Survey of Trauma Registry Data on Tourniquet Use in Pediatric War Casualties

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Objectives: Previously, we reported on the use of emergency tourniquets to stop bleeding in war casualties, but virtually all the data were from adults. Because no pediatric-specific cohort of casualties receiving emergency tourniquets existed, we aimed to fill knowledge gaps on the care and outcomes of this group by surveying data from a trauma registry to refine device designs and clinical training.

Methods: A retrospective review of data from a trauma registry yielded an observational cohort of 88 pediatric casualties at US military hospitals in theater on whom tourniquets were used from May 17, 2003, to December 25, 2009.

Results: Of the 88 casualties in the study group, 72 were male and 16 were female patients. Ages averaged 11 years (median, 11 years; range, 4 17 years). There were 7 dead and 81 survivor outcomes for a trauma survival rate of 93%. Survivor and dead casualties were similar in all independent variables measured except hospital stay duration (median, 5 days and 1 day, respectively). Six casualties (7%) had neither extremity nor external injury in that they had no lesion indicating tourniquet use.

Conclusions: The survival rate of the present study's casualties is similar to that of 3 recent large nonpediatric-specific studies. Although current emergency tourniquets were ostensibly designed for modern adult soldiers, tourniquet makers, perhaps unknowingly, produced tourniquets that fit children. The rate of unindicated tourniquets, 7%, implied that potential users need better diagnostic training.

Levels of Evidence: Level 4; case series, therapeutic study.

Key Words: first aid, resuscitation, damage control, hemorrhage, shock

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Tourniquet use has been associated with improved survival by stopping traumatic bleeding, but virtually all the data have been from adults. Recent emergency tourniquet reports gave evidence of lifesaving benefit with low morbidity in battle casualties, but those reports did not specifically focus on children, who have smaller limbs compared with adults.[1–5]

Although most war casualties are limb injured adults,[6,7] specific knowledge gaps exist for the pediatric casualties. For example, no pediatric specific cohort exists in a casualty study of emergency tourniquet use. Devices used on children may or may not fit, and there is no pediatric specific data evidencing survival rates. No research findings guide tourniquet designers as to what, if any, problems occur in children. The US military cares for some pediatric casualties that present to military treatment facilities on the battlefield, including those with tourniquets used, but the number is unknown. The military experts are in fact the world experts, and so the criteria to design the devices mainly come from the military. For example, the 1998 US Army Anthropometry helped guide military experts in consultation with device designers.[8] Designers used those data to guide development of their devices, but children were not included. Filling these knowledge gaps may help device makers improve designs and may help refine tourniquet training for use of tourniquets in children. Lessons learned from the epidemic of war casualties can inform civilian trauma care; bleeding from a traumatic amputation can differ little whether from a bomb, a car crash, or farm accident.

The goal of this study was to measure tourniquet use in pediatric trauma care to help identify if a gap in device design or clinical training exists.

METHODS

This survey is a retrospective review of deidentified data extracted from the Joint Trauma System's Joint Theater Trauma Registry at the US Army Institute of Surgical Research. A case count under a preparatory research agreement indicated that there were enough cases to proceed with a protocol. The protocol was reviewed by the US Army Medical Research and Materiel Command's Institutional Review Board staff, which determined that the protocol comprised research not involving human

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FIGURE 1. A prehospital tourniquet. Combat Application Tourniquet (CAT, North American Rescue Products used with permission). This tourniquet is a common prehospital tourniquet used in the current war. The CAT shown is the sixth version and is also known as a Generation 6 CAT.

subjects (Survey of Tourniquet Data in Pediatric Casualties, Study number: H 10 017, Log Number A 15950). This study was con ducted in accordance with the approved protocol.

The source of the data was the registry. The design was an observational cohort of those pediatric (age, <18 years) regis trants; that is, casualties at any US military hospital in theater. For a case to be included, tourniquet use was required; we ex cluded detainees and prisoners. The study period was May 17, 2003, to December 25, 2009. The study group had 88 casualties.

We collected the following data: age in years at time of injury; month and year of injury; sex; dominant injury cause (mechanism of injury); extremity Abbreviated Injury Scale (AIS, 2005 version) by maximum suffix, value 0 (injury ab sent), 1 (injury of minor severity) to 6 (maximal severity and unsurvivable with current care); Injury Severity Score (ISS, 2005 version); care information such as tourniquet use; death or survival outcome; and hospital stay duration. Tourniquet use was defined as a care code of either Tourniquet Use or Hemo static Not Otherwise Specified (Fig. 1). The latter was used infrequently for improvised tourniquets by some coders, mostly early in the war when tourniquet use was novel; in such cases, the electronic copies of the health care record confirmed tourniquet use. Extremity AIS codes are limited to injuries at or deep to the fascia. External injuries included burns and superficial injuries.

Analysis for continuous data was by Student *t* test using Bonferroni correction. We plotted data with Sigmaplot (version

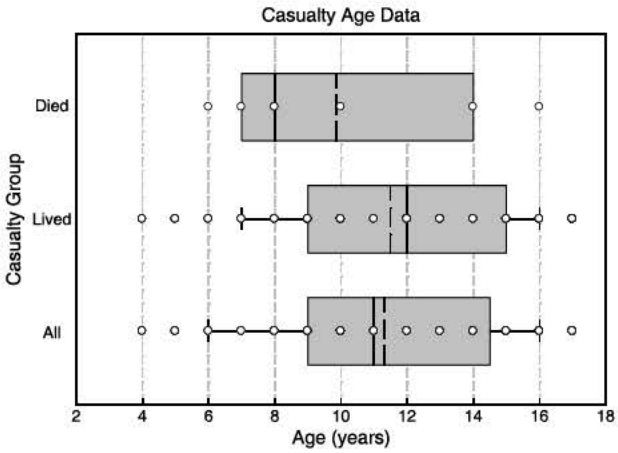

FIGURE 3. Children age data by group: those who died, those who lived, and all. Children ages in years for 3 groups: a subgroup of those 7 who died (top), a subgroup of those 81 who lived (middle), and all (bottom) 88 children. Circles in the horizontal point plot are the individuals' ages (whole number of years). The parameters are shown as a horizontal box plot with the right edge as the 75th percentile and the left edge as the 25th percentile. The box median is the solid line, whereas the dashed line is the average; and the 5th and 95th percentiles are left and right whiskers, respectively. For all children, the ages are slightly skewed to the right as the average is just right of the median. However, the ages of those that lived is skewed to the left. The ages of those who died are skewed to the right, opposite of those who lived. Although the groups were not statistically different by age overall, there was a trend that those who died were younger than those who lived ($P = 0.15$). Furthermore, data are near normally distributed (median and mean nearly equal) for those who lived and all but not for those who died.

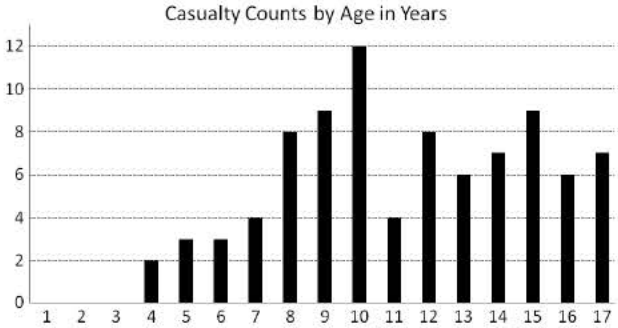

FIGURE 2. Study group age data. Column plot of counts of all 88 children by age. The *y* axis is casualty count; the *x* axis is age.

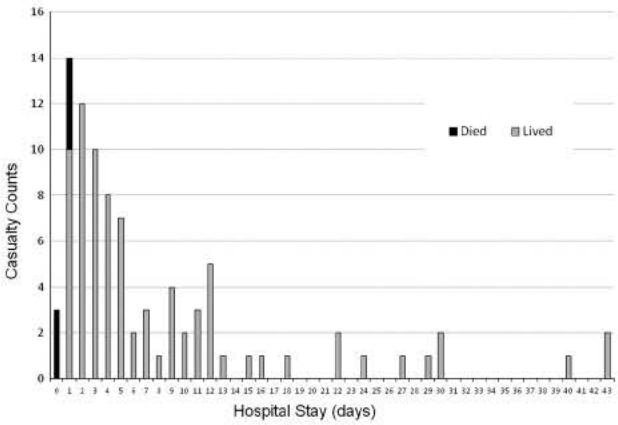

FIGURE 4. Hospital stay duration data by casualties who lived or died. Casualty counts by duration of hospital stay for 88 children by whether they lived (gray) or died (black).

TABLE 1. Injury Severity Data

	AIS Extremity Body Region			ISS		
Parameter	**All (N = 88)**	**Lived (n = 81)**	**Died (n = 7)**	**All (N = 88)**	**Lived (n = 81)**	**Died (n = 7)**
Mean	2	2	2	13	12	27
Median	3	3	1	10	10	16
Mode	3	3	1	10	10	None
Minimum	0	0	0	1	1	8
Maximum	4	4	4	75	41	75
SD	1.4	1.4	1.5	10.9	7.8	25.3
5% confidence limit	1.85	1.89	0.17	10.93	10.28	3.87
95% confidence limit	2.43	2.48	2.97	15.53	13.74	50.71

11, Systat Software, Point Richmond, CA) and MS Excel 2003 (Microsoft, Redmond, WA).

RESULTS

Study Group

Of the 88 casualties in the study group, 72 were male and 16 were female patients (82% and 18%, respectively). Ages averaged 11 years (range, 4 17 years; median, 11 years; mode, 10 years; Figs. 2 and 3). Sixty nine casualties were battle injuries, and 19 were nonbattle injuries. Fifty casualties (56%) were from Operation Iraqi Freedom, and 38 casualties (43%) were from Operation Enduring Freedom. The dominant mechanisms of injury were explosions (64%, 56/88), gunshot wounds (30%, 26/88), machinery accidents (3%, 3/88), knife (1%, 1/88), motor vehicle crash (1%, 1/88), and other blunt trauma (1%, 1/88). The mean (SD) duration of hospital stay was 8 (9.6) days (range, 0 43 days; median, 4 days; Fig. 4).

Outcome Analysis of the Survivors Versus the Dead

Of the 88 casualties, 7 died and 81 survived, resulting in an overall survival rate of 93%. For the 88 casualties, the mean (SD) AIS score was 2 (1.4) (range, 0 4; median, 3; mode, 3), and the mean (SD) ISS was 13 (10.9) (range, 1 75; median, 10; mode, 10; Table 1, Figs. 5 and 6). The extremity AIS data indicated that the proportion of those casualties with no (0) or minor (1) extremity injury had a relatively higher mortality than those with moderate (2), serious (3), or severe (4) injuries although those with no or minor extremity were cases that do not indicate tourniquet use, whereas those with moderate, serious, or severe injury often do; the latter have a higher threat to life.

The living and dead casualties were similar in all independent variables (including age, sex, and injury severity) measured, but living and dead casualties obviously differed for survival and hospital stay duration (Table 2). The 7 dead casualties died in or before the emergency department in 3 cases and on the first hospital day in the remaining 4 cases. The median hospital stay for the 7 dead casualties was thus 1 day, whereas the median for those casualties who lived was 5 days. For the dead, hospital stay was survival duration because they died in the hospital. For the 7 dead casualties, the mean ISS was 27 (range, 8 75; median, 16; Fig. 6). For the 7 dead casualties, one had the extremity as the highest AIS score of all body regions (eg, suffix 3 for extremity vs 2 for thorax), 2 had the extremity injured equally severe with another body region (eg, suffix 2 for both extremity and external injuries), and 4 had a nonextremity area as the most severely injured body area (eg, head, 6).

Analysis of Casualties With Versus Without Extremity Injury

Those casualties with a coded extremity injury (extremity AIS) numbered 67 children; the other 21 casualties had no extremity injury (extremity AIS suffix of 0). Of the 21 casualties with an extremity AIS score of 0, 14 had a burn or a superficial injury (external suffix of 1 or higher), and 7 had no external injury (external suffix of 0). Six (7%) of 88 casualties had neither extremity nor external injury; 5 lived. Of 81 living casualties, 19 (23%) had no extremity injury (extremity AIS suffix of 0), whereas of 7 dead casualties, 2 (29%) of 7 had no extremity injury (extremity AIS suffix of 0).

DISCUSSION

Although no previous report included an analysis of emergency tourniquet use in a cohort of children, the main finding of the present survey was that the general results seem similar to those recently reported for adults. The case count, the demographics, the injury severities, and the outcomes were within our expectations. We found the results interesting because they filled a specific knowledge and treatment gap, but there were no surprising findings. The survival rate of the present study, 93%, is

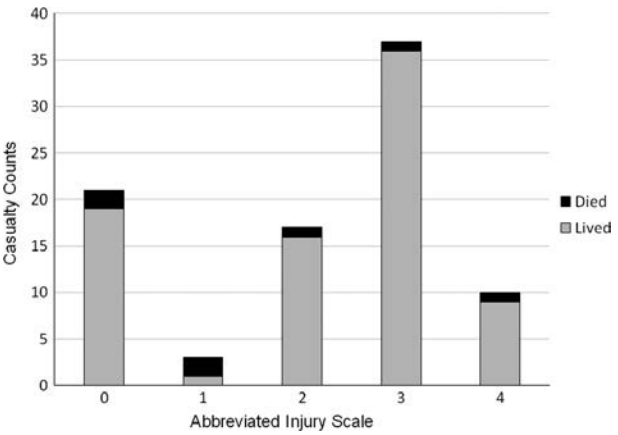

FIGURE 5. Casualty counts by AIS data and survival. The extremity AIS data indicated that the proportion of those casualties with no (AIS, 0) or minor (AIS, 1) extremity injury (17%, 4/24) had a relatively higher mortality despite not meeting a conventional indication for tourniquet use than those with moderate, serious, or severe extremity injury (respectively for AIS scores 2, 3, and 4; 5%, 3/64).

TABLE 2. Hospital Length of Stay Data

Parameter	Hospital Length of Stay		
	All (N = 88)	Lived (n = 81)	Died (n = 7)
Mean	8	9	1
Median	4	5	1
Mode	1	2	1
Minimum	0	1	0
Maximum	43	43	1
SD	9.5	9.7	0.5
5% confidence limit	5.9	6.4	0.1
95% confidence limit	9.9	10.7	1.1

similar to that of 3 recent large cohort studies: 87% each time it was measured.[2,3,9] The children primarily had extremity wounds for which the routine indication for tourniquets was possible exsanguination. Optimal use of tourniquets has been shown as lifesaving in adults by stopping bleeding.[4] A key problem evi denced in the present study is that although the mechanics of the user applying tourniquets to children seem satisfactory, the diagnostic or decision capacity of the person indicating the tour niquet use seems in need of help or clinical training. The goal of this study was to measure tourniquet use in pediatric casualty care to help identify if a gap in device design or clinical training exists; no design gap was found, but a clinical training gap was found.

Most of the deaths occurred in children with a lower in jury severity (ISS) than would be predicted. Four recent reports help understand the injury severity finding in pediatric hospital admissions during the current war. First, McGuigan et al[10] reported a period of study in 2004 in which 99 pediatric casu alties at a combat support hospital had similar demographics and outcomes as the present study. Second, a 2008 war casualty report by Matos et al[11] addressed indirectly the issue of a high mortality rate in the presence of low ISSs in children. Matos et al found that younger children who present to a combat support hospital have increased severity of injury compared with older children and adults. They concluded that in a popu lation with primarily penetrating injuries, after adjustment for severity of injury, younger children may also have an indepen dently increased risk for death compared with older children and adults.[11] Although the present survey did not confirm a differential survival propensity by age, indicators of such were oppositely skewed age data (Fig. 3). Perhaps, tourniquets in the acute care of children may have improved outcomes in the present study compared with those of the 2004 study by Matos et al when tourniquet use was less common. Third, in 2009, Creamer et al[12] reported 2000 wartime pediatric admissions to US military combat support hospitals; approximately 10% of all such admissions in Afghanistan and Iraq were children, and 38% had extremity wounds, the most common body region injured. More than half of the children required 2 or more in vasive or surgical procedures, 19.8% needed a transfusion, and the overall mortality rate was 6.9% (the same as in the pre sent study). The primary causes of death cited in the study by Creamer et al[12] involved head trauma and burns, in contrast to the low fatality rate for all other body regions. Fourth, Lundy et al[13] reported in 2010 that the most common pediatric ad mission diagnosis was trauma related such as gunshot wounds. The present study and these 4 referent studies begin to evidence the pediatric casualty experience in the current war.

Although current emergency tourniquets were ostensibly designed for modern adult soldiers, tourniquet makers, perhaps unknowingly, produced tourniquets that fit children. Although the use of emergency tourniquets such as the Combat Appli cation Tourniquet (Composite Resources, Inc, Rock Hill, SC and distributed by North American Rescue Products, Greer, SC) may look odd if 30 inches of its 37 inch strap hangs out loose past the buckle on a 4 year old child's arm, it can be entirely effective. Although the anthropometry of the US Army soldiers has been well studied and such data are useful to understand the limb circumferences that a tourniquet may be likely used for in combat, these data have limited application in children.[8] Be cause the wrist circumference of small soldiers (female first percentile, 13.61 cm) can approximate an infant's thigh (mean for males and females age 0 2 months, 9.1 cm), there may be a good fit for most children,[8,14,15] except perhaps in the smallest wrist of the smallest child, a hypothetical problem we have not yet seen. No pediatric specific problems were identified re garding device design. Given tourniquets of a set width and smaller limbs of children compared with those of adults, estab lished science indicates that the mechanical effectiveness, that is, capacity to occlude arterial flow, is more likely in smaller limbs.[14] In our experience, the children injured in war do not have pre injury comorbidities impairing tourniquet effectiveness occa sional to adults like calcified and incompressible arteries. Of 6 children with neither extremity nor external injury (no lesion indicating tourniquet use), 83% (5 of 6) died, whereas 2% of remaining 82 children died; attempts to do anything for a dying child may indicate user desperation. The current report can in crease awareness of pediatric issues in tourniquet use.

Limitations of the present report are several. The work was a retrospective survey of trauma care data and not a controlled experiment. The observations were limited to those data avail able in a trauma registry; the care records had limited data to

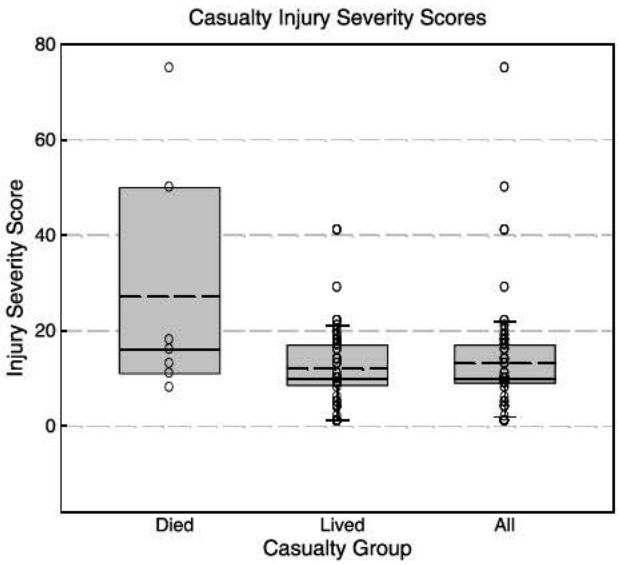

FIGURE 6. Injury Severity Score by survival. Casualty ISSs for 3 groups: a subgroup of those 7 who died (left), a subgroup of those 81 who lived (middle), and all (right) 88 children. The circles in the vertical point plot are the individuals' scores, the parameters are shown as a vertical box plot with the top as the 75th percentile and the bottom as the 25th percentile. The box median is the solid line, whereas the dashed line is the mean; and the 5th and 95th percentiles are bottom and top whiskers, respectively. Note that the group of those casualties who died had higher ISSs.

code. The AIS is a threat to life score, but it is only a crude surrogate of hemorrhage control need. An AIS score of 3 can be both femoral shaft fracture (simple spiral or transverse pat tern [Winquist I], 853251.3) with only minor blood oozing from an open wound in one case and a transtibial amputation injury (below knee, at or above ankle, 811003.3), with rapid death by exsanguination in another case. One may not indicate tour niquet use and may respond to a dressing and splint, whereas the other may indicate a tourniquet despite identical AIS se verities. Only broad findings can be made from such a score. Unfortunately, there is little else in the registry for hemor rhage control indication. A hemorrhage control measure is not the same thing as a hemorrhage control indication. A measure is only coded when enacted; there is no code for indication indication is inferred from other data. Furthermore, the circumstances of indication (care under fire, mass casualty situation, multiply in jured casualty requiring concurrent lifesaving interventions) are not routinely available for study in the registry. Therefore, the current survey is neither a detailed nor a direct look at whether the tourniquets were truly indicated in all cases.

Future directions for research are several. Civilian hospi tals and investigators may be able to survey pediatric casualties in need of extremity hemorrhage control to evidence civilian trauma gaps or care outcomes for comparison to war reports. A multicentered civilian survey may answer relevant questions. Although civilian and war trauma are often dealt with categor ically different, there are often overlaps in lessons learned de spite differences in rates and severities of injury; any such survey (eg, Survey of Tourniquet Use in a Combat Support Hos pital, 2006 2007; NCT00517166 at ClinicalTrials.gov which overlapped the present study for a period) or registry analysis may yield new knowledge. A detailed survey of casualties (as opposed to data from a registry) by a knowledgeable clinician scientist may address the topics of interest in greater depth than the present study, especially if at or near a busy hospital. Differential survival propensity by age deserves further re search. A prehospital hemorrhage control device for abdomi nal exsanguination is conceivable. A new device was recently approved and fielded for difficult inguinal bleeds; it has been used but needs further research. Many prehospital data gaps remain for tourniquet use such as hemorrhage control mea sures done with tourniquets and casualty responses to tour niquet release. Pediatric anthropometry referents may assist tourniquet designers in the future.[15]

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