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RESEARCH ARTICLE

Does Weather Matter? The Effect of Weather Patterns and Temporal Factors on Pediatric Orthopedic Trauma Volume

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Abstract:

Objectives:

Orthopaedists often speculate how weather and school schedule may influence pediatric orthopedic trauma volume, but few studies have examined this. This study aims to determine: how do weather patterns, day, month, season and public school schedule influence the daily frequency of pediatric orthopedic trauma consults and admissions?

Methods:

With IRB approval, orthopedic trauma data from a level 1 pediatric trauma center, including number of daily orthopedic trauma consults and admissions, were collected from July 2009 to March 2012. Historical weather data (high temperatures, precipitation and hours of daylight), along with local public school schedule data were collected for the same time period. Univariate and multivariate regression models were used to show the average number of orthopedic trauma consults and admissions as a function of weather and temporal variables.

Results:

High temperature, precipitation, month and day of the week significantly affected the number of daily consults and admissions. The number of consults and admissions increased by 1% for each degree increase in temperature ($p=0.001$ and $p<0.001$, respectively), and decreased by 21% for each inch of precipitation ($p<0.001$, $p=0.006$). Daily consults on snowy days decreased by an additional 16% compared to days with no precipitation. November had the lowest daily consult and admission rate, while September had the highest. Daily consult rate was lowest on Wednesdays and highest on Saturdays. Holiday schedule was not independently significant.

Conclusion:

Pediatric orthopedic trauma consultations and admissions are highly linked to temperature and precipitation, as well as day of the week and time of year.

Keywords: Admission, Consult, Pediatric, Season, Trauma, Weather.

INTRODUCTION

Orthopaedists often speculate how weather and school schedule may influence pediatric orthopedic trauma volume, but few studies have assessed this. A warm and sunny summer weekend may keep orthopedic trauma surgeons busy,

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while a cold rainy fall day may yield a lighter workload. In general, the assumption that weather patterns influence orthopedic trauma is supported in the literature [1 - 12]. Several studies in the general surgery and orthopedic literature show adult trauma to be positively correlated with temperature and negatively correlated with precipitation [4, 8, 9] while others have shown that snowfall can increase consults in the winter due to sledding accidents and slipping on ice [1, 2, 6, 10, 11]. Few studies, however, have looked at daily weather patterns and temporal factors as they effect a population of children, whose play activities are particularly influenced by weather and school schedules [7, 9]. However, because of variability in climate, study results may not be generalizable.

The purpose of this retrospective analysis is to determine how weather patterns, as well as day of the week, month, season and public school schedule influence the daily frequency of orthopedic trauma in children at a level 1 pediatric trauma center. We hypothesize that these factors significantly impact pediatric othopaedic trauma volume, and we believe this information is important when planning to staff pediatric orthopedic emergency departments and operating rooms.

MATERIALS AND METHODS

Study Design

The study took place at a level 1 pediatric trauma center. Our emergency department cares for about 60,000 patients per year.

With IRB approval, pediatric orthopedic trauma data from July 2009 to March 2012 were collected from our institutional database (Data Utility for Documentation and Education). The data included number of consults per day for acute traumatic orthopedic injuries (soft tissue injury, fractures or dislocations) and the number of those consults that resulted in admission to the hospital. When one person sustained multiple injuries or fractures, they were counted as one trauma consult (or admission). This study did not stratify based on type, severity or mechanism of injury.

Weather data was gathered from "Weather Underground", www.wunderground.com, as well as www.timeanddate.com, including daily temperatures (high, average, and low in °F), amount (inches) and type of precipitation, and hours of daylight for the duration of the study period. In addition to the potential effects of weather on consults and admissions, we also considered season, month, day of the week, weekend (versus weekday), school vacations, and non-school days, and analyzed whether the number of consults or admissions varied according to these variables. School vacation schedules were obtained from the public schools calendars, understanding that children from other schools (*e.g*. from other states as well as private schools) were also treated at our institution.

Seasonal analysis was also performed. "Winter" was defined as winter solstice to spring equinox. "Spring" was defined as spring equinox to summer solstice. "Summer" was defined summer solstice to fall equinox. "Fall" was defined as fall equinox to winter solstice.

Statistical Analysis

Univariate and multivariable negative binomial regression were used to assess the impact of weather and temporal factors on daily consult and admission rates. Unadjusted analyses were conducted to compare the impact of individual variables on the number of daily consults and number of daily admissions using likelihood ratio statistics. Multivariate negative binomial regression models were developed for each outcome using a stepwise model selection procedure in which variables were added and removed based on Akaike Information Criterion (AIC). In the adjusted analysis, incidence rate ratios were estimated for all model factors along with 95% confidence intervals. Sub-analysis was conducted to analyze the impact of precipitation on individual seasons. The amount of precipitation (on the same day, one day prior, and two days prior) and the type of precipitation were analyzed across seasons. Analyses were conducted in SAS version 9.3 (SAS Institute, Inc., Cary NC). All tests were two-sided and p-values less than 0.05 were considered significant.

RESULTS

During the 957 days (2.62 years) in the study period, there were 5,772 orthopedic trauma consults and 1,572 orthopedic trauma admissions. On average, there were 6 consults per day, ranging from 0 to 22, and 1.6 admissions per day, ranging from 0 to 8. Daily consults and admissions are summarized by weather and temporal factors in Table **1**. The number of consults varied by day of the week, but the number of admissions was more consistent (Fig. **1**). Wednesdays presented the fewest daily consults and admissions while Saturdays had the highest. The highest rates of

daily consults and admissions were in September, followed by May and June. The number of consults and admissions follow the pattern of daily high temperature, except for in the mid-summer months. Both consults and admissions experienced a drop during June, July, and August (Fig. **2**). The lowest rates of daily consults and admissions were in November, followed by December. Overall, the greatest number of consults and admissions were observed in the summer season, with the fewest in winter. Also, more consults were seen on non-school days compared to days when school was in session.

Table 1. Summary of consults and admissions by weather and temporal factors.

	Days	Consults	Admissions
Month			
January	90	417	134
February	85	422	117
March	63	294	79
April	60	395	100
May	62	500	126
June	60	446	140
July	75	498	124
August	93	604	174
September	90	792	216
October	93	646	131
November	93	365	74
December	93	393	109
Season			
Winter	249	1136	323
Spring	186	1291	352
Summer	252	1839	509
Fall	270	1506	340
Weekend			
Non-weekend day	684	3910	1064
Weekend day	273	1862	460
Non-school day			
School day	473	2543	696
Non-school day	484	3229	828
Day of the week			
Monday	137	871	217
Tuesday	137	729	210
Wednesday	137	718	195
Thursday	137	752	224
Friday	136	840	218
Saturday	136	959	230
Sunday	137	903	230
Rain or snow			
None	573	3733	971
Rain	295	1694	451
Snow	89	345	102

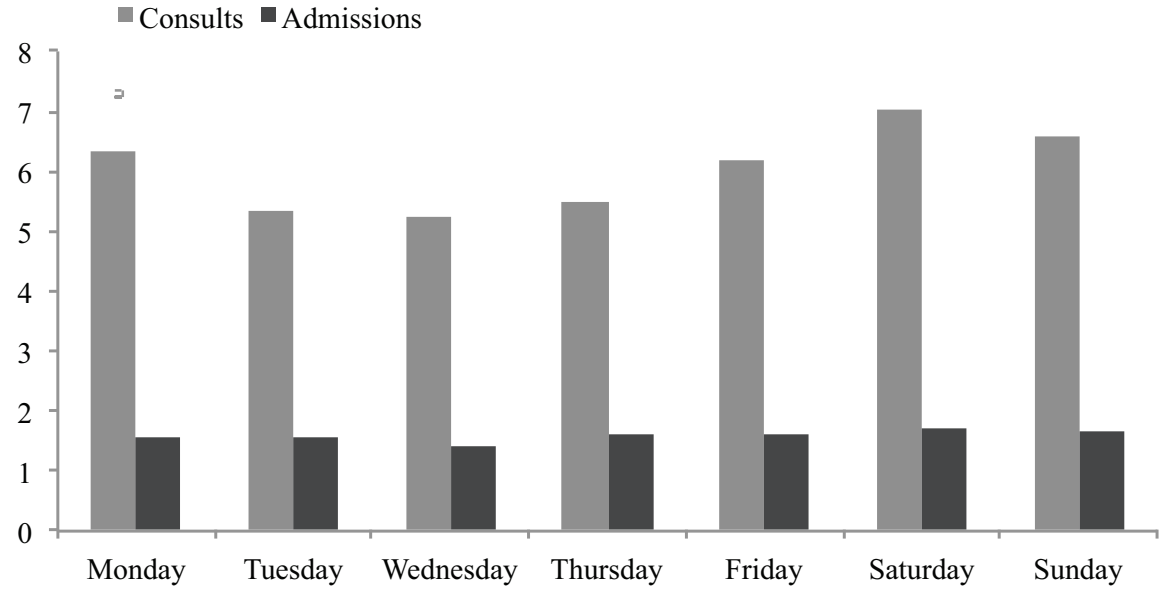

Fig. (1). Average daily consults and admissions by day of the week.

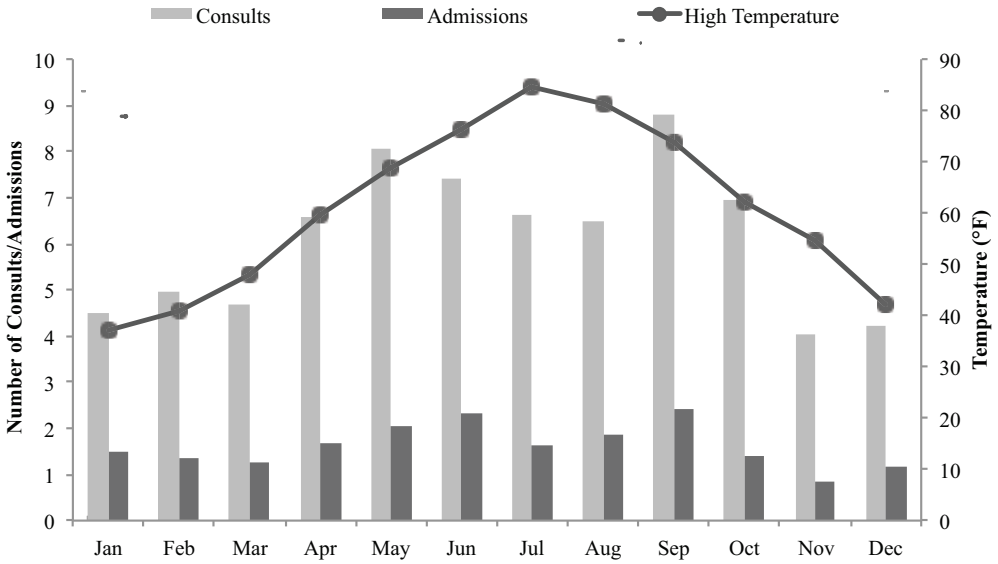

Fig. (2). Average daily consults and admissions with average high temperature by month.

In addition to temporal factors, weather conditions also affected consults and admissions. Days without precipitation showed higher average consults and admissions compared to days with rain or snow. Days with snow had the lowest number of consults and admissions. Comparable to dry days, days with more daylight and higher temperatures also showed increases in the number of consults and admissions.

Consults

Unadjusted, univariate analysis determined that daily high temperature ($P<0.001$), the amount of precipitation one day prior ($P=0.03$), the amount of precipitation on the same day ($P<0.001$), the type of precipitation (rain $P=0.01$ and snow $P<0.001$), and the hours of daylight ($P<0.001$) all significantly affected the average number of consults per day (Table **2**). It was also found that weekends ($P<0.001$), non-school days ($P<0.001$), month ($P<0.001$), day of week ($P<0.001$) and season ($P<0.001$) all significantly affected the average number of consults.

Multivariable analysis for consults determined that high temperature, amount of precipitation one day prior, amount of precipitation on the same day, snow, non-school day, month, and day of the week were significantly associated with number of daily consults. The corresponding adjusted incidence rate ratios are reported in the adjusted section of Table

2. It was found that when all other factors were held constant, a one degree increase in the daily high temperature led to a 1% increase in the relative daily consult rate. Conversely, for each inch of precipitation on the same day, the consult rate decreased by 21% when holding all other factors constant. Daily consults on days with snow decreased by an additional 16% compared to days with no precipitation. Compared with November, the month with the fewest daily consults, January through October had significantly higher rates of daily consults with the highest rates occurring during the months of September and May (87% and 77% more daily consults, respectively). Compared to Wednesday, the day of the week with the lowest daily consults, Mondays, Fridays, Saturdays and Sundays had significantly higher unadjusted and adjusted consult rates, with Saturdays being the busiest.

Table 2. Unadjusted and adjusted incidence rate ratios for the daily number of consults.

		Unadjusted			Adjusted	
	IRR	**95% CI**	**P**	**IRR**	**95% CI**	**P**
High Temp	1.01	(1.01, 1.01)	<0.001	1.01	(1.00, 1.01)	0.001
Precipitation two days prior	0.95	(0.84, 1.07)	0.36			
Precipitation one day prior	0.87	(0.78, 0.98)	0.03	0.92	(0.82, 1.02)	0.11
Precipitation same day	0.72	(0.63, 0.82)	<0.001	0.79	(0.69, 0.90)	<0.001
Rain or snow						
Rain	0.88	(0.81, 0.85)	0.005	0.95	(0.87, 1.03)	0.22
Snow	0.60	(0.51, 0.69)	<0.001	0.84	(0.72, 0.98)	0.03
Daylight	1.10	(1.08, 1.12)	<0.001			
Weekend	1.19	(1.09, 1.30)	<0.001			
Non-school day	1.20	(1.11, 1.31)	<0.001	1.10	(0.98, 1.22)	0.10
Month						
January	1.11	(0.92, 1.33)	0.28	1.29	(1.06, 1.57)	0.01
February	1.22	(1.02, 1.47)	0.03	1.38	(1.15, 1.67)	0.001
March	1.15	(0.94, 1.41)	0.17	1.30	(1.07, 1.58)	0.01
April	1.62	(1.34, 1.97)	<0.001	1.54	(1.28, 1.86)	<0.001
May	1.99	(1.65, 2.40)	<0.001	1.77	(1.46, 2.14)	<0.001
June	1.83	(1.51, 2.22)	<0.001	1.60	(1.30, 1.96)	<0.001
July	1.64	(1.36, 1.97)	<0.001	1.26	(1.00, 1.57)	0.046
August	1.60	(1.34, 1.91)	<0.001	1.27	(1.03, 1.57)	0.02
September	2.17	(1.83, 2.58)	<0.001	1.87	(1.56, 2.24)	<0.001
October	1.71	(1.44, 2.04)	<0.001	1.65	(1.39, 1.95)	<0.001
November	--	--	--	--	--	--
December	1.04	(0.87, 1.25)	0.66	1.16	(0.96, 1.40)	0.12
Weekday						
Monday	1.21	(1.04, 1.41)	0.01	1.19	(1.04, 1.36)	0.009
Tuesday	1.02	(0.87, 1.18)	0.85	1.00	(0.87, 1.14)	0.97
Wednesday	--	--	--	--	--	--
Thursday	1.05	(0.90, 1.22)	0.55	1.05	(0.91, 1.20)	0.52
Friday	1.18	(1.01, 1.37)	0.03	1.17	(1.03, 1.34)	0.02
Saturday	1.35	(1.16, 1.56)	<0.001	1.26	(1.09, 1.47)	0.002
Sunday	1.26	(1.08, 1.46)	0.003	1.18	(1.01, 1.37)	0.04
Season						
Winter	--	--	--			
Spring	1.52	(1.35, 1.71)	<0.001			
Summer	1.60	(1.44, 1.78)	<0.001			
Fall	1.22	(1.10, 1.36)	<0.001			

IRR=Incidence rate ratio; CI = Confidence Interval

Admissions

The proportion of consults that became admissions remained fairly constant between 20-30% with no significant association with any factors under investigation.

Univariate, unadjusted analysis determined that daily high temperature (P<0.001), the amount of precipitation on

the same day (P=0.01), presence of snow (P=0.001), and hours of daylight (P<0.001) all significantly affected the average number of admissions per day (Table **3**). It was also found that non-school days (P=0.048), month (P<0.001), and season (P<0.001) all significantly affected the average number of daily admissions.

Table 3. Unadjusted and adjusted incidence rate ratios for the daily number of admissions.

		Unadjusted			Adjusted	
	IRR	**95% CI**	**P**	**IRR**	**95% CI**	**P**
High Temp	1.01	(1.01, 1.01)	<0.001	1.01	(1.00, 1.02)	<0.001
Precipitation two days prior	0.85	(0.70, 1.02)	0.10			
Precipitation one day prior	0.83	(0.68, 1.00)	0.06			
Precipitation same day	0.76	(0.62, 0.92)	0.006	0.79	(0.64, 0.95)	0.006
Rain or snow						
Rain	0.90	(0.79, 1.03)	0.13			
Snow	0.68	(0.53, 0.85)	0.001			
Daylight	1.11	(1.07, 1.14)	<0.001			
Weekend	1.08	(0.94, 1.23)	0.26			
Non-school day	1.13	(1.00, 1.28)	0.048			
Month						
January	1.79	(1.32, 2.45)	<0.001	2.16	(1.56, 3.02)	<0.001
February	1.67	(1.22, 2.31)	0.002	1.94	(1.40, 2.71)	<0.001
March	1.53	(1.08, 2.16)	0.02	1.69	(1.19, 2.40)	0.001
April	2.03	(1.45, 2.84)	<0.001	1.90	(1.37, 2.67)	<0.001
May	2.47	(1.80, 3.42)	<0.001	2.11	(1.51, 2.95)	<0.001
June	2.84	(2.07, 3.91)	<0.001	2.26	(1.61, 3.21)	<0.001
July	2.01	(1.47, 2.77)	<0.001	1.47	(1.01, 2.14)	0.03
August	2.28	(1.69, 3.09)	<0.001	1.74	(1.23, 2.47)	<0.001
September	2.92	(2.18, 3.94)	<0.001	2.38	(1.74, 3.28)	<0.001
October	1.71	(1.26, 2.35)	0.001	1.60	(1.17, 2.20)	0.001
November	--	--	--	--	--	--
December	1.43	(1.03, 1.97)	0.03	1.63	(1.18, 2.28)	0.002
Weekday						
Monday	1.11	(0.88, 1.40)	0.34			
Tuesday	1.09	(0.87, 1.38)	0.46			
Wednesday	--	--	--			
Thursday	1.15	(0.91, 1.45)	0.24			
Friday	1.13	(0.89, 1.42)	0.32			
Saturday	1.19	(0.94, 1.50)	0.14			
Sunday	1.18	(0.94, 1.49)	0.16			
Season						
Winter	--	--	--			
Spring	1.45	(1.21, 1.73)	<0.001			
Summer	1.54	(1.31, 1.82)	<0.001			
Fall	0.96	(0.81, 1.14)	0.661			

IRR=Incidence rate ratio; CI = Confidence Interval

Multivariable analysis for admissions determined that high temperature, amount of precipitation on the same day, and month independently affected the number of admissions each day. The corresponding adjusted incidence rate ratios are reported in the adjusted section of Table **3**. For every one degree increase in the daily high temperature, the relative incidence rate of admissions increased by about 1%, and for a one inch increase in precipitation the relative admission rate decreased by 21% when the other factors were held constant. Compared to November, all other months yielded higher admission rates, with the highest increases in September and June (138% and 126% higher, respectively).

Sub Analysis

Given that the proportion of admissions was consistent at 20-30% of consults, sub-analysis was conducted on number of consults only, with respect to season and precipitation (Table **4**).

Table 4. Number of consults by season and type of precipitation.

		Number of consults		
Season	**Number of days**	**No rain or snow**	**Rain**	**Snow**
Winter	249	133	44	72
Spring	186	112	69	5
Summer	252	163	89	0
Fall	270	165	93	12

There were 249 days of winter logged in the study. Of 249 days, 133 days had no precipitation, 44 days had rain and 72 had snow. In winter alone there was no significant difference between the expected number of consults on days when it rained compared to days without precipitation. On days with snow, however, there was a significant reduction in the expected number of consults; decreasing by about 23% when compared to days with no precipitation (IRR: 0.77; CI= 0.63-0.93). When rain and snow were combined, we found a 20% reduction in the expected number of consults on days with any precipitation (IRR: 0.80; CI: 0.67-0.94).

Of the 186 days of spring analyzed, 112 days had no precipitation, 69 days had rain and 5 days had snow. Days with rain or snow had a 22% reduction in the number of consults compared to days without precipitation (IRR=0.78; CI=0.67-0.91).

Of the 252 days of summer analyzed, 89 days had precipitation and 163 days had none. Days with rain had a significantly lower number of expected consults; about a 17% reduction in the number of consults on summer days with precipitation compared to days when there was none (IRR: 0.83; CI=0.72-0.96).

Of the 270 days of fall analyzed, 165 days had no precipitation, 93 days had rain and 12 days had snow. There was no significant association between precipitation and the number of consults in the fall.

There was no evidence that precipitation either one or two days prior had a significant effect on the expected number of consults on a given day.

DISCUSSION

Our city is an ideal place to study the effect of weather on trauma, as all four seasons are distinctly represented with a wide spectrum of weather phenomena and temperatures. That said, this study may not apply to places with significantly different climates or where all four seasons are not represented. This study has confirmed that weather and temporal phenomena do indeed affect the workload of the pediatric orthopedic trauma service, which is not surprising considering previous studies have found that over 1/3 of pediatric fractures occur during sport and recreational activity and 71% occur outdoors [3, 13, 14]. However, the results and associations of our study may not be generalizable to other settings due to climate variability, and this is a limitation of this study.

At our institution, there were more consults and admissions on warm, dry, non-school days during warmer months, with fewer on cold, wet, school days during winter. However, we also found that trauma tended to wane at the peak of summer with the highest rates of consults and admissions in May/June and September and fewer in July and August. This has not been previously reported and in fact is quite different from other reports of adult trauma patterns [1, 4]. Given that this represents three years of summer data (2009-2011), this is not likely a transient phenomenon. This may be a reflection of the fact that, in summer, there are fewer organized team sports, which leads to fewer opportunities for injury despite ample outdoor playtime. Similarly, it was surprising that school vacations actually yield fewer consults and admissions, perhaps due to the fact that many families travel or that many organized sports also take a hiatus during these school vacations.

The effect of precipitation is also somewhat surprising. We found that most seasons show a modulation of consults when precipitation occurs. The greatest effect of precipitation occurs during the winter, where snow can cause a 23% decrease in number of consults. Precipitation provided less of an effect on number of consults in summer (17%), and in the fall precipitation had a negligible effect. We did not end up seeing a rise of trauma with snowfall during the winter as some previous studies have suggested [1, 2, 6, 10, 11]. Our initial hypothesis that snowfall the day prior would increase trauma (slippery sidewalks, sledding accidents) did not prove true.

The negative binomial regression model used in this analysis sufficiently identifies weather and temporal factors that directly impact the number of consults but is not an appropriate instrument to predict the specific number of consults on a given day. The results of the current study indicate that one can estimate the effect of a particular factor

while other factors are held constant. For example, if the day in question is in June, our data indicates that we can expect the mean number of consults to be around 7. If there is no precipitation, this estimate will remain unchanged, however, if it is raining, we would expect the estimate to decrease. If it is warm outside we can expect the number of consults to increase, and, moreover, if it is a Friday, Saturday, Sunday or Monday, the number of consults may increase further. Thus adjustments in staffing can be made based on approaching weather forecasts in addition to date and season.

These findings are helpful in predicting the work load that will face the on-call pediatric orthopedic trauma team, both in the number of consults seen in the emergency department, and the number of patients who will be admitted to the orthopedic trauma service. The number of admissions is a good, though not perfect, indicator of number of operative cases, as most of the trauma admissions at our facility are admitted for the purpose of surgical treatment. These results, therefore, can be instructive in resource allocation with regard to operating room staffing and may indicate a greater need for a dedicated orthopedic trauma operating room in the busier times of year. Although day of the week ended up not significantly affecting the number of admissions, it did affect the number of consults. This may indicate that there should be additional support available for the provider seeing orthopedic consults in the emergency department on Mondays, Fridays, Saturdays and Sundays. These findings also suggest that, with a higher incidence of orthopedic trauma on hot, dry weekend days during the school year and during organized sports, it is important to provide anticipatory guidance to parents so they understand the importance of supervision during these times.

Potential weaknesses of this study include its retrospective nature and the fact that we were limited to only 2.7 years of data. Another potentially significant limitation is the lack of generalizability, as the information comes from a single center with specific weather characteristics. We were also unable to stratify types of injuries (*i.e* high energy *vs*. low energy trauma) as a function of weather and temporal factors, which would be an interesting future study.

CONCLUSION

Pediatric orthopedic trauma consults and admissions at our level 1 pediatric trauma center do vary significantly with the weather. We found an increase with warmer temperatures; however saw a relative lull during the peak of summer in July and August. This may reflect the relative impact of organized team sports on orthopedic trauma. We found (with some seasonal variation) an average of 20% decrease in consults on days with precipitation. Additionally, we found a significant increase in number of consults on Fridays through Mondays. This information can be used to shape expectations of on-call orthopaedists and help with resource allocation and planning.

CONFLICT OF INTEREST

The authors confirm that this article content has no conflict of interest.

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Declared none.

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