT are all valuable tools that have been used to predict outcomes after trauma but unfortunately require coding of the healthcare information in AIS nomenclature that may not be readily available at the bedside early in the post-injury period [17-20]. Studies have demonstrated that the RTS, a physiologic score which can be applied at the bedside, does not predict mortality as well as the anatomic scores [18]. The APACHE score has been demonstrated to predict mortality and healthcare outcomes but has limited applicability clinically at the bedside early after injury as the score necessitates complex calculations [19]. Scores that require extensive calculation or data from the hospitalization are highly valuable for retrospective analyses but their role is limited in informing resource use prospectively and in evaluating the severity of illness and the potential need for secondary triage early in the post-injury period [18].

The Denver ED TOF Score is easily applied at the bedside in the first few hours of the acute post-injury phase. In this study we found the associations between high risk (as determined by the Denver ED TOF Score) and healthcare resource utilization outcomes were statistically significant for all outcome measures with the exception of the duration of mechanical ventilation. The duration of mechanical ventilation

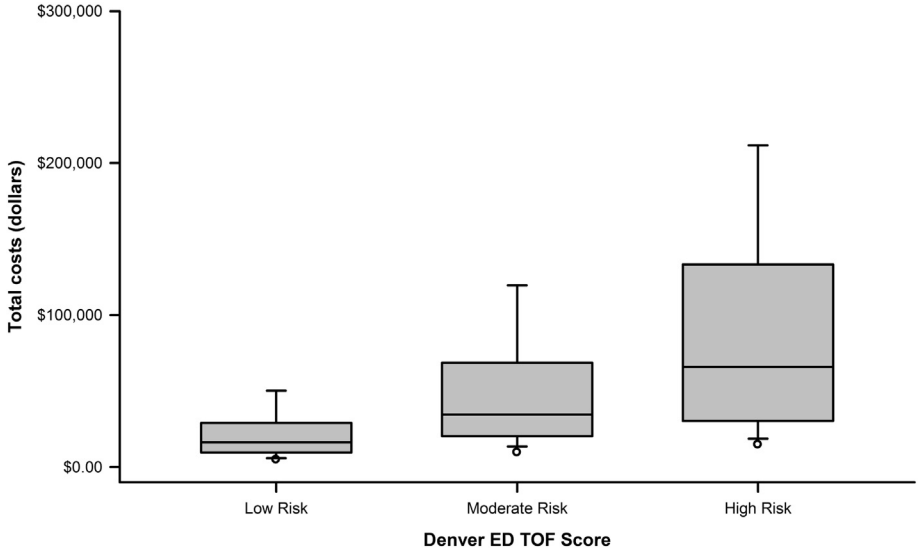

Fig. 2. Association between total hospital costs and the Denver Emergency Department Trauma Organ Failure Score.

Table 5
Adjusted associations between measures of healthcare resource utilization and risk as determined by the Denver Emergency Department (ED) Trauma Organ Failure (TOF) score.[a,b]

Measure of healthcare resource utilization	Odds ratio	(95% CI)
Arterial line		
High versus low risk	4.75	(3.87, 5.83)
Moderate versus low risk	1.14	(0.95, 1.36)
Central venous catheter		
High versus low risk	6.38	(5.16, 7.88)
Moderate versus low risk	1.13	(0.93, 1.38)
Parenteral nutrition		
High versus low risk	2.27	(1.47, 3.62)
Moderate versus low risk	1.04	(0.63, 1.72)
Gastrostomy tube		
High versus low risk	4.00	(2.91, 5.50)
Moderate versus low risk	1.70	(1.21, 2.39)
Tracheostomy		
High versus low risk	20.98	(14.18, 31.03)
Moderate versus low risk	9.19	(6.19, 13.65)
Operative intervention[c]		
High versus low risk	1.90	(1.53, 2.38)
Moderate versus low risk	0.77	(0.65, 0.92)

Abbreviations: confidence interval, CI; emergency department, ED; Trauma Organ Failure, TOF.

[a] High risk is defined as a Denver ED TOF score of ≥4; moderate risk is defined as a Denver ED TOF score of 2–3; and low risk is defined as a Denver ED TOF score of 0–1.

[b] Each model was adjusted for age, number of comorbidities, median household income of home zip code as a measure of socioeconomic status, and payer source with commercial as the reference.

[c] Defined as operative intervention by any surgeon during hospitalization.

among high and low risk trauma patients was not significantly different. One potential explanation for the lack of association between duration of mechanical ventilation and high risk status is that these patients may have died sooner after injury, thereby limiting the duration of the post-injury mechanical ventilation period.

This study demonstrates that the Denver ED TOF Score could serve as a useful clinical prediction instrument for early identification of those patients at risk for necessitating specialized intensive care resources thereby facilitating aggressive, goal-directed resuscitation and secondary triage of these critically ill patients to highly-specialized facilities. The transfer of patients at high risk for in-hospital mortality and specialized care needs to a higher level of trauma care with a cadre of trauma specialists may improve resource allocation and trauma outcomes thereby reducing healthcare costs associated with such patients.

Before implementing the Denver ED TOF Score into clinical practice, additional investigations of the performance of the score in diverse settings are indicated. A trial of use of the score in a regional fashion to identify those patients in need of specialized healthcare resources and who may benefit from transfer to a higher level of care as compared to current regional triage criteria may be helpful. This would include an evaluation of the outcomes for patients who were transferred based upon the Denver ED TOF score and a comparison of the score to physician gestalt for the need for transfer to a higher level of trauma care. These studies would further the knowledge of the utility and application of the Denver ED TOF Score in clinical practice.

The primary limitation of this study is that the study was conducted at a single urban Level I Trauma center. While we have a diverse trauma population, additional multi-center studies are needed to evaluate the performance of the Denver ED TOF Score in both urban and rural healthcare settings with heterogeneous trauma populations. We included patients from the Denver Health Trauma Registry and excluded patients who died in the ED and who were discharged home. It is possible that some of the patients discharged home, and therefore not included in the trauma registry, had a subsequent decline in their condition and developed a later need for hospital-based procedures; these data would not have been captured by this study. It is possible that bias may have occurred as a result of the data abstracted from the medical record by the physician abstractors for the study. However, the potential for this type of bias to occur was significantly mitigated by the use of a rigorous training and abstraction process and use of physician abstractors blinded to the purpose of our study. We also completed re-abstraction of 10% of the charts and compared these results to verify agreement of the abstraction process which demonstrated excellent inter-rater reliability.

5. Conclusions

The Denver ED TOF Score predict healthcare resource utilization in an adult trauma population at a single center. The Denver ED TOF Score may be a useful tool to identify patients early in the post-injury phase who are at high risk for needing significant healthcare resources and specialized trauma care. Early identification of these patients may facilitate targeted resuscitation and secondary triage to improve resource allocation and outcomes in trauma.

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Author contributions

Dr. Vogel had full access to all of the data in the study and takes responsibility for the integrity of the data and the accuracy of the data analysis.

Study concept and design: Vogel, Haukoos
Acquisition of data: Vogel, Sungar, Ryan, Murphy, Loar, Boatright, Adams
Analysis and interpretation of data: Vogel, Sungar, Ryan, Murphy, Loar, Boatright, Adams, Haukoos
Drafting of the manuscript: Vogel
Critical revision of the manuscript for important intellectual content: Vogel, Sungar, Ryan, Murphy, Loar, Boatright, Adams, Haukoos
Statistical analysis: Vogel
Obtained funding: Vogel, Haukoos
Administrative, technical, or material support: Vogel, Haukoos
Study supervision: Vogel, Haukoos

Additional contributions

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