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Factors and Prediction Models for Unplanned Hospital Readmissions at a Pediatric Tertiary Centre

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Abstract

Unplanned Hospital Readmissions (UHRs) are associated with increased morbidity and mortality, and may be preventable. This study identified factors associated with pediatric UHRs and developed prediction models. UHRs for pediatric patients from 2007-2009 and 2017-2019 at British Columbia Children's Hospital were retrospectively reviewed. Factors for UHRs were analyzed, and prediction models were derived and tested. 5.26% (411/8387) of patients from 2007-2009 and 3.95% (329/8316) from 2017-2019 experienced at least one UHR. Varying by time period, factors for UHRs included: home health authority, age, previous ER visits, preadmission comorbidities, admission type, in-hospital interventions, and intensive care unit stay. Prediction models had areas under the receiver operating characteristic curve of .61 (2007-2009) and .67 (2017-2019). This study identified variables associated with UHRs. Differences in predictor variables between two time periods suggest that UHRs may not reflect quality of care, and future prediction models need to be iteratively refined.

Unplanned Hospital Readmissions (UHRs) affect almost 200,000 Canadians annually and 20-40% may be preventable [1]. Patients with UHRs have increased morbidity and mortality rates, and are at higher risk of hospital-associated adverse events [2,3]. Furthermore, UHRs can add psychosocial stress and overall life disruption for patients and their families [4]. UHRs cost the Canadian healthcare system $1.8 billion annually and can erode public trust in provincial healthcare systems with rates above the national average [1,5].

Preventable adult UHRs can result from insufficient discharge planning or post-discharge follow-up, the care received during the index admission, and inadequate coordination among providers [6]. Pediatric UHRs occur less frequently and their associated factors have not been investigated as extensively [6-8]. These risk factors may change over time. Furthermore, few predictive models exist for pediatric UHRs [8,9]. One systematic review found 94 predictive models with performance reported for adult UHRs and 6 for pediatric UHRs [8].

As there is limited information on Canadian pediatric UHRs and few predictive models exist, this study aimed to identify factors associated with pediatric UHRs at British Columbia (BC) Children's Hospital and to develop risk-prediction models for their occurrence. BC Children's Hospital is located in Vancouver, BC. It provides health services to children 0-18 years old in BC and the Yukon Territory, and is BC's sole pediatric tertiary care centre.

Method

This retrospective case-controlled study of two cohorts, was approved by the Children and Women's Research Ethics Board of the University of British Columbia, H20-01160. A waiver of consent was obtained.

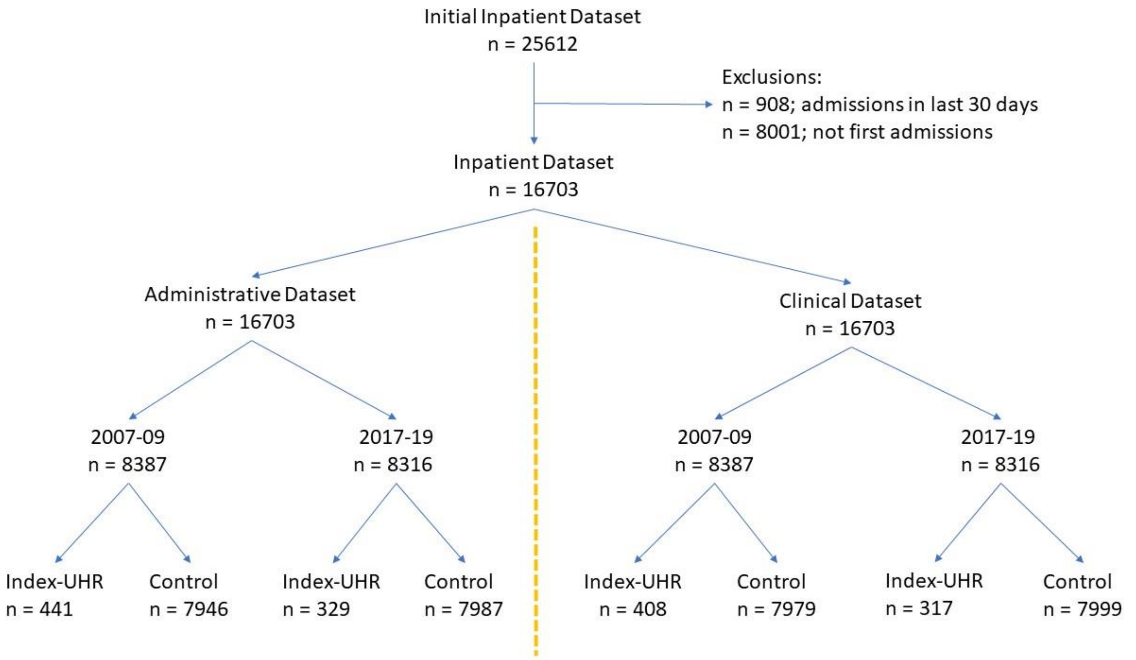
Study Population

Patients aged 29 days to 18 years admitted to BC Children's Hospital between April 1, 2007 – March 31, 2009 and April 1, 2017 – March 31, 2019 were included. These two cohorts were chosen a decade apart to look for changes in risk over time. Neonates (0-28 days of age) were excluded due to unique factors that could influence readmission (e.g., maternal health, gestational age, length of postpartum stay) [10]. Potential index admissions within the last 30 days of each study period were excluded, and only the first admission was included for patients with multiple admissions.

Dataset Categorization

Admission data was extracted from the BC Children's Hospital Discharge Abstract Database (DAD), managed by the Canadian Institute for Health Information (CIHI). Index-UHRs were defined as admissions followed by a UHR within 30 days, while control admissions were not followed by a UHR within 30 days. As UHRs from the administrative DAD dataset may reflect discordant diagnoses, the first and senior author analyzed each UHR in the administrative dataset excluding those not clinically related to their index admission or incorrectly labelled as UHRs (e.g., where a patient was admitted at regular intervals for chemotherapy and one session was mislabelled as a UHR). This created a clinical dataset for each study period (Figure 1).

Figure 1. Flow chart of data organization.



Primary Outcome Variable

The primary outcome variable was a 30-day unplanned hospital readmission (UHR). In the administrative and clinical datasets, this was defined as an urgent/emergent admission within 30 days of discharge. In the clinical dataset, the diagnosis code description for the UHR also had to be relevant to its index admission.

Extracted Variables

Variables were selected to parallel previous studies to allow for comparison of results [8]. Data included patient demographics, details on hospital admission and interventions, and hospitalization history (Table 1). The number of in-hospital interventions included surgical and procedural interventions only. The Resource Intensity Weight (RIW), a CIHI-derived variable, was collected as a proxy for admission complexity; higher RIWs indicated more costly admissions [11,12].

Table 1. Distribution of extracted variables for the administrative dataset.

Variable		2007-2009		2017-2019	
		Index-UHR (n = 441)	Control (n = 7946)	Index-UHR (n = 329)	Control (n = 7987)
Demographics	Age (years)	6.00 [1.58;13.0]	6.00 [1.33;12.0]	6.00 [1.58;12.0]	6.00 [1.92;13.0]
	No. of preadmission comorbidities	0 [0;1]	0 [0;1]	0 [0;2]	0 [0;1]
	No. of postadmission comorbidities	0 [0;0]	0 [0;0]	0 [0;0]	0 [0;0]
Gender	Female	205 (46.5)	3457 (43.5)	164 (49.8)	3615 (45.3)
	Male	236 (53.5)	4489 (56.5)	165 (50.2)	4372 (54.7)
Entry Code	Clinic admission	20 (4.5)	131 (1.7)	4 (1.2)	99 (1.2)
	Direct/scheduled	111 (25.2)	3047 (38.3)	101 (30.7)	3398 (42.5)
	ER admission	310 (70.3)	4750 (59.8)	224 (68.1)	4483 (56.1)
	Day surgery admission	0 (0.0)	18 (0.2)	0 (0.0)	7 (0.09)
Hospital Stay	Length of stay (days)	4 [2;9]	2 [1;5]	3 [2;7]	2 [1;5]
	Pediatric ICU length of stay (days)	0 [0;0]	0 [0;0]	0 [0;0]	0 [0;0]
	No. in-hospital interventions	1 [0;2]	1 [0;1]	1 [0;2]	1 [0;2]

	Resource Intensity Weight	0.96 [0.51;2.76]	0.69 [0.43;1.45]	0.93 [0.53;1.96]	0.74 [0.50;1.56]
	Surgical admission	141 (32.0%)	3684 (46.4%)	131 (39.8%)	4021 (50.3%)
	Medical admission	300 (68.0%)	4262 (53.6%)	198 (60.2%)	3966 (49.7%)
Previous Visits	No. ER visits past 6 months	1 [0;1]	1 [0;1]	1 [1;2]	1 [0;1]
	No. SDC visits past 6 months	0 [0;0]	0 [0;0]	0 [0;0]	0 [0;0]
Health Authority	Unknown	0 (0.0)	0 (0.0)	1 (0.3)	19 (0.2)
	Vancouver Coastal	171 (38.8)	3117 (39.2)	137 (41.6)	2696 (33.8)
	Fraser	198 (44.9)	3213 (40.4)	148 (45.0)	3329 (41.7)
	Interior	27 (6.1)	631 (7.9)	13 (4.0)	704 (8.8)
	Vancouver Island	23 (5.2)	437 (5.5)	18 (5.5)	518 (6.5)
	Northern	17 (3.9)	345 (4.3)	10 (3.0)	480 (6.0)
	BC*	1 (0.2)	33 (0.4)	0 (0.0)	3 (0.04)
	Out of Province/Country	4 (0.9)	170 (2.1)	2 (0.6)	238 (3.0)

Note. Continuous data is displayed as median [IQR] and categorical as n (%) unless otherwise specified. No. = number; ER = emergency room; ICU = intensive care unit; SDC = surgical day care. * BC health authority refers to patients who reside in BC, but for whom there is not enough information to determine exactly where in the province.

Data Analysis

The distribution of the extracted variables was described as medians and interquartile ranges for continuous data and as counts and percentages for categorical data (Table 1).

Prediction of readmission was performed using a multivariable logistic regression analysis. Data within each period (2007-2009 and 2017-2019) and reporting type (clinical or administrative) were split using complete random sampling with 80% for model training and 20% for internal validation. Model fit and prediction was assessed using the receiver operator characteristic (ROC) area under the curve (AUC) calculated using the trapezoidal method. The AUC summarizes a test's diagnostic accuracy and enables the comparison of diagnostic tests [13].

All variables were included within the multivariable model, and their importance was assessed by ROC analyses and comparisons of their adjusted odds ratios and associated p-values ($p < 0.05$ = significant). 95% confidence intervals for AUC were estimated using 2000 bootstrap replicates. No variables had missing values, so imputation was not applicable. Analysis was performed using R version 4.0.4, caret 6.0.86, and tidyverse 1.3.0. This follows the method of DeLong [14].

Results

Study Population

The initial dataset included 25,612 admissions to BC Children's Hospital between April 1, 2007 – March 31, 2009 and April 1, 2017 – March 31, 2019. After excluding ineligible admissions, 16,703 remained; 8387 occurred from 2007-2009 and 8316 from 2017-2019. There were 441 Index-UHRs from 2007-2009 (5.3%) and 329 from 2017-2019 (4.0%) (Figure 1).

Clinical vs Administrative Data

The analysis resulted in the recategorization of 33 and 12 Index-UHRs to control admissions in 2007-2009 and 2017-2019, respectively (Figure 1). Due to administrative and clinical datasets being similar, we only reported an analysis of the administrative data. Any notable differences between the datasets are described, and the distribution of the variables, multivariable analysis, and receiver operator curves for the clinical dataset are reported in the Online Supplementary Material.

Descriptive Data

Index-UHR vs Control – 2017-2019

Compared to control admissions, Index-UHRs from 2017-2019 were found to have: a longer median length of stay (3.00 vs 2.00 days), a greater median RIW (0.93 vs 0.74), and a greater proportion of medical (60.2% vs 49.7%) and ER admissions (68.1% vs 56.1%). Index-UHRs had a smaller proportion of direct/scheduled (30.7% vs 42.5%) and surgical admissions (39.8% vs 50.3%). The Index-UHR and control groups had the same median age (6.00 years), number of pre- and postadmission comorbidities (0), number of ER visits in the six months prior (1.00), number of surgical day care visits (0.00), proportion of clinic admissions (1.2%), and number of in-hospital interventions (1.00) (Table 1).

Index-UHR vs Control – 2007-2009

The 2007-2009 data had similar trends, except Index-UHRs had a greater percentage of clinic admissions (4.5% vs 1.7%) than the control group.

Index-UHR 2017-2019 vs Index-UHR 2007-2009

Compared to the 2017-2019 Index-UHRs, the 2007-2009 Index-UHRs had a longer median length of stay (4.00 vs 3.00 days) and a greater proportion of clinic (4.5% vs 1.2%), ER (70.3% vs 68.1%), and medical admissions (68.0% vs 60.2%). The 2007-2009 Index-UHRs contained a smaller proportion of surgical (32.0% vs 39.8%) and direct/scheduled admissions (25.2% vs 30.7%) (Table 1).

Clinical Dataset

The clinical and administrative datasets had similar trends. However, the 2007-2009 Index-UHR group in the clinical dataset included older median age (7.00 vs 6.00 years) and a smaller number of in-hospital interventions (0 vs 1) (Table S1, see Online Supplementary Material).

Most Common Interventions

The administrative dataset included 933 surgical/procedural interventions in 2007-2009 and 964 in 2017-2019. In 2007-2009, the most common in the Index-UHR group was the implantation of a central venous catheter, while in the control group it was an MRI of the brain without enhancement. In 2017-2019, the most common intervention in both groups was a total appendectomy using a laparoscopic approach.

Multivariable Analysis

Of the 13 variables, 8 were significantly associated with UHRs in 2007-2009 and 3 were significant in 2017-2019 (Table 2).

Table 2. Results of multivariate analysis testing associations between extracted variables and UHR occurrence in the administrative dataset

Variable		2007-2009		2017-2019	
		Multivariate OR (upper - lower 95% CI)	P-value	Multivariate OR (upper - lower 95% CI)	P-value
Demographics	Age (years)	**1.04 (1.02 - 1.06)**	**<0.001**	0.99 (0.97 - 1.02)	0.504
	No. of preadmission comorbidities	1.07 (0.98 – 1.16)	0.161	**1.09 (1.01 – 1.18)**	**0.026**
	No. of postadmission comorbidities	1.07 (0.95 - 1.21)	0.24	1.01 (0.89 - 1.16)	0.848
Gender	Female	Reference		Reference	
	Male	0.9 (0.73 - 1.12)	0.354	0.88 (0.69 - 1.12)	0.297
Entry Code	Clinic admission	Reference	-	Reference	-

	Direct/scheduled	**0.34 (0.19 - 0.6)**	**<0.001**	1.24 (0.37 - 4.14)	0.731
	ER admission	**0.48 (0.28 - 0.84)**	**0.01**	1.52 (0.46 - 5.04)	0.49
	Day surgery admission	-	-	-	-
Hospital Stay	Length of stay (days)	1.01 (1 - 1.02)	0.108	1 (0.98 - 1.01)	0.566
	Pediatric ICU length of stay (days)	**0.97 (0.95 - 1)**	**0.034**	1.02 (0.98 - 1.05)	0.345
	No. in-hospital interventions	**1.13 (1.06 - 1.21)**	**<0.001**	1.02 (0.96 - 1.08)	0.613
	Resource Intensity Weight	0.99 (0.96 - 1.02)	0.533	1.04 (0.99 – 1.09)	0.084
	Surgical admission	**0.56 (0.44 - 0.73)**	**<0.001**	0.8 (0.6 - 1.05)	0.108
Previous Visits	No. ER visits past 6 months	**1.27 (1.16 - 1.4)**	**<0.001**	**1.23 (1.08 - 1.4)**	**0.001**
	No. SDC visits past 6 months	1.08 (0.78 - 1.49)	0.64	1.34 (0.97 - 1.84)	0.073
Health Authority	Vancouver Coastal	Reference	-	Reference	-
	Unknown	-	-	-	-
	Fraser	**1.31 (1.03 - 1.68)**	**0.027**	0.98 (0.75 - 1.29)	0.905
	Interior	1 (0.61 - 1.63)	1	**0.43 (0.22 - 0.84)**	**0.013**
	Vancouver Island	0.98 (0.57 - 1.68)	0.929	0.96 (0.56 - 1.66)	0.88
	Northern	1.17 (0.66 - 2.08)	0.58	0.5 (0.24 - 1.05)	0.067
	BC	0.79 (0.11 - 5.9)	0.818	-	-
	Out of Province/Country	0.64 (0.23 - 1.77)	0.391	0.25 (0.06 - 1.02)	0.053

Note. Values in bold are statistically significant. No. = number; - = not applicable, ER = emergency room; ICU = intensive care unit; SDC = surgical day care.

The results for the two time periods are not identical.

In 2007-2009, Index-UHRs were significantly associated with: residing within the Fraser Health Authority (OR = 1.31 [95% CI: 1.03 - 1.68]), having a greater number of ER visits in the 6 months prior (OR = 1.27 [95% CI: 1.16 - 1.4]), more in-hospital interventions (OR = 1.13 [95% CI: 1.06 - 1.21]), and older age (OR = 1.04 [95% CI: 1.02 - 1.06]). UHRs were significantly less likely to follow direct/scheduled (OR = 0.34 [95% CI: 0.19 - 0.6]), ER (OR = 0.48 [95% CI: 0.28 - 0.84]) or surgical admissions (OR = 0.56 [95% CI: 0.44 - 0.73]) and those with longer pediatric ICU stays (OR = 0.98 [95% CI: 0.95 - 1]).

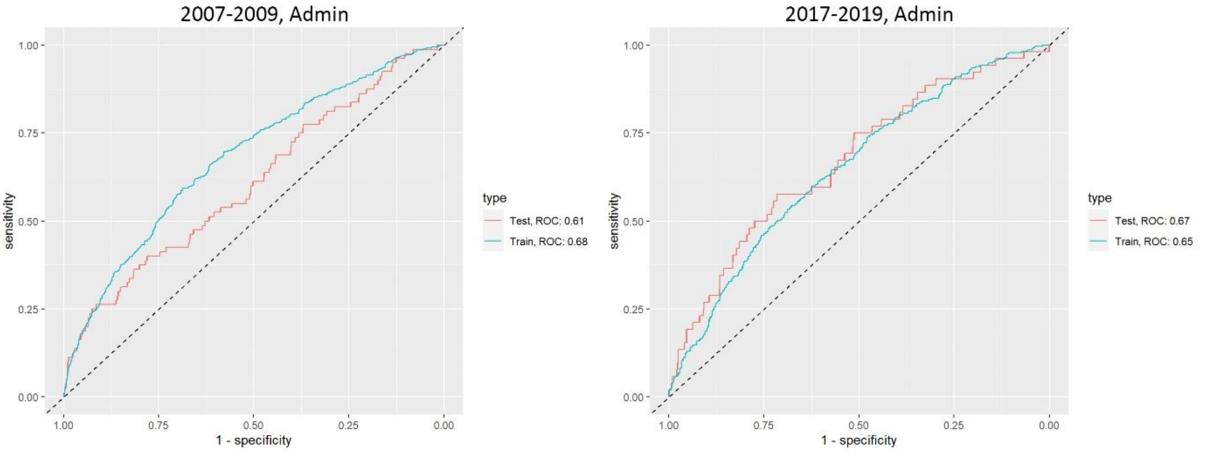
In 2017-2019, Index-UHRs were significantly associated with: a greater number of ER visits in the six months prior (OR = 1.23 [95% CI: 1.08 - 1.4]), and a greater number of preadmission comorbidities (OR = 1.09 [95% CI: 1.01 – 1.18]). UHRs were significantly less likely to occur for patients from the Interior of BC (OR = 0.43 [95% CI: 0.22 - 0.84]).

Results for the clinical dataset are presented in the Online Supplementary Material (Table S1, Table S2).

Receiver Operator Characteristic (ROC) Curves

The 2007-2009 model achieved an area under the curve (AUC) of 0.68 (95% CI 0.55 - 0.71) for the Train ROC curve and 0.61 (95% CI 0.54 - 0.67) for the Test ROC curve. The 2017-2019 model achieved an AUC of 0.65 (95% CI 0.62 – 0.68) for the Train ROC curve and 0.67 (95% CI 0.60 – 0.75) for the Test ROC curve (Figure 2). For a sensitivity of 80%, the 2007-2009 and 2017-2019 Test models achieved a specificity of 31.70% and 39.37%, respectively. For a sensitivity of 70%, the 2007-2009 and 2017-2019 Test models achieved a specificity of 40.41% and 51.68%, respectively.

Figure 2. Receiver Operator Curves (ROCs) for the 2007-2009 and 2017-2019 UHR prediction models using the administrative dataset.



The models for both study periods in the clinical dataset achieved an area under the Test ROC curve of 0.64 (95% CI 0.58 – 0.71 in 2007-2009 and 0.57 – 0.71 in 2017-2019) (Figure S1, see Online Supplementary Material).

Discussion

Using an administrative dataset containing one admission per patient, this study found pediatric UHR rates of 5.26% and 3.95% between 2007-2009 and 2017-2019, respectively. In both periods, the number of ER visits in the six months prior was significantly associated with UHRs. Other significant factors varied between the study periods (Table 3). A risk-prediction model for UHRs approached an acceptable discriminative ability (AUC = 0.7-0.8) [13]. While this study provides data on the incidence and associated factors of pediatric UHRs in the Canadian healthcare system, we were unable to develop an excellent all-cause UHR risk-prediction model (AUC > 0.8) [13]. Therefore, we currently cannot reliably identify patients at high risk of UHRs who could benefit from changes to care prior to discharge.

The UHR rate at BC Children’s Hospital in both periods was lower than the risk-adjusted British Columbian 30-day readmission rate of 9.7% reported in 2015-2016 [1]. This study focuses on a single pediatric tertiary care centre, while the provincial statistics reported by Shuster et al. considered all adult BC care centres, including small rural ones [1], where rural location and small patient volume were hospital-specific risk factors for readmission [1]. Furthermore, this study examined unplanned 30-day emergent/urgent readmissions, whereas the provincial 30-day readmission rate included all patients readmitted within 30 days [1].

Analyzing two time periods revealed that, over a decade, variables associated with UHRs can change. This likely reflects the evolution of medicine and surgery, and any attempt to create a pediatric UHR risk-prediction model with excellent discriminative ability may need to determine which variables are significantly associated with UHRs at any given time.

Analysis of the clinical dataset showed minimal differences, indicating that future studies on readmissions can reliably utilize administrative CIHI data.

There were multiple significant variables in this study that could be markers for patient complexity or disease severity, including the number of: ER visits in the six months before admission, in-hospital interventions, and preadmission comorbidities. Health service usage prior to an index admission was previously cited as a significant variable associated with pediatric UHRs [1,8,10,15]. In this study, the number of ER visits in the previous six months was a significant variable in both study periods (Table 2). The number of in-hospital interventions was associated with UHRs from 2007-2009, while the number of preadmission comorbidities was significant from 2017-2019, albeit both had a small magnitude of association (Table 2). These variables might increase complication risk, explaining their significance.

A Canadian study by Beck et al. found that undergoing surgery was a protective factor for 30-day pediatric UHRs [10]. Similarly, we found that surgical admission was protective in 2007-2009 (OR = 0.56). The most common procedures in Beck et al.'s study were appendectomy and tonsillectomy with adenoidectomy, which are routine surgeries with predictable post-operative courses and otherwise healthy patients. These surgeries were also among the most common interventions in our control groups (Table 3). Thus, surgical admission could be protective due to the prevalence of high volume, low risk surgeries. Surgical admission may have become less protective in 2017-2019 (OR = 0.80) due to a potentially greater number of complex surgeries at BC Children's Hospital, reflecting evolving surgical practice and the development of peripheral care centres where routine surgeries can be performed.

Table 3. Most common principal interventions.

2007-2009			
Index-UHR		Control	
Intervention	Count (n, %)	Intervention	Count (n, %)
Implantation of internal device, vena cava (superior and inferior) totally implanted central venous catheter (with injection port) (e.g., Port-a-cath) using open approach	16, 7.0%	Magnetic resonance imaging [MRI], brain without enhancement	151, 3.7%
Magnetic resonance imaging [MRI], brain without enhancement	15, 6.6%	Excision total, appendix using endoscopic [laparoscopic] approach	145, 3.6%
Implantation of internal device, vena cava (superior and inferior) tunnelled central venous catheter using percutaneous tunnelling technique (e.g., Hickman, Broviac, Groshong, Leonard)	11, 4.8%	Repair by decreasing size, tonsils and adenoids using (percutaneous) endoscopic approach and scraping device (e.g., microdebrider)	129, 3.2%
2017-2019			
Index-UHR		Control	
Intervention	Count (n, %)	Intervention	Count (n, %)
Excision total, appendix using endoscopic [laparoscopic] approach	11, 6.5%	Excision total, appendix using endoscopic [laparoscopic] approach	224, 5.1%
Implantation of internal device, vena cava (superior and inferior) totally implanted central venous catheter (with injection port) (e.g., Port-a-cath) using open approach	10, 6.0%	Excision total, tonsils and adenoids tonsillectomy with Adenoidectomy using device NEC	160, 3.7%
Implantation of internal device, vena cava (superior and inferior) non-tunnelled central venous catheter using percutaneous transluminal venous approach	8, 4.7%	Implantation of internal device, vena cava (superior and inferior) non-tunnelled central venous catheter using percutaneous transluminal venous approach	136, 3.1%
Excision total, tonsils and adenoids tonsillectomy with Adenoidectomy using device NEC	8, 4.7%		

The UHR risk-prediction models developed for each time period approached an acceptable discriminative ability (AUC = 0.7-0.8) [13]. In Zhou et al.'s systematic review, five studies reported acceptable discriminative abilities for 30-day pediatric UHRs [8]. However, rather than examining all-cause UHRs, they focused on those following cardiac conditions, all surgical admissions, or plastic, thoracic, or scoliosis surgeries. The models described here focused on all-cause, 30-day pediatric UHRs, broadening the scope of the outcome measure and perhaps explaining their slightly worse performance. Another large multi-center study from the USA generated a model with an excellent discriminative ability (AUC = 0.81) for 12-month all-cause pediatric UHRs, and identified a patient's primary payer and race as strong factors associated with the likelihood of readmission [16]. This larger study likely developed models with greater power and utilized variables that were either unavailable in the DAD or irrelevant to Canadian healthcare, perhaps explaining why the models here displayed lower discriminative ability.

There are limitations to the design and data source for this study. As a single-centered study, the results may not be generalizable to other children's hospitals or geographic regions. This study may have missed patients with an index admission at BC Children's Hospital and a UHR at another institution or an index admission at another institution and a UHR at our BC Children's Hospital. One study reported that approximately 14% of pediatric readmissions in New York State occur at a different hospital than the one at which the index admission occurred, representing a potential substantial source of missed UHRs [17]. The CIHI data source was an administrative database providing generalized clinical information that might suffer from human error in data entry. Furthermore, CIHI algorithms are updated annually, which may disrupt the comparison of data across time. However, a strength of using CIHI data is that it is collected at other Canadian centres which can facilitate comparative research.

This study highlights the utility of administrative data to study UHRs. It emphasizes potential key variables associated with UHRs at BC Children's Hospital, suggests their evolution over time, and reports the performance of a UHR risk-prediction model for each period. However, we still cannot reliably identify the Canadian pediatric patients most at risk of UHRs that could benefit from changes to pre-discharge care. This also suggests that UHRs should not be used as a metric for the quality of pediatric care. Furthermore, the finding that significant factors for UHRs change with time, combined with the knowledge that how CIHI codes their variables, hospital policy, and medical practice also change with time, indicates that future UHR risk-prediction models would need to be iteratively explored and updated to ensure their accuracy.

Declarations

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Disclosure Statement

No potential conflict of interest was reported by the authors.

Ethics Approval

This study was approved by the Children and Women's Research Ethics Board of the University of British Columbia (H20-01160). A waiver of consent was obtained.

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