Factors That Drive Annual Variation in Pediatric Elbow Fracture Occurrence, Severity, and Resource Utilization

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Background: Elbow fractures are the most common pediatric fractures requiring operative treatment. To date, few studies have examined what annual factors drive pediatric elbow fracture incidence and no studies have examined which annual factors drive elbow fracture severity or resource utilization. The goal of this study was to not only document the annual patterns of pediatric elbow fracture incidence and severity but also the impact of these patterns on resource utilization in the emergency department, emergency medical service transportation, and the operating room (OR).

Methods: Retrospective cohort study of 4414 pediatric elbow fractures from a single tertiary hospital (2007 to 2017). Exclusion criteria included outside treatment or lack of diagnosis by an orthopaedist. Presentation information, injury patterns, transport, and treatment requirements were collected. Pearson correlations were used to analyze factors influencing fracture incidence, severity, and resource utilization.

Results: Pediatric elbow fracture incidence positively correlated with monthly daylight hours, but significantly fewer elbow fractures occurred during summer vacation from school compared with surrounding in school months. While fewer overall fractures occurred during summer break, the fractures sustained were greater in severity, conferring higher rates of displacement, higher risk of neurovascular injury, and greater needs for emergency transportation and operative treatment. Yearly, elbow fractures required 320.6 OR hours (7.7% of all pediatric orthopaedic OR time and 12.3% of all pediatric orthopaedic operative procedures), 203.4 hospital admissions, and a total of 4753.7 miles traveled by emergency medical service transportation to manage. All-cause emergency department visits were negatively correlated with daylight hours, inversing the pattern seen in elbow fractures.

Conclusion: Increased daylight, while school was in session, was a major driver of the incidence of pediatric elbow fractures. While summer vacation conferred fewer fractures, these were of higher severity. As such, increased daylight correlated strongly with monthly resource utilization, including the need for emergency transportation and operative treatment. This study provides objective data by which providers and administrators can more accurately allocate resources.

Level of Evidence: Level III—Retrospective comparative study.

Key Words: pediatric, elbow, fractures, resource allocation, annual variation, elbow fracture, fracture severity, operating room usage, emergency medical services, tertiary care center

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Pediatric fractures are a frequent cause for presentation to an emergency department (ED).[1,2] Elbow fractures account for a large proportion of these, second only to forearm and hand fractures.[1–4] Unlike forearm and hand fractures, which are commonly managed with sedated reduction and casting, pediatric elbow fractures have higher rates of neurovascular injury and operative fixation.[5,6] Thus, resources including emergency transport, ED evaluation, orthopaedic consultation, operating room (OR) usage, and hospital admission are required to care for elbow fractures.[7–9]

Prior epidemiological surveys have demonstrated that the incidence of pediatric fractures, overall, peaks during warmer months. Some studies found increased fracture incidence during summer vacation,[1,10–12] while

others noted peaks in spring and autumn with lower rates in the summer.[3,13–17] There are many suggested causes for these trends, including weather patterns,[1,11,14,15] increased hours of daylight,[4,10,14,18,19] increased vacation or outdoor activities,[3,4,13,14,20] and biological and nutritional factors affecting bone.[16,18] While broadly examined across fracture types, few studies have specifically examined which annual factors drive pediatric elbow fracture incidence and severity. Furthermore, no studies to date have examined the impact of these annual trends on resource utilization by health care facilities.

Through retrospectively examining 10 years of pediatric elbow fractures, this study tested the hypothesis that the warmer temperatures, increased daylight during daylight saving time (DST), and children being out of school for summer vacation would positively correlate with the incidence and severity of pediatric elbow fractures treated at a tertiary care center in Tennessee. We further hypothesized that resource utilization would vary throughout the year in concordance with the patterns of incidence and severity. In addition to providing empirical evidence to the annual trends of pediatric elbow fracture incidence and severity, this study presents novel information to guide optimization of yearly resource allocation for the treatment of pediatric elbow injuries.

METHODS

After Institutional Review Board review and approval (IRB#171899), Current Procedural Terminology (CPT) codes for the treatment of elbow fractures were used to identify pediatric patients (0 to 17 y of age) treated at a single center from November 2007 to October 2017. Exclusion criteria included lack of diagnosis by an orthopaedist and/or treatment at an outside facility. The electronic medical record was used to retrospectively gather data on presentation, home county, transport, injury pattern, evaluation, and management for these patients. Deidentified study data were collected and managed using REDCap (Vanderbilt University, Nashville, TN).[21,22] Monthly temperature[23] and daylight hours[24] were strongly correlated ($r = 0.88$), thus all correlations will be presented against average daylight hours. School summer vacation schedule was based on the public-school calendar for Davidson County where the study institution is located. The population of Davidson County, TN was ~690,000 by the end of 2017 with ~142,000 citizens under 18 years of age (20.6%).[25]

Total volume of ED visits, total OR time and cases, consultation requests to orthopaedics, and total clinic visits for the entire study period were obtained from departmental databases.

The injury pattern as diagnosed by an orthopaedist was recorded. To estimate severity, fractures were sorted based on the presence of neurovascular injury and fracture displacement (displaced or nondisplaced, Supplemental Index 1, Supplemental Digital Content 1, http://links.lww.com/BPO/A374).

Because of failed normality testing, nonparametric testing was used throughout. Comparisons of categorical data were made using the Pearson χ^2 tests and continuous data were made using Mann-Whitney, Friedman, or Kruskal-Wallis tests. Pearson correlations were calculated to analyze the trends between daylight and main study variables. A P-value < 0.05 was significant. All statistical calculations and figures were generated with GraphPad Prism version 8.0.0 (Graphpad Software, La Jolla, CA).

RESULTS

During the study period, 4609 elbow fractures were identified in 4489 patients. Patients were excluded to yield a final cohort of 4414 fractures in 4309 patients (Fig. 1) with an average age of 6.48 years (SD ± 3.29 y). Those experiencing multiple elbow fractures during the study had an average duration of 2.30 (SD ± 1.74) years between fractures.

Elbow Fracture Volume

Elbow fracture volume did not vary considerably between years across the study period (Supplemental Fig. 1, Supplemental Digital Content 2, http://links.lww.com/BPO/A375). Average elbow fracture volume varied by month ($P < 0.05$) with peaks in April (48.6/month), May (50.1/month), and September (44.3/month) (Fig. 2), resulting in a positive correlation with average daylight hours (ADH, $r = 0.79$). Elbow fracture incidence increased in months during DST (March to October, 42.6 fractures/month) compared with those outside DST (November to February, 26.2 fractures/month, $P < 0.05$). Within DST, elbow fracture volume decreased during summer vacation months (DST-vacation; June to August) compared with school months (DST-school; March to May, September to

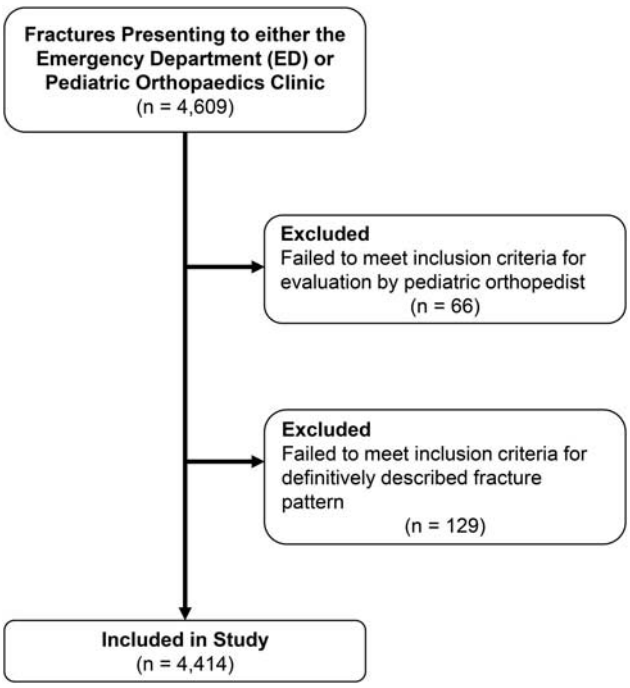

FIGURE 1. Exclusion criteria. A total of 4609 elbow fractures were identified based on Current Procedural Terminology codes and age filters (age under 17 y). Patients were excluded if fracture pattern was not diagnosed by a pediatric orthopaedist (n = 195). The total sample size was 4414 elbow fractures.

October), with 11.4% more fractures per month occurring in DST-school. This difference approached significance ($P = 0.052$).

Fracture Severity

During the study period, 51.9% (N = 2291) of fractures were displaced whereas 42.0% (N = 1854) were nondisplaced. Degree of displacement could not be determined retrospectively in 6.1% of fractures. Displaced fractures occurred more often during DST, leading to a strong positive correlation between the monthly number of displaced fractures and ADH ($r = 0.82$, Fig. 3A). In contrast to incidence, the rate of displaced elbow fractures during DST-vacation was higher than during DST-school. Aligning with rates of displaced fractures, neurovascular injury occurred more frequently during DST, causing a positive correlation between monthly neurovascular injuries and ADH ($r = 0.67$, Fig. 3B). During DST-vacation, 8.7% of patients with fractures experienced neurovascular injury compared with 7.9% during DST-school. In total, across the 10-year study period, 302 patients (6.8%) experienced concurrent neurovascular injuries.

Presentation of Elbow Fractures

All-cause visits to the pediatric ED varied predictably[26–29] by month with peaks in December (4825.2/month) and March (4754.3/month) (Fig. 4A). During DST-vacation, the number of ED visits dropped, causing a negative correlation between total monthly pediatric ED visits and ADH ($r = -0.70$). Of patients with elbow fractures, 41.2% (N = 1819) first presented to the ED or orthopaedics clinic, whereas 58.5% (N = 2582) were referred from an outside clinic or hospital [outside hospital (OSH), Table 1]. Yearly, pediatric elbow fractures accounted for 6 of every 1000 ED visits, but the proportion of monthly ED visits secondary to elbow fractures varied by over 200% throughout the year (5.0 elbow fractures/1000 visits in December vs. 11.1/1000 in May). Aligning with increased fracture severity, patients were 12% more likely to present to the ED than to clinic during DST-vacation ($P > 0.05$, Fig. 4B). Aligning with fracture incidence, we observed an increase in total consultations to the pediatric orthopaedic service in DST ($r = 0.77$, Fig. 4C) with elbow fractures accounting for 14.7% of all pediatric orthopaedic surgery consultations yearly. Notable less dynamic, total orthopaedics clinic visits varied minimally between months, resulting in a weak, positive correlation, with ADH ($r = 0.55$).

Transport of Elbow Fractures

The study encompassed a wide geographic region. In total, 1637 elbow fractures (36.2%) were from patients residing in Davidson County, TN, the same county as the tertiary

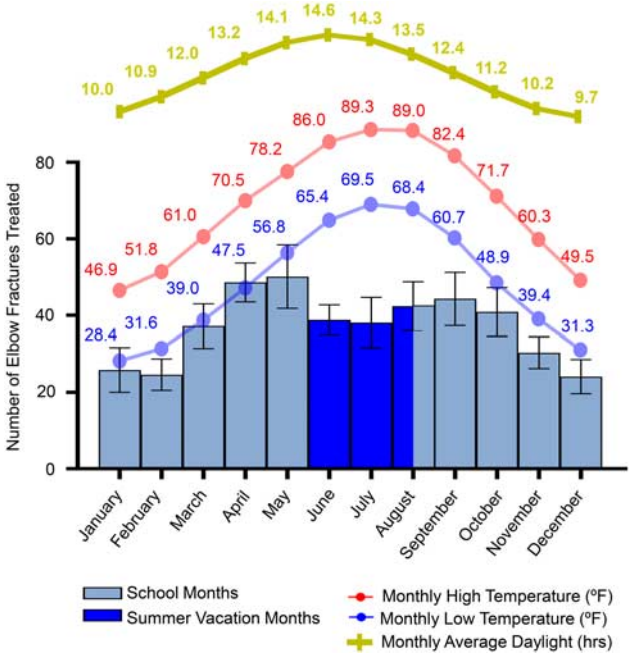

FIGURE 2. Average monthly variation of pediatric elbow fracture incidence. Monthly variation in pediatric elbow fracture volume was observed. Monthly average daylight hours and temperatures significantly correlated with fracture incidence ($r = 0.79$). Graph presented as mean ± SD.

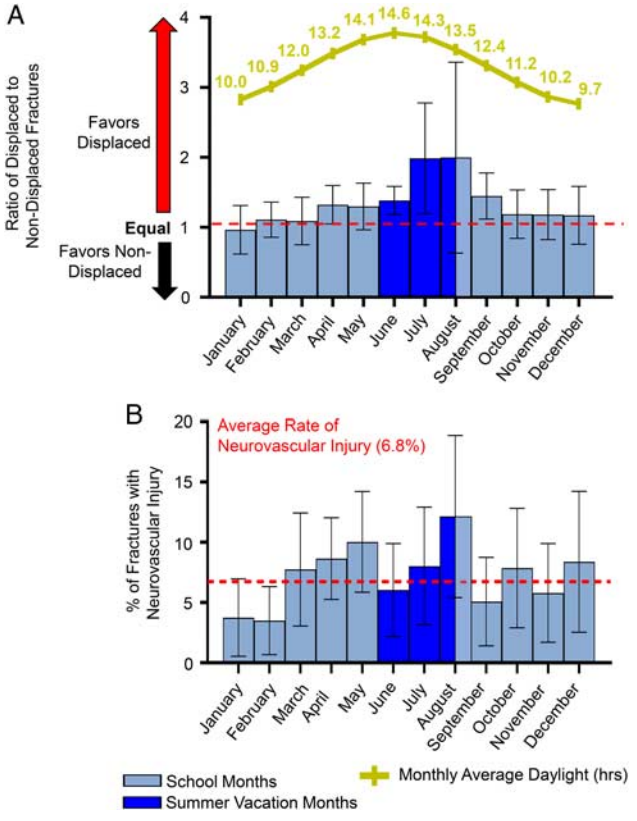

FIGURE 3. Average monthly variation in elbow fracture severity. A, The ratio of displaced to nondisplaced elbow fractures. B, Rate of neurovascular injury were averaged monthly. Dotted lines represent (A) equal displaced and nondisplaced rates and (B) average rate of neurovascular injury in the study population. Daylight correlated significantly with displacement ($r = 0.85$) and neurovascular injury ($r = 0.67$) by month. Graphs presented as mean ± SD.

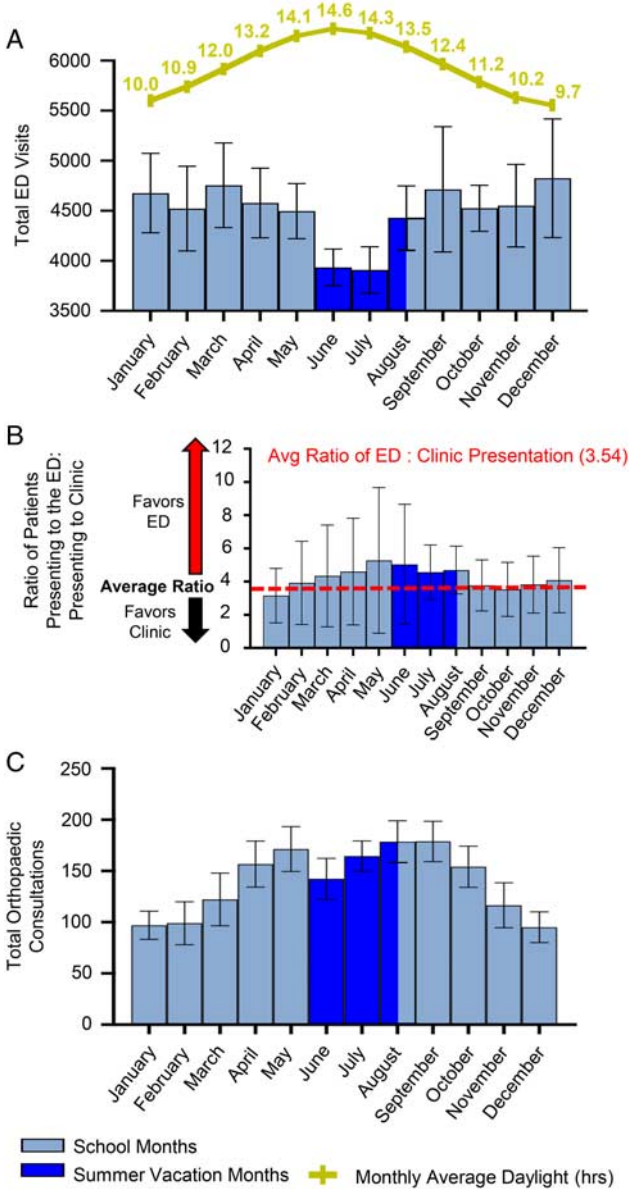

FIGURE 4. Location of presentation of elbow fractures. A, Monthly variation in total pediatric emergency department (ED) visits was observed and demonstrated a significant negative correlation between daylight hours ($r = -0.70$). B, Ratio of patients presenting to the ED versus a clinic correlated with daylight hours ($r = 0.85$). C, The number of total orthopaedic consultations was observed. Dotted line represents average ratio of ED visits to clinic visits in the study population. Graphs presented as mean ± SD.

care center. An additional 1562 patients (35.1%) presented from the immediately adjacent counties, and the remaining 1247 patients (28.0%) presented from other counties in Tennessee, Kentucky, or Alabama (Fig. 5A). Patients traveled an average of 32.4 miles for evaluation of their fractures. Aligning with variable fracture incidence, total distance traveled by patients per month positively correlated with ADH ($r = 0.78$, Fig. 5B).

Of the 2582 patients transferred from an OSH (55.1% of all fractures), 38.2% (N = 986) arrived through emergency medical service (EMS) transportation (ambulance or air) (Table 2, Fig. 5C). Of those transported through air (n = 20), 19 were displaced fractures that eventually required operative fixation and 1 was a nondisplaced fracture. The nondisplaced fracture was a polytrauma with additional open fractures and a high-velocity mechanism (dirt bike wreck). A positive correlation between fractures transferred by EMS monthly and ADH was observed ($r = 0.81$). Mirroring fracture severity, patients required proportionately more EMS transport during DST-vacation than DST-school ($P > 0.05$). Of those referred from an OSH, those transported through EMS traveled an average of 51.0 miles while those who self-transported traveled an average of 37.1 miles. Those transported by EMS traveled an average of 4753.7 total miles annually compare to an average of 5428.2 miles traveled annually by those self-transporting. Following referral from an OSH, the distance traveled by patients (all travel or EMS only transport, respectively) significantly correlated with ADH ($r = 0.76$, 0.78, Fig. 5D).

Treatment of Pediatric Elbow Fractures

A total of 2258 operative procedures were performed for elbow injuries. On average, 225.8 operative fractures occurred yearly, accounting for 12.3% of all pediatric orthopaedic surgeries conducted at our institution (Fig. 6A). There was an increase in operatively treated elbow fractures during DST, resulting in a positive correlation between OR usage and ADH ($r = 0.88$). In total, pediatric elbow fractures required 320.6 OR hours per year (range: 285.9 to 353.8 h), accounting for 7.7% of the yearly pediatric orthopaedic OR time (Figs. 6B, C). There was no significant difference in average case length per month ($P > 0.05$). Elbow fractures required 203.4 hospital admissions yearly and required admission more often during DST (20.4 admissions/month vs. 10.6 admissions/month, $P < 0.05$, Fig. 6D). Aligning with increased severity, a significantly higher proportion of operative injuries occurred during DST-vacation ($P < 0.05$), but, compared with DST-school when incidence is greater, no difference was observed in total number of operative cases, OR time, or admissions per month ($P > 0.05$).

DISCUSSION

Pediatric elbow fractures are overwhelmingly common and potentially devastating injuries. This is the first and largest comprehensive, directed analysis of annual variation in the incidence, severity, and resource utilization for the treatment of pediatric elbow injuries. Elbow fracture incidence and severity both strongly correlated with monthly ADH, producing a similar monthly variation in resource utilization. This contrasted the all-cause number of ED visits, which peaked outside of DST (Fig. 4A). This finding is consistent with previous studies showing variable volume in pediatric EDs through the year mirroring peak rates of annual viral epidemics and other chronic conditions.[26,27] Furthermore, the incidence of elbow fractures was highest during DST-school with a slight

TABLE 1. Incidence of Location of First Encounter for Care of Pediatric Elbow Fractures (2007 to 2017)

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sept	Oct	Nov	Dec
Study Institute Emergency Department	86 (33)	84 (34)	132 (35)	179 (37)	192 (38)	130 (34)	134 (35)	151 (36)	165 (37)	119 (32)	108 (36)	89 (37)
Outside Hospital Emergency Department	105 (41)	104 (42)	157 (42)	199 (41)	209 (42)	180 (46)	173 (45)	192 (45)	180 (41)	158 (43)	117 (39)	97 (40)
Study Institution Orthopaedics Clinic	19 (7)	20 (8)	21 (6)	29 (6)	27 (5)	19 (5)	19 (5)	22 (5)	23 (5)	24 (6)	13 (4)	14 (6)
Other clinic	36 (14)	33 (13)	49 (13)	61 (13)	56 (11)	43 (11)	42 (11)	47 (11)	56 (13)	59 (16)	49 (16)	31 (13)
Other or not specified	11 (4)	5 (2)	13 (3)	18 (4)	17 (3)	16 (4)	13 (3)	12 (3)	19 (4)	11 (3)	16 (5)	10 (4)
Total	257	246	372	486	501	388	381	424	443	371	303	241

Data presented as N (%).

decrease in the incidence of elbow fractures in DST-vacation. However, this drop in incidence was accompanied by a marked increase in the severity of elbow fractures. Together, these findings detail the annual patterns in pediatric elbow injuries with peak incidence occurring in DST-school, but peak severity occurring in DST-vacation. These data provide helpful patterns by which tertiary care centers may predict the required resource needs to care for these patients throughout the year.

Evaluating pediatric elbow fractures required substantial resources, accounting for 0.6% of all ED visits throughout this study period. However, in contrast to all-cause ED visits, visits for elbow fractures demonstrated peak incidences primarily during DST. Thus, the relative resource need for elbow fractures in pediatric EDs varied throughout the year, with the rate of visits secondary to elbow fracture peaking at over 1% in May. Beyond ED resource utilization, this study demonstrated that children with elbow fractures accounted for 14.7% of pediatric

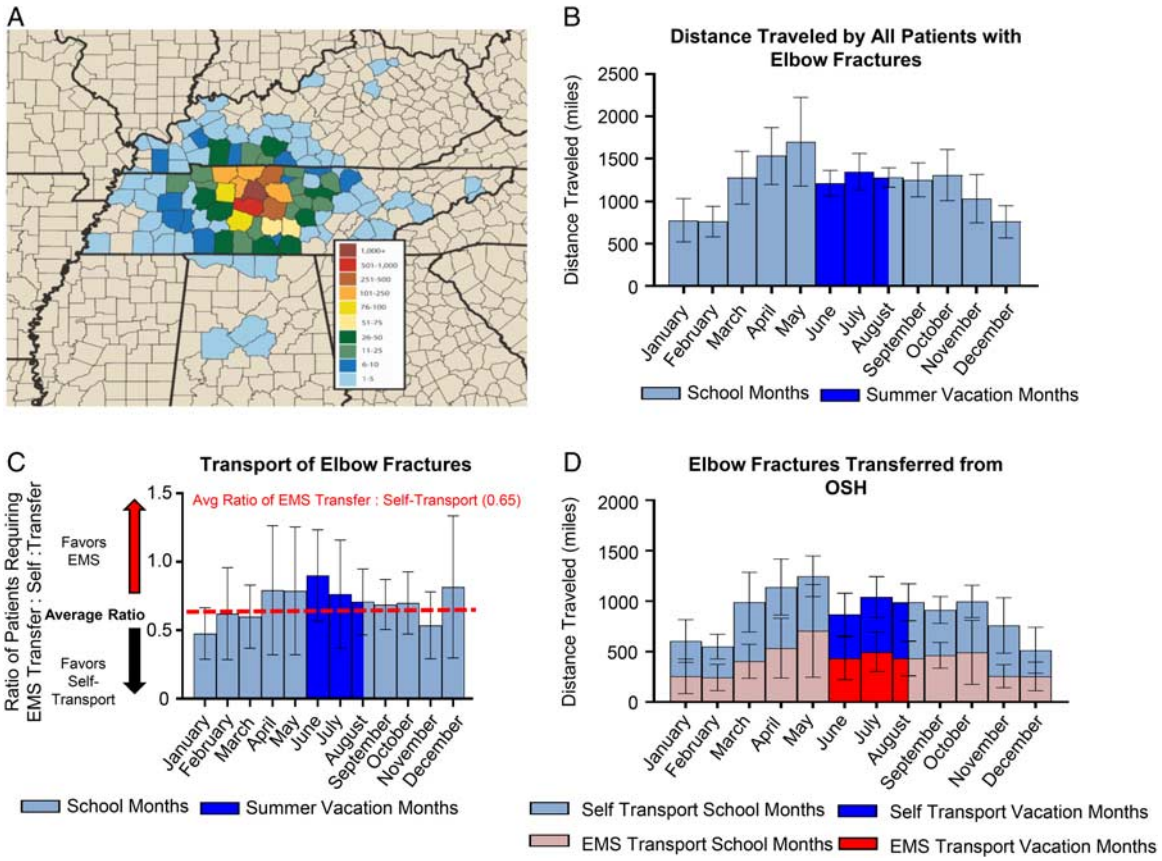

FIGURE 5. Transportation of elbow fractures. A, Map of the study region with counties shaded by volume of patients presenting from each county. The distance traveled by (B) all patients and (D) those referred from OSH as well as (C) the ratio of those transported by EMS versus self-transport was observed. All graphs presented as mean ± SD.

TABLE 2. Incidence of Mode of Transport to Study Institute for Care of Pediatric Elbow Fractures (2007 to 2017)

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sept	Oct	Nov	Dec
Ambulance	44 (29)	50 (35)	76 (34)	104 (38)	118 (42)	99 (42)	91 (40)	97 (39)	97 (38)	89 (39)	53 (29)	48 (35)
Fixed wing or helicopter	1 (1)	0	2 (1)	3 (1)	4 (1)	2 (1)	2 (1)	1 (< 1)	1 (< 1)	0	2 (1)	2 (1)
Self-transport	104 (68)	89 (63)	138 (63)	162 (59)	155 (55)	124 (52)	130 (57)	146 (58)	147 (58)	132 (58)	121 (67)	78 (57)
Other or not specified	3 (2)	3 (2)	3 (1)	6 (2)	4 (1)	10 (4)	5 (2)	7 (3)	9 (4)	6 (3)	5 (3)	9 (7)
Total	152	142	219	275	281	235	228	251	254	227	181	137

Data presented as N (%).

orthopaedic surgery consultations and 12.3% of pediatric orthopaedic surgeries yearly. In addition, significant resources were required to transport patients with elbow fractures, with a yearly average of 4753.7 miles traveled by EMS for the transportation of elbow fractures and an additional 5428.2 miles traveled by patients and their families.

Fracture Incidence and Severity

The annual variation in the incidence of all pediatric fractures has been documented with an increased fracture burden in warmer months with greater daylight hours.[4,15,18–20,30] This trend was demonstrated in this study of elbow fractures, with monthly ADH significantly correlating with fracture volume. While hypothesized that this increased volume could be because of local school schedules, with more fractures occurring during DST-vacation, our study supports contrasting findings that incidence decreases slightly during DST-vacation.[3,13–15,17] Since first noted by Landin, the literature has offered various explanations for this phenomenon.[3,13,14,16] We suggest that the increase in elbow fracture volume is relative to the extra hour of daylight and warmer weather that occurs during DST. However, given the decreased elbow fracture volume in DST-vacation, the warmest months with the longest days, there appear to be additional contributing factors such as spring and fall sport seasons, vacationing out of state in the summer months, or local severely warm temperatures in DST-vacation that limit outdoor time for some children.

Similar to elbow fracture volume, fracture severity also increased during DST. However, unlike the decreased incidence seen during DST-vacation, elbow fracture severity increased during these months. Elbow fractures were more likely to be displaced and had higher rates of neurovascular injury during DST-vacation, which likewise coincides with the beginning of the academic year for ED and orthopaedic trainees at tertiary care institutions. Therefore, newly promoted house-staff are likely to encounter relatively more severe elbow fractures. Combined, this information offers training hospitals an opportunity to improve patient care with targeted education on severe pediatric elbow fractures for house-staff likely to encounter these injuries.

Annual Resource Utilization

A gap in the literature exists connecting annual variation of elbow fracture incidence and severity to resource requirements of providers and health care facilities. Masterson et al[19] showed an increased admission rate because of fractures in months with more daylight, and Khoshbin et al[12] reported increased operative supracondylar fractures in the summer. To the authors knowledge, there is no literature on the transport and treatment of pediatric elbow fractures relative to the time of year. This study demonstrates that the increased volume and severity of elbow fractures during DST significantly impacts resource utilization. Both the rates of elbow fractures requiring EMS transport (vs. self-transport) and first presenting to the ED (vs. a clinic) were positively correlated with ADH. This resulted in significant increases in the distance traveled by EMS and patients for care. The same trend was seen in both OR usage and the number of hospital admissions. Importantly, there was no difference in average OR time per case by month, meaning that the variation in total OR time per month was not solely because of fracture severity. In addition, the relatively lower incidence of elbow fractures during DST-vacation was balanced by the increased severity during these months, resulting in no difference in number of operations, operative time, or admissions per month between DST-school and DST-vacation. These findings together suggest that along with increased incidence and severity, fractures occurring during DST also require significantly more resources to manage. This study supports the need for optimization of staffing of EMS, EDs, pediatric orthopaedic services, and ORs during DST to more accurately address varying requirements.

Strengths and Limitations

This is the largest comprehensive cohort of pediatric elbow fractures from a single center. However, given the retrospective nature of the study, there were limitations in our ability to collect and analyze the mechanism and time of day of injury, limiting our ability to make statements about causation and prevention of injuries. Furthermore, as a tertiary referral center, our population is likely biased toward severe cases requiring ED services, treatment from specialists, and hospital admission (ie, less severe fractures stay at regional hospitals and medical centers). Many fractures do not present to tertiary pediatric care centers and our population may overestimate the severity of some fractures. In addition, as a single-center study, this study can only be representative of the surrounding region. We acknowledge these limitations and believe that the data remain a useful guide for clinicians and hospital administrators at pediatric tertiary referral centers. Future

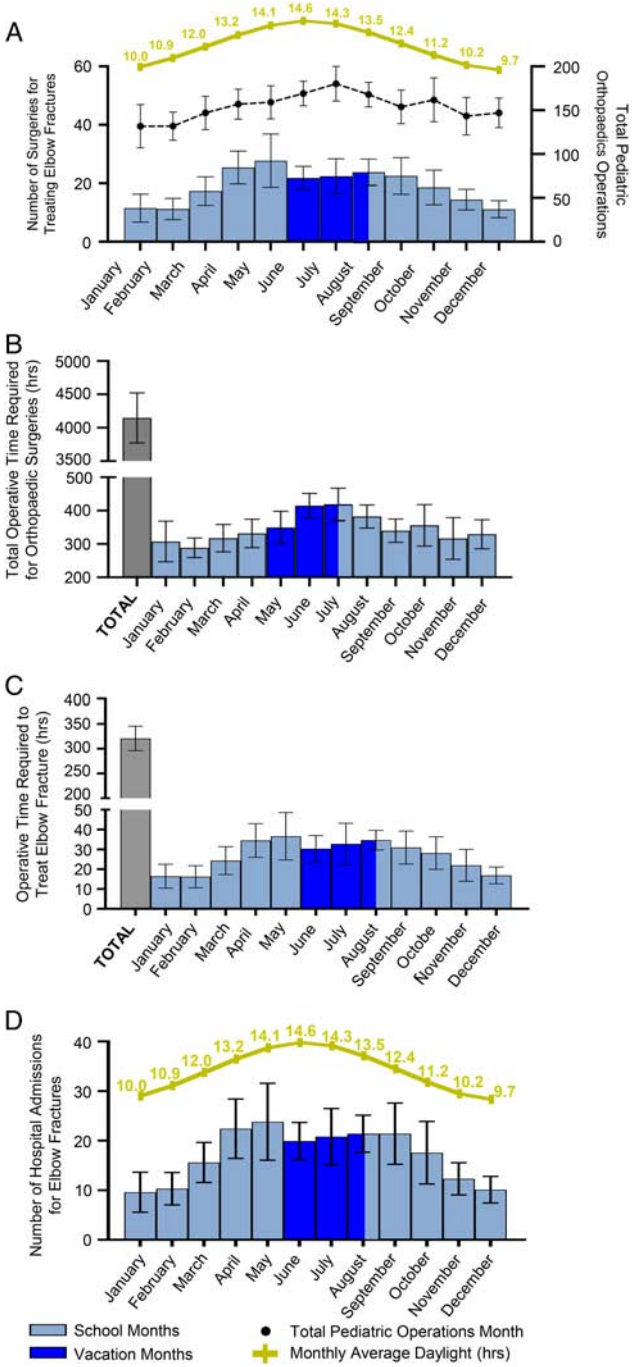

FIGURE 6. Operative treatment requirements for pediatric elbow fractures by month. A, The average number of all pediatric orthopaedic and elbow fracture operations, average OR time for (B) all pediatric orthopaedic surgeries and (C) elbow fractures, and (D) average number of hospital admissions for elbow fractures were. There was a strong positive correlation between the number of admissions and ADH ($r = 0.88$). All graphs presented as mean ± SD. ADH indicates average daylight hours; OR, operating room.

studies utilizing a standardized, prospective data collection method at multiple centers are warranted.

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