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Socioeconomic Status Affects Postoperative Time to Union in Pediatric Patients with a Surgically Treated Fracture

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Background: Fractures account for 10% to 25% of all pediatric injuries, and surgical treatment is common. In such cases, postoperative healing can be affected by a number of factors, including those related to socioeconomic status (SES). The purpose of this study was to investigate the relationship between time to fracture union and SES, which was measured with use of the median household income (MHI) and Child Opportunity Index (COI).

Methods: A retrospective review was conducted of pediatric patients with a long-bone fracture that had been surgically treated at a Level-I pediatric trauma center between January 2010 and June 2020. Demographic and relevant medical data were collected. Patients were sorted into union and nonunion groups. The ZIP code of each patient was collected and the MHI and COI of that ZIP code were identified. Income brackets were created in increments of $10,000 ranging from $20,000 to $100,000, with an additional category of >$100,000, and patients were sorted into these groups according to MHI. Comparisons among the income groups and among the union status groups were conducted for each of the collected variables. A multiple regression analysis was utilized to determine the independent effect of each variable on time to union.

Results: A total of 395 patients were included in the final sample, of whom 51% identified as Hispanic. Patients in the union group had a higher mean COI and MHI. Nonunion occurred in only 8 patients. Patients who achieved fracture union in ≤4 months had a significantly higher mean COI and MHI. When controlling for other demographic variables, the time to union increased by a mean of 9.6 days for every $10,000 decrease in MHI and increased by a mean of 6.8 days for every 10-unit decrease in the COI.

Conclusions: The present study is the first, to our knowledge, to investigate the relationship between SES and time to fracture union in pediatric patients. When controlling for other demographic factors, we found a significant relationship between SES and time to union in pediatric patients with a surgically treated fracture. Further investigations of the relationship between SES and time to union in pediatric patients are needed to determine potential mechanisms for this relationship.

Level of Evidence: Therapeutic Level III. See Instructions for Authors for a complete description of levels of evidence.

Fractures are a common occurrence within the pediatric population, accounting for nearly 10% to 25% of all pediatric injuries[1]. Injury rates have been shown to be highest among toddlers and adolescents and lowest among infants and elementary-school-aged children, particularly in boys[2,3]. Falls are the most common mechanism of injury and are usually associated with long-bone fractures, whereas fractures of the hand, foot, and axial skeleton often have a much broader etiology, including collisions, blunt trauma, and traffic accidents[4]. Pediatric fractures most commonly occur in the upper extremity, with distal radial fractures having the highest incidence, followed by finger and wrist fractures, respectively[5].

Deciding between operative and nonoperative treatment for a pediatric fracture depends on a variety of factors, including age, location, the stability of the fracture, and the degree of displacement[6]. Generally, pediatric fractures have a high degree of remodeling and callus formation, leading to lower complication rates than fractures in the adult population[7]. In recent

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years, surgery has become increasingly utilized for pediatric fractures because it decreases the likelihood of functional deficits and cosmetic deformities while allowing early mobilization, even in patients with a heavier body profile[8]. Many risk factors have been associated with pediatric fractures, including being overweight or obese, participation in an organized sport activity, and socioeconomic status (SES)[4,9-11]. In addition, several factors have been shown to affect the postoperative healing of pediatric fractures as measured by time to union, including marijuana use, tobacco use, the degree of postoperative displacement, increased body mass index (BMI), age, the type of surgical procedure, cardiovascular disease, and vitamin D deficiency[12-14].

Socioeconomic factors affect the behavioral development, cognitive and language development, and overall health of children[15-17]. In the present study, SES was measured with use of the median household income (MHI) and Child Opportunity Index (COI). The COI quantifies and maps the quality of resources and conditions available to children based on the area in which they live[18]. Children who live in areas with better access to quality education, safe housing, healthy food, parks, and playgrounds have a higher COI than children who live in areas without access to such resources. The COI has been identified as a useful tool for mapping area resources and highlighting inequalities between regions[19]. The goal of the present study was to evaluate the relationship between SES and time to union in pediatric patients who underwent operative fixation of a long-bone fracture. We predicted that lower SES would be associated with a longer time to union.

Materials and Methods

We conducted a retrospective review of pediatric patients from 3 to 17 years old who had been treated for a common fracture at a Level-I, accredited pediatric trauma center between January 2010 and June 2020. A research team was assembled that included faculty (i.e., pediatric orthopaedic surgeons), residents, and medical students. Pediatric patients with fractures were identified using International Classification of Diseases (ICD)-9 and 10 codes. Patients who did not sustain a long-bone fracture of the extremity were excluded from the study, along with patients who underwent nonoperative fracture treatment and those who required reoperation for reasons other than nonunion or standard implant removal. Demographic and medical data were collected, including age, BMI, race, ethnicity, ZIP code, date of injury, type of fracture, type of surgical procedure, presence or absence of surgical infection, nerve injury and wound healing, and time to union of the fracture.

Fracture union in the present study was defined radiographically according to the definition outlined by Heath et al. in their investigation of the effects of marijuana use on time to union in pediatric patients with surgically treated fractures[12]. Union was defined as radiographic evidence of a healing callus on all sides of the fracture with resolution of the original fracture line. Nonunion was defined as no evidence of interval healing on 2 consecutive radiographs made ≥2 months apart and ≥9 months after injury.

Statistical Analysis

MHIs and COI scores at the time of surgery were obtained with use of patient ZIP codes. The MHI and COI for each ZIP code

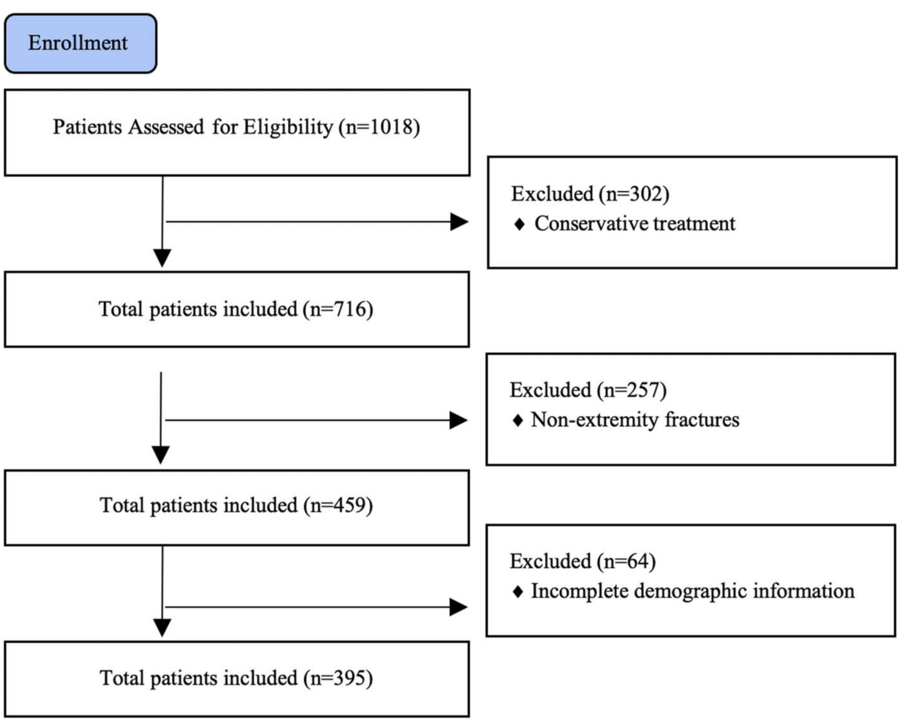

Fig. 1

Flow diagram of patient inclusion in the study.

over the previous 10 years were collected and averaged to accommodate for changes over the 10-year period. MHI data were then categorized into income brackets in increments of $10,000, ranging from $20,000 to $100,000, with an additional category of >$100,000. The relationship between the MHI and each of the following variables was analyzed: BMI, age, sex, race, ethnicity, rate of fracture union, and time to fracture union. The relationship between the COI and each of the aforementioned variables was analyzed.

Data were analyzed with use of SPSS Statistics 28 (IBM). A power analysis was conducted with use of the G*Power statistics tool (Heinrich-Heine-Universität Düsseldorf) in conjunction with built-in SPSS tools. Confidence intervals (CIs) were set at 95%, and significance was set at 0.05. Independent sample t tests and analysis of variance (ANOVA) were utilized to compare normally distributed data. Post-hoc analysis and between-group comparisons were conducted with use of the Tukey honestly significant difference test. For non-normally distributed data, the Wilcoxon rank-sum test was performed. Figures, graphs, and tables were generated with use of a combination of Microsoft Excel and SPSS. Categorical variables were assessed with use of a Fisher exact test or a chi-square test with the Kendall rank correlation coefficient. Multiple linear regression and multiple logistic regression were utilized to determine whether assumptions were met; the normality of the distribution and multicollinearity were both assessed in any residuals. We also compared the effect sizes and p values of each variable that was significant in the multivariable model with the effect size and p value from the univariate model of that variable to make sure that they were consistent and that none of the p values appeared to be an artifact.

Source of Funding
There was no external funding for this study.

Results

A total of 1,018 patients were identified, of whom 302 were excluded for having received nonoperative treatment, 257 for having sustained a non-extremity fracture, and 64 for incomplete demographic information. Thus, a total of 395 patients were included in the study for statistical analysis (Fig. 1).

The mean patient age was 11.41 years (standard deviation [SD], 2.92 years). The mean BMI was 23.26 kg/m^2 (SD, 8.54 kg/m^2). There were 173 female patients (44%) and 222 male patients (56%). Most of the patients were White (97%, n = 383) and Hispanic (51%, n = 201). Demographic information and the distribution of the MHI are shown in Table I. This sample had a wide distribution of long-bone fractures, including fractures of the femur (25.6%, n = 101), humerus (20.8%, n = 82), tibia (14.9%, n = 59), radius (12.9%, n = 51), ankle (2.5%, n = 10) ulna (9.4%, n = 37), phalanx (5.6%, n = 22), fibula (5.1%, n = 20), and metacarpal (3.3%, n = 13). The distribution of fractures by location is presented in Table II.

Demographic information and distribution of long-bone fractures were stratified by union (≤4 months), delayed union (>4 months), and nonunion. There were no significant differences in sex, race, ethnicity, or fracture location across the union, delayed union, and nonunion groups. Furthermore, when demographic data were stratified by income, no significant differences in sex, race, ethnicity, or fracture location were found across the income groups. As shown in Table III, the mean COI and MHI were significantly higher in the union group (COI, 38 [SD, 24]; MHI, $57,039 [SD, $20,682]) than in the nonunion group (COI = 17 [15]; MHI = $37,119 [$11,160]) ($p < 0.001$). Furthermore, the mean COI and MHI were significantly higher in the union group (COI = 42 [25]; MHI = $60,233 [$21,184]) than in the delayed union group (COI = 31 [23]; MHI = $50,270 [$18,640]) ($p < 0.001$).

Linear and logistic regression models that controlled for all demographic variables were created to further analyze the data. These models showed that time to union increased by a

TABLE I Demographics

Variable	Mean (SD)
MHI *($)*	56,629 (20,716)
COI	38 (24)
Time to union *(day)*	104 (65)
Follow-up time *(day)*	228 (239)
Age *(yr)*	11.41 (2.92)
BMI *(kg/m^2)*	23.26 (8.54)
Variable	**No. of Patients (%)**
Sex	
Female	173 (44)
Male	222 (56)
Race	
Black	12 (3)
White	383 (97)
Ethnicity	
Hispanic	201 (51)
Non-Hispanic	194 (49)
Final union status	
Nonunion	8 (2)
Union	387 (98)
Categorical MHI*	
$20,000-$30,000	12 (3.0)
>$30,000-$40,000	84 (21.6)
>$40,000-$50,000	78 (20.1)
>$50,000-$60,000	73 (18.8)
>$60,000-$70,000	63 (16.2)
>$70,000-$80,000	31 (8.0)
>$80,000-$90,000	15 (3.9)
>$90,000-$100,000	8 (2.1)
>$100,000	25 (6.4)

*MHI data were unavailable for 6 of the 395 patients included in the study.

TABLE II Fracture Frequencies and Corresponding AO/OTA Classifications

Fractured Bone	No. (%)	AO/OTA Classifications[56]
Ankle	10 (2.5%)	15.2, 44C2.2, 76.1B, 81
Femur	101 (25.6%)	31A, 31A1, 31A2, 31B3, 31C, 31C1, 32C3, 32A, 32A1, 32A1b, 32A2, 32A2b, 32A2c, 32A3, 32A3a, 32A3b, 32B3, 32B3b, 32C2, 32C3, 32C3k, 33A2, 33A2.2, 33A2.3, 33A3, 33A3.2, 33B1, 33C1, 41C, 42A, 61A
Fibula	20 (5.1%)	43B2.2, 44B2, 44C2, 4F2A, 4F2Aa, 4F2Ac, 4F2B, 4F3, 4F3B
Humerus	82 (20.8%)	11A2, 11A2.1, 11B1, 11C1, 12A, 12A1, 12A3, 12C3, 13A, 13A1, 13A1.1, 13A1.2, 13A2.3, 13A3.2, 13B1, 13B2, 13C, 13C1, 13C2
Metacarpal	13 (3.3%)	77.1, 77.1.2, 77.3.2, 77.3.2A, 77.4, 77.4.1, 77.5.1, 77.5.2, 78.5
Phalanx	22 (5.6%)	19.8, 77.1, 77.4, 78, 78.1, 78.1.1.2, 78.2, 78.2.1, 78.2.2, 78.3.1, 78.4.1, 78.4.3, 78.5, 78.5.1, 78.5.1.1A, 78.5.1.2C, 78.5.1.3, 88.1.2.1
Radius	51 (12.9%)	2R1A, 2R1C1, 2R2A, 2R2A1a, 2R2A2, 2R2A3, 2R3A, 2R3A2, 2R3A2.1, 2R3B1, 2R3B2, 2R3C, 2R3C1, 2R3C2.1, 2U2C3
Tibia	59 (14.9%)	41A, 41A1, 41A1.2, 41A2.2, 41B1.1, 41C1, 41C1.1, 42, 42A, 42A/43A1, 42A, 42A1, 42A2, 42A3, 42A3b, 42C2, 43A, 43A1, 43A1.3, 43A2, 43A2.1, 43B1, 43B1.1, 43B2.2, 43B2.3, 43B3, 43C1, 44B2, 44B3
Ulna	37 (9.4%)	2R2A/2U2A, 2U, 2U1, 2U1B1, 2U2A, 2U2A2, 2U2A2a, 2U2A2b, 2U2A3, 2U2B3, 2U2C, 2U3, 2U3A2, 2U3A2.3, 2U3B

mean of 9.6 days for each $10,000 decrease in MHI and increased by a mean of 6.8 days for each 10-unit decrease in the COI ($p < 0.001$). Furthermore, the odds of delayed union (>4 months) increased by 29% for each $10,000 decrease in MHI and increased by 19% for each 10-unit decrease in the COI ($p < 0.001$). The odds of union increased by 2.6% for each $10,000 increase in MHI ($p = 0.012$) and increased by 10.7% for each 10-unit increase in the COI ($p = 0.032$). The relationship of the MHI and COI to the time to fracture union is shown in Figures 2 through 5.

Discussion

We found that timely postoperative union of pediatric long-bone fractures was more common among patients who lived in a ZIP code with a higher COI and in those whose ZIP codes had a higher MHI. In addition, the odds of fracture union following operative fixation were greater in patients with a higher COI and MHI. These results are clinically relevant as they show the importance of SES in pediatric health care and outcomes.

Although the relationship between SES and health has been well established, the mediators of this effect are not entirely clear. Nutrition is one potential mediator. Singh et al., in their cross-sectional analysis of 450 children <5 years old in India, found that malnutrition was correlated with lower SES[20]. Research has shown not only that people with lower SES have worse nutrition, but also that, within the United States, higher SES is correlated with increased fruit and vegetable intake, which is a critical component of a well-balanced diet[21]. Patients with worse nutrition are also known to have increased complication rates following orthopaedic surgical procedures[22]. Specifically, nutritional factors have been postulated to affect immunological aspects of physiological fracture healing[23]. Although nutritional optimization likely has benefit for patients who have sustained orthopaedic trauma, well-designed clinical trials are needed to clarify this effect[22].

In addition to general malnourishment, patients with low SES may have low vitamin D or calcium levels. In a study of Mexican women of reproductive age, the risks of having vitamin D deficiency and insufficiency were found to be significantly

TABLE III COI, MHI, BMI, and Age Compared with Respect to Union Versus Nonunion and Union Time ≤4 Versus >4 Months*

	COI	MHI	BMI *(kg/m²)*	Age *(yr)*
Nonunion	**17 (15)**	**$37,119 ($11,160)**	24.72 (2.43)	13.26 (2.92)
Union	**38 (24)**	**$57,039 ($20,682)**	23.24 (8.61)	12.46 (2.92)
Time to union <4 mo	**42 (25)**	**$60,233 ($21,184)**	22.98 (9.83)	11.14 (2.88)
Time to union >4 mo	**31 (23)**	**$50,270 ($18,640)**	24.03 (6.17)	12.02 (2.81)

*Values are given as the mean (SD). Values that differed significantly between union and nonunion or between union at ≤4 and >4 months are bolded; all were $p < 0.001$.

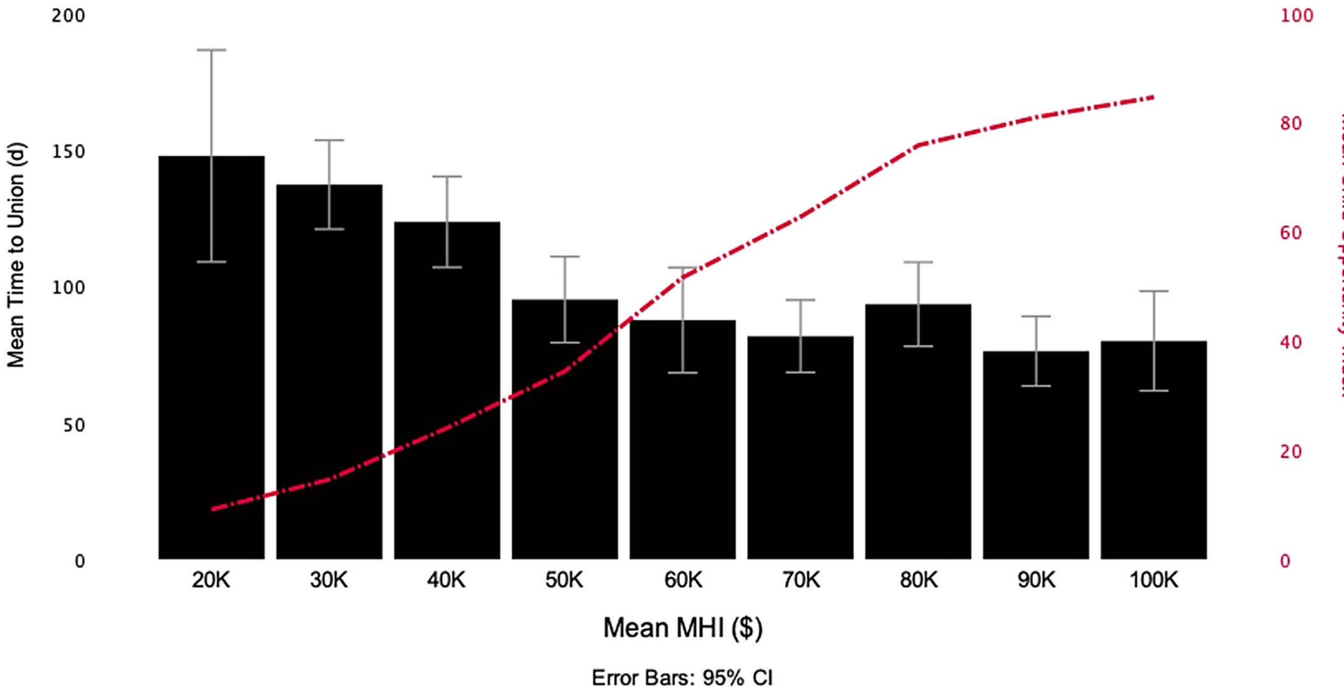

Fig. 2
Plot showing the relationship of mean MHI to mean time to union (in days) and to mean COI.

higher in those who were in the lower one-third income bracket[24]. A separate study of women in rural China also demonstrated that lower SES was associated with a higher risk of vitamin D deficiency and insufficiency in women of childbearing age[25]. Vitamin D deficiency at the time of fracture is known to increase the duration of time to union[26]. The effect of vitamin D on calcium levels may in part explain the relationship between low vitamin D and time to union. This relationship has been observed in animal models in which hypocalcemia caused by vitamin D deficiency affected rates of fracture-callus mineralization[27]. Saeed et al. found hypocalcemia to be more prevalent in a sample of pregnant women who presented with preeclampsia than in those without preeclampsia[28]. Adherence to medications and treatment may also be a factor affecting time to union. Unson et al. found that, in older patients, lower SES and being part of a minority racial group were both correlated with lower rates of adherence to osteoporosis treatment[29]. Studies have shown that lower SES is associated with lower health literacy, and lower health literacy is well established as a factor negatively affecting treatment compliance[30-32].

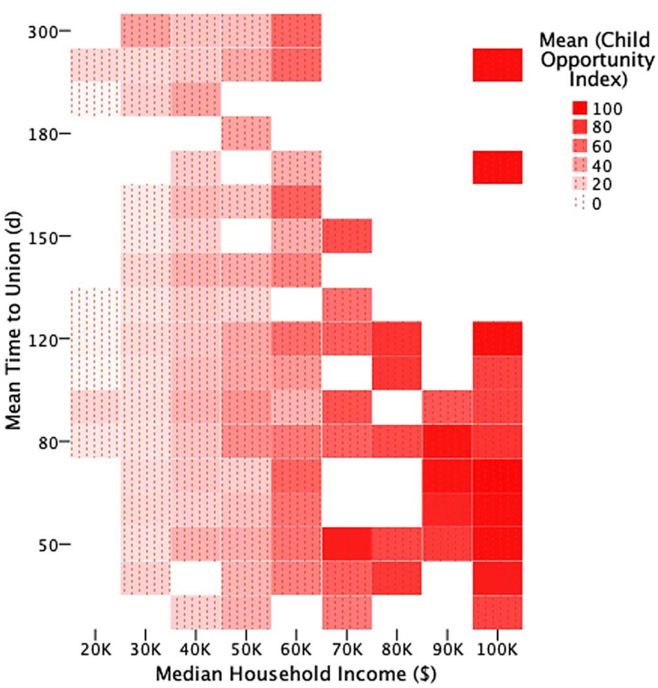

Fig. 3
Chart showing the mean COI for patients according to mean MHI and mean time to union.

Pediatric patients with lower SES are known to have worse health outcomes, and these outcomes can impact fracture healing. Research has shown that obesity is more prevalent in pediatric patients who have less access to healthy foods, recreational venues, and safe housing—all factors that have been directly correlated with lower SES[33-37]. Obesity has also been correlated with increased time to union in pediatric patients with surgically treated fractures[38]. In addition to the difference in pediatric obesity prevalence across SES, a 2019 scoping review demonstrated that many of the interventions meant to target pediatric obesity were more effective in higher SES groups, generating further inequity[39]. Additionally, among German pediatric patients with type-1 diabetes, those with lower SES had higher hemoglobin A1C levels and more inpatient days per year compared with their counterparts with

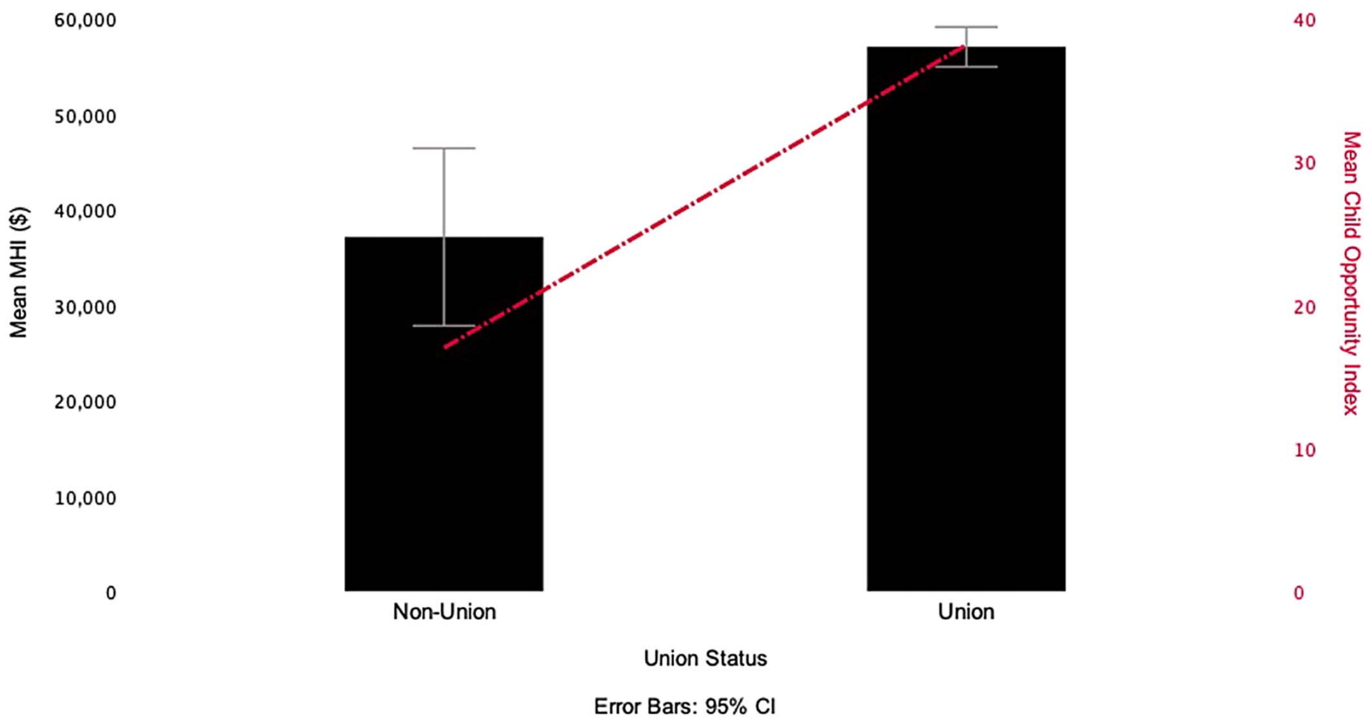

Fig. 4
Plot showing the relationship of union status to mean MHI and to mean COI.

higher SES[40]. Both type-1 diabetes and obesity have been shown to negatively affect rates of fracture healing[41,42]. However, the literature is not definitive. In 1 study, pediatric patients with long-bone fractures who were overweight or obese did not have a longer time to return to activity compared with pediatric patients with similar injuries who were a normal weight[43]. Among patients with asthma, relative upregulation of pro-inflammatory markers was observed in the monocytes

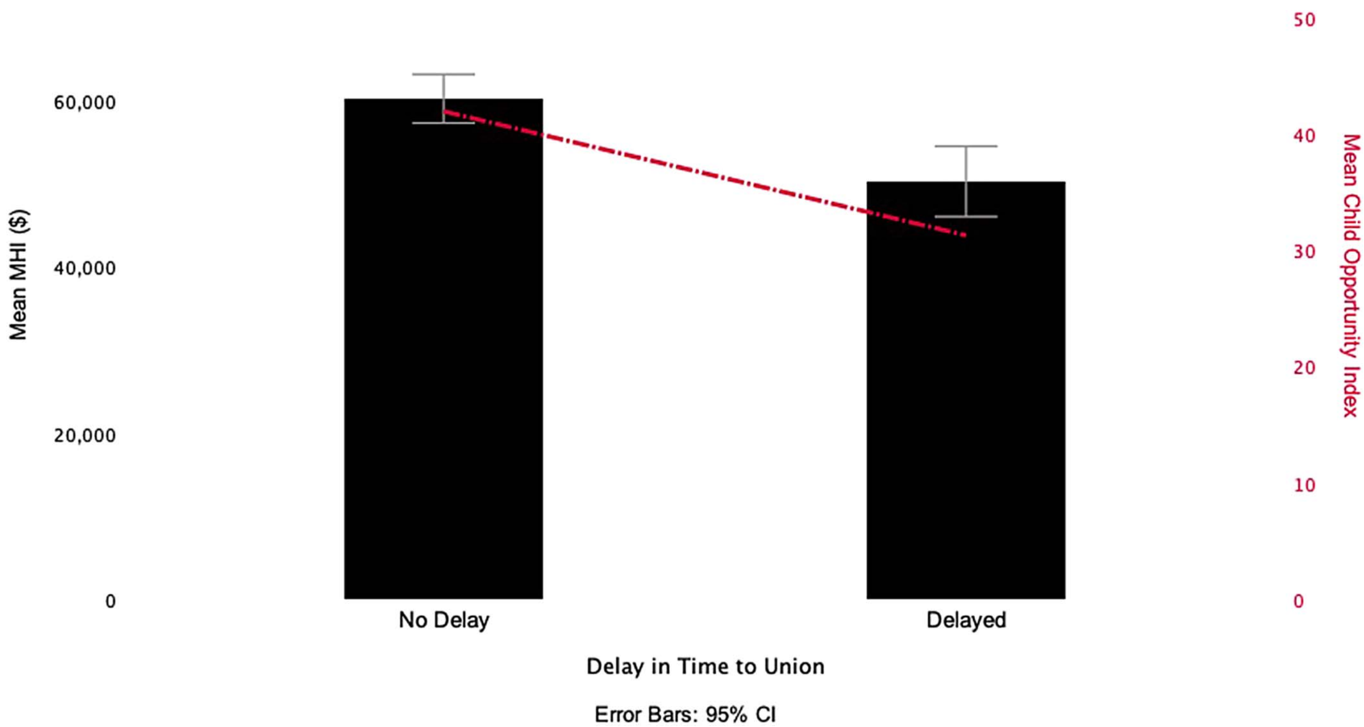

Fig. 5
Plot showing the relationship of union timing to mean MHI and to mean COI.

of patients with lower SES compared with those of patients with higher SES[44]. This result was replicated by Chen et al., who found relative upregulation in interleukin (IL)-5 and IL-13—important ILs in the pathogenesis of asthma—in patients with lower SES compared with those with higher SES[45]. The upregulation of IL-5 and IL-13 can impact bone healing, as the inflammatory response is important for the mediation of initial fracture healing[46].

Addressing health-care inequities in pediatric patients who have nutritional deficiencies or pathologies is a unique problem for orthopaedic surgeons. Patient education can be a powerful tool to improve nutritional deficiencies and to promote a healthy diet from a young age[47]. Creating experiential learning environments at school may prove to be an effective means to help children learn about eating healthier foods and getting sufficient exercise, which in turn can improve vitamin D and calcium levels while simultaneously lowering the rate of childhood obesity[47,48]. Although such school-led programs demonstrate a lot of promise, they do not address the social barriers that prevent patients with low SES from undertaking healthier behaviors. Physicians must continue to play an important role in lobbying government entities to improve access to healthy foods and educational opportunities in order to protect patients with low SES from having worse health outcomes.

Although it is well established that SES affects both morbidity and mortality, few studies have been conducted that attempt to evaluate the impact of SES on long-bone fractures[49]. Ortega et al. found a significant difference between socioeconomic groups in the amount of time from injury to arrival at the emergency department[50]. Kitchen et al. also identified significant delays in access to care among patients with lower SES, particularly among those who relied on government-funded insurance. In that study, the time between injury and referral was 2.8 times greater, and the overall time between injury and orthopaedic evaluation was 2 times greater, in the group with government funding than in the group with private insurance[51]. Furthermore, pediatric fractures and treatment pose a great financial burden on affected families[52,53]. Whereas direct costs to an institution are often measurable, the expenses that families pay outside of the hospital are unknown and possibly large, which may lead to disparities in access to postoperative care[52]. Physicians can help to address the burden of health-care costs by choosing cheaper treatment modalities, such as in-office procedures or splinting rather than operating on certain fractures. However, utilizing suboptimal treatment regimens for patients with low SES is inherently discriminatory and may cause additional damage to these patients[54]. In order to inform our decision-making, future studies should analyze the differences in outcomes among socioeconomic groups following both operative and nonoperative treatment modalities[55].

The present study was not without limitations. Although this was a retrospective case-control study, it would be difficult to replicate the premise of this study in a randomized control trial[50]. Because of its retrospective nature, certain variables, such as nutrition status, comorbidities, and long-term postoperative complications, were not collected. MHI may also not be fully representative of the SES of a patient because of the heterogeneity of incomes within a ZIP code; however, ZIP-code-level MHI has been cited as a preferred indicator of area-based SES[51]. Interestingly, most patients in this study identified as Hispanic, which may have been a function of the geographic location of our trauma center. Because other locations may not have a high prevalence of Hispanic patients, the results of a study at such a location may vary, and therefore additional studies should be conducted to verify these findings. Further studies should be conducted to understand more specific disparities attributed to differences in SES that would affect time to union and odds of union.

Conclusions

The present study was the first, to our knowledge, to investigate the relationship between SES and time to union in pediatric patients with a surgically treated fracture. We found a significant relationship between SES and time to union when controlling for other demographic factors. As the MHI and COI decreased, time to union increased. Additionally, as the MHI and COI increased, the odds of fracture union increased. Additional investigations of the relationship between SES and time to union in pediatric patients are needed to validate these findings. ■

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