Comorbidities and Complications of Spinal Fusion for Scoliosis

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abstract

BACKGROUND AND OBJECTIVES: General pediatricians and hospitalists are increasingly summoned to optimize the comorbid conditions of children with medical complexity (CMC) undergoing major surgery. We assessed the relationship between specific chronic conditions of CMC and hospital resource use with spinal fusion for scoliosis, an operation with high cost and morbidity.

METHODS: Retrospective analysis of 7252 children age ≥5 years with an underlying complex chronic condition undergoing spinal fusion between January 1, 2010 through December 31, 2014 in 41 children's hospitals. Hospital length of stay (LOS), cost, and 30-day readmission rate were compared across comorbid conditions by using linear and logistic regression accounting for demographic characteristics and clustering of patients by hospital.

RESULTS: Fifty-nine percent of children had ≥4 comorbid conditions. As the number of chronic conditions increased from 1–3 to ≥10, median LOS increased 60% (5 [interquartile range (IQR), 4–7] to 8 [IQR, 5–13] days); median hospital cost increased 53% ($52 319 [IQR, $37 937–71 513] to $80 429 [IQR, $58 602–$111 965]); and readmission rates increased 293% (5.4% to 15.8%) (*P* < .001 for all). In multivariable analysis, conditions strongly associated with LOS and cost were chronic respiratory insufficiency (LOS: +2.1 days; cost: +$12 070; and bladder dysfunction (LOS: +0.8 days; cost: +$4014) (*P* < .001 for all). Readmission likelihood was highest with bladder dysfunction (odds ratio, 1.5; 95% confidence interval, 1.1–2.0) and epilepsy (odds ratio, 1.2; 95% confidence interval, 1.0–1.5).

CONCLUSIONS: Chronic respiratory insufficiency, bladder dysfunction, and epilepsy had significant associations with hospital resource use for CMC undergoing spinal fusion. Pediatricians, patients, and families may find it useful to consider these conditions when striving to benefit the children's perioperative health and outcomes.

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WHAT'S KNOWN ON THIS SUBJECT: General pediatricians and hospitalists are increasingly summoned to help optimize control of comorbid conditions and contain hospital resource use in children with medical complexity undergoing major surgery, such as spinal fusion for scoliosis.

WHAT THIS STUDY ADDS: Spinal fusion hospital resource use increases with the number of comorbid conditions; chronic respiratory insufficiency, bladder dysfunction, and epilepsy had the strongest associations. Pediatricians assisting with perioperative care may find it useful to consider these conditions.

ARTICLE

Children with medical complexity (CMC) are a rapidly growing pediatric population[1,2] with a substantial impact on the health care system.[3,4] These children have lifelong, life-limiting chronic conditions and multiple comorbidities related to the impairment of multiple organ systems,[2] which make coordinating their care and optimizing their health a challenge. They experience frequent, costly hospitalizations that are often lengthy and include major surgical interventions required to improve their daily functioning.[5–8] Due to their associated medical complexity and fragility, surgery in these children may be complicated and have a high likelihood of perioperative adverse events and other suboptimal outcomes.

General pediatricians and hospitalists are increasingly summoned to optimize the health of CMC underdoing major surgery. To help achieve the triple aim of increased patient satisfaction, improved quality of care, and decreased cost,[9] pediatricians are integrating[10] with surgeons, anesthesiologists, specialists, and other providers to help assess and manage the children's comorbid conditions before, during, and after surgery.[11–15] Despite the promise of involving pediatricians in the perioperative management of comorbid conditions for CMC, little is known about which comorbidities have the strongest associations with health outcomes and use of expensive hospital resources after major surgical interventions. Identifying the conditions with these associations may help inform the development and implementation of specific perioperative clinical pathways designed to best manage the conditions.

Therefore, the goal of the current study is to assess the comorbid conditions on a recent cohort of CMC undergoing spinal fusion for scoliosis across multiple children's hospitals. Spinal fusion was selected as a representative procedure because it has a high cost and high complication rate and it is associated with prolonged recovery, which can be physiologically stressful for the children.[16] After spinal fusion, CMC are known to have an increased risk of postoperative complications and hospital readmissions.[17–22] Although national efforts to optimize the health for CMC undergoing spinal fusion are underway,[23] no standardized guidelines for perioperative care exist. Therefore, the objectives of this study were to (1) assess the relationship between specific chronic conditions and other clinical characteristics on hospital resource use for children with complex neuromuscular or genetic conditions undergoing spinal fusion; and (2) distinguish which characteristics are associated with the highest resource use.

METHODS

Study Design and Setting

This study is a multicenter, retrospective cohort analysis of the Pediatric Health Information System (PHIS). PHIS is an administrative database of 41 not-for-profit, tertiary-care children's hospitals, located in all US geographic regions, who are affiliated with the Children's Hospital Association (Overland Park, KS) that submitted data to PHIS consistently between January 1, 2010 and December 31, 2014; an additional 3 PHIS hospitals not submitting data consistently in this period were not included for analysis. PHIS data quality and reliability are assured through Children's Hospital Association and participating hospitals. In accordance with the policies of Boston Children's Hospital Institutional Review Board, this study of deidentified data was not considered human subjects research.

Study Population

The study population was children age ≥5 years with an underlying neuromuscular or genetic complex chronic condition (CCC) undergoing spinal fusion for the first time during the study period in any of the PHIS hospitals. We withheld instituting an age ceiling for the cohort because, even for older patients (eg, age ≥21 years), there was likely a clinical reason that led to the decision for pediatric surgeons to operate and care for them in a freestanding children's hospital. Children with 1 of these CCCs were identified from *International Classification of Diseases, Ninth Revision, Clinical Modification* (ICD-9-CM) diagnosis codes contained in Feudtner's set of CCCs (version 2).[24] Hospitalizations for spinal fusion were identified with a primary ICD-9-CM procedure code for primary spinal fusion (81.0X).

Main Outcome Measures

The main outcome measures were hospital length of stay (LOS), 30-day, unplanned, all-cause hospital readmission, and hospital cost. LOS was measured in days. Hospital readmissions, for any unplanned reason, were measured within 30 days of discharge from the spinal fusion admission by using criteria endorsed by the National Quality Forum. National Quality Forum criteria define planned readmissions as those that are usually scheduled in advance of the readmission for a planned procedure; when one of them was coded as the primary procedure, the readmission was classified as a planned readmission.[25] Reasons for readmission were described by using All Patient Refined Diagnosis Related Groups (3M Health Systems). Hospital cost included patient room, medications, equipment, therapies, treatment, procedures, etc. Hospital cost did not include professional (eg, physician) services because this information is not available in PHIS.

Demographic and Clinical Characteristics

We also assessed patient demographic characteristics that might correlate with outcomes after spinal fusion for children in the cohort. Demographic characteristics included sex, age at admission in years, payer (eg, Medicaid, private insurer, and other), and race/ethnicity (Hispanic, non-Hispanic black, non-Hispanic white, and other).

We assessed the type and number of comorbid conditions, of any complexity, experienced by the children using the Agency for Healthcare Research and Quality (AHRQ) Chronic Condition Indicator (CCI) system, which categorizes >14 000 ICD-9-CM diagnosis codes into chronic versus nonchronic conditions.[26] The CCI system was used for this method over the CCC system described above because the CCCs, by design, do not include all of the comorbid conditions known to affect children, including asthma, bladder dysfunction, dysphagia, gastroesophageal reflux, etc. The CCI system includes these conditions. The number and the exact CCIs were used for all statistical analyses of comorbid conditions. For exact CCIs, the 10 most prevalent (Fig 1) comorbid conditions were selected for analysis. In addition to the children's chronic conditions (identified by using the AHRQ CCI system), we assessed the number and type (eg, antiinfective, cardiac, etc) of medications administered during their hospitalization using Truven Analytics' (Ann Arbor, MI) Clinical Transaction Classification pharmacy codes.[27,28]

We also assessed acute illnesses (eg, acute renal failure, pneumonia, sepsis, seizure, etc) that occurred during the spinal fusion hospitalization that might also be associated with hospital resource use. The acute illnesses, informed by previous studies of spinal fusion as
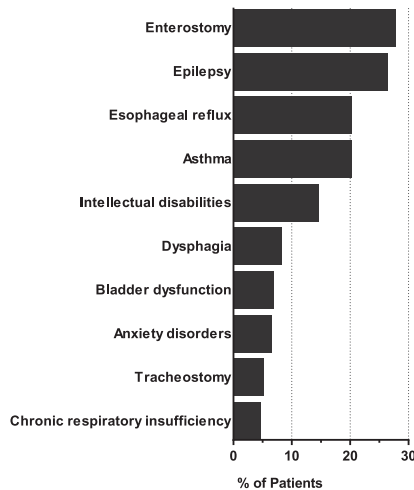
well as our own clinical experiences, were identified with ICD-9-CM diagnosis codes used in previous studies.[29–33] The acute illnesses were not recognized as chronic conditions in the AHRQ CCI system. However, some of the illnesses could have been associated with an acute exacerbation of a chronic health condition (eg, a child with chronic respiratory insufficiency [categorized as a chronic condition] experienced respiratory arrest [categorized as an acute illness] during the hospitalization) (Supplemental Information).

Statistical Analysis

In univariable analysis, we used Rao-Scott χ^2 tests, accounting for hospital clustering, to assess the relationship between outcomes and patients' clinical and demographic characteristics. To assess these relationships in multivariable analysis, we derived a generalized log-linear regression model (for the LOS and hospital charges outcomes) and a generalized binary estimating equation model (for the hospital readmission outcome). The main independent variables in the models

were the patient's actual acute illness and chronic comorbid conditions, identified by using ICD-9-CM codes from previous studies and the AHRQ CCI system, respectively. Both models were derived by simultaneously entering all of the fixed effects for acute illnesses, comorbid conditions, and confounders (eg, underlying CCC type, age, sex, and race/ethnicity) as well as a random effect for hospital. By using the coefficients from the multivariable models, adjusted LOS, hospital charges, and hospital readmission rates were estimated for each characteristic. All analyses were performed by using SAS version 9.4 (SAS Institute, Inc, Cary, NC), and P values <.05 were considered statistically significant.

RESULTS

Study Population

There were 7252 patients with a complex neuromuscular or congenital/genetic CCC who underwent spinal fusion between 2010 and 2014 in the study cohort. The most common complex conditions in the cohort were cerebral palsy (33.4%), brain malformation (15.8%), and chromosomal syndrome (12.2%) (Table 1). The median age in years at admission was 13 (interquarile range [IQR], 11–15). Most patients were non-Hispanic white (62.5%), female (53.4%), and were covered under Medicaid (50.2%). Most patients (68.9%) had ≥9 vertebrae fused during the spinal fusion (Table 1).

Multiple chronic conditions were prevalent among the cohort; 95.6% of patients had ≥2 chronic conditions in addition to the orthopedic abnormality (eg, scoliosis) that led to the indication for spinal fusion (Table 1). The majority (58.9%) of patients had ≥4 chronic conditions. Epilepsy (26.5%), gastroesophageal reflux disease (20.3%), asthma (20.3%), and dysphagia (8.4%) were among the most common chronic conditions

TABLE 1 Demographic, Clinical, and Hospitalization Characteristics of Children With A Complex Neuromuscular or Genetic Condition Undergoing Complex Spinal Fusion Across US Freestanding Children's Hospitals

Characteristics	N (%)	Median (Interquartile Range) Hospital Cost		
		Median (Interquartile Range) LOS, d	US Dollars	30-d Readmission Rate, %
Overall cohort	7252	6 (4–8)	61275 (43626–86240)	8.7
Demographic Characteristics[a]				
Age at admission, y				
5–10	1381 (19.0)	6 (4–8)	56087 (38663–81070)	8.7
11–15	4236 (58.4)	6 (4–8)	62303 (45577–85664)	8.5
16–20	1519 (20.9)	6 (4–8)	62745 (43845–91031)	8.8
≥21[b]	116 (1.6)	7 (5–12)	61244 (40308–93920)	17.2
Sex				
Female	3378 (46.6)	6 (4–9)	63391 (44774–90734)	8.8
Male	3874 (53.4)	5 (4–8)	59145 (42752–81976)	8.6
Race/ethnicity				
Non-Hispanic white	4529 (62.5)	6 (4–8)	60254 (41655–85208)	8.3
Non-Hispanic black	832 (11.5)	6 (4–9)	63735 (46376–91003)	8.8
Hispanic	1130 (15.6)	6 (5–9)	62370 (48319–85737)	11.0
Other	761 (10.5)	6 (4–9)	62177 (44206–87513)	7.5
Payor				
Public insurance	3628 (50.2)	6 (4–9)	63540 (46152–89241)	10.1
Private insurance	3335 (46.1)	5 (4–8)	59761 (42173–84576)	7.5
Other	268 (3.7)	6 (4–8)	48573 (32848–67836)	5.2
Clinical Characteristics[a]				
Underlying CCC				
Cerebral palsy	2420 (33.4)	7 (5–10)	71569 (53476–98083)	11.7
Brain malformation	1144 (15.8)	7 (5–11)	71439 (52831–101776)	11.2
Chromosomal syndrome[c]	887 (12.2)	5 (4–8)	58234 (44231–77226)	7.0
Central nervous system degeneration	636 (8.8)	7 (5–10)	70823 (52137–101661)	11.7
Other genetic syndrome[d]	606 (8.4)	6 (5–8)	62857 (46431–90040)	9.4
Muscular dystrophy	487 (6.7)	7 (5–9)	70174 (53655–101608)	10.7
Spina bifida	485 (6.7)	6 (5–9)	64980 (48432–90724)	14.8
Hydrocephalus[e]	415 (5.7)	6 (5–9)	70418 (52092–102008)	10.6
No. of chronic conditions				
0	317 (4.4)	4 (3–5)	34632 (25014–51116)	2.2
1–3	2668 (36.8)	5 (4–7)	52319 (37937–71513)	5.4
4–6	1936 (26.7)	6 (5–8)	62824 (46497–85620)	8.9
7–9	1072 (14.8)	7 (5–11)	71197 (53324–100563)	10.2
≥10	1259 (17.4)	8 (5–13)	80429 (58602–111965)	15.8
Technology assistance				
Any	3068 (42.3)	7 (5–11)	72275 (53255–101635)	12.3
Digestive	1320 (18.2)	7 (5–12)	75785 (55505–105570)	13.6
Respiratory	409 (5.6)	9 (6–17)	82695 (58012–125784)	15.4
Nervous	575 (7.9)	7 (5–10)	73930 (53655–101968)	15.1
Renal	141 (1.9)	7 (5–13)	72449 (55019–101826)	9.9
Cardiovascular	109 (1.5)	7 (5–12)	68799 (52495–109996)	11.0
Other	423 (5.8)	7 (5–11)	68233 (46207–100616)	10.4
Medication classes prescribed during admission				
1–3	27 (0.4)	5 (3–7)	36016 (21929–44910)	7.4
4–5	1202 (17.5)	5 (4–6)	47813 (34145–64843)	7.2
6–7	3912 (56.8)	5 (4–7)	58869 (43345–79787)	7.9
≥8	1742 (25.3)	8 (5–14)	80724 (59258–112084)	11.0

[a] Hospital resource use (LOS, cost, and readmission rate) varied significantly ($P < .001$) across the categories for each characteristic.

[b] Most patients age ≥21 years were age 21 to 25 years.

[c] Chromosomal syndromes included, but were not limited to, velocardiofacial syndrome, Down syndrome, and Edward syndrome.

[d] Other genetic syndromes included, but were not limited to, Marfan syndrome and multiple congenital anomalies.

[e] The hydrocephalus category does not include patients with spina bifida.

experienced by the patients. Forty-two percent of patients were assisted with medical technology (Fig 1). Among the most common technologies were those related to the digestive system (27.9%) (eg, gastrostomy), nervous system (7.9%) (eg, cerebrospinal fluid ventricular shunts), and respiratory system (5.6%) (eg, tracheostomy) (Fig 1, Table 1).

LOS, Hospital Cost, and 30-day Readmissions

Median hospital LOS and cost for spinal fusion was 6 days (IQR, 4–8 days) and $61 275 (IQR, $43 626–$86 240), respectively. The 30-day, all-cause readmission rate was 8.7%. Musculoskeletal health issues (eg, spinal hardware complication and infection) were the most common reason for readmission (45.6% [n = 288]), followed by skin (eg, wound dehiscence, seroma, or hematoma) (16.5% [n =104]), and respiratory (eg, pneumonia) (9.5% [n = 60]) issues (Fig 1). An array of 10 health problems accounted for an additional 19.8% of readmissions; constipation/gastrointestinal dysmotility (3.2% [n = 20]), pyelonephritis/urinary tract infection (3.0% [n = 19]), and seizure (2.7% [n = 17]) were the most common (Fig 2).

Univariable Analysis of Chronic Conditions and Hospital Resource Use

In univariable analyses, as the number of chronic conditions increased, LOS, hospital cost, and readmission rates increased significantly (P < .001). For example, as the number of chronic conditions increased from 1–3 to ≥10, median LOS increased by 60% from 5 days (IQR, 4–7 days) to 8 days (IQR, 5–13 days); median hospital cost increased by 53% from $52 319 (IQR, $37 937–$71 513) to $80 429 (IQR, $58 602–$111 965); and 30-day readmission rates increased nearly 3 times from 5.4% to 15.8% (P < .001 for all) (Table 1). Of all forms of

631 Total Readmissions

→ Musculoskeletal Readmissions (45.6%)
Spinal hardware infection or complication (31.9%)
Second spine surgery (6.7%)
Nonspine orthopedic surgery (4.9%)
Other musculoskeletal problem (eg, fracture) (2.2%)

→ Skin Readmissions (16.5%)
Wound dehiscence, seroma, or hematoma (15.5%)
Decubitus ulcer (1.0%)

→ Respiratory Readmissions (9.5%)
Respiratory infection (eg, pneumonia) (4.5%)
Respiratory distress (3.8%)
Other respiratory problem (1.2%)

→ 10 Most Common Other Readmissions (19.8%)
Constipation/Gastrointestinal dymotility/Obstruction (3.2%)
Kidney and urinary tract infection (3.0%)
Seizure (2.7%)
Fever (2.2%)
Gastroenteritis and hypovolemia (2.1%)
Pain, altered mental status (1.9%)
Malnutrition, failure to thrive (1.6%)
Other nervous system problem (eg, shunt malfunction) (1.3%)
Cerebrovascular accident, dura problem (1.1%)
Septicemia and disseminated infections (0.8%)
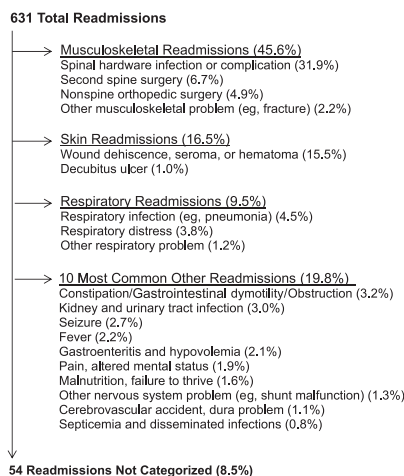
↓
54 Readmissions Not Categorized (8.5%)

FIGURE 2
Reasons for 30-day readmissions in children with a complex neuromuscular or genetic condition after hospital discharge for spinal fusion. Displayed are the most common reasons for readmission, organized by All Patient Refined Diagnosis Related Groups.

technology assistance, respiratory was associated with the longest median LOS (9 days [IQR, 6–17 days]), highest median hospital cost ($82 695 [IQR, $58 012–$125 784]), and highest 30-day readmission rate (15.4%).

Univariable Analysis of Other Patient Characteristics and Hospital Resource Use

In univariable analysis, age, race/ethnicity, payor, and number of medications were all significantly (P < .001) associated with hospital resource use (Table 1). Regarding these attributes, patients with the greatest hospital resource use had the following characteristics: age ≥21 years, Hispanic race/ethnicity, public insurance (eg, Medicaid), and administration of ≥8 therapeutic classes of medications during the admission (Table 1).

Multivariable Analysis of Patient Characteristics and Hospital Resource Use

In multivariable analysis, the base (ie, intercept) cost and LOS of the spinal fusion hospitalization were $48 557 and 5.7 days, respectively (Figs 3 and 4).

Chronic Conditions

There was significant variation in the individual contributions of specific chronic conditions, accounting for the presence of each other as well as demographic characteristics and acute illnesses, on hospital resource use (Fig 3). The chronic conditions with the strongest associations with LOS and cost were chronic respiratory insufficiency (LOS: +2.1 days; cost: +$12 070); and bladder dysfunction (LOS: +0.8 days; cost: +$4014) ($P$ < .001 for all). The additive effect of multiple chronic conditions on hospital resource use was substantial. For example, asthma, enterostomy, epilepsy, esophageal reflux, intellectual disability, dysphagia, respiratory insufficiency, and bladder dysfunction, collectively, added $25 720 and 4.6 hospital days. Readmission likelihood was highest with bladder dysfunction (odds ratio [OR], 1.5; 95% confidence interval [CI], 1.1–2.0) and epilepsy (OR, 1.2; 95% CI, 1.0–1.5) (Fig 3). Bladder dysfunction was the only chronic condition assessed that was significantly associated (P < .001) with higher hospital cost, longer LOS, and a greater likelihood of hospital readmission (Fig 3).

Acute Illnesses

Similarly, there was significant variation in the individual contributions of specific acute illnesses, accounting for the presence of each other as well as demographic characteristics and chronic conditions, on hospital resource use (Fig 4). For example, urinary tract infection added $14 272 (95% CI, $11 809–$16 735) and 3.5 days (95% CI, 3.1–3.9) to hospitalization cost and LOS, respectively, after controlling for chronic bladder dysfunction and spina bifida. Acute respiratory arrest added $16 328 (95% CI, $13 763–$18 893) and 2.6 days (95% CI, 2.2–3.0) after controlling for asthma, chronic respiratory insufficiency, and
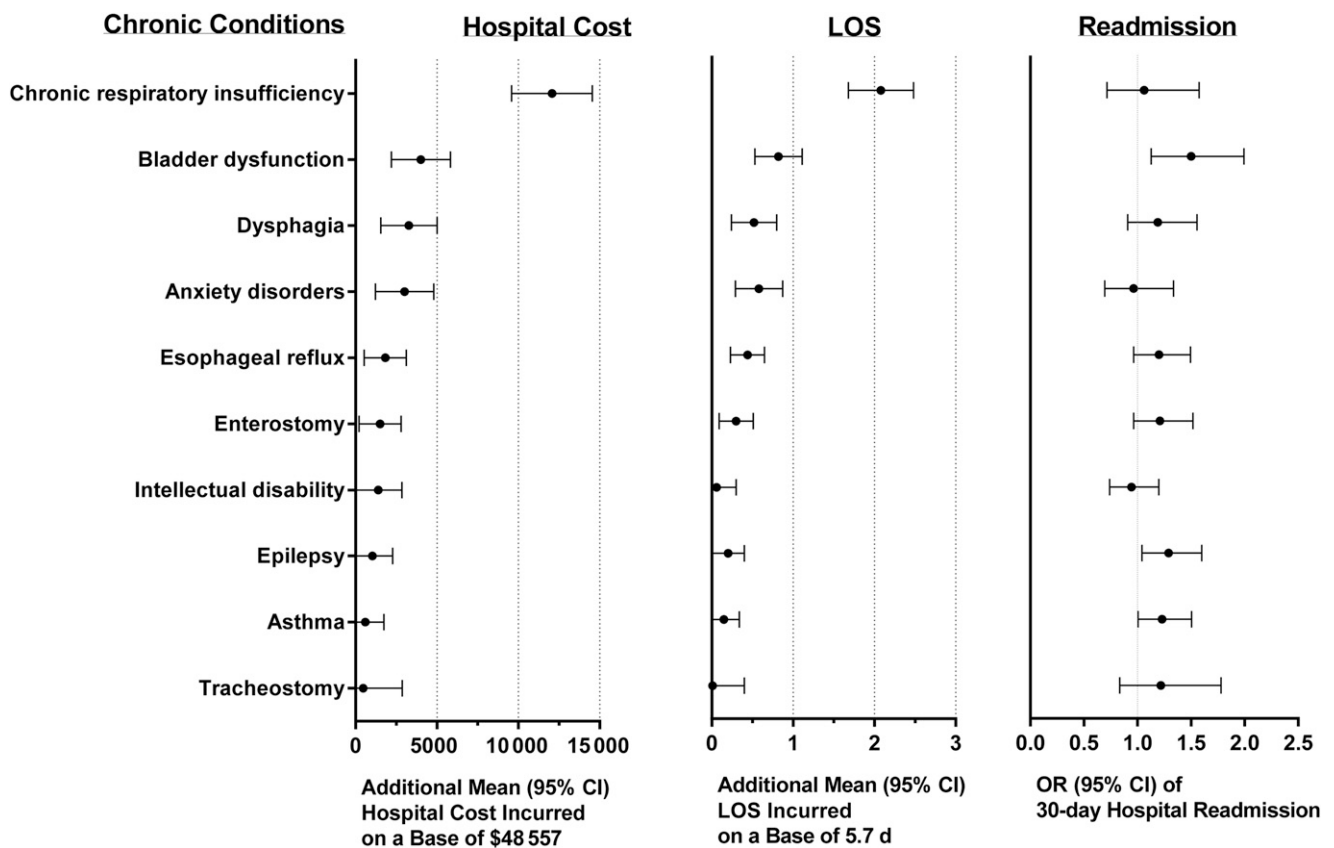
FIGURE 3
Associations of comorbid conditions and hospital resource use for children with a complex neuromuscular or genetic condition spinal fusion. All point estimates and variance were derived from multivariable analysis of generalized linear regression (for LOS and hospital cost) and generalized estimating equations (for hospital readmission). All models included the comorbid conditions displayed, which were the 10 most prevalent conditions in the cohort, as well as age, sex, race/ethnicity, and acute illnesses. Data were clustered by hospital in each model.

tracheostomy. Three of the acute illnesses assessed, decubitus ulcer, hypertension, and respiratory arrest, were significantly ($P < .001$) associated with all 3 measures of hospital resource use: higher hospital cost, longer LOS, and a greater likelihood of hospital readmission (Fig 4).

DISCUSSION

The findings from the current study highlight the importance of chronic conditions and acute illnesses in children with a complex neuromuscular or genetic condition undergoing spinal fusion, a high-risk, expensive surgery. The array of organ systems affected by children's chronic conditions, including digestive, emotional, neurologic, respiratory, and urinary, reflect the children's high degree of medical complexity. As the patients' number of chronic conditions increased, the LOS, hospital charges, and likelihood of hospital readmission increased substantially. Of all the chronic conditions assessed, chronic respiratory insufficiency, bladder dysfunction, and epilepsy had significant associations with increased LOS, cost, and readmission. Three acute illnesses that occurred during the hospitalization, decubitus ulcer, hypertension, and respiratory arrest, were also associated with increased hospital LOS, cost, and readmission, resulting in the use of additional hospital resources.

Although the current study highlights several associations of conditions with increased hospital resource use

for spinal fusion, it is not positioned to determine the true clinical mechanisms responsible for those associations. For example, chronic respiratory insufficiency could have led to delayed or failed extubation and decreased ventilatory reserve with exposure to pain medications, respiratory arrest, or other respiratory challenges that impeded health recovery and prolonged LOS. Alternatively, chronic respiratory insufficiency could have been a proxy indicator of severe neurologic impairment, which could have been the main factor that necessitated longer hospitalization. Assessment of these potential mechanisms in subsequent studies might help reveal opportunities that may exist to precipitate health recovery after spinal fusion.
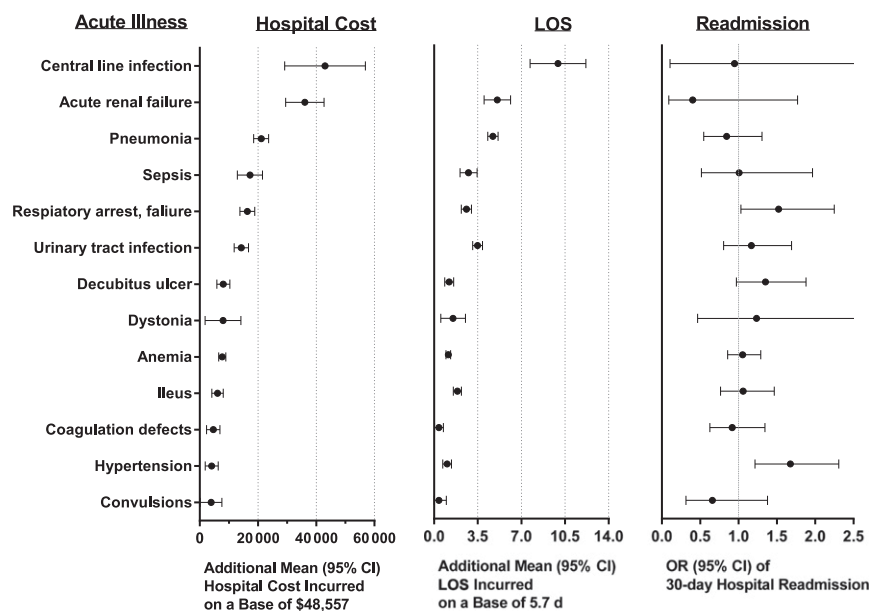
FIGURE 4
Associations of acute illnesses and hospital resource use for children with a complex neuromuscular or genetic condition undergoing spinal fusion. All point estimates and variance were derived from multivariable analysis of generalized linear regression (for LOS and hospital cost) and generalized estimating equations (for hospital readmission). All models included the acute illnesses displayed, chosen by previous studies and our clinical experiences, as well as age, sex, race/ethnicity, and comorbid conditions. Data were clustered by hospital in each model.

Additional investigation is needed to assess how well controlled, ahead of surgery, were the myriad chronic conditions associated with increased hospital resource use in CMC undergoing spinal fusion. A detailed assessment of the preoperative severity as well as intra- and postoperative exacerbations of the conditions may improve understanding of how to best manage them in the perioperative period. There is substantial variation across institutions and clinics in the conditions included in preoperative spinal fusion health evaluations.[15,34,35] Although assessments of respiratory insufficiency and cardiac dysfunction are commonly included, additional conditions, such as bladder dysfunction and epilepsy, may be worthwhile to consider. Systematic screening, severity profiling, and care management for these conditions, and others, preoperatively could potentially preclude the likelihood that they

adversely affect the health of the child during and after spinal fusion.

Central to this discussion, additional attention to perioperative management of chronic bladder dysfunction and acute urinary tract infection, in particular, may be warranted; they were both independently associated with increased hospital resource use. Certainly, children with complex chronic neuromuscular conditions (eg, cerebral palsy) are at risk for impaired innervation of bladder musculature[36] that often subsists silently, going undetected while steadily increasing in severity.[37] The severity could potentially worsen with perioperative exposures (eg, shifts in fluid volume, pain medications, etc) and result in subsequent pain from overfilling as well as constipation and infection. In a systematic review, bladder dysfunction has been highlighted as major risk factor for surgical site infection after spinal fusion.[38] Perhaps subsequent investigations

may wish to identify the true reasons why bladder dysfunction is associated with increased hospital resource use in CMC undergoing spinal fusion, which may inform how to best diagnose, manage, and control the dysfunction ahead of surgery.[39,40]

In the current study, nearly one-third of hospital readmissions after spinal fusion in CMC were for reasons beyond musculoskeletal and skin issues related directly to the operation. Future studies should assess the capability of contingency planning in spinal fusion discharge care to potentially avoid some of the readmissions. For example, it might be effective to plot and implement instructions and action plans to avoid entirely or mitigate the severity of a variety of acute illnesses that resulted in hospital readmission in the current study, including respiratory infections, gastrointestinal dysmotility, kidney/urinary tract infections, and seizures.[41] Additional attention to the involvement and ability of postdischarge clinicians, including primary, rehabilitation, and home care providers, to assist the children with their recovery and health optimization after acute-care discharge may be warranted.[42] Future efforts to standardize this planning into discharge care might have an effect on reducing unnecessary hospital readmissions after spinal fusion in CMC.

This study has several limitations. The identification of the assessed comorbid and acute conditions were dependent on their coding in each hospital's administrative billing record by discharge. Given the suspected variation in coding practices across hospitals, relying on ICD-9-CM codes may have led to underdetection and undercounting of the conditions. Other methods, such as chart review or prospective data collection, may reveal a higher prevalence of chronic conditions. The PHIS administrative data from the current study are not

positioned to distinguish the degree to which the chronic conditions were appropriately recognized and managed before spinal fusion. In addition, the PHIS data cannot reveal when during the hospitalization particular events (eg, hypertension or respiratory arrest) occurred. Important clinical information about the spinal fusion operation itself, including the duration of procedure and blood loss, is not available in PHIS. Younger children (eg, those age <10 years) included in the study may have had a different clinical trajectory and surgical approach to their spine pathology than older children; all multivariable analyses in the current study controlled for younger children. Although we measured hospital readmissions, other important postdischarge outcomes, including missed school days, improvements in functional status, etc, were not available for measurement in PHIS. The study findings may be best generalized to CMC undergoing spinal fusion in children's hospitals because non–children's hospitals were not included in the study.[43]

Despite these limitations, the findings from the current study underscore the importance of both chronic conditions and acute illnesses in children with a complex neuromuscular or genetic condition undergoing spinal fusion. General pediatricians, hospitalists, anesthesiologists, intensivists, surgeons, and others may find it useful to review these conditions and illnesses as they continue to assess how to best optimize the children's health recovery. In particular, it may be important for subsequent initiatives to understand the clinical mechanisms predominately responsible for the relationships between the conditions and hospital resource use. It may also be important to investigate how careful assessment and planning, especially ahead of the operation and at hospital discharge, may help manage the conditions in the perioperative period. Hopefully, these efforts and others will help ensure that CMC achieve the maximum benefit, experience, and outcomes from their spinal fusion operation as well as other types of operations that they may need.

ABBREVIATIONS

AHRQ: Agency for Healthcare Research and Quality
CCC: complex chronic condition
CCI: Chronic Condition Indicator
CI: confidence interval
CMC: children with medical complexity
ICD-9-CM: *International Classification of Diseases, Ninth Revision, Clinical Modification*
IQR: interquartile range
LOS: length of stay
OR: odds ratio
PHIS: Pediatric Health Information System

REFERENCES

1. Cohen A, Kuo D, Agrawal R, et al Children with medical complexity: an emerging population for clinical and research activities. *Pediatrics*. 2011;127(3): 529–538

2. Berry JG, Hall M, Cohen E, O'Neill M, Feudtner C. Ways to identify children with medical complexity and the importance of why. *J Pediatr*. 2015;167(2):229–237

3. Berry JG, Hall M, Neff J, et al. Children with medical complexity and Medicaid: spending and cost savings. *Health Aff (Millwood)*. 2014;33(12): 2199–2206

4. Berry JG, Hall M, Hall DE, et al. Inpatient growth and resource use in 28 children's hospitals: a longitudinal, multi-institutional study. *JAMA Pediatr*. 2013;167(2):170–177

5. Ananth P, Melvin P, Feudtner C, Wolfe J, Berry JG. Hospital use in the last year of life for children with life-threatening complex chronic conditions. *Pediatrics*. 2015;136(5): 938–946

6. Berry JG, Graham DA, Graham RJ, et al. Predictors of clinical outcomes and hospital resource use of children after tracheotomy. *Pediatrics*. 2009;124(2):563–572

7. Srivastava R, Berry JG, Hall M, et al. Reflux related hospital admissions after fundoplication in children with neurological impairment: retrospective cohort study. *BMJ*. 2009;339:b4411

8. Murphy NA, Hoff C, Jorgensen T, Norlin C, Firth S, Young PC. A national perspective of surgery in children with cerebral palsy. *Pediatr Rehabil*. 2006;9(3):293–300

9. Berwick DM, Nolan TW, Whittington J. The triple aim: care, health, and cost. *Health Aff (Millwood)*. 2008;27(3):759–769

10. Kash BA, Zhang Y, Cline KM, Menser T, Miller TR. The perioperative surgical home (PSH): a comprehensive review of US and non-US studies shows predominantly positive quality and cost outcomes. *Milbank Q*. 2014;92(4):796–821

11. Dadure C, Sola C, Capdevila X. Preoperative nutrition through a prehabilitation program: A key

component of transfusion limitation in paediatric scoliosis surgery. *Anaesth Crit Care Pain Med*. 2015;34(6): 311–312

12. DiCindio S, Arai L, McCulloch M, et al. Clinical relevance of echocardiogram in patients with cerebral palsy undergoing posterior spinal fusion. *Paediatr Anaesth*. 2015;25(8): 840–845

13. McPhail GL, Ehsan Z, Howells SA, et al. Obstructive lung disease in children with idiopathic scoliosis. *J Pediatr*. 2015;166(4):1018–1021

14. Khirani S, Bersanini C, Aubertin G, Bachy M, Vialle R, Fauroux B. Non-invasive positive pressure ventilation to facilitate the post-operative respiratory outcome of spine surgery in neuromuscular children. *Eur Spine J*. 2014;23(suppl 4):S406–S411

15. Rappaport DI, Cerra S, Hossain J, Sharif I, Pressel DM. Pediatric hospitalist preoperative evaluation of children with neuromuscular scoliosis. *J Hosp Med*. 2013;8(12):684–688

16. Rappaport DI, Adelizzi-Delany J, Rogers KJ, et al. Outcomes and costs associated with hospitalist comanagement of medically complex children undergoing spinal fusion surgery. *Hosp Pediatr*. 2013;3(3):233–241

17. Ramo BA, Roberts DW, Tuason D, et al. Surgical site infections after posterior spinal fusion for neuromuscular scoliosis: a thirty-year experience at a single institution. *J Bone Joint Surg Am*. 2014;96(24):2038–2048

18. Minhas SV, Chow I, Feldman DS, Bosco J, Otsuka NY. A predictive risk index for 30-day readmissions following surgical treatment of pediatric scoliosis. *J Pediatr Orthop*. 2016;36(2):187–192

19. Duckworth AD, Mitchell MJ, Tsirikos AI. Incidence and risk factors for post-operative complications after scoliosis surgery in patients with Duchenne muscular dystrophy : a comparison with other neuromuscular conditions. *Bone Joint J*. 2014;96-B(7):943–949

20. McLeod LM, Keren R, Gerber J, et al. Perioperative antibiotic use for spinal surgery procedures in US children's hospitals. *Spine*. 2013;38(7):609–616

21. Pugely AJ, Martin CT, Gao Y, Ilgenfritz R, Weinstein SL. The incidence and risk factors for short-term morbidity and mortality in pediatric deformity spinal surgery: an analysis of the NSQIP pediatric database. *Spine*. 2014;39(15):1225–1234

22. Martin CT, Pugely AJ, Gao Y, Weinstein SL. Causes and risk factors for 30-day unplanned readmissions after pediatric spinal deformity surgery. *Spine*. 2015;40(4):238–246

23. Vitale MG, Riedel MD, Glotzbecker MP, et al. Building consensus: development of a Best Practice Guideline (BPG) for surgical site infection (SSI) prevention in high-risk pediatric spine surgery. *J Pediatr Orthop*. 2013;33(5):471–478

24. Feudtner C, Feinstein JA, Zhong W, Hall M, Dai D. Pediatric complex chronic conditions classification system version 2: updated for ICD-10 and complex medical technology dependence and transplantation. *BMC Pediatr*. 2014;14:199

25. Berry JG, Toomey SL, Zaslavsky AM, et al. Pediatric readmission prevalence and variability across hospitals [published correction appears in *JAMA*. 2013;309(10):986.] *JAMA*. 2013;309(4):372–380

26. Agency for Healthcare Research and Quality. Chronic condition indicator. Available at: www.hcup-us.ahrq.gov/toolssoftware/chronic/chronic.jsp. Accessed September 26, 2012

27. Gupta P, Robertson MJ, Beam BW, Rettiganti M. Outcomes associated with preoperative use of extracorporeal membrane oxygenation in children undergoing heart operation for congenital heart disease: a multi-institutional analysis. *Clin Cardiol*. 2015;38(2):99–105

28. Benneyworth BD, Downs SM, Nitu M. Retrospective evaluation of the epidemiology and practice variation of dexmedetomidine use in invasively ventilated pediatric intensive care admissions, 2007-2013. *Front Pediatr*. 2015;3:109

29. McLeod L, Flynn J, Erickson M, Miller N, Keren R, Dormans J. Variation in 60-day readmission for surgical-site infections (SSIs) and reoperation following spinal fusion operations for neuromuscular scoliosis. *J Pediatr Orthop*. 2016;36(6):634–639

30. Agency for Healthcare Research and Quality. Appendix A - Clinical Classification Software - DIAGNOSES. Available at: www.hcup-us.ahrq.gov/toolssoftware/ccs/AppendixASingleDX.txt. Accessed September 12, 2011

31. Whittaker SA, Mikkelsen ME, Gaieski DF, Koshy S, Kean C, Fuchs BD. Severe sepsis cohorts derived from claims-based strategies appear to be biased toward a more severely ill patient population. *Crit Care Med*. 2013;41(4):945–953

32. Harris JM II, Gay JC, Neff JM, Patrick SW, Sedman A. Comparison of administrative data versus infection control data in identifying central line-associated bloodstream infections in children's hospitals. *Hosp Pediatr*. 2013;3(4):307–313

33. Conway PH, Keren R. Factors associated with variability in outcomes for children hospitalized with urinary tract infection. *J Pediatr*. 2009;154(6):789–796

34. Children's Hospital of Orange County. Spinal fusion for neuromuscular scoliosis care guideline. Available at: www.choc.org/wp/wp-content/uploads/careguidelines/SpinalFusionNMSCareGuideline.pdf. Accessed January 12, 2017

35. Children's Hospital Los Angeles, Children's Orthopaedic Center. Spinal fusion preparation and recovery: Children's Hospital Los Angeles. Available at: www.chla.org/sites/default/files/atoms/files//CHLA-COC-Spinal-Fusion-Preparation-and-Recovery-English.pdf. Accessed January 12, 2017

36. Samijn B, Van Laecke E, Renson C, et al. Lower urinary tract symptoms and urodynamic findings in children and adults with cerebral palsy: A systematic review [published online ahead of print February 21, 2016]. *Neurourol Urodyn*. 10.1002/nau.22982

37. Murphy KP, Boutin SA, Ide KR. Cerebral palsy, neurogenic bladder, and outcomes of lifetime care. *Dev Med Child Neurol*. 2012;54(10): 945–950

38. Glotzbecker MP, Riedel MD, Vitale MG, et al. What's the evidence? Systematic literature review of risk factors and preventive strategies for surgical site infection following pediatric spine surgery. *J Pediatr Orthop.* 2013;33(5): 479–487

39. Fernandes Silva JA, Borges Carrerette F, Damião R. Uroflowmetry in the management of lower urinary tract symptoms of children and adolescents with cerebral palsy. *J Pediatr Urol.* 2014;10(3):413–417

40. Ersoz M, Kaya K, Erol SK, Kulakli F, Akyuz M, Ozel S. Noninvasive evaluation of lower urinary tract function in children with cerebral palsy. *Am J Phys Med Rehabil.* 2009;88(9): 735–741

41. Berry JG, Blaine K, Rogers J, et al. A framework of pediatric hospital discharge care informed by legislation, research, and practice. *JAMA Pediatr.* 2014;168(10):955–962; quiz 965–966

42. Berry JG, Hall M, Dumas H, et al. Pediatric hospital discharges to home health and postacute facility care: A national study. *JAMA Pediatr.* 2016;170(4):326–333

43. Berry JG, Lieu TA, Forbes PW, Goldmann DA. Hospital volumes for common pediatric specialty operations. *Arch Pediatr Adolesc Med.* 2007;161(1):38–43