Child's Nervous System (2019) 35:657–664
https://doi.org/10.1007/s00381-018-4012-6

ORIGINAL PAPER

Outcomes and resource utilization in surgery for Chiari I malformation in a national network of children's hospitals

Melissa A. LoPresti[1,2] · I-Wen Pan[1] · Nisha Gadgil[1,2] · Kathryn Wagner[1,2] · Sandi Lam[1,2]

Received: 22 August 2018 / Accepted: 22 November 2018 / Published online: 10 December 2018

Abstract

Introduction Chiari malformation type 1 (CM-1) is a common congenital or acquired malformation of the posterior fossa. We aimed to characterize preoperative risk factors, perioperative complications, and postoperative outcomes related to CM-1 surgery in pediatric populations across a nationwide network of pediatric hospitals in the United States (US).

Methods The Children's Hospital Association's Pediatric Health Information System (PHIS) database was used to examine patients < 21 years old in the US-based nationwide database who underwent inpatient surgery for CM-1 from 2007 to 2015. Data analyzed included patient characteristics, preoperative comorbidities, perioperative outcomes, short-term postoperative surgical and medical complications, and healthcare resource utilization.

Results Among the 5976 patients identified, those age 0–4 years had higher medical and surgical complication rates compared to older patients. Those with pre-existing comorbidity of hydrocephalus had higher odds of 30- and 90-day medical and surgical complications. Those with any complications at 90 days had an increased length of stay and higher healthcare costs compared to those without complications. 6.88% of complications were surgical and 1.67% medical. Patients with medical complications had the longer mean stay and associated costs compared to those with surgical complications (13 vs. 6.9 at 95% CI, and $71,300–94,500 vs. $110,400–195,000 at 95% CI).

Conclusions Use of a US-based national children's hospital database presents outcomes and resource utilization from a multi-institutional, real-world experience in pediatric hospitals. There was a higher risk of perioperative complications in younger patients and those with pre-existing comorbidities, namely hydrocephalus. Understanding preoperative risk factors, perioperative complications, and postoperative outcomes, as well as healthcare utilization and costs, can help target areas for improvement and guide preoperative counseling and risk stratification.

Keywords Chiari malformation · Outcomes · Pediatric · National database

Introduction

Chiari malformation type 1 (CM-1) is a caudal displacement of the medulla with a displacement of the cerebellar tonsils through the foramen magnum [2]. Due to tonsillar displacement across the foramen magnum, CM-1 is associated with altered cerebrospinal flow and syringomyelia, which is thought to be due to differential craniospinal pressure gradients across the foramen magnum, changing normal CSF circulation and pressure equilibration [14]. CM-1 can present with a variety of symptoms. It is a common diagnosis in pediatric populations and is often treated with elective surgery in those that are symptomatic [14].

Understanding perioperative risks and postoperative complications associated with CM-1 may help identify target areas for quality improvement and reduction in variations in hospitalization costs. A previous examination of a United States (US)–based national database revealed that the overall rates of adverse events with surgery for Chiari type 1 malformation are low, and longer operative times and longer hospital stays

Portions of this work were presented in electronic poster form at the American Association of Neurological Surgeons Annual Scientific Meeting, Los Angeles, CA, 2017.

✉ Melissa A. LoPresti
lopresti@bcm.edu

[1] Department of Neurosurgery, Baylor College of Medicine, Division of Pediatric Neurosurgery, Texas Children's Hospital, Houston, TX, USA

[2] Department of Neurosurgery, Baylor College of Medicine, 7200 Cambridge St, Ste. 9A, Houston, TX 77030, USA

were associated with perioperative adverse events [15]. Additionally, complications and the presence of complex chronic conditions have been associated with increased hospitalization costs in pediatric patients undergoing surgery for CM-1 [9]. Further understanding of risk factors that may influence preoperative counseling, perioperative complications, and short-term postoperative outcomes can help guide treatment and optimize value. In this study, we aim to characterize and define these preoperative risk factors, perioperative complications, and short-term postoperative outcomes as they relate to CM-1 surgery in the pediatric population across a national network of pediatric hospitals in the US.

Methods

Data source

The US Children's Hospital Association's Pediatric Health Information System (PHIS) data was used in this study [12]. Excluding healthy newborns, PHIS represents 13.3% of the national volume of all hospitalized pediatric patients in the US. PHIS contains inpatient, emergency department, ambulatory surgery, and observation encounter-level data from 49 freestanding children's hospitals. PHIS data included patient demographics, detailed charges, and treatment information. All encounter-level data are de-identified, though trackable longitudinally by individual record identifiers. Data extracted included markers of healthcare resource utilization, surgical and medical complications within 90 days of surgery, and readmission rates.

Study cohort

Inclusion criteria included patients < 21 years of age in the US Children's Hospital Association's PHIS database who underwent inpatient surgery for Chiari 1 malformation as identified in the same way as previously published algorithms [6, 8]. The database was queried for all patients with a primary ICD-9-CM diagnosis code of 348.4 and procedure codes consistent with CM-1 decompression, 01.24 for cranial decompression or 03.09 spinal decompression or laminectomy; patient records associated with Chiari type 2 malformation (741.0) were excluded. Patients included in this cohort had hospital discharges between July 1, 2007 and June 30, 2015 with a minimum of 90 days of prior screening, to screen for and reduce the effect of any prior treatments along with a minimum 90-day follow-up period.

The costs per CM-1 procedure were calculated with PHIS-defined adjusted total costs based on the ratio of cost to charges (RCCs) submitted by the hospitals with their respective Medicare cost reports. RCCs are database tools to assess the inpatient costs associated with the hospitalization compared to the hospital charges, and RCCs are used to approximate the cost of resources related to an inpatient stay to compare across location, condition, and cohort [1]. Charges were adjusted by the Centers of Medicare and Medicaid (CMS) wage/price index for the hospital's location; CMS is an American government–sponsored health insurance system which also provides nationwide information regarding cost and resource utilization. All costs were converted to 2009 US dollars. The 30-day and 90-day postoperative complication rates were recorded. All complication and infection events were identified through ICD 9-CM diagnosis codes also in accordance with previously published studies [4–6, 8, 9].

Statistical analysis

Chi-squared tests and multivariate logistic regression models were used to determine factors associated with perioperative complications in CM-1 surgery. A multivariate regression model was used to determine the association between patient characteristics and perioperative complications. Any covariate in univariate analysis with a p value < 0.2 was included in the multivariate logistic regression model or multivariate regression model. Because each inpatient visit is nested within a hospital, a multilevel analysis with a random effect for each hospital was used to account for interclass correlation (individual inpatient visit and hospital) in the final model. Analyses were conducted with SAS® 9.4 (SAS Institute, Cary, NC) and STATA® 13.0 software (StataCorp, College Station, TX). p-values of < 0.05 were considered statistically significant.

Results

Of the included 5976 patients < 21 years of age, just over half were female (54%). Table 1 depicts the demographic and clinical characteristics associated with short-term postoperative complications in pediatric patients undergoing Chiari 1 malformation surgery. Those in the younger age group (0–4 years) had higher medical and surgical complication rates compared to older patients. Those specifically with pre-existing comorbidity of hydrocephalus had higher odds of both medical and surgical complications at perioperative surgical admission and at 30-day and 90-day time points. There were no differences in complication rates by gender, race, or insurance, though there were differences in perioperative surgical admission complication rates by geographic region and hospital volume.

Table 2 examines postoperative complications and the relationship with healthcare resources used in this population. Those with any complications at 90 days had an increased length of stay and higher healthcare costs compared to those without complications. Patients with medical complications had longer mean hospital stay and more associated costs compared to those with surgical

Table 1 Demographic and clinical characteristics associated with postoperative complications

		Index admission		30 days postoperative		90 days postoperative	
	No.	Surgical complication	Medical complication	Surgical complication	Medical complication	Surgical complication	Medical complication
Total	5976						
Age		0.146	0.005	< 0.001	< 0.001	0.003	< 0.001
0–4	1053 (17.6)	41 (3.9)	24 (2.3)	88 (8.4)	34 (3.2)	98 (9.3)	36 (3.4)
5–9	1784 (29.9)	43 (2.4)	13 (0.7)	73 (4.1)	15 (0.8)	98 (5.5)	20 (1.1)
10–14	1472 (24.6)	35 (2.4)	19 (1.3)	74 (5.0)	20 (1.4)	93 (6.3)	23 (1.6)
15–17	1224 (20.5)	34 (2.8)	11 (0.9)	66 (5.4)	13 (1.1)	88 (7.2)	15 (1.2)
18–20	443 (7.4)	11 (2.5)	5 (1.1)	26 (5.9)	5 (1.1)	34 (7.7)	6 (1.4)
Gender		0.304	0.247	0.277	0.196	0.547	0.158
Male	2750 (46.0)	69 (2.5)	38 (1.4)	160 (5.8)	46 (1.7)	195 (7.1)	53 (1.9)
Female	3226 (54.0)	95 (2.9)	34(1.1)	167 (5.2)	41 (1.3)	216 (6.7)	47 (1.5)
Race		0.734	0.015	0.329	0.007	0.220	0.017
White	4472 (74.8)	123 (2.8)	46 (1.0)	257 (5.8)	58 (1.3)	320 (7.2)	68 (1.5)
Black	406 (6.8)	9 (2.2)	3 (0.7)	18 (4.4)	3 (0.7)	27 (6.7)	5 (1.2)
Hispanic	555 (9.3)	17 (3.1)	9 (1.6)	27 (4.9)	9 (1.6)	34 (6.1)	10 (1.8)
Asian and others	436 (7.3)	14 (3.2)	13 (3.0)	23 (5.3)	16 (3.7)	28 (6.4)	16 (3.7)
Unspecified	107 (1.8)	1 (0.9)	72 (1.2)	2 (1.9)	1 (0.9)	2 (1.9)	1 (0.93)
Insurance		0.116	0.616	0.083	0.265	0.113	0.106
Public	2407 (40.3)	61 (2.5)	34 (1.4)	139 (5.8)	42 (1.7)	172 (7.2)	50 (2.1)
Private	3178 (53.2)	85 (2.7)	34 (1.1)	158 (5.0)	39 (1.2)	203 (6.4)	43 (1.4)
Other	313 (5.2)	15 (4.8)	4 (1.3)	26 (8.3)	6 (1.9)	31 (9.9)	7 (2.2)
Self-pay	78 (1.3)	3 (3.9)	0 (0.0)	4 (5.1)	0 (0.0)	5 (6.4)	0 (0.0)
Region		0.038	0.159	0.328	0.210	0.175	0.116
Northeast	1067 (17.9)	44 (2.5)	20 (1.1)	68 (6.4)	17 (1.6)	76 (7.1)	18 (1.7)
Midwest	1762 (29.5)	41 (3.8)	14 (1.3)	90 (5.1)	27 (1.5)	116 (6.6)	31 (1.8)
South	1881 (31.5)	40 (2.1)	16 (0.9)	94 (5.0)	19 (1.0)	116 (6.2)	22 (1.2)
West	1266 (21.2)	39 (3.1)	22 (1.7)	75 (5.9)	24(1.9)	103 (8.1)	29 (2.3)
Comorbidities		< 0.001	< 0.001	< 0.001	< 0.001	< 0.001	< 0.001
No	4253 (71.2)	88 (2.1)	30 (0.7)	168 (4.0)	35 (0.8)	217 (5.1)	40 (0.9)
Yes	1723 (28.8)	76 (4.4)	42 (2.4)	159 (9.2)	52 (3.0)	194 (11.3)	60 (3.5)
Hydrocephalus (comorbidities)		< 0.001	< 0.001	< 0.001	< 0.001	< 0.001	< 0.001
No	5738 (96.0)	130 (2.3)	61 (1.1)	272 (4.7)	72 (1.3)	350 (6.1)	82 (1.4)
Yes	238 (4.0)	34 (14.3)	11 (4.6)	55 (23.1)	15 (6.3)	61 (25.6)	18 (7.6)
Syrinx (comorbidities)		0.036	0.776	0.180	0.362	0.380	0.374
No	4057 (67.9)	99 (2.4)	50 (1.2)	211 (5.2)	63 (1.6)	271 (6.7)	72 (1.8)
Yes	1919 (32.1)	65 (3.4)	22 (1.2)	116 (6.0)	24 (1.3)	140 (7.3)	28 (1.5)
Hospital volume		0.023	0.738	0.066	0.211	0.019	0.399
< 21 (Q3*)	2939 (49.2)	95 (3.2)	34 (1.2)	177 (6.0)	37 (1.3)	225 (7.7)	45 (1.5)
> = 21 (Q3)	3037 (50.8)	69 (2.3)	38 (1.3)	150 (4.9)	50 (1.7)	186 (6.1)	55 (1.8)

*Q3 is the third quartile, meaning that 75% of the numbers lie below Q3 and 25% lie above Q3

complications (mean 13 days (95% CI 9.5–16.5 days) for 90-day medical complications versus mean 6.9 days (95% CI 5.8–8.1 days) for 90-day surgical complications) and associated costs of $153,100 (95% CI $110,400–$195,600) for 90-day medical complications versus mean $82,900 (95% CI $71,300-94,500) for 90-day surgical complications.

Postoperative complications are itemized in Table 3. 6.88% of patients had a surgical complication and 1.67% medical (Table 3). The most common surgical complications were

Table 2 Postoperative complication and healthcare resources used (length of stay and charges)

	No.		Yes	
	Mean (95%CI)	Median (min, max)	Mean (95%CI)	Median (min, max)
90-day surgical complication				
LOS (days)	3.6 (3.5–3.7)	3 (1–72)	6.9 (5.8–8.1)	4 (1–160)
Total charges, 2009 USD ($1000)	49.8 (48.8–50.9)	42.2 (7.2–1506.8)	82.9 (71.3–94.5)	54.7 (3.6–1591.7)
90 Days Medical Complication				
LOS (days)	3.7 (3.6–3.8)	3 (1–160)	13 (9.5–16.5)	4 (2–94)
Total charges, 2009 USD ($1000)	50.4 (49.3–51.4)	42.5 (3.5–1591.7)	153.1 (110.4–195.6)	67.3 (21.4–1506.7)
90 Days with any Complication				
LOS (days)	3.5 (3.5–3.6)	3 (1–66)	7.2 (6.2–8.3)	4 (1–160)
Total charges, 2009 USD ($1000)	49.0 (48.1–49.8)	42.0 (7.2–540.4)	88.2 (76.0–100.5)	55.8 (3.6–1591.7)

neurosurgery-specific, including the need for CSF shunting, including revision or exploration, as well as meningitis and wound infection. The most common medical complications were pulmonary complications. While the number of surgical sequelae is greater than the number of medical complications, the number of surgical complications has declined over the course of the study epoch from 2007 to 2015, while the number of medical complications remains grossly stable (Fig. 1).

Differences in outcomes by age, gender, race, insurance status, region, presence of syrinx, and hospital volume were not found to be significant in relation to complication rates. However, the presence of other comorbidity or a concomitant diagnosis of hydrocephalus was significantly associated with increased complication rates (Table 4).

Discussion

Using the Children's Hospital Association's Pediatric Health Information System (PHIS) database to examine CM-1 surgery complications and resource utilization in nearly 6000 patients, we found an overall low complication rate. While complications were both surgical and medical in nature, surgical complications were more common, while medical complications were costlier with longer lengths of hospital stays. Among surgical complications, the most common complications were related to CSF dynamics, including shunt placement, revision or exploration, and neurosurgery-specific complications related to CSF such as pseudomeningocele and CSF leak.

Our findings from data from the Children's Hospital Association are congruent with other studies which examined large US-based nationwide databases not specific to pediatric-focused hospitals with regard to postsurgical outcomes in CM-1. Demographic variables (age, race, gender, insurance type) measured in our study had minimal correlation with outcomes. Our study identified a 6.88% surgical complication rate, with a 3.01% rate of shunt complications at 90 days postoperatively. The American College of Surgeon's National Surgical Quality Improvement Program-Pediatric data also reported an overall postoperative adverse event rate of 5.3% in the 30-day postoperative period, with wound complications being the most common [15]. Our findings are congruent with results from Greenberg et al., who examined the State Inpatient Databases in three states (CA, FL, and NY) and found a surgical complication rate of 4.5% during admission and 12.7% at the 90-day follow-up, with the most common category of postoperative events involving CSF shunt placement and revisions (4%) [6].

There is a known association between hydrocephalus and CM-1 [10]. Our study also notes this relationship with increased postoperative complications identified in those with a known comorbidity of hydrocephalus following CM-1 surgery. Greenberg et al. also recognized this association and specifically excluded hydrocephalus from their analysis of chronic complex conditions in children to study it separately, highlighting hydrocephalus as a key variable of interest [6]. We agree that hydrocephalus, whether an underlying cause of CM-1, a sequela of CM-1 alterations in CSF flow, or an associated diagnosis in a subset of patients diagnosed with CM-1, should be a unique variable to study when looking at preoperative risk factors, perioperative complications, and postoperative outcomes. CM-1 is often described as either congenital or acquired in etiology [13]. Acquired CM-1 may be due to increased intracranial hypertension, secondary to tonsillar displacement into the foramen magnum resulting in a CSF outflow obstruction, and this may be due to a mass lesion, cerebral edema, or underlying hydrocephalus [3, 13]. In cases of acquired CM-1, the pathophysiology of the disease may be contributing to the postoperative complications of hydrocephalus and need for CSF diversion. Additionally, in congenital CM-1, it may be

Table 3 Surgical and medical complications diagnosed within 90 days postoperative of Chiari malformation type I surgery

	Number of cases	%
Surgical complications		
Other neurosurgery-specific complications (CSF leak, pseudomeningocele)	211	3.53
Shunt insertion, revision, or exploration	180	3.01
Meningitis	40	0.67
Wound infection	40	0.67
Wound disruption	27	0.45
Bleeding complication	23	0.38
Iatrogenic cerebrovascular infarction or hemorrhage	11	0.18
Total surgical complications 90 days	411	6.88
Medical complications		
Pulmonary complication/pneumonia	58	0.97
Urinary-renal complication	16	0.27
Gastrostomy	15	0.25
Cardiac complication	13	0.22
Tracheostomy	7	0.12
Catheter-associated infection	3	0.05
Thrombotic complication	2	0.03
Total medical complications 90 days	100	1.67

postulated that unrecognized hydrocephalus is unmasked, or hydrocephalus develops after surgery that manipulates the CSF spaces. In clinical practice, carefully evaluating and addressing hydrocephalus prior to Chiari 1 decompression is considered prudent.

A published review of the Kid's Inpatient Database (KID) demonstrated increased representation of prevalence of CM-1 from 2003 to 2012, from 45 to 96 per 100,000 [10]. Due to the increasing identification of CM-1, it is important to better understand the disease process as well as the preoperative risk factors and common postoperative complications. Identifying and understanding perioperative risks and postoperative complications associated with CM-1 can help target areas for quality improvement and address variation in healthcare costs. Our study found that younger children (age 0–4 years), as

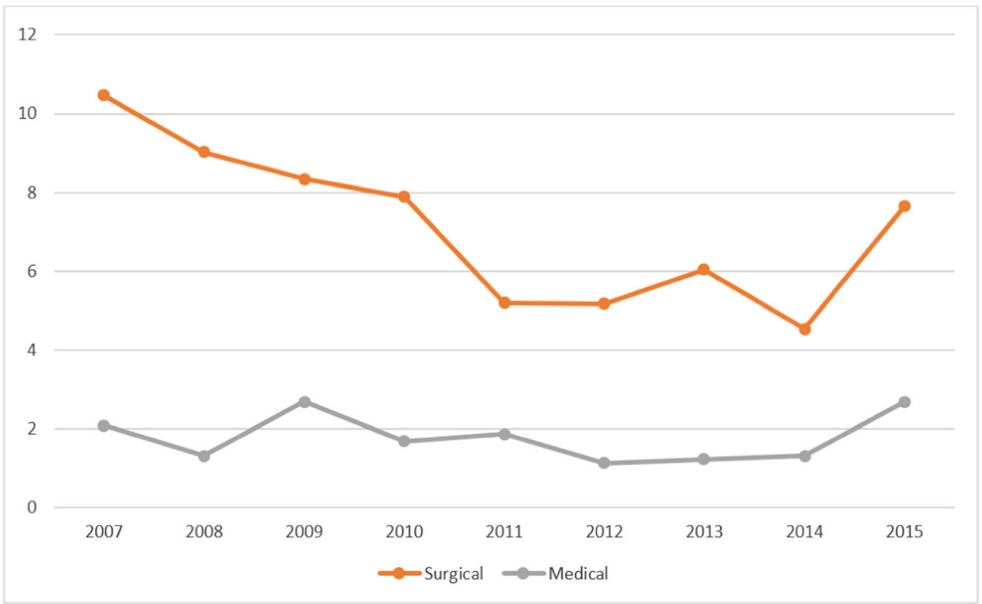

Fig. 1 Complication Rates by Year, 2007-2015

Table 4 Medical and surgical complication rates in the 90-day postoperative period

		Surgical complication rate 90 days postoperative (unadjusted)		Surgical complication rate 90 days postoperative (adjusted individual hospital effect)		Medical complication rate 90 days postoperative		Medical complication rate 90 days postoperative (adjusted individual hospital effect)	
Covariates	Categories	Odds ratio	*p* value	Odds ratio	*p* value	Odds ratio	*p* value	Odds ratio	*p* value
Age	0–4	Ref		Ref		Ref		Ref	
	5–9	0.636	0.003	0.636	0.002	0.393	0.001	0.393	0.008
	10–14	0.721	0.040	0.721	0.055	0.572	0.048	0.572	0.082
	15–17	0.847	0.300	0.847	0.162	0.437	0.011	0.437	0.074
	18–20	0.863	0.491	0.863	0.549	0.463	0.106	0.463	0.160
Gender	Male	Ref		Ref		Ref		Ref	
	Female	1.000	0.982	1.000	0.983	0.858	0.462	0.858	0.323
Race	White	Ref		Ref		Ref		Ref	
	Black	0.861	0.494	0.861	0.438	0.780	0.598	0.780	0.562
	Hispanic	0.714	0.083	0.714	0.021	1.033	0.929	1.033	0.943
	Asian/Other	0.781	0.239	0.781	0.404	2.277	0.007	2.277	0.003
	Unspecified	0.241	0.053	0.241	0.104	0.642	0.675	0.642	0.675
Insurance	Private	Ref		Ref		Ref		Ref	
	Public	0.913	0.417	0.913	0.374	0.739	0.180	0.739	0.162
	Other	1.438	0.084	1.438	0.121	1.335	0.489	1.335	0.380
	Self-pay	0.882	0.786	0.882	0.677	–	–	–	–
Region	West	Ref		Ref		Ref		Ref	
	Northeast	1.032	0.858	1.032	0.903	0.758	0.391	0.758	0.390
	Midwest	0.814	0.162	0.814	0.348	0.798	0.410	0.798	0.463
	South	0.751	0.048	0.751	0.124	0.572	0.054	0.572	0.110
Comorbidity	None	Ref		Ref		Ref		Ref	
	Yes	1.872	< 0.001	1.872	< 0.001	2.998	< 0.001	2.998	< 0.001
Hydrocephalus	None	Ref		Ref		Ref		Ref	
	Yes	3.451	< 0.001	3.451	< 0.001	2.397	0.003	2.397	0.014
Syrinx	None	Ref		Ref		Ref		Ref	
	Yes	1.197	0.112	1.197	0.123	0.985	0.949	0.985	0.945
Hospital volume	< 21 (Q3^)	Ref		Ref		Ref		Ref	
	≥ 21 (Q3)	0.751	0.013	0.751	0.123	1.242	0.322	1.242	0.395

*Number of cases included in final model were 5670; 28 outliners were excluded (cost > 100,000 or cost < 1000); 278 were excluded due to without cost information

^Q3 is the third quartile, meaning that 75% of the numbers lie below Q3 and 25% lie above Q3

well as those with pre-existing comorbidities, specifically hydrocephalus, experienced higher complication rates within 90 days of index surgery. This, in turn, was associated with longer lengths of surgical hospital stay and higher healthcare costs. Our findings are in agreement with Greenberg et al. who, when examining adults in an administrative database, found that surgical complications were more commonly documented than medical complications at 30 days (14.3% vs 4.4%) and 90 days postoperatively (18.7% and 5.0%) [4].

Further, in line with Greenberg et al., our study found that patient records with medical complications were found to have longer lengths of stay than surgical complications and subsequently higher healthcare costs [4]. While this study cannot identify causal relationships, the presence of comorbidities typically indicates cases of higher medical complexity, with an increased risk of perioperative adverse outcomes. These scenarios may thereby extend the length of stay and incur higher costs. These results highlight the importance of risk adjustment; techniques for risk adjustment in this arena are not yet widely applied. Prior studies examining hospitalization costs in relation to the pediatric surgical treatment of CM-1 reported found higher costs at freestanding children's hospitals

and higher costs associated with device-dependent chronic conditions and complex chronic conditions [9]. These cost drivers are known in other diagnoses and treatments across pediatric healthcare. Acknowledging these cost disparities, opportunities for improvement may still exist and may benefit from increased attention to preoperative medical optimization or perioperative coordination of care and discharge planning in this population of patients with more complex chronic conditions. These efforts may help minimize readmissions and adverse outcomes.

Limitations

Limitations of this study included the inherent nature of databases, despite rigorous data verification processes Children's Hospital Association's PHIS program. Clinical granularity is limited in databases based on coding, and due to the de-identified nature of the data, we are not able to verify independently the diagnoses or procedures by chart review. Ladner et al. and Greenberg et al. presented excellent validation studies for the identification of CM-1 surgery in large administrative databases, and we cite this standard for the present study [5, 8]. Furthermore, clinical indications for surgery and specific surgical technique are not known from the data. Specific clinical and functional outcomes were not included and cannot be measured in this study. Further work is needed to define and examine clinical outcomes, readmission, reoperation, and other quality metrics. In surgery for CM-1, surgical technique and clinical management are topics of debate. Outcomes from variations in clinical approach are not fully understood. Here, we are unable to distinguish important surgical details such as the presence or absence of dural opening. This is a known limitation of this type of database study; while it can provide a large cohort, it cannot address clinical details such as surgical technique. Additionally, when evaluating and quantifying costs, we were limited in assessing hospitalization costs only; this data source does not account for the economic impact on families regarding time away from work, indirect costs, and additional out-of-pocket expenses. Further work is necessary to define the broader economic burden and resource utilization healthcare delivery, in this case, elective CM-1 surgery.

While the use of this national database from children's hospitals may provide descriptive data across a large population and help to motivate further clinical research questions, this study complements and highlights the need for ongoing rigorous clinical research study designs to explore and characterize the specifics of CM-1 surgical care in practice. The Patient-Centered Outcomes Research Institute (PCORI) is supporting an ongoing randomized clinical trial looking at posterior fossa decompression with or without duraplasty for CM-1 with syringomyelia to assess if expansile duraplasty with bony decompression or bony decompression alone maximizes symptom relief and improved clinical outcomes while minimizing risk [11]. This work, along with other clinical research being conducted by the Park-Reeves Syringomyelia Research Consortium, may help quantify surgical indications and predict clinical outcomes after surgical intervention [7]. Ongoing research will help define surgical techniques and best practices in regard to CM-1 surgery and postoperative clinical and functional outcomes.

Conclusion

The use of a national children's hospital database presents outcomes and resource utilization from a multi-institutional, real-world experience in pediatric hospitals across America. We identify risk factors for complications and for increased resource utilization for surgery on Chiari type 1 malformation. Understanding preoperative risk factors, perioperative complications, and postoperative outcomes as well as healthcare utilization and costs in this population can help target areas for improvement and guide preoperative counseling and risk stratification. Examination of the Children's Hospital Association's PHIS database identified a higher risk of perioperative complications in younger patients and those with pre-existing comorbidities, namely hydrocephalus. Those with medical and surgical complications had a longer length of stay for their surgical hospitalization and incurred higher costs.

Compliance with ethical standards

Conflict of interest On behalf of all authors, the corresponding author states that there is no conflict of interest.

Publisher's Note Springer Nature remains neutral with regard to jurisdictional claims in published maps and institutional affiliations.

References

1. Cost-to-charge ratio files. Healthcare Cost and Utilization Project (HCUP). Accessed at: https://www.hcup-us.ahrq.gov/db/state/costtocharge.jsp. Accessed on: Nov 6, 2018
2. Dure LS, Percy AK, Cheek WR, Laurent JP (1989) Chiari type 1 malformation in children. J Pediatr 115(4):573–576
3. Fukuoka T, Nishimura Y, Hara M, Haimoto S, Eguchi K, Yoshikawa S, Wakabayaski T, Ginsberg HJ (2017) Chiari type 1 malformation-induced intracranial hypertension with diffuse brain edema treated with foramen magnum decompression: a case report. NMC Case Rep J 4(4):115–120
4. Greenberg JK, Ladner TR, Olsen MA, Shannon CN, Liu J, Yarbrough CK, Piccirillo JF, Wellons JC 3rd, Smyth MD, Park TS, Limbrick DD (2015) Complications and resource use

associated with surgery for Chiari malformation type 1 in adults: a population perspective. Neurosurgery 77:261–268
5. Greenberg JK, Lander TR, Olsen MA, Shannon CN, Liu J, Yarbrough CK, Piccirillo JF, Wellons JC 3rd, Smyth MD, Park TS, Limbrick DD (2015) Validation of an ICD-9 code algorithm for identifying Chiari malformation type 1 surgery in adults. Neurosurgery 77:269–273
6. Greenberg JK, Olsen MA, Yarbrough CK, Ladner TR, Shannon CN, Piccirillo JF, Anderson RC, Wellons JC 3rd, Smyth MD, Park TS, Limbrick DD Jr (2016) Chiari malformation type I surgery in pediatric patients. Part 2: complications and the influence of comorbid disease in California, Florida, and New York. J Neurosurg Pediatr 17:525–532
7. Hankinson TC, Tuite GF, Moscoso DI, Robinson LC, Torner JC, Limbrick DD Jr, Park TS, Anderson RCE (2017) Analysis and interrater reliability of pB-C2 using MRI and CT: data from the Park-Reeves Syringomyelia Research Consortium on behalf of the Pediatric Craniocervical Society. J Neurosurg Pediatr 20(2): 170–175
8. Ladner TR, Greenberg JK, Guerrero N, Olsen MA, Shannon CN, Yarbrough CK, Piccirillo JF, Anderson RC, Feldstein NA, Wellons JC 3rd, Smyth MD, Park TS, Limbrick DD Jr (2016) Chiari malformation type I surgery in pediatric patients. Part 1: validation of an ICD-9-CM code search algorithm. J Neurosurg Pediatr 17:519–524
9. Lam SK, Mayer RR, Luerssen TG, Pan IW (2016) Hospitalization cost model of pediatric surgical treatment of Chiari type 1 malformation. J Pediatr 179:204–210
10. Passias PG, Pyne A, Horn SR, Poorman GW, Janjua MB, Vasquez-Montes D, Bortz CA, Segreto FA, Frangella NJ, Siow MY, Sure A, Zhou PL, Moon JY, Diebo BG, Vira SN (2018) Developments in the treatment of Chiari type 1 malformations over the past decade. J Spine Surg 4(1):45–54
11. Patient-Centered Outcomes Research Institute (USA) (2015) Posterior fossa decompression with or without duraplasty for Chiari type 1 malformation with syringomyelia. Patient-Centered Outcomes Research Institute, Washington, DC (https://www.pcori.org/research-results/2015/posterior-fossa-decompression-or-without-duraplasty-chiari-type-i-malformation) [Accessed July 5, 2018]
12. PHIS. Pediatric Health Information System. Children's Hospital Association. Accessed at: https://www.childrenshospitals.org/phis. Accessed on: 11/6/2018
13. Ramon C, Gonzales-Madly A, Pascual J (2011) What differences exist in the appropriate treatment of congenital versus acquired adult Chiari type 1 malformation? Curr Pain Headache Rep 15(3): 157–163
14. Tubbs RS, McGirt MJ, Oakes WJ (2003) Surgical experience in 130 pediatric patients with Chiari I malformations. J Neurosurg 99(2):291–296
15. Vendantam A, Mayer RR, Staggers KA, Harris DA, Pan IW, Lam SK (2016) Thirty-day outcomes for posterior fossa decompression in children with Chiari type 1 malformation from the US NSQIP-Pediatric database. Childs Nerv Syst 32(11):2165–2171