Open Fractures in Pediatric Orthopaedics—Can Pathways Improve Care? A 1-Year Pre and Postimplementation Analysis

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Background: In the care of open fractures, time to antibiotic administration has been shown to be a critical factor in preventing infection. To help improve outcomes at our institution we designed and implemented an open fracture pathway with the goal of reducing the time from emergency department (ED) arrival to antibiotic administration. Here we evaluate the success of this pathway, propose improvements in the protocol, and provide a framework for initiation at other institutions.

Methods: We compared a retrospective prepathway cohort with a prospective postpathway cohort for 1-year pre and postpathway implementation. First, we analyzed the number of patients from outside facilities who had received antibiotics before transfer. For patients who had not received antibiotics before arriving at our institution, we reviewed pathway metrics including time from ED arrival to the ordering and administration of antibiotics, whether the correct antibiotic type was selected, and time to surgical debridement.

Results: There were 50 patients in the prepathway cohort and 29 in the postpathway cohort. Prepathway 60.5% of transfers (23 of 38) received antibiotics before transfer, whereas postpathway 90.0% of transfers (18 of 20) received antibiotics ($P = 0.032$). For patients who had not received antibiotics before arriving at our institution and were included in pathway metric analysis, there were no differences in demographics or fracture characteristics. Time from ED arrival to antibiotic order decreased from 115.3 to 63.5 minutes ($P = 0.016$). Time from antibiotic order to administration was similar between groups (48.0 vs. 35.7 min, $P = 0.191$), but the overall time from ED arrival to antibiotic administration decreased from 163.3 to 99.2 minutes ($P = 0.004$). There were no significant differences in whether the correct antibiotic type was chosen ($P = 0.354$) or time from ED arrival to surgery ($P = 0.783$).

Conclusions: This study provides evidence that for pediatric patients presenting with open fractures, a care pathway can successfully decrease the time from ED arrival to antibiotic administration.

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Time from injury to antibiotic administration has been shown to be a critical factor in preventing infections in open fractures.[1,2] In type III open tibia fractures, time from injury to antibiotics of >66 minutes independently predicts infection.[3] Furthermore, recently Roddy et al[4] found open fracture patients that received intravenous antibiotics more than 2 hours after injury had higher rates of surgical site infections. Rapid administration of antibiotics depends on recognition and triaging in the emergency department (ED),[5] with some even advocating for antibiotic administration in the field by emergency care personnel.[6]

Care pathways are evidence-based treatment algorithms designed to optimize patient care. In pediatric orthopaedics, they have been shown to improve patient safety and clinical outcomes across the field from fracture care[7] to recovery protocols after scoliosis surgery.[8,9] In an effort to improve patient outcomes, our institution recently implemented an open fracture care pathway. This was developed in a collaboration between the orthopaedic, emergency medicine, trauma, and pharmacy teams with the goal of reducing the time from ED arrival to antibiotic administration.

On the basis of these findings, our pathway was designed to start from the time of patient triage in the ED to identify and fast track open fractures. We hypothesized that the delay from time of ED admission to administration of parenteral antibiotics would decrease after inception of the pathway compared with data before the pathway.

METHODS

Intervention

The open fracture pathway (Fig. 1) was designed by a multidisciplinary working group including orthopaedic, emergency medicine, trauma, radiology, infection

prevention, and pharmacy staff and providers. Implementation involved the creation of an electronic medical record open fracture order set, which included clinical decision support, to guide treatment. The pathway was published on both external and internal facing websites, and links to the pathway were placed within the new order set. An educational campaign was developed for all ED staff and orthopaedic trainees, along with a job aide and education from ED providers to front line ED staff to inform them of the importance of early antibiotic administration and the details of the pathway. All patients arriving to our ED, including transfers from other facilities, were evaluated by a triage nurse and the skin overlying the injury examined. For those with concern for open fracture, that information was communicated to a provider who would place the order for antibiotics per the pathway. For patient transfers from other facilities, those who had not yet received antibiotics were given the first dose in our ED per the pathway, whereas those who had previously received antibiotics were given subsequent doses per the pathway recommendations (Fig. 2).

Study Design

The study compares a retrospective prepathway cohort to a prospective postpathway cohort. After obtaining IRB approval, patients were selected based on international classification of diseases-10 and current procedural terminology codes for open fracture for 1-year pre and postpathway implementation with a 2-month washout period (date of implementation April 1, 2018, study period April 1, 2017 to May 31, 2019). Inclusion criteria were pediatric patients ages 0 to 18 years with open pelvic and extremity fractures. Exclusion criteria were spine, hand and foot fractures, and ballistic injuries. Our primary outcome was the time from ED arrival to the ordering and administration of antibiotics. We also examined other metrics included in the pathway, including selection of correct antibiotic type and duration (Fig. 2), and the time from ED arrival to surgical debridement. Data collected included age, fracture location, Gustilo-Anderson open fracture type,[10] whether patients were transferred from outside facilities and received antibiotics before transfer, time of ED admission, times of antibiotic ordering and administration, antibiotic type and duration, and time to surgery. For transfers from other facilities, patients who received antibiotics before transfer were included to note the percentage receiving antibiotics but excluded when considering time from ED arrival to the ordering and administration of antibiotics and other pathway metrics. Transfers who had not received antibiotics before arriving at our ED were given antibiotics as per the pathway and included in the pathway metric analysis.

Data Analysis

Data were analyzed from cohorts pre and postpathway inception. We calculated basic statistics including means and 95% confidence intervals and compared them using t tests. Although there is debate among statisticians, the t test is felt the be robust and resistant to moderate variations from normality, even in small sample sizes.[11–13] For binary variables, we used χ^2 (and Fisher exact test when needed for small sample sizes) under the assumption that the outcome of the test would be independent of the QI initiative with the alternative that they were related. All statistics were calculated using SPSS ver 25. (SPSS Inc.; Chicago, IL).

RESULTS

After applying inclusion and exclusion criteria, there were 50 patients available for analysis in the prepathway cohort and 29 patients in the postpathway cohort (Fig. 3). Regarding transfers from outside facilities, prepathway 60.5% of transfers (23 of 38) received antibiotics before transfer, whereas postpathway 90.0% of transfers (18 of 20) received antibiotics ($P = 0.032$) at outside facilities.

For patients that had not received antibiotics before arriving at our institution who were included in the pathway metric analysis, there were no differences in demographics or fracture characteristics between cohorts (Table 1). The majority of fractures were both bone forearm fractures, and most were type I open injuries. The time from ED arrival to antibiotic order decreased from an average of 115.3 to 63.5 minutes ($P = 0.016$), and time from ED arrival to antibiotic administration decreased from an average of 163.3 to 99.2 minutes ($P = 0.004$). Between the pre and postpathway cohorts, there were no differences in time from antibiotic order to administration (48.0 vs. 35.7 min, $P = 0.191$), correct antibiotic choice (92.6% vs. 100%, $P = 0.354$) or time from ED arrival to surgical debridement (12 vs. 11.1 h, $P = 0.783$). All patients in this study were treated with surgical irrigation and debridement, and all patients in both cohorts underwent surgical debridement within 24 hours of arrival (Table 2).

DISCUSSION

Time from injury to antibiotic administration in open fractures has been shown to be a primary factor in preventing infection.[1,2] No study to date that we know of has evaluated time to antibiotics exclusively in pediatric open fractures. Patzakis et al[2] report on a mixed group of 55 pediatric and 1049 adult patients. They found an infection rate of 4.7% in those given antibiotics within 3 hours of injury, and 7.4% in those receiving antibiotics after 3 hours, although no statistics were performed by the authors to demonstrate this as a significant difference. There are studies evaluating time to surgery for irrigation/debridement and infection rates,[14,15] finding no difference in groups treated before or after 6 hours. On the basis of this, the authors conclude that for patients given early antibiotics, time to surgery is a less important factor. Although there is a limited literature in pediatrics, information can be drawn from the adult studies. In type III open tibia fractures, time from injury to antibiotics of >66 minutes was found to independently predict infection.[3] Zuelzer et al[16] had similar findings with greatest risk of infection after 2.5 hours to have over 5 times higher rates of infection. More broadly across all open fractures,

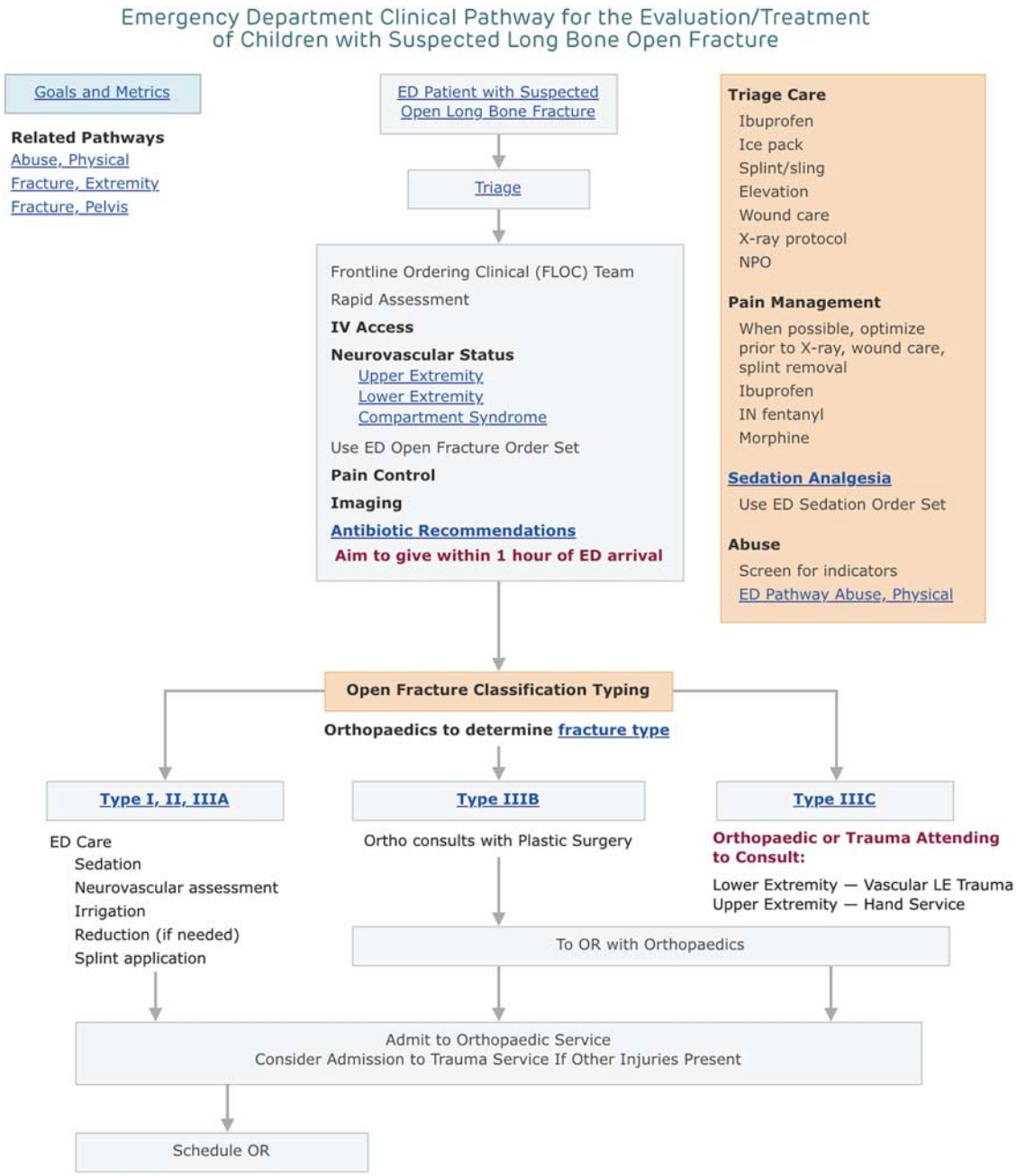

FIGURE 1. Open fracture care pathway. ED indicates emergency department; IV, intravenous; OR, operating room.

Roddy et al[4] found open fracture patients that received intravenous antibiotics more than 2 hours after injury had higher rates of surgical site infections. Although the exact time point varies among these studies, for both children and adults the message remains the same – that decreased time to antibiotics after open fractures reduces infection rates. With this in mind, we describe a pathway to decrease the time to antibiotics in pediatric patients with suspected open fractures.

Previous studies focusing on optimizing time to antibiotic administration in open fractures are limited to adult patients. Within those studies, several different approaches have been utilized to create and implement the protocols. Johnson et al[17] formed a multidisciplinary working group and created a pathway based on their recommendations. This included adopting new ED triage protocols, developing open fracture order sets in the electronic medical record, and keeping premixed antibiotics on hand in the ED. They found improved time from ED admission to antibiotic administration, decreasing from an average time of 123.1 to 35.7 minutes ($P < 0.001$). They also found significantly decreased time from admission to antibiotic order and from order to administration. In a follow-up study, these results were found to persist even 2 years after the protocol

Antibiotic Recommendations for Open Long Bone Fractures

Fracture Type	First Line	Allergy	Duration	Common Pathogens
I or II	**Cefazolin IV** 30 mg/kg/dose q 8 hrs MAX 2g/dose Concern for soil/fecal/farm contamination **ADD** **Penicillin IV** 100,000 units/kg/dose q 6 hrs MAX 4 million units/dose	**Clindamycin IV** 14 mg/kg/dose q 8 hrs MAX 900 mg/dose Type II fractures with significant contamination **ADD** **Gentamicin IV** 2.5 mg/kg/dose q 8 hours	24 hrs	Staphylococcus spp. Streptococcus spp. Anaerobes (*Clostridium spp.*) - soil/fecal/farm contamination
III A,B, or C	**Cefazolin IV** 30 mg/kg/dose every 8 hours; max: 2g/dose **AND** **Gentamicin IV** 2.5 mg/kg/dose q 8 hours Concern for soil/fecal/farm contamination **ADD penicillin IV** 100,000 units/kg/dose q 6 hrs MAX 4 million units/dose	**Clindamycin IV** 14 mg/kg/dose q 8 hrs MAX 900 mg/dose **AND** **Gentamicin IV** 2.5 mg/kg/dose q 8 hours	24 hours May go up to 72 hours if a delay in repair or incomplete debridement	Staphylococcus spp. Streptococcus spp. Gram-negatives Anaerobes (*Clostridium spp.*) - soil/fecal/farm contamination

FIGURE 2. Antibiotic recommendations for open fracture care pathway.

implementation.[18] Average time from admission to antibiotic administration did increase after 2 years from 35.7 to 50 minutes, but there was no statistically significant difference between these times, and the reduction in time compared with pre intervention remained significant ($P = 0.007$).

Collinge et al[19] developed a protocol with a focus on multidisciplinary education efforts to reduce the time to antibiotic administration, with a goal of under 1 hour. After initiation, average time from admission to antibiotic administration decreased from an average of 70.5 to 32.4 minutes ($P < 0.001$). Before the protocol 50% of patients received antibiotics within 1 hour of admission compared with 78% in group 2 ($P < 0.001$). In a similar performance improvement project, Siebler et al[20] developed a protocol with a goal of antibiotic administration under 60 minutes. After implementation, time to antibiotics decreased from 97 to 46 minutes ($P < 0.001$), with 34% of preprotocol patients and 84% of postprotocol patients receiving antibiotics within 60 minutes of admission ($P < 0.001$). Oliphant et al[21] established a pay-for-performance metric for patients receiving antibiotics within 120 minutes of arrival in the ED within a statewide trauma collaborative. They met their goal of 85% of patients receiving antibiotics in under 120 minutes by year 2 after implementation (87.9%) and reached 88.5% by 3 years [mean time to antibiotics 57.9 min at baseline compared with 43.3 min after 3 y ($P < 0.05$)].

Common factors among the successful strategies implemented by these studies include a multidisciplinary approach, a focus on educational efforts, optimizing the use of the electronic medical record, and early triage in the ED. Similarly, our pathway utilized each of these strategies to reduce the time to antibiotics in pediatric patients with suspected open fractures.

Although we significantly reduced the time from ED arrival to antibiotic administration from 163.3 to 99.2 minutes ($P = 0.004$), 3 remains room for improvement. On the basis of our results and comparing them with prior studies, we note several areas for improvement to the pathway that have been proposed and implemented. Starting at the beginning of the process, our average time from arrival to order was just over 1 hour. This likely reflects the inefficiencies of the ED where patients need to be triaged, their vital signs obtained, placed in a room, and seen by a practitioner (only providers/physicians and advanced practitioners can place orders), all in the context of the evaluation and treatment of other nonorthopaedic patients. Certainly, there is a room for improvement and efforts are ongoing to streamline the process of alerting providers of the need for an antibiotic order. In addition, our institution has been working with pharmacy and ED nursing to decrease the time from antibiotic order to administration.There was a nonsignificant improvement in this metric after implementation of the pathway, but with an average time of 35.7 minutes, we believe this can be optimized. This indicates the need for a more direct and/or prominent communication method between the ordering provider, nursing, and pharmacy, and perhaps using the strategy of keeping premixed antibiotics in the ED. In addition, our study highlighted the role of outside institutions,

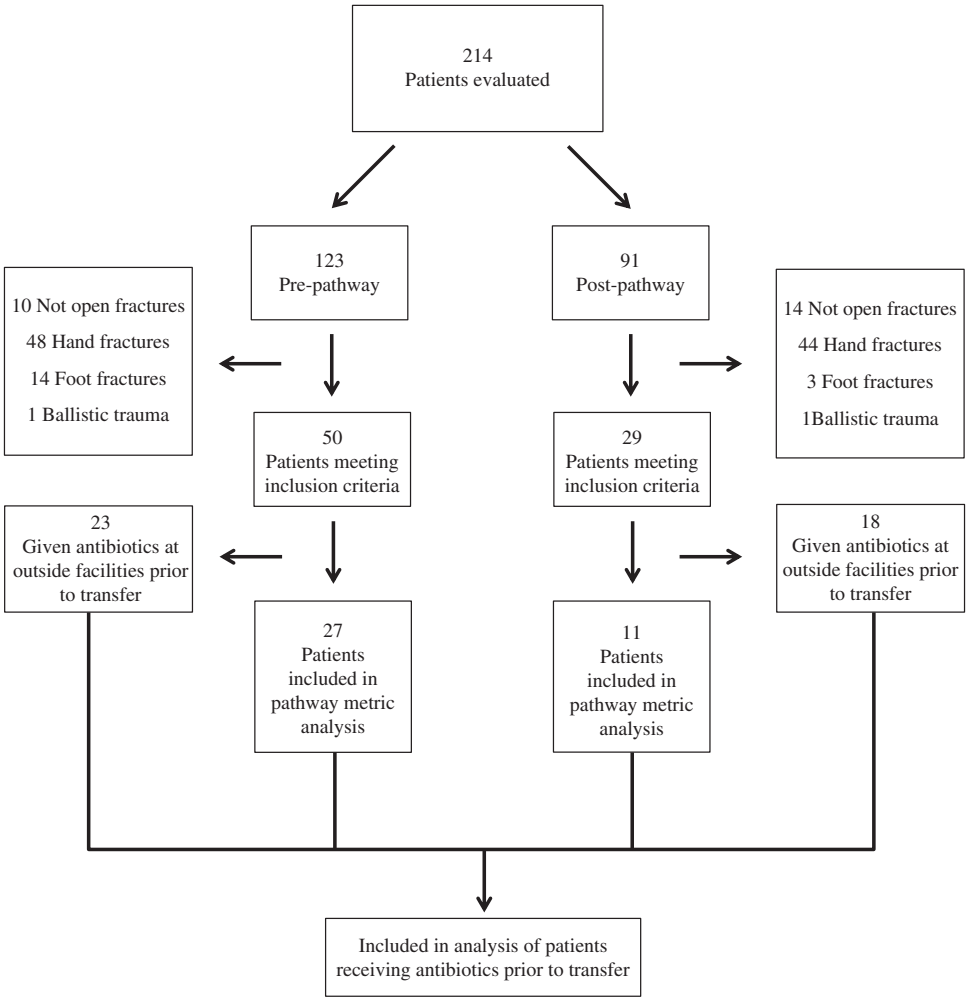

FIGURE 3. Flow diagram of patient selection with exclusion criteria.

TABLE 1. Patient and Fracture Characteristics for Patients Included in Pathway Metric Analysis

	Prepathway n = 27	Postpathway n = 11	*P*
Age (y)	9.6 (8.6,10.6)	10.1 (6.7,13.6)	0.46
Sex			
Female	8 (29.6%)	1 (9.1%)	0.237
Male	19 (70.4%)	10 (90.9%)	
Laterality			
Left	14 (51.9%)	5 (45.5%)	0.728
Right	12 (44.4%)	6 (54.5%)	
Bilateral	1 (3.7%)	0	
Fracture location			
Bbffx	17 (63%)	6 (54.5%)	0.722
Distal radius	2 (7.4%)	1 (9.1%)	
Ulna/monteggia	1 (3.7%)	0 (0.0%)	
SCH	2 (7.4%)	0 (0.0%)	
Femur	0 (0.0%)	1 (9.1%)	
Tib/fib	5 (18.5%)	3 (27.3%)	
Gustilo type			
1	22 (81.5%)	8 (72.7%)	0.667
2	4 (14.8%)	3 (27.3%)	
3	1 (3.7%)	0 (0.0%)	
Transfers from OSH	15 (55%)	2 (20%)	0.7

Bbffx indicates both bone forearm fracture; OSH, outside hospital; SCH, supracondylar humerus fracture; Tib/fib, tibia/fibula.

particularly the consideration for administration of antibiotics in cases of suspected open fractures before transfer to our center. Although this was not initially a part of the formal protocol, we did note that more patients received antibiotics before transfer in the postpathway time period compared with prepathway, perhaps due to heightened awareness. Our hope is that with formalization into the protocol we can further increase the percentage of patients receiving antibiotics before transfer. Some authors have even proposed antibiotic administration in the field by emergency medical personnel, with a small series demonstrating that this can be done safely,[6] which warrants consideration. Further efforts could be made to improve communication between the ED and emergency medical personnel in the field to allow for even earlier triage and antibiotic administration.

There are several limitations of this study. First, our time points all begin with admission to the ED, and due to variability in reporting we are not able to calculate time from actual injury to antibiotic administration. In addition, we do not have access to several other data points that may be important for quality improvement, including method of transport to the ED and whether an IV was placed before

TABLE 2. Pathway Metrics Before and After Implementation of the Open Fracture Protocol

	Prepathway cohort n = 27	Postpathway cohort n = 11	*P*
ED arrival to Abx order (min)*	115.3 (85.0,145.5)	63.5 (32.5, 94.4)	0.016†
Abx order to Abx admin (min)*	48.0 (32.6, 63.7)	35.7 (23.7,47.7)	0.191
ED arrival to Abx admin (min)*	163.3 (133.0, 193.6)	99.2 (66.8, 131.5)	0.004†
Abx admin within 1 h of arrival [n (%)]	3 (11.1%)	2 (18.2%)	0.615
Correct Abx choice [n (%)]	25 (92.6%)	11 (100%)	0.354
ED arrival to surgery (h)	12.0 (7.9,16.1)	11.4 (9.4, 13.4)	0.783
Surgery within 24 h of ED arrival [n (%)]	27 (100%)	11 (100%)	0.999

*The values are given as the mean followed by the 95% confidence interval in parentheses.
†Significant ($P \leq 0.05$).
ED indicates emergency department.

arrival. Improved data collection could be implemented to improve recording of this important information. In addition, it is likely that after the implementation of this pathway staff knew they were being observed, raising concerns for the Hawthorne effect. We also do not yet know the long-term sustainability of this project, and whether the demonstrated improvements can be maintained. We hope that with continued educational efforts we will be able to improve our times, but continued monitoring will be needed to ensure this. Although this study was based at a large tertiary referral center, we have relatively small numbers of patients, possibly introducing type II error, although we do find significant results in our primary outcomes. Post hoc power analysis for the outcomes we did not find significance in could be considered; however, there is evidence that this approach does not provide meaningful information.[22] This work could potentially serve as a pilot study for a larger multicenter study to expand the number of patients. In addition, we do not consider clinical outcomes, and so we do not know in our study population whether this decrease in time to antibiotic administration decreased infection rates, although as discussed above there is an abundant evidence supporting this goal.

CONCLUSION

This study demonstrates that an open fracture care pathway can decrease the time from ED arrival to antibiotic administration for pediatric open fractures. This study can serve as a template for initiation of similar protocols at other institutions.

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