ORIGINAL ARTICLE

Surgical treatment strategies in pediatric trauma patients: ETC vs. DCO—an analysis of 316 pediatric trauma patients from the TraumaRegister DGU®

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Abstract

Purpose External fixation within the damage control concept in unstable multiple trauma patients is widely accepted. Literature about its usage in the pediatric trauma population, however, is rare. The aim of the present study was to elucidate the factors associated with the application of external fixation in the severely injured child.

Methods Patients with severe trauma aged 0–54 years documented in the TraumaRegister DGU® were included in this study. Demographic data, pattern of injury, injury severity, use of the damage control orthopedics (DCO) or early total care (ETC) concept, duration of mechanical ventilation, intensive care stay, and total hospital stay as well as the occurrence of complications and mortality were evaluated. Statistical evaluation was performed using SPSS (Version 21.0.0) using Chi square tests and linear regression models.

Results While injury severity was comparable between children and adults, type of accident and injury patterns showed significant differences, Overall, the majority of surgical fracture stabilization in $AIS_{Extremity} \geq 3$ injuries followed the DCO concept in adults (60.3%) and the ETC protocol in children (49.4%). Conservative treatment was chosen for only 11.6% of all children and 9.6% of all adults. An increasing injury severity, $AIS_{Extremity} \geq 3$ and $AIS_{Extremity} \geq 3$ in ≥ 2 body regions, and a more advanced age were found to be independent factors in the use of the DCO concept in children.

Conclusion Use of external fixation increases with age and plays a minor role in the very young trauma population. However, this does not produce a difference in outcome between children and adults.

Keywords ETC · DCO · Children · Severely injured

Abbreviations

ACCP	American College of Chest Physicians
AIS	Abbreviated injury score
CNS	Central nervous system
CT	Computer tomography
DCO	Damage control orthopedic surgery
ESIN	Elastic intramedullary nailing
ETC	Early total care
ICU	Intensive care unit
ICM	Intensive care medicine

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MOF   Multi organ failure
MODS   Multi organ dysfunction syndrome
ISS   Injury Severity Score
SOFA   Sequential Organ Failure Assessment Score
TR-DGU   TraumaRegister DGU®

Introduction

Pediatric trauma is of high significance, as more than 10 million children require emergency department care for the evaluation and treatment of traumatic injuries in the western world each year [1]. Furthermore, the World Health Organization estimates that traumatic injuries result in almost 1 million deaths annually worldwide [2]. Beside life-threatening injuries such as traumatic brain injury, chest trauma or hemorrhagic shock, fractures, and soft-tissue injuries of the extremities and their surgical treatment also have a significant impact on both the acute clinical course and the long-term outcome [3].

For the adult trauma population, most patients clearly benefit from early definitive fracture stabilization [early total care (ETC)]. However, in specific subgroups (e.g., unstable hemodynamic condition, severe chest trauma) initial application of an external fixator with subsequent conversion to definitive treatment [damage control orthopedics (DCO)] has been suggested to reduce the incidence of posttraumatic complications (e.g., adult respiratory distress syndrome, ARDS or multiple organ failure, MOF) [4].

Despite this impact of surgical treatment strategies on the clinical course, the relevance of the ETC and DCO concepts in pediatric trauma patients has not been investigated so far. It is well accepted that knowledge gained from treatment of adults cannot be uncritically transferred to the pediatric situation, as children are known not to be just "small adults" [5, 6].

With this study, we therefore aimed to analyze and compare surgical treatment strategies for different age groups in the pediatric trauma population and adults as well as to determine variables in the decision to employ one or the other treatment strategy. Furthermore, outcome variables such as organ dysfunction, duration of hospital and ICU stay, and mortality were evaluated.

Materials and methods

The TraumaRegister DGU® (TR-DGU) of the German Trauma Society (Deutsche Gesellschaft für Unfallchirurgie, DGU) was founded in 1993 [7]. The aim of this multi-center database is a pseudonymized and standardized documentation of severely injured patients.

Data are collected prospectively in four consecutive time phases from the site of the accident until discharge from hospital: (A) pre-hospital phase, (B) emergency room and initial surgery, (C) intensive care unit (ICU) and (D) discharge. The documentation includes detailed information on demographics, injury pattern, comorbidities, pre- and in-hospital management, course during ICU treatment, relevant laboratory findings including data on transfusion, and the outcome of each individual. The inclusion criteria are admission to hospital via the emergency room with subsequent ICU/ICM care or reaching the hospital with vital signs and dying before admission to the ICU.

The infrastructure for documentation, data management, and data analysis is provided by the AUC—Academy for Trauma Surgery (AUC—Akademie der Unfallchirurgie GmbH), a company affiliated with the German Trauma Society. The scientific leadership is provided by the Committee on Emergency Medicine, Intensive Care and Trauma Management (Sektion NIS) of the German Trauma Society. The participating hospitals submit their pseudonymized data to a central database via a web-based application. Scientific data analysis is approved according to a peer review procedure established by Sektion NIS.

The participating hospitals are primarily located in Germany (90%), but an increasing number of hospitals from other countries contribute data as well (at the moment from Austria, Belgium, China, Finland, Luxembourg, Slovenia, Switzerland, the Netherlands, and the United Arab Emirates). Participation in the TR-DGU is voluntary. For hospitals associated with TraumaNetzwerk DGU®, however, the entry of at least a basic data set is obligatory for reasons of quality assurance.

The present study is in line with the publication guidelines of the TR-DGU and registered as TR-DGU project ID 2014-013. Injuries were coded according to the Abbreviated Injury Scale (AIS, version 2005/2008, Association for the Advancement of Automotive Medicine, Barrington, IL, USA). The severity of injuries was recorded according to the AIS as 1 (minor), 2 (moderate), 3 (severe, not life threatening), 4 (serious, life threatening), 5 (critical, survival uncertain), and 6 (maximum, currently untreatable).

Inclusion and exclusion criteria

All patients (aged 1–50 years) treated in a German hospital, presenting with an extremity fracture trauma (AIS ≥ 2) documented in the TR-DGU from January 1, 2009 until December 31, 2014 were included in the present study. An Injury Severity Score (ISS) ≥ 16 points was required for participation. According to different trauma mechanisms during childhood, adolescence, and adulthood, children were defined as all patients aged ≤ 15 years, while adults were defined as patients ≥ 16 years. In addition, subgroup analysis focused on

detailed information for patients aged 1–5 years, 6–10 years, 11–15 years, 16–17 years, and 18+ years.

Patients who were secondarily transferred to the reporting hospital were excluded because the initial treatment was missing. Also, patients transferred out early (< 48 h) were excluded because the final outcome was unknown. Patients documented with the basic core dataset only were excluded because there was no information about the type of surgery (DCO or ETC) in these cases.

Treatment strategies for extremity fractures were classified as conservative when no operative treatment was performed in any fracture, in early total care (ETC) or external fixation (DCO). In multiple fractures, patients were classified as DCO as soon as at least one fracture was treated by external fixation. The duration of ventilation and hospital stay were recorded. Furthermore, the occurrence of organ failure according to the Sequential Organ Failure Assessment Score (SOFA) was analyzed [8]. Organ function was considered to be inappropriate and defined as organ failure when the SOFA score was 3 or 4 points. Multiple organ failure (MOF) was defined as simultaneous failure of at least two organs. The incidence of systemic organ impairment (sepsis and MOF) was analyzed. The diagnosis of sepsis was made according to the criteria of the American College of Chest Physicians/Society of Critical Care Medicine (ACCP-SCCM) consensus conference committee [9, 10]. Mortality was reported as in-hospital mortality. Furthermore, we used the Revised Injury Severity Score, version II (RISC II) to predict the risk of death in severely injured patients that were primarily admitted to one of the reporting trauma centers and compared the data to mortality in the same group of patients [11].

Statistics

Categorical variables are presented as percentages only if the underlying total is obvious. Metric data are presented as mean and median with standard deviation (SD). Statistical comparisons between children and adults were performed with the chi-squared test and Mann–Whitney U test for categorical and continuous variables, respectively. Results were considered statistically significant at $P < 0.05$. However, due to the large sample size, even minor differences could become statistically significant. Therefore, interpretation of the results should focus on the clinical relevance of a difference rather than on statistical significance. All statistical analyses were performed using SPSS statistical software (SPSS 22.0; IBM Inc., Armonk, NY, USA).

Results

Epidemiology

In total, 5512 patients fulfilled the inclusion criteria. Of these patients, 316 were children while the remaining 5196 patients were adults. Of these patients, the majority in both groups suffered from blunt trauma (Table 1). The most common additional injuries (AIS ≥ 3) were to the head (children) and the thorax (adults) (Table 1). While children were most often injured as pedestrians or as cyclists, the majority of adults were involved in traffic accidents with a car or motorbikes (Table 1). Injury mechanisms are displayed in Table 1.

Independent factors for the application of external fixators

Multivariate analysis was performed to analyze the different treatment strategies (conservative, ETC, and DCO). The overall trauma severity ($P < 0.001$) and two or more affected body regions ($P = 0.032$) were significantly associated with the application of an external fixator. Furthermore, a relevant fracture of the extremities (AIS grade 3 or more; $P < 0.001$) as well as multiple fractures of the extremities (counted if AIS ≥ 2; $P < 0.001$) were also found to be independent predictors of the application of external fixation. Furthermore, it was found that external fixation was applied more often with increasing patient age. When comparing application of external fixators and early total care in subgroup analysis, the smallest number of fixators was applied in the age group 1–5 years ($P < 0.001$), followed by 6–10 years ($P < 0.001$) and children aged 11–15 ($P = 0.001$). In adolescent patients aged 16–17 years there was no such statistical significance between application of external fixation and early total care ($P = 0.200$), while in adults, usage of external fixation was found to be statistically significantly higher than early total care ($P = 0.049$). Figure 1 displays the choice of treatment in different age groups (Fig. 1).

Age-related differences in the ETC and DCO concepts

When $AIS_{Extremity}$ was ≥ 3, the application of external fixation increased significantly in both children and adults. However, an external fixator was still applied significantly more often than in children (39.0% vs. 60.3%, $P < 0.001$). Even with an $AIS_{Extremity}$ ≥ 3, children received more frequent definitive care than adults (49.4% vs. 30.2%, $P < 0.001$), whereas the number of applied external fixators doubled in adults when $AIS_{Extremity}$ was graded ≥ 3 (Table 2). Furthermore, an AIS ≥ 3 in ≥ 2 body regions doubled the numbers of applied external fixators in both groups (Table 2).

Table 1 Demographics, trauma mechanisms, injury pattern, and outcome in children and adults with extremity fracture

Demographics and baseline characteristics	Children n = 316	Adults n = 5196	P value
Demographics			
Age (years)	10/11 (12)	33/32 (11)	< 0.001
Male (%)	61.7	77.5	< 0.001
ISS	28.0/24 (12.1)	29.4/27 (12.3)	0.016
Hospital stay (days)	18.8/16 (15.1)	27.8/23 (23.2)	< 0.001
Days on ICU	8.8/4 (12.5)	11.1/6 (12.7)	< 0.001
Ventilation days	3.6/1 (5.7)	5.8/1 (9.1)	0.001
Trauma mechanism (%)			
Blunt	98.0	97.2	0.41
Penetrating	2.0	2.8	
Mode of accident			
Car	18.8	37.2	< 0.001
Motorbike	4.9	25.9	< 0.001
Bicycle	14.8	3.6	< 0.001
Pedestrian	33.6	6.8	< 0.001
High fall > 3 m	23.0	21.4	< 0.001
Low fall < 3 m	2.6	1.8	< 0.001
Other	2.3	3.2	< 0.001
Injury pattern (%)			
Head AIS ≥ 3	56.6	38.7	< 0.001
Thorax AIS ≥ 3	50.6	64.5	< 0.001
Abdomen AIS ≥ 3	18.0	23.4	0.029
Extremity AIS ≥ 3	62.0	71.8	< 0.001
Outcome			
Hospital mortality (%)	10.1	9.2	0.57
Expected mortality according to RISC II (%)	11.9	11.3	0.10
Multiple organ failure (%)	24.9	30.0	0.065
Sepsis (%)	5.6	7.3	0.28

Continuous values are presented as mean/median (standard deviation)
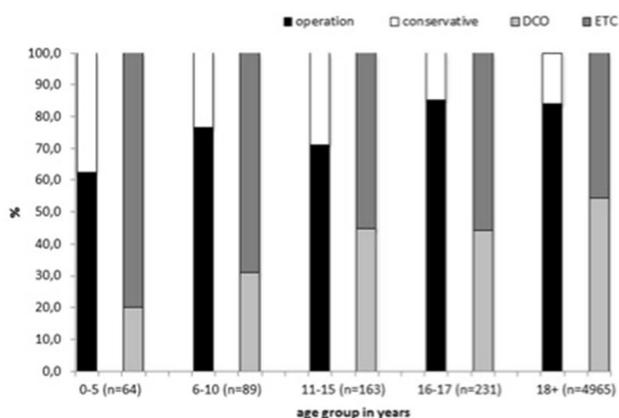
Fig. 1 Treatment strategies in different age groups of multiple injured children, adolescents, and adults

ISS ≥ 25 led to increased application of external fixation in children and adults, although its use in adults was significantly higher than in children (50.0% vs. 29.1%, P < 0.001). However, children with an ISS ≥ 25 were found to be treated conservatively equally often, whereas only 17.5% of adults received conservative treatment when ISS was graded ≥ 25 (Table 2). Multiple fractures (AIS ≥ 2) led to an increased use of external fixators in children. The same trends were seen in adults. In parallel with the increasing number of fractures, a definitive surgical strategy was chosen less frequently (Table 2).

Impact of trauma center level and time of admission

Treatment in trauma center levels 1 and 2 did show only minor differences. Children admitted to levels 1 and 2 trauma centers received conservative, definitive, or temporary fixation with equal frequency, whereas all children in trauma center level 3 were treated by a definitive strategy. In contrast, adults who

Table 2 Determinants of conservative or definitive surgical care or external fixation in children and adults

Baseline characteristics	Children	Children		Adults	Adults	
Severity of fracture	AIS 2	AIS ≥ 3		AIS 2	AIS ≥ 3	
n	144	172		1985	3211	
Conservative (%)	50.0	11.6		26.3	9.6	
Definitive (%)	40.3	49.4		52.5	30.2	
External fixator (%)	9.7	39.0		21.1	60.3	
Injured body regions (AIS ≥ 3)	1 Region	≥ 2 Regions		1 Region	≥ 2 Regions	
n	108	208		1380	3816	
Conservative (%)	38.9	24.0		20.0	14.5	
Definitive (%)	45.4	45.2		51.4	34.1	
External fixator (%)	15.7	30.8		28.6	51.3	
ISS	≤ 25	≥ 25		≤ 25	≥ 25	
n	168	148		2387	2809	
Conservative (%)	26.8	31.8		14.2	17.5	
Definitive (%)	50.6	39.2		46.0	32.5	
External fixator (%)	22.6	29.1		39.8	50.0	
Multiple fractures (≥ AIS 2)	1	2	3+	1	2	3+
n	219	71	26	2788	1371	1037
Conservative (%)	34.7	18.3	11.5	21.3	11.5	7.8
Definitive (%)	47.5	45.1	26.9	47.2	34.8	21.2
External fixator (%)	17.8	36.6	61.5	31.6	53.8	71.0
Trauma center	Level 1	Level 2	Level 3	Level 1	Level 2	Level 3
n	279	35	2	4583	564	49
Conservative (%)	29.4	28.6	0.0	15.7	18.1	16.3
Definitive (%)	44.4	48.6	100.0	37.9	43.4	57.1
External fixator (%)	26.2	22.9	0.0	46.3	38.5	26.5
Time of admission	Core time	On-call duty		Core time	On-call duty	
n	82	233		1506	3642	
Conservative (%)	30.5	28.8		15.0	16.4	
Definitive (%)	43.9	45.5		42.3	37.3	
External fixator (%)	25.6	25.8		42.7	46.2	
Mortality	Yes	No		Yes	No	
n	32	284		477	4719	
Conservative (%)	23.9	76.1		32.5	67.5	
Definitive (%)	1.4	98.6		2.6	97.4	
External fixator (%)	9.9	90.1		6.6	93.4	

were admitted to a level 1 trauma center received external fixation most often, whereas in level 2 and 3 definitive surgical fixation was preferred (Table 2). There was only a slight trend towards application of external fixation in adult patients during on-call shifts. Shifts did not influence treatment strategies in children. Mortality was highest in patients with conservative treatment in both groups, followed by those initially treated with external fixation (Table 2).

Discussion

The vast majority of previous studies investigated the relevance of the ETC and DCO concepts only in different subgroups of adult multiple trauma patients. With this study we aimed to extend this knowledge to the pediatric

trauma population. The main findings of the present study can be summarized as follows:

(a) The mode of accident and injury patterns varied significantly between adults and children
(b) ISS, injuries to multiple body regions, severe extremity fractures, and numerous extremity fractures were all independent predictors of the use of external fixation in adults and children.
(c) The use of external fixation increased with age
(d) The majority of children immediately received ETC.
(e) Expected and observed mortality as well as complications, such as sepsis and MOF, did not show significant differences between adults and children

Demographics, trauma mechanism, and injury pattern

Whereas pediatric and adult trauma patients both mainly suffered from blunt trauma, the mode of accident varied significantly between children and adults. While adults more often were injured in car accidents or as motorcyclists, children were affected as pedestrians or cyclists. Our data confirm the results published by other authors [12, 13]. Reichmann et al. compared 117 children (age 3–15 years) with 1159 adults (16–59 years) and found that injury frequency was comparable and extremity fractures were the most frequent injuries in both groups [12]. In agreement with Remmers et al. [13], we found severe head injury to be significant more often in children than in adults. It is well accepted that head injuries in children are more common due to the head being proportionally larger with respect to the body during growth [14]. In contrast, we and others found a higher incidence of severe thoracic trauma in adults [12]. This might represent a potential reason for the longer ventilation time and prolonged ICU stays in the adult trauma population [12, 15]. In contrast to data presented by Remmers et al., we could not prove higher mortality rates in children [13]. Furthermore, we did not find a higher MOF incidence in adults as described by Reichmann et al. [12]. These differences between our results and the aforementioned studies [18, 19] conducted in the late 1990s might be explained by accident prevention strategies and optimized treatment algorithms, which resulted in a lower MOF incidence and mortality rates in children and adults in recent decades. In this context, the mortality rate due to unintentional death in children decreased by 50% between 1970 and 1990, followed by another decrease of 29% between 2000 and 2009 and was reported to be 9.3% per 100.000 in 2013 [16, 17].

Usage of external fixation

The concept of DCO with initial external fixation and secondary definitive treatment is widely accepted in specific subgroups of adult multiple trauma patients. Those in an unstable or "in extremis" condition are considered especially for this surgical treatment strategy [18]. Pape et al. concluded that in these patients the DCO concept might be suitable to reduce the risk of developing systemic complications, such as MOF and ARDS [19]. However, literature in regard to the DCO concept and its application in the pediatric population is rare and was investigated only in very few studies with small cohorts [20–22]. In agreement with a previous study, we found a higher incidence of external fixation with increasing age in pediatric trauma patients [23]. This association might be explained by the fact that a higher proportion of younger children can be treated conservatively due to the higher correction potential in these patients. Furthermore, more invasive techniques for surgical fracture fixation must be used with increasing age (e.g., plate osteosynthesis in adolescents vs. K-wires or conservative treatment in younger children) [23, 24].

We also found that a high injury severity was associated with the application of external fixation rather than definitive surgical care. This finding was confirmed by Humphrey et al., who described a higher frequency of DCO treatment in cases of pediatric multiple trauma and in the presence of open fractures [21]. Also, Tolo et al. reported that the use of external fixation might be most favorable in children with injuries to multiple organ systems [25]. On the other hand, a high injury severity also seems to be associated with conservative treatment in the pediatric trauma population. This might be a result of prioritization of treatment of life-threatening injuries; in this scenario, fracture stabilization is of secondary importance [26].

In our study we found that, comparable to the adult situation, $AIS_{Extremity} \geq 3$ is an independent factor in the use of external fixation in children. Severe extremity injuries are most commonly associated with complex fracture patterns as well as severe soft-tissue injury [27]. For this situation, Tolo et al. clearly recommends external fixation for temporary stabilization to postpone definitive care until the general status of the pediatric patient has stabilized and local soft tissues have conditioned [25]. The time-saving effects might represent the most relevant reason for the use of the DCO concept in patients with an $AIS_{Extremity} \geq 3$ in ≥ 2 body regions in our study. Additionally, it is well described that external fixation has the potential to reduce the additional systemic burden of surgical procedures after severe trauma, thereby potentially decreasing the incidence of complications, such as MOF [28–30]. Accordingly, in multiple trauma patients with femoral fractures, DCO treatment was associated with both a decreased SIRS severity and duration compared to

primary intramedullary nailing, despite the higher overall injury severity in DCO patients [31].

Although children seem to present generally with a lower incidence of complications, sepsis, organ failure, or MOF [12, 32], no differences between adults and children were observed in the present study. Reasons such as a generally better physical condition in children than in adults, fewer co-morbidities, and a different posttraumatic inflammatory response are discussed in the literature [32–34]. To what extent treatment strategies such as DCO or ETC contribute the development of organ failure and outcome will therefore be the subject of future studies.

Strengths and limitations

Despite the typical pitfalls of registry analysis, such as completeness of reporting and different care policies, which should be taken into consideration [35], this study presents a large patient population, which has not been studied in such detail elsewhere. Although we only used data from German hospitals, which represents a trauma population with a majority of blunt trauma [36], these results might not be representative of the whole European population due to, e.g., different economical and structural properties. Finally, there is an increase in the number of participating hospitals per year presenting different levels of trauma care. However, approximately 80–85% of all data are contributed by Level I centers, whereas Level II facilities contribute approximately 15–19% and Level III centers, < 2% of all data. Therefore, we do not think that this distribution negatively biases our results.

Conclusion

High injury severity and severe extremity injures as well as multiple extremity injuries were found to be independent factors in the application of external fixation. Although the use of the DCO concept increases with age and is rarely used in the very young child, future studies should focus on identification of independent factors that predict pediatric trauma populations that will benefit from its usage.

Compliance with ethical standards

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