RESEARCH ARTICLE

Clinical and Geographic Characterization of 30-Day Readmissions in Pediatric Sickle Cell Crisis Patients

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ABSTRACT

BACKGROUND AND OBJECTIVES: Sickle cell disease (SCD) is a blood disorder affecting many US children that is often associated with hospital readmission. Although previous studies have reported on the clinical factors that influence readmission risk, potential geographic factors have not been fully investigated. The goal of this study was to investigate the importance of geographic risk factors and to confirm previously derived clinical risk factors that influence readmissions for SCD pain crises.

METHODS: Retrospective analyses were performed on pediatric inpatients with sickle cell crises at a single center. Readmission rates and risk factors were assessed. Geospatial analysis was conducted on point variables that represented health service access, and multivariable logistic regression models were constructed.

RESULTS: The study identified 373 patients experiencing sickle cell crises, with 125 (33.5%) having at least one 30-day readmission. Age (mean difference: 2.2 years; $P < 0.001$), length of stay (median difference: 1 day; $P < .001$), admission pain score >7 of 10 (odds ratio [OR]: 2.21; $P < 0.01$), discharge pain score >4 of 10 (OR: 2.098; $P < .01$), living within 5 miles of the center's main hospital (OR: 0.573; $P = .04$), and >3 hospital utilizations in the previous 12 months (OR: 5.103; $P < .001$) were identified as potential indicators of 30-day readmission risk. Logistic regression models for 30-day readmissions yielded similar results.

CONCLUSIONS: Increased age, high admission and discharge pain scores, decreased length of stay, and increased hospital utilizations were found to be associated with an increased risk of readmission for sickle cell crisis. Patient's residence was also found to be a significant risk indicator, supporting the utility of geospatial analysis in assessing readmission risk.

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Thirty-day readmission rates have been gaining ground as an indicator of health care quality in both adult and pediatric populations.[1] Specifically, the Agency for Healthcare Research and Quality has set 30-day readmission benchmarks to measure care quality in children.[2–4] The Patient Protection and Affordable Care Act of 2012 also requires the US Department of Health and Human Services to develop and implement a readmission reduction program, which could include reduction in reimbursement for patients who are readmitted.[5,6] As such, health care institutions have focused efforts on developing readmission improvement plans, often including risk modeling to better allocate limited resources.[7,8]

For the purposes of the present article, "sickle cell crisis" is the broad term used to describe the acute painful episodes that occur in patients with sickle cell disease (SCD). These painful episodes generally last <7 days and may be precipitated by dehydration, infections such as pneumonia, other acute illnesses, or acute changes in temperature.[9] Sickle cell crisis is the leading cause of hospital utilization among children with SCD.[10] There is also a heightened risk for hospital readmission among these children.[4,8,10,11] Sickle cell crisis readmissions were added to the National Association of Children's Hospitals and Related Institutions 30-day readmission benchmarks in an attempt to characterize the health of patients with SCD.[8]

Several historic studies have evaluated factors influencing the likelihood of readmission in children experiencing sickle cell crises.[4,8,10,12] Most of these investigations developed clinical models for evaluating the risk of readmission. Pain level, opiate administration, and insurance payer were identified as correlates of future hospital readmission.[4,8] Although these studies evaluated key clinical risk factors, they did not examine geographic factors affecting the patient's likelihood of being readmitted.

Studies have shown that geographic factors, such as poverty, public transit access, and neighborhood conditions, are correlated with readmission risk in other disease-specific populations.[13–16] These same factors have been identified as potentially influencing sickle cell crisis readmissions, but they were not fully explored in earlier studies.[4,17] Some studies examined climate data by using geospatial techniques as they relate to sickle cell crises, and they found that temperature and rain days may be associated with hospital admission.[18–20] However, to our knowledge, no previous study has examined the combination of clinical and geographic data as they relate to sickle cell crisis readmissions. Due to the growing interest in 30-day readmission rates for patients with SCD, as well as the limited data relating to the geographic distribution of patients presenting with sickle cell crises, the present study aimed to fill this gap left by previous research. By using data sets obtained from the electronic health record (EHR) at our institution, the goal of this study was to provide a large sample base for running geostatistical risk models and eliminate certain bias by using data collected through routine clinical interactions. We hypothesized that geographic risk factors for sickle cell crisis readmissions could be identified and would remain significant when analyzed with clinical factors in a multivariable analysis.

METHODS

Study Population

EHR-derived data were queried regarding pediatric inpatients who presented for care at Children's National Health System (CNHS) in Washington, DC. CNHS is the largest provider of SCD care for the greater Washington, DC, metropolitan region and serves >1250 patients with SCD. SCD patients who receive comprehensive care at CNHS seek emergency care for sickle cell crises in the CNHS emergency department or the CNHS outpatient hematology clinic. Standardized clinical care pathways are used to treat sickle cell crises throughout CNHS, and inpatient admission is recommended if the pain is not improved after 3 doses of intravenous opioids.

All patients, ages 0 to 21 years, presenting for care between January 1, 2010, and December 31, 2012, with an admission or discharge diagnosis of sickle cell crisis (*International Classification of Diseases, Ninth Revision*, codes: 282.42, 282.62, 282.64, 282.69; SNOMED: 2549357014, 2548566019, 2553695011, 2549972019, 2548998015, 2548386016, and 120100012) were eligible for inclusion in this study. Data were also obtained on admissions occurring in January 2013 to assess 30-day readmissions for patients presenting for care in December 2012. In addition, hospital utilizations occurring from January 2009 through December 2009 were obtained to assess previous hospital utilizations for patients presenting from January 2010 through December 2010.

A sphere of influence was created to assess only patients who had the greatest likelihood of utilizing the CNHS resources. The radius of the sphere of influence was calculated to incorporate 95% of all SCD admissions during the study period and included CNHS primary and secondary service areas. This 22-mile radius sphere was centered on the CNHS main campus in northwest Washington, DC, and encompassed Washington, DC, southern Maryland, and northern Virginia. Only patients whose home residence was located within this sphere were included in the study sample.

Data Sources

All subject data were obtained from the EHR used at CNHS (Cerner Millennium, Cerner Corporation, Kansas City, MO). Data stored in the EHR is entered by clinicians and administrative staff during the normal course of care delivery and were not collected specifically for research purposes.

Geographic information was obtained from the US Census Bureau[21] and the District of Columbia Geographic Information System division.[22] Pharmacies capable of compounding and dispensing liquid or tablet opioid pain medications, as well as hydroxyurea, were obtained from the Center for Cancer and Blood Disorders at CNHS (recommended pharmacies).

Institutional Review Board

This study was reviewed and approved by the CNHS institutional review board. A waiver of informed consent was granted by the institutional review board.

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Data Acquisition, Validation, and De-Identification

Data queries were constructed in Cerner Command Language to acquire subject data from the EHR, including patient medical record number, name, gender, race, ethnicity, preferred language, admission type, and admission and discharge diagnoses. Data queries were constructed in Standard Query Language to acquire data from the financial platform (McKesson/STAR, San Francisco, CA), including the patient's street address, city, state, and zip code. Clinical data not available in structured data fields were collected by using EHR review of the clinical progress notes.

Diagnoses of sickle cell crisis were validated with the use of methods presented by Sobota et al[23]; that is, examining each admission and discharge pain score and use of narcotics during admission. Subjects were excluded from the study if they had both an admission and discharge pain score of zero with no narcotic medication administration during the index admission.

The primary outcome variable for the present study was whether a hospitalization (index admission) was immediately followed by an all-cause readmission within 30 days. Two cohorts were created for analysis; the first included patients who experienced a 30-day readmission and the second included patients who did not experience a 30-day readmission in the study period. This design created person-level readmission rates, which were preferred for analysis of geographic variables to reduce the possibility of colinearity. Multiple clinical and demographic variables were chosen as candidate risk factors based on previous research.[4,7,8,10–12,23,24] These variables included patient demographic characteristics (eg, age, gender), hospital and health service utilization, hospitalization factors (eg, length of stay, oxygen administration), comorbidities, and disease severity indicators (eg, genotype, pain scores).

To comply with the regulations of the Health Insurance Portability and Accountability Act, the data set was de-identified for all 18 protected health information variables.[25] Access to the encrypted identified data were restricted to 1 of the coinvestigators (J.E.M.).

Spatial Analysis

Each subject's home address was converted to latitude and longitude point data in decimal degree format by using geographic address locators in ArcGIS version 10.2 (Esri, Redlands, CA). Using previously published methods,[26] geographic parameters were rounded to ± 0.015 decimal degree (approximately ± 528 feet) to de-identify the data.

Density clusters were used to best determine geographic differences between the 2 cohorts. Geographic densities were defined as the number of patients in and near (within 0.6 mile) a given area (in this case, 0.01 square mile) and were then smoothed across the geographic area by using algorithms developed by Esri.[27] Geographic differences between cohorts were calculated by subtracting assigned nonreadmission density values from assigned readmission density values for each 0.01 square mile subsection across the geographic agrea. Difference values were assigned to the designated geographic area and visualized on a geographic plane.

Euclidean distances (ie, the shortest line between 2 points) between the subject's residence and the CNHS main campus and between the subject's residence and the closest CNHS-affiliated primary care facility, recommended pharmacy, emergency department, and public transit access point were calculated and added to the data set. These distances were dichotomized by using fixed distance bands of 2, 5, and 10 miles determined a priori for analysis. In stratifying the values categorically, the likelihood of assigning significance to randomly distributed points across the geographic area is reduced. Census tract level median household income was also assigned to each subject, based on their home residence census tract and the 2009–2014 American Community Survey results.

Statistical Analysis

Index admissions were identified with the associated first 30-day readmission. Because it was possible for each patient to have multiple index–readmission pairs in the 3-year period, the first identified index hospitalization with a 30-day readmission in the time period was used. For patients with no 30-day readmissions, the first admission in the time period was used for analysis. In combination, the 2 methods resulted in 1 unique index admission, with a possible 30-day readmission pair, for each patient in the sample.

Examination of hypothesized risk factors was conducted with SAS version 9.3 (SAS Institute, Inc, Cary, NC). Continuous variables were tested for normality by using the Kolmogorov-Smirnov method.[28] Those variables approximating a normal distribution were compared by using Student's t tests, whereas those not approximating a normal distribution were assessed by using a Wilcoxon rank-sum test. Categorical variables were evaluated by using χ^2 or Fisher's exact tests.

Regression Analysis

Once compared, variables with a test statistic–associated P value of $<.25$ were identified as possible risk factors for sickle cell crisis readmission. These variables were compiled into logistic regression models to yield adjusted odds ratios. In cases in which ≥ 2 geographic distance variables (of the same type) met the model inclusion criteria, only the largest distance was included in the model to provide the greatest subject coverage. Models were evaluated for 30-, 14-, and 7-day readmissions. Seven- and 14-day readmissions were selected for modeling due to previous identification as possible quality indicators.[10,12] Models were adjusted (by using techniques suggested by Altman[28]) until the final logistic models were produced. The final models were assessed for correlation and covariance in their dependent variables. All variables were found to have low correlation and covariance values, indicating assumed independence.

RESULTS

Patient Characteristics

During the study period, 2230 sickle cell crisis hospitalizations occurred among 501

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unique patients. Of those, 373 patients (71.6%) resided within the hospital's sphere of influence and had a valid sickle cell crisis, thus comprising the final study sample (Fig 1). Approximately one-half of the patients in the sample were male ($n = 193$ [51.7%]), and the majority were African American ($n = 358$ [96.0%]). A total of 125 patients had a 30-day readmission in the time period, yielding a 3-year, overall crude patient-level readmission rate of 33.5% and an approximate 18.8% visit-level readmission rate. The median time to readmission for all readmitted patients was 12 days (range: 1–30 days; interquartile range: 3–20). Of those patients experiencing a readmission, 93 (74.4%) were readmitted for sickle cell crisis.

Geographic Distribution of Patients

The number of patients in and around a given area (in this case, 0.01 square mile) was used to determine the density of readmitted and nonreadmitted patients across the geographic area. Density analysis of the study sample revealed areas of difference between the cohorts. Specifically, areas of higher readmission density (over nonreadmitted density) were noted in Washington, DC; Prince George's County, Maryland; and Charles County, Maryland (Fig 2).

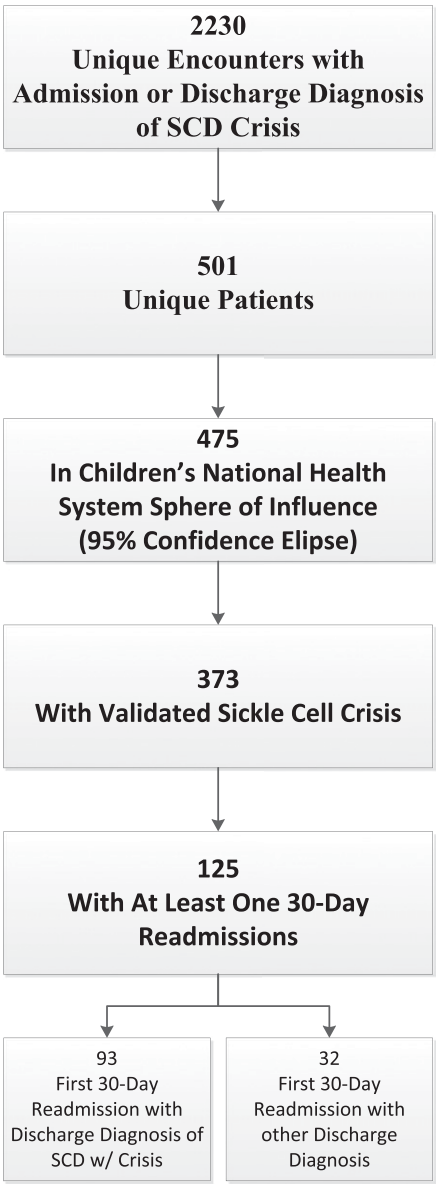

FIGURE 1 Derivation of the final study sample from all hospitalizations.

Characteristics Affecting 30-Day Readmission

Uncorrected characteristic differences between the 2 cohorts are indicated in Table 1. Patients experiencing a 30-day readmission were older and had a shorter length of stay than those who did not experience a readmission. A pain score >7 on a 10-point scale at admission, >4 on the same 10-point scale at discharge, and >3 hospital utilizations in the previous 12 months led to a significantly higher risk of readmission within 30 days. In addition, subjects with a residence within 2 and 5 miles of CNHS's main hospital campus had a significantly lower risk of readmission than those residing outside that distance.

Multivariable Models

The adjusted odds ratios developed from each model are listed in Table 2. In the 30-day readmission model, patients' age, pain score on admission and discharge, and number of hospital utilizations in the previous 12 months were associated with higher odds of readmission. Index admission length of stay and residing within 5 miles of the CNHS main campus were both associated with lower odds of readmission. As the time to readmission was reduced, admission pain score, patient's residence, and index length of stay became less significant.

DISCUSSION

The quality of health care in the United States has been the subject of investigation and lawmaking since the late 1990s.[5,6,29] Since that time, improvement in quality of care has become a top priority for many health care organizations.[3,24,30] In pediatrics, unadjusted 30-day readmission rates tend to be relatively low compared with the adult population (6.5% vs 19.6%, respectively).[24,31] The same holds true for CNHS, whose annual readmission rate is ~6.6%. The readmissions experienced by our population tend to involve chronic disease diagnoses common in pediatrics.[24]

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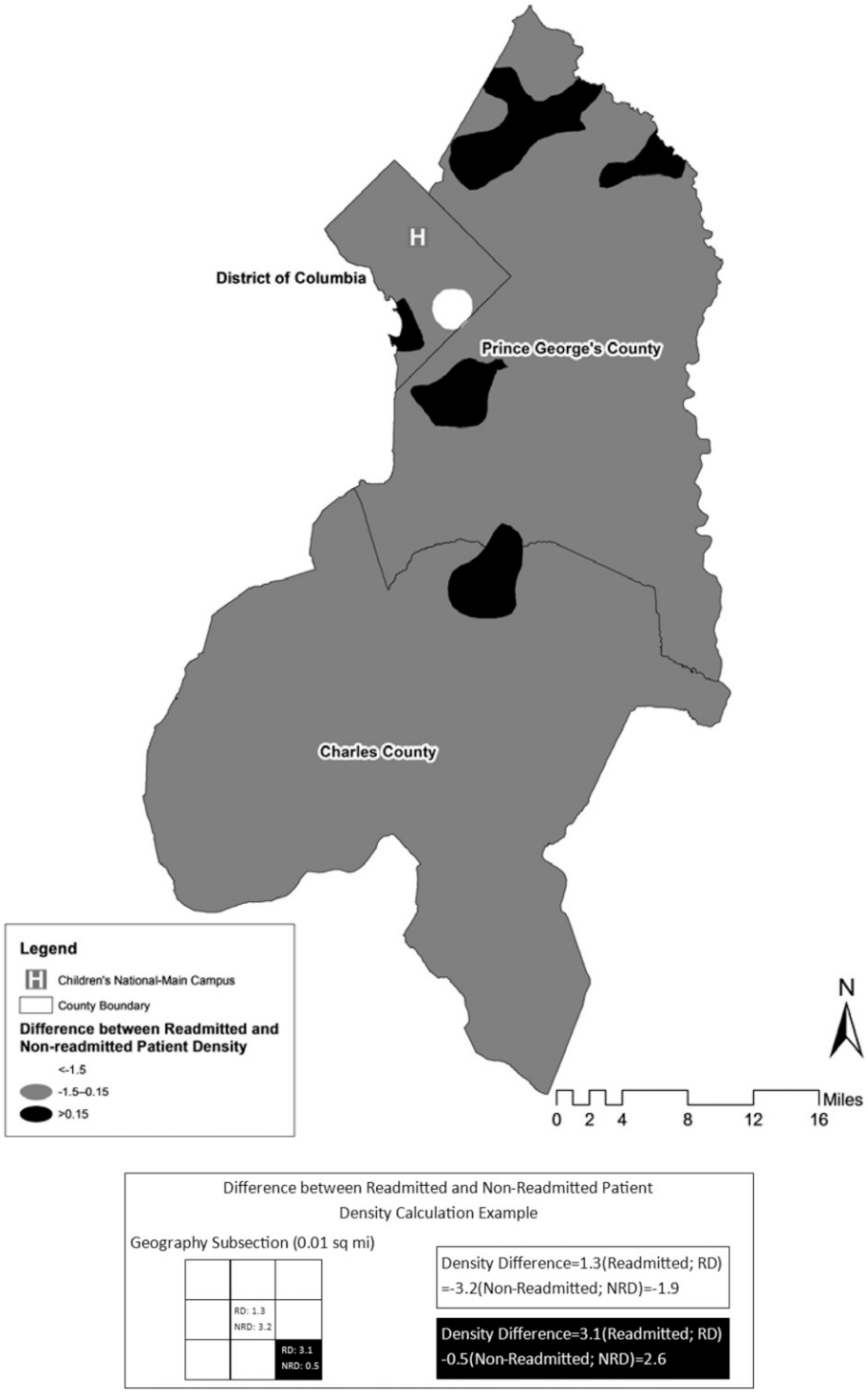

FIGURE 2 Geographic differences between readmitted patients and nonreadmitted patients in the Washington, DC, metropolitan region, 2010–2012.

The present study represented a novel approach to characterizing sickle cell crisis readmissions by using detailed EHR-derived data, as well as relevant geographic factors. The crude patient-level readmission rate for patients with sickle cell crises in this study was nearly 34%. In addition, we found an approximate visit-level readmission rate of 18.3% for the 3-year period, which is higher than rates reported in previous research.[4,24] This increase could be due to the large population of patients with SCD in the study area. As the primary servicer for these patients, CNHS has a higher than

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TABLE 1 Characteristics of Hospital Inpatient Admissions That Did and Did Not Result in a 30-Day Readmissions

Variable	Sample (n = 373)	Readmitted (n = 125)	Not Readmitted (n = 248)	Unadjusted Odds of Readmission (95% CI)
Admission pain at ≥7/10 at index**	103 (27.6%)	52 (42%)	51 (20.6%)	2.201 (1.408–3.443)
Admitted from CNHS emergency department	318 (85.3%)	107 (86%)	211 (85.1%)	1.042 (0.567–1.917)
Admission hemoglobin at index, mean	8.6	8.6 (95% CI: 8.1–9.0)	8.5 (95% CI: 8.3–8.9)	NA
African American	358 (96.0%)	121 (97%)	237 (95.6%)	1.404 (0.438–4.502)
Age at index, mean***	11.2	12.7 (95% CI: 11.7–13.7)	10.5 (95% CI: 9.7–11.2)	NA
Census tract household income, median, $	63 194.00	61 321.00 (IQR: 50 142.00–85 193.00	63 796.50 (IQR: 48 186.50–93 030.00)	
Comorbidities				
Acute chest syndrome	63 (16.9%)	17 (14%)	46 (18.5%)	0.691 (0.378–1.264)
Asthma	49 (13.1%)	16 (13%)	33 (13.3%)	0.956 (0.504–1.814)
Discharge pain at ≥4/10 at index**	84 (22.5%)	41 (33%)	43 (17.3%)	2.098 (1.300–3.388)
Distance from appropriate emergency department				
Residence <2 miles	174 (46.6%)	58 (46%)	116 (46.8%)	0.985 (0.640–1.516)
Residence <5 miles	323 (86.6%)	110 (88%)	213 (85.9%)	1.205 (0.631–2.302)
Residence <10 miles	370 (99.2%)	123 (98%)	247 (99.6%)	0.249 (0.022–2.773)
Distance from appropriate pharmacy				
Residence <2 miles	203 (54.4%)	66 (53%)	137 (55.2%)	0.906 (0.589–1.395)
Residence <5 miles	334 (89.5%)	114 (91%)	220 (88.7%)	1.319 (0.637–2.746)
Residence <10 miles	372 (99.7%)	125 (100%)	247 (99.6%)	NA
Distance from CNHS main campus				
Residence <2 miles*	23 (6.2%)	3 (2%)	20 (8.1%)	0.280 (0.082–0.962)
Residence <5 miles*	93 (24.9%)	23 (18%)	70 (28.2%)	0.573 (0.337–0.974)
Residence <10 miles	248 (66.5%)	88 (70%)	160 (64.5%)	1.308 (0.822–2.080)
Distance from CNHS primary care physician				
Residence <2 miles	123 (33.0%)	37 (30%)	86 (34.7%)	0.792 (0.498–1.260)
Residence <5 miles	324 (86.9%)	110 (88%)	214 (86.3%)	1.165 (0.609–2.231)
Residence <10 miles	368 (98.7%)	124 (99%)	244 (98.4%)	2.033 (0.225–18.382)
Female	180 (48.3%)	58 (46%)	122 (49.2%)	0.894 (0.581–1.375)
>3 hospital utilizations in the 12 months before index***	75 (20.1%)	48 (38%)	27 (10.9%)	5.103 (2.979–8.739)
Hydroxyurea administration at index	58 (15.5%)	22 (18%)	36 (14.5%)	1.257 (0.704–2.247)
ICU admission at index	26 (7.0%)	5 (4%)	21 (8.5%)	0.450 (0.166–1.224)
Length of stay, median, d***	3	2 (IQR:1–4)	3 (IQR:2–5)	NA
Narcotic administration at index	330 (88.5%)	114 (91%)	216 (87.1%)	1.535 (0.746–3.159)
Prefer English language	370 (99.2%)	123 (98%)	247 (99.6%)	0.249 (0.022–2.773)
SCD genotype				
HbS-S	262 (70.2%)	88 (70%)	174 (70.2%)	1.011 (0.632–1.619)
HbS-C	79 (21.2%)	24 (19%)	55 (22.2%)	0.834 (0.488–1.426)
Hb-S β + thalassemia	11 (2.9%)	4 (3%)	7 (2.8%)	NA
Hb-S β 0 thalassemia*	13 (3.5%)	8 (6%)	5 (2.0%)	NA
Use of oxygen therapy at index	106 (28.4%)	29 (23%)	77 (31.0%)	0.671 (0.409–1.100)

χ^2 test statistics equate to: *$P < .05$; **$P < .01$; ***$P < 0.001$. CI, confidence interval; IQR, interquartile range; NA, not available or applicable.

average representation of SCD patients among the population and thus a higher propensity for readmissions. The high readmission rates indicate a need for investigating potential system changes at the local level.

The need for appropriate care in urban, suburban, and rural areas was indicated by the geographic distribution differences

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TABLE 2 Risk Factors Associated With 30-, 14-, and 7-Day Readmissions

Readmission	Model Variables	Adjusted Odds Ratio (95% CI)	*P*
Within 30 days	Index length of stay	0.858 (0.772–0.954)	.005
	Age at index admission	1.059 (1.013–1.108)	.011
	Number of hospital utilizations in previous 12 months	1.280 (1.154–1.421)	<.001
	Admission pain ≥7	2.077 (1.234–3.497)	.006
	Discharge pain ≥4	1.581 (0.907–2.756)	.10
	Address within 5 miles from CNMC main campus	0.460 (0.256–0.827)	.009
Within 14 days	Index length of stay	0.900 (0.801–1.011)	.08
	Age at index admission	1.072 (1.019–1.128)	.007
	Number of hospital utilizations in previous 12 months	1.065 (1.050–3.693)	.003
	Discharge pain ≥4	2.063 (1.152–3.693)	.01
	Address within 5 miles from CNMC main campus	0.390 (0.190–0.798)	.01
Within 7 days	Age at index admission	1.081 (1.016–1.150)	.01
	Number of hospital utilizations in previous 12 months	1.112 (1.015–1.218)	.02
	Discharge pain ≥4	2.443 (1.264–4.724)	.008

between patients with and without readmission. Patients in suburban communities, such as Charles County, Maryland, have historically had less access to appropriate subspecialty medical care than their urban counterparts.[32] This study identified differences between those patients readmitted and those not readmitted, particularly in areas of Charles County and Prince George's County, Maryland. Both counties had areas in which the readmitted patient density was greater than the density of those patients who were not readmitted. We speculate that these areas require continued outreach and professional training in the appropriate management of SCD patients to reduce the risk of readmissions.

This study examined several geographic factors (identified by limitations in previous research) in an attempt to improve risk evaluation.[4,7,8,10] Although distances from emergency departments and public transportation access points were hypothesized to impact the risk of readmissions, neither factor was identified as being significantly associated with readmission risk. However, distance to the CNHS main campus (ie, the location for admission for the study sample) provided a significant protection from readmission to patients who lived within 5 miles of the campus. The CNHS main campus houses a SCD-specific outpatient clinic that can provide specialized care without the need for inpatient admission. In addition, it is also possible that children residing farther away may only visit the hospital when their sickle cell crisis is more severe, thus requiring inpatient admission. In either scenario, the protective effect provided could be an indication that having appropriate, SCD-specific care close to a patient's residence may decrease the likelihood they will use expensive hospital resources.

Patient age in each cohort was significantly different; readmitted patients were older than those not readmitted. Previous research has reported similar findings, concluding that increased age plays a critical role in the risk of readmission.[4,23] Older children have a greater ability to determine their level of pain and therefore have a greater ability to communicate it to their caregivers and physicians. They also have greater external life pressures, such as school and social interactions, which have been shown to increase children's susceptibility to sickle cell crises.[33] As such, we believe more robust, age-appropriate pain management plans should be developed.

Previous hospital utilizations in patients with SCD have long been hypothesized as a primary indicator of likely readmission, both in this trial and in historic studies.[8,10] In the present study, patients with >3 previous hospitalizations in 12 months were 5 times more likely to be readmitted. In addition, each previous hospital utilization increased the risk for readmission by 28% in the 30-day readmission model. We speculate that allocation of specialized care coordination resources to patients with high hospital utilizations may alter their cycle of readmissions.[34]

As a primary indicator of patient comfort, pain scores are used to judge the effectiveness of analgesic treatment and fitness for discharge. This study found that a high admission pain score (≥7 on a 10-point scale) and discharge pain score (≥4 on a 10-point scale) were associated with an increased risk of readmission. This outcome is in contrast to other reports in which patient's complaint of pain was a nonsignificant factor.[8] Although the 95% confidence interval for discharge pain score covers 1 in the 30-day readmission model, it was found to be critical to the overall model. Removing the discharge pain score significantly changed the adjusted odds ratios of the other variables and significantly reduced the concordance rate of the model. In addition, discharge pain score was found to be a significant indicator for 14- and 7-day readmissions. We speculate that admission pain management plans, more informed fitness for discharge decisions, and postdischarge care coordination may be important in reducing the hospital readmissions of patients experiencing sickle cell crisis.

CONCLUSIONS

This study found that older SCD patients with shorter lengths of stay, numerous hospital utilizations, and high admission and discharge pain scores were at greater risk for hospital readmission. In addition, this study found that living close to specialized health care facilities reduced a patient's risk of readmission. This geographic feature remained significant throughout the analysis in conjunction with the clinical variables identified. Patient-level

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clinical factors would likely benefit from specific care planning and coordination through admission, discharge, and transition to home, as well as using these findings to better inform clinical care. Reducing the risk presented by a patient's residence likely requires changes to the health care system, such as the addition of specific SCD care locations in identified areas.

We suggest that future studies test the multivariable model in a prospective fashion to validate and determine its sensitivity and specificity. We also suggest that our findings be assessed at inpatient facilities across the United States to better understand the validity of the model, as well as local factors that may be influencing these readmissions. Finally, we encourage health care providers and institutions to incorporate the findings of this study by increasing the resources provided for coordination and engagement for patients admitted for sickle cell crisis.

This study was limited to the inpatient setting of a single, tertiary care facility in a large metropolitan region. Although the facility is associated with several urban pediatric primary care locations, including an on-site SCD clinic, this study is lacking outpatient follow-up data, which may play a role in reducing the risk of readmissions. In addition, data are missing from neighboring regional hospital inpatient facilities and emergency department revisits, resulting in possible misidentification of patients as not having readmissions.

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