The Impact of the COVID-19 Pandemic on Routine Childhood Vaccination Rates in an Academic Family Health Team.

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Abstract:	BACKGROUND There has been concern about the risk of declining routine vaccination rates during the COVID-19 pandemic. This study aimed to examine the impact of the COVID-19 pandemic on early childhood vaccination rates at a multi-site Academic Family Health Team (FHT). METHODS Vaccination records up to November 30, 2020 were collected for a cohort of children born between January 1, 2018 through August 31, 2020, from the FHT's electronic medical record (EMR). The proportion of children receiving timely, delayed, or no vaccination for 10 guideline-recommended childhood vaccines was estimated for the pre- and post-COVID-19 pandemic periods. Timeliness was determined based on vaccine recommended time intervals with a window of 28 days; vaccines

	administered after this window were considered delayed. We estimated median time to vaccination for each vaccine and present cumulative incidence curves. RESULTS Most children were up to date with vaccinations (422 out of 506 (83.4%)). The rates were comparable in children under 12 months old in the pre- and post-COVID-19 pandemic periods. Lower rates of timely vaccinations seemed to be amplified during the pandemic. For children between 12- and 18-months cumulative incidence curves illustrate a mild pre- and post-COVID-19 differences. INTERPRETATION Our local findings suggest a modest deterioration in the uptake of routine childhood vaccines during the COVID-19 pandemic, in children between 12 and 18 months of age. Further study in Canada is needed to determine the true extent of the vaccination gap in children due to the pandemic.

Appendix 1: Ontario's Publicly Funded Immunization Schedules (19)

Publicly Funded Immunization Schedules for Ontario – January 2021

Publicly funded vaccines may be provided only to eligible individuals and must be free of charge

Routine Schedule: Children Starting Immunization in Infancy

Vaccine \ Age	2 Months	4 Months	6 Months	1 Year Φ	15 Months	18 Months	4 Years	Grade 7	14 Years	24 Years	≥34 Years Ψ	65 Years
DTaP-IPV-Hib Diphtheria, Tetanus, Pertussis, Polio, *Haemophilus influenzae* type b	◆	◆	◆			◆						
Pneu-C-13 Pneumococcal Conjugate 13	◆	◆		◆								
Rot-5 Rotavirus	▲	▲	▲									
Men-C-C Meningococcal Conjugate C				◆								
MMR Measles, Mumps, Rubella				■								
Var Varicella					■							
MMRV Measles, Mumps, Rubella, Varicella							■					
Tdap-IPV Tetanus, diphtheria, pertussis, Polio							◆					
HB Hepatitis B								●				
Men-C-ACYW Meningococcal Conjugate ACYW-135								●				
HPV-9 Human Papillomavirus								●				
Tdap Tetanus, diphtheria, pertussis									◆	◆		
Td (booster) Tetanus, diphtheria											◆ Every 10 years	
HZ Herpes Zoster												❙
Pneu-P-23 Pneumococcal Polysaccharide 23												■
Inf Influenza				*Every year in the fall								

◆ - A single vaccine dose given by intramuscular injection

■ - A single vaccine dose given by subcutaneous injection

▲ - A single vaccine dose given by mouth

● - Provided through school-based immunization programs. Men-C-ACYW is a single dose; HB is a 2 dose series (see Table 6); HPV-9 is a 2 dose series (see Table 10). Each vaccine dose is given by intramuscular injection

Φ - Given no earlier than the 1st birthday, and prior to 16 months of age

Ψ - Once a dose of Tdap is given in adulthood (24 years of age), adults should receive Td boosters every 10 years thereafter

❙ - HZ is a 2 dose series (see Table 12) given by intramuscular injection

★ - Children 6 months to 8 years of age who have not previously received a dose of influenza vaccine require 2 doses given ≥4 weeks apart. Children who have previously received ≥1 dose of influenza vaccine should receive 1 dose per season thereafter

Note: A different schedule and/or additional doses may be needed for high risk individuals (see Table 3) or if doses of a vaccine series are missed (see appropriate Tables 4-24)

Appendix 2

Number of births in each month of the study. Number of vaccinations administered in each month, for each vaccination class.

Month-Year	Number Births	Number DTaP-IPV-Hib	Number Pneu-C-13	Number MMR	Number Men-C-C	Number Varicella	Total Number Vaccinations
18-Jan	16	NA	NA	NA	NA	NA	0
18-Feb	14	NA	NA	NA	NA	NA	0
18-Mar	13	13	13	0	0	0	26
18-Apr	20	13	13	0	0	0	26
18-May	14	25	25	0	3	0	53
18-Jun	16	28	26	0	0	0	54
18-Jul	13	38	25	0	1	0	64
18-Aug	14	47	35	0	2	0	84
18-Sep	16	31	21	0	0	0	52
18-Oct	20	49	34	0	1	0	84
18-Nov	12	45	30	1	0	0	76
18-Dec	12	45	31	0	2	0	78
19-Jan	16	37	37	11	12	0	97
19-Feb	12	51	43	12	11	0	117
19-Mar	13	43	43	15	14	0	115
19-Apr	12	41	38	22	19	11	131
19-May	13	48	45	17	13	10	133
19-Jun	16	37	37	17	16	9	116
19-Jul	12	48	43	17	22	15	145
19-Aug	25	43	37	17	14	4	115
19-Sep	23	54	41	16	16	16	143
19-Oct	19	67	58	17	16	15	173
19-Nov	13	53	47	15	17	11	143
19-Dec	10	62	43	11	8	9	133
20-Jan	15	75	60	18	16	28	197
20-Feb	19	60	36	12	14	14	136
20-Mar	16	52	38	11	10	7	118
20-Apr	22	59	36	8	9	8	120
20-May	21	52	39	11	12	7	121
20-Jun	15	64	59	17	17	12	169
20-Jul	18	69	50	13	12	9	153
20-Aug	16	62	50	21	21	14	168
20-Sep	NA	76	71	25	27	12	211
20-Oct	NA	65	47	17	12	15	156
20-Nov	NA	50	39	21	17	21	148

Table 1: Number of vaccine-eligible patients in pre-vs-post COVID-19 groups based on age for selected childhood vaccinations

Age	Vaccination	DOB Interval Pre	DOB Interval Post	N eligible pre	N eligible post	N ineligible
2mos	**DTaP-IPV-Hib** (Diphtheria, Tetanus, Pertussis, Polio, Haemophilus influenzae type b)	(2018-Jan-01)-(2020-Jan-17)	(2020-Jan-17)-(2020-Aug-31)	375	131	0
	Pneu-C-13 (Pneumococcal Conjugate 13)	(2018-Jan-01)-(2020-Jan-17)	(2020-Jan-17)-(2020-Aug-31)	375	131	0
4mos	**DTaP-IPV-Hib** (Diphtheria, Tetanus, Pertussis, Polio, Haemophilus influenzae type b)	(2018-Jan-01)-(2019-Nov-17)	(2019-Nov-17)-(2020-June-30)	348	124	34
	Pneu-C-13 (Pneumococcal Conjugate 13)	(2018-Jan-01)-(2019-Nov-17)	(2019-Nov-17)-(2020-June-30)	348	124	34
6mos	**DTaP-IPV-Hib** (Diphtheria, Tetanus, Pertussis, Polio, Haemophilus influenzae type b)	(2018-Jan-01)-(2019-Sep-17)	(2019-Sep-17)-(2020-Apr-30)	315	121	70
12mos	**MMR** (Measles, Mumps, Rubella)	(2018-Jan-01)-(2019-Mar-17)	(2019-Mar-17)-(2019-Oct-31)	214	127	165
	Pneu-C-13 (Pneumococcal Conjugate 13)	(2018-Jan-01)-(2019-Mar-17)	(2019-Mar-17)-(2019-Oct-31)	214	127	165
	Men-C-C (Meningococcal Conjugate C)	(2018-Jan-01)-(2019-Mar-17)	(2019-Mar-17)-(2019-Oct-31)	214	127	165
15mos	**Var** (Varicella)	(2018-Jan-01)-(2018-Dec-17)	(2018-Dec-17)-(2019-Jul-31)	175	99	232
18mos	**DTaP-IPV-Hib** (Diphtheria, Tetanus, Pertussis, Polio, Haemophilus influenzae type b)	(2018-Jan-01)-(2018-Sep-17)	(2018-Sep-17)-(2019-Apr-31)	129	104	273

Table 2: Percentage of patients receiving timely, delayed, and no immunization pre-vs-post COVID-19. 95% confidence intervals are displayed for each estimated percentage. Fisher's exact test is used to assess changes in vaccination uptake pre-vs-post COVID-19.

	Pre COVID-19			Post COVID-19			
	Percentage Vaccinated On-Time (95% CI)	Percentage Delated Vaccination (95% CI)	Percentage Not Vaccinated (95% CI)	Percentage Vaccinated On-Time (95% CI)	Percentage Delayed Vaccination (95% CI)	Percentage Not Vaccinated (95% CI)	Fisher Exact Test P-Value
2mos DTaP-IPV-Hib (Diphtheria, Tetanus, Pertussis, Polio, Haemophilus influenzae type b)	94.67 (91.88 - 96.71)	3.73 (2.06 - 6.18)	1.60 (0.59 - 3.45)	94.66 (89.30 - 97.82)	4.58 (1.70 - 9.70)	0.76 (0.02 - 4.18)	0.7586
2mos Pneu-C-13 (Pneumococcal Conjugate 13)	93.6 (90.63 - 95.86)	3.73 (2.06 - 6.18)	2.67 (1.29 - 4.85)	94.66 (89.30 - 97.82)	4.58 (1.70 - 9.70)	0.76 (0.02 - 4.18)	0.4511
4mos DTaP-IPV-Hib (Diphtheria, Tetanus, Pertussis, Polio, Haemophilus influenzae type b)	90.80 (87.27 - 93.63)	5.75 (3.55 - 8.74)	3.45 (1.79 - 5.95)	94.35 (88.71 - 97.70)	3.23 (0.89 - 8.05)	2.42 (0.50 - 6.91)	0.5374
4mos Pneu-C-13 (Pneumococcal Conjugate 13)	91.09 (87.59 - 93.87)	5.46 (3.32 - 8.40)	3.45 (1.79 - 5.95)	92.74 (86.67 - 96.63)	4.03 (1.32 - 9.16)	3.23 (0.89 - 8.05)	0.9180
6mos DTaP-IPV-Hib (Diphtheria, Tetanus, Pertussis, Polio, Haemophilus influenzae type b)	88.89 (84.89 - 92.14)	6.03 (3.67 - 9.26)	5.08 (2.93 - 8.12)	81.82 (73.78 - 88.24)	9.09 (4.63 - 15.68)	9.09 (4.63 - 15.68)	0.1272
12mos MMR (Measles, Mumps, Rubella)	81.31 (75.43 - 86.30)	12.62 (8.48 - 17.82)	6.07 (3.27 - 10.16)	69.29 (60.49 - 77.17)	18.90 (12.50 - 26.80)	11.81 (6.76 - 18.73)	0.0321
12mos Pneu-C-13 (Pneumococcal Conjugate 13)	79.44 (73.40 - 84.65)	10.75 (6.94 - 15.69)	9.81 (6.18 - 14.61)	68.50 (59.67 - 76.45)	18.90 (12.50 - 26.80)	12.60 (7.38 - 19.65)	0.0589
12mos Men-C-C (Meningococcal Conjugate C)	80.84 (74.92 - 85.89)	13.55 (9.27 - 18.88)	5.61 (2.93 - 9.59)	66.14 (57.21 - 74.30)	20.47 (13.83 - 28.54)	13.39 (8.00 - 20.56)	0.0063
15mos Var (Varicella)	64.00 (56.41 - 71.10)	24.57 (18.39 - 31.64)	11.43 (7.12 - 17.10)	52.53 (42.24 - 62.66)	24.24 (16.19 - 33.89)	23.23 (15.33 - 32.79)	0.0324

18mos DTaP-IPV-Hib (Diphtheria, Tetanus, Pertussis, Polio, Haemophilus influenzae type b)	66.67 (57.83 - 74.72)	17.83 (11.65 - 25.54)	15.50 (9.73 - 22.92)	58.65 (48.58 - 68.23)	24.04 (16.20 - 33.41)	17.31 (10.59 - 25.97)	0.4195

The RECORD statement – checklist of items, extended from the STROBE statement, that should be reported in observational studies using routinely collected health data.

	Item No.	STROBE items	Location in manuscript where items are reported	RECORD items	Location in manuscript where items are reported
Title and abstract					
	1	(a) Indicate the study's design with a commonly used term in the title or the abstract (b) Provide in the abstract an informative and balanced summary of what was done and what was found	3	RECORD 1.1: The type of data used should be specified in the title or abstract. When possible, the name of the databases used should be included. RECORD 1.2: If applicable, the geographic region and timeframe within which the study took place should be reported in the title or abstract. RECORD 1.3: If linkage between databases was conducted for the study, this should be clearly stated in the title or abstract.	1 1
Introduction					
Background rationale	2	Explain the scientific background and rationale for the investigation being reported	4		
Objectives	3	State specific objectives, including any prespecified hypotheses	4		
Methods					
Study Design	4	Present key elements of study design early in the paper	5		
Setting	5	Describe the setting, locations, and relevant dates, including periods of recruitment, exposure, follow-up, and data collection	5		

Participants	6	*(a) Cohort study* - Give the eligibility criteria, and the sources and methods of selection of participants. Describe methods of follow-up *Case-control study* - Give the eligibility criteria, and the sources and methods of case ascertainment and control selection. Give the rationale for the choice of cases and controls *Cross-sectional study* - Give the eligibility criteria, and the sources and methods of selection of participants *(b) Cohort study* - For matched studies, give matching criteria and number of exposed and unexposed *Case-control study* - For matched studies, give matching criteria and the number of controls per case	5	RECORD 6.1: The methods of study population selection (such as codes or algorithms used to identify subjects) should be listed in detail. If this is not possible, an explanation should be provided. RECORD 6.2: Any validation studies of the codes or algorithms used to select the population should be referenced. If validation was conducted for this study and not published elsewhere, detailed methods and results should be provided. RECORD 6.3: If the study involved linkage of databases, consider use of a flow diagram or other graphical display to demonstrate the data linkage process, including the number of individuals with linked data at each stage.	5-6
Variables	7	Clearly define all outcomes, exposures, predictors, potential confounders, and effect modifiers. Give diagnostic criteria, if applicable.	6	RECORD 7.1: A complete list of codes and algorithms used to classify exposures, outcomes, confounders, and effect modifiers should be provided. If these cannot be reported, an explanation should be provided.	N/A
Data sources/ measurement	8	For each variable of interest, give sources of data and details of methods of assessment (measurement). Describe comparability of assessment methods if there is more than one group	5-8		

Bias	9	Describe any efforts to address potential sources of bias	5		
Study size	10	Explain how the study size was arrived at	5-6		
Quantitative variables	11	Explain how quantitative variables were handled in the analyses. If applicable, describe which groupings were chosen, and why	7-8		
Statistical methods	12	(a) Describe all statistical methods, including those used to control for confounding (b) Describe any methods used to examine subgroups and interactions (c) Explain how missing data were addressed (d) *Cohort study* - If applicable, explain how loss to follow-up was addressed *Case-control study* - If applicable, explain how matching of cases and controls was addressed *Cross-sectional study* - If applicable, describe analytical methods taking account of sampling strategy (e) Describe any sensitivity analyses	7-8		
Data access and cleaning methods		..		RECORD 12.1: Authors should describe the extent to which the investigators had access to the database population used to create the study population.	5

				RECORD 12.2: Authors should provide information on the data cleaning methods used in the study.	6
Linkage		..		RECORD 12.3: State whether the study included person-level, institutional-level, or other data linkage across two or more databases. The methods of linkage and methods of linkage quality evaluation should be provided.	6
Results					
Participants	13	(a) Report the numbers of individuals at each stage of the study (*e.g.*, numbers potentially eligible, examined for eligibility, confirmed eligible, included in the study, completing follow-up, and analysed) (b) Give reasons for non-participation at each stage. (c) Consider use of a flow diagram	7	RECORD 13.1: Describe in detail the selection of the persons included in the study (*i.e.*, study population selection) including filtering based on data quality, data availability and linkage. The selection of included persons can be described in the text and/or by means of the study flow diagram.	5
Descriptive data	14	(a) Give characteristics of study participants (*e.g.*, demographic, clinical, social) and information on exposures and potential confounders (b) Indicate the number of participants with missing data for each variable of interest (c) *Cohort study* - summarise follow-up time (*e.g.*, average and total amount)	9-10		
Outcome data	15	*Cohort study* - Report numbers of outcome events or summary measures over time *Case-control study* - Report numbers in each exposure	9-10		

		category, or summary measures of exposure *Cross-sectional study* - Report numbers of outcome events or summary measures			
Main results	16	(a) Give unadjusted estimates and, if applicable, confounder-adjusted estimates and their precision (e.g., 95% confidence interval). Make clear which confounders were adjusted for and why they were included (b) Report category boundaries when continuous variables were categorized (c) If relevant, consider translating estimates of relative risk into absolute risk for a meaningful time period	11-12		
Other analyses	17	Report other analyses done—e.g., analyses of subgroups and interactions, and sensitivity analyses	13		
Discussion					
Key results	18	Summarise key results with reference to study objectives	9		
Limitations	19	Discuss limitations of the study, taking into account sources of potential bias or imprecision. Discuss both direction and magnitude of any potential bias	16	RECORD 19.1: Discuss the implications of using data that were not created or collected to answer the specific research question(s). Include discussion of misclassification bias, unmeasured confounding, missing data, and changing eligibility over time, as they pertain to the study being reported.	14-17
Interpretation	20	Give a cautious overall interpretation of results considering objectives,	14-17		

		limitations, multiplicity of analyses, results from similar studies, and other relevant evidence			
Generalisability	21	Discuss the generalisability (external validity) of the study results	17		
Other Information					
Funding	22	Give the source of funding and the role of the funders for the present study and, if applicable, for the original study on which the present article is based	19		
Accessibility of protocol, raw data, and programming code		..		RECORD 22.1: Authors should provide information on how to access any supplemental information such as the study protocol, raw data, or programming code.	N/A

*Reference: Benchimol EI, Smeeth L, Guttmann A, Harron K, Moher D, Petersen I, Sørensen HT, von Elm E, Langan SM, the RECORD Working Committee. The REporting of studies Conducted using Observational Routinely-collected health Data (RECORD) Statement. *PLoS Medicine* 2015; in press.

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ABSTRACT (250 words)

BACKGROUND

There has been concern about the risk of declining routine vaccination rates during the COVID-19 pandemic. This study aimed to examine the impact of the COVID-19 pandemic on early childhood vaccination rates at a multi-site Academic Family Health Team (FHT).

METHODS

Vaccination records up to November 30, 2020 were collected for a cohort of children born between January 1, 2018 through August 31, 2020, from the FHT's electronic medical record (EMR). The proportion of children receiving timely, delayed, or no vaccination for 10 guideline-recommended childhood vaccines was estimated for the pre- and post-COVID-19 pandemic periods. Timeliness was determined based on vaccine recommended time intervals with a window of 28 days; vaccines administered after this window were considered delayed. We estimated median time to vaccination for each vaccine and present cumulative incidence curves.

RESULTS

Most children were up to date with vaccinations (422 out of 506 (83.4%)). The rates were comparable in children under 12 months old in the pre- and post-COVID-19 pandemic periods. Lower rates of timely vaccinations seemed to be amplified during the pandemic. For children between 12- and 18-months cumulative incidence curves illustrate a mild pre- and post-COVID-19 differences.

INTERPRETATION

Our local findings suggest a modest deterioration in the uptake of routine childhood vaccines during the COVID-19 pandemic, in children between 12 and 18 months of age. Further study in Canada is needed to determine the true extent of the vaccination gap in children due to the pandemic.

INTRODUCTION

Childhood vaccination programs are a critical public health intervention that have virtually eliminated previously common and usually fatal infectious diseases (1). In Canada, vaccination programs exist in various forms in each province and territory. In Ontario, publicly funded vaccinations begin at two months of age (see appendix 1) and are largely delivered by family physicians and general pediatricians.

On March 17, 2020, the Ontario government declared a public emergency under the province's Emergency Management and Civil Protection Act in response to the COVID-19 pandemic. The province faced two key issues: the uncertainty of the supply of personal protective equipment (PPE) for healthcare workers and an acute-care system already facing capacity issues (2). In the early response to the pandemic, part of the efforts to combat these challenges revolved around a coordinated public campaign urging citizens to stay home except for essential services.

Furthermore, available billing data from Ontario suggested that there was a dramatic decrease in overall patient visits since the emergence of the COVID-19 pandemic (3). While family physicians continued to see more patients than specialists overall in February and March, family physician total visit volumes in Ontario were still 15% lower in June 2020 compared to June 2019 inclusive of virtual and in-person visits. Given reports of reduced vaccinations from other jurisdictions (4,5), an important question is whether these observed volume decreases have affected routine childhood vaccinations in Ontario.

The objective of this study was to examine the impact of the COVID-19 pandemic environment on vaccine uptake rates in early childhood at a multi-site Family Health Team (FHT), with an urban academic center in downtown Toronto and a suburban community site in Vaughan, Ontario. We investigated the percentage of patients receiving timely, delayed, or no vaccinations, pre-vs-post the start of the COVID-19 pandemic. We also examined time to routine vaccination both pre- and post-the start of the COVID-19 pandemic.

METHODS

STUDY SETTING AND PARTICIPANTS

Our FHT combines the expertise and services of an interprofessional team to provide preventive and acute care throughout the age spectrum (pediatric, adult and geriatric) as well as full spectrum maternity care (including individual and group prenatal, birth and postpartum care), and is affiliated with a large teaching hospital. Our downtown academic primary care team serves a population of approximately 12,000 patients and includes family physicians, family medicine residents, nurses and other interprofessional health care providers. Our growing community site in Vaughan serves approximately 10,000 patients and is composed of a similar interprofessional team, without trainees. Our FHT maintained our usual hours of operation throughout the pandemic, offering both virtual and in-person appointments in large part due to support provided by our affiliated hospital. Of note, we prioritized and had the capacity to offer uninterrupted routine childhood vaccinations administered by physician and nursing staff, with clinic staff having access to adequate PPE, infection control and prevention resources, and physical distancing in the clinic space.

Our patient population of interest were children less than 2 years of age. Study participants included all patients born between January 1, 2018 through August 31, 2020 (i.e. 2mos + 28d from study endpoint, ensuring all patients could be included in a least one comparison). Vaccination data was collected up until November 30, 2020.

DATA SOURCES

We extracted information regarding patient demographics and timing of routine childhood vaccinations from the FHT's electronic medical record (EMR). Demographic information reported includes date of birth (DOB) and sex (M/F). Information regarding administration and timing of early childhood vaccinations was

initially extracted via the chart review function from the EMR's database of comprehensive patient profiles (CPP) within individual health records. For any charts with incomplete vaccination records or no vaccinations recorded, we undertook a secondary manual chart review to identify if the vaccination had in fact been given but incorrectly documented outside of the CPP.

OUTCOME MEASURES

We estimated pre-post COVID-19 differences in the proportion of patients receiving 1) timely administration (within 28 days of indicated age), 2) delayed administration (more than 28 days after indicated age), or 3) no immunization for 10 guideline-recommended early childhood vaccinations. We excluded rotavirus vaccination as an outcome measure due to the added complexity in data reporting resulting from two rotavirus vaccine options available in Ontario, each with differing administration schedules. In this study, the COVID-19 intervention date was assumed to be March 17, 2020 - the date when the province of Ontario declared the COVID-19 pandemic an emergency. Depending on the timing of patient DOB relative to the COVID-19 intervention date, patients were assigned to the pre-COVID-19 group, post-COVID-19 group, or declared ineligible for the comparison if during the study period they were not old enough for the specified vaccination. Table 1 below specifies each of the 10 vaccinations under consideration in this study, their recommended timing of administration, and the associated date of birth intervals for eligibility for the pre-post comparison.

Table 1: Number of vaccine-eligible patients in pre-vs-post COVID-19 groups based on age for selected childhood vaccinations

Age	Vaccination	DOB Interval Pre	DOB Interval Post	N eligible pre	N eligible post	N ineligible
2mos	**DTaP-IPV-Hib** (Diphtheria, Tetanus, Pertussis, Polio, Haemophilus influenzae type b)	(2018-Jan-01)-(2020-Jan-17)	(2020-Jan-17)-(2020-Aug-31)	375	131	0
	Pneu-C-13 (Pneumococcal Conjugate 13)	(2018-Jan-01)-(2020-Jan-17)	(2020-Jan-17)-(2020-Aug-31)	375	131	0
4mos	**DTaP-IPV-Hib** (Diphtheria, Tetanus, Pertussis, Polio, Haemophilus influenzae type b)	(2018-Jan-01)-(2019-Nov-17)	(2019-Nov-17)-(2020-June-30)	348	124	34
	Pneu-C-13 (Pneumococcal Conjugate 13)	(2018-Jan-01)-(2019-Nov-17)	(2019-Nov-17)-(2020-June-30)	348	124	34
6mos	**DTaP-IPV-Hib** (Diphtheria, Tetanus, Pertussis, Polio, Haemophilus influenzae type b)	(2018-Jan-01)-(2019-Sep-17)	(2019-Sep-17)-(2020-Apr-30)	315	121	70
12mos	**MMR** (Measles, Mumps, Rubella)	(2018-Jan-01)-(2019-Mar-17)	(2019-Mar-17)-(2019-Oct-31)	214	127	165
	Pneu-C-13 (Pneumococcal Conjugate 13)	(2018-Jan-01)-(2019-Mar-17)	(2019-Mar-17)-(2019-Oct-31)	214	127	165
	Men-C-C (Meningococcal Conjugate C)	(2018-Jan-01)-(2019-Mar-17)	(2019-Mar-17)-(2019-Oct-31)	214	127	165
15mos	**Var** (Varicella)	(2018-Jan-01)-(2018-Dec-17)	(2018-Dec-17)-(2019-Jul-31)	175	99	232
18mos	**DTaP-IPV-Hib** (Diphtheria, Tetanus, Pertussis, Polio, Haemophilus influenzae type b)	(2018-Jan-01)-(2018-Sep-17)	(2018-Sep-17)-(2019-Apr-31)	129	104	273

STATISTICAL ANALYSIS

We used descriptive statistics to characterize our study sample. We estimated the percentage of patients receiving 1) timely, 2) delayed or 3) no vaccination for each of the 10 routine vaccinations pre and post COVID-19. 95% confidence intervals are provided for each of the estimated percentages using the Clopper-Pearson method. Fisher's exact test was used to test whether the percentage of patients

receiving 1) timely, 2) delayed, or 3) no vaccination differs pre-vs-post COVID-19. We estimated median time to vaccination (and 95% CI) for each of the routine childhood vaccinations. Cumulative incidence functions were plotted and log-rank tests were used to examine differences in time to each of the 10 routine childhood vaccinations, pre versus post COVID-19. A nominal $\alpha = 0.05$ threshold was used for declaring statistical significance of hypothesis tests.

ETHICS APPROVAL

Ethics approval was received from the Research Ethics Board at Sinai Health.

RESULTS

The study included N=506 patients born between January 1, 2018 and August 31, 2020. The patient population was approximately balanced between males (52.4%) and females (47.6%). The average age of the included children as of November 30, 2020 was 18.5 months (median=17.7 months; IQR= 10.0 – 26.6). The oldest child was born January 1, 2018 and the youngest child was born August 29, 2020. The number of patients born in each study month is given in Appendix 2.

Table 2 illustrates the percentage of patients receiving 1) timely, 2) delayed, or 3) no vaccination pre-vs-post COVID-19. Median time to vaccination is presented in Table 3 (along with 95% CI). Cumulative incidence functions for each routine childhood vaccination, pre- vs post-COVID-19 are illustrated in Figure 1. For the early childhood vaccinations recommended at 2, 4 and 6 months of age, we observed few clinically meaningful differences in timeliness of vaccination, or up-to-date status pre-vs-post COVID-19. For the later vaccines administered at 12, 15, and 18 months, the results were suggestive of modest declines in timeliness of vaccination and up-to-date vaccination status in the post-COVID-19 period compared to the pre-COVID-19 period. Overall, at the end of the study period (November 30, 2020), 422/506 (83.4%) of patients were up to date for their required vaccinations.

Table 2: Percentage of patients receiving timely, delayed, and no immunization pre-vs-post COVID-19. 95% confidence intervals are displayed for each estimated percentage. Fisher's exact test is used to assess changes in vaccination uptake pre-vs-post COVID-19.

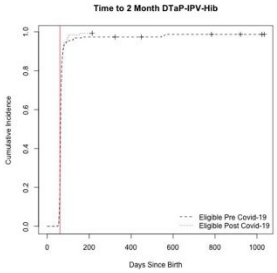
	Pre COVID-19			Post COVID-19			
	Percentage Vaccinated On-Time (95% CI)	Percentage Delated Vaccination (95% CI)	Percentage Not Vaccinated (95% CI)	Percentage Vaccinated On-Time (95% CI)	Percentage Delayed Vaccination (95% CI)	Percentage Not Vaccinated (95% CI)	Fisher Exact Test P-Value
2mos DTaP-IPV-Hib (Diphtheria, Tetanus, Pertussis, Polio, Haemophilus influenzae type b)	94.67 (91.88 - 96.71)	3.73 (2.06 - 6.18)	1.60 (0.59 - 3.45)	94.66 (89.30 - 97.82)	4.58 (1.70 - 9.70)	0.76 (0.02 - 4.18)	0.7586

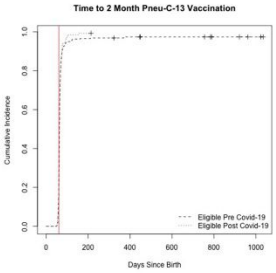
2mos Pneu-C-13 (Pneumococcal Conjugate 13)	93.6 (90.63 - 95.86)	3.73 (2.06 - 6.18)	2.67 (1.29 - 4.85)	94.66 (89.30 - 97.82)	4.58 (1.70 - 9.70)	0.76 (0.02 - 4.18)	0.4511
4mos DTaP-IPV-Hib (Diphtheria, Tetanus, Pertussis, Polio, Haemophilus influenzae type b)	90.80 (87.27 - 93.63)	5.75 (3.55 - 8.74)	3.45 (1.79 - 5.95)	94.35 (88.71 - 97.70)	3.23 (0.89 - 8.05)	2.42 (0.50 - 6.91)	0.5374
4mos Pneu-C-13 (Pneumococcal Conjugate 13)	91.09 (87.59 - 93.87)	5.46 (3.32 - 8.40)	3.45 (1.79 - 5.95)	92.74 (86.67 - 96.63)	4.03 (1.32 - 9.16)	3.23 (0.89 - 8.05)	0.9180
6mos DTaP-IPV-Hib (Diphtheria, Tetanus, Pertussis, Polio, Haemophilus influenzae type b)	88.89 (84.89 - 92.14)	6.03 (3.67 - 9.26)	5.08 (2.93 - 8.12)	81.82 (73.78 - 88.24)	9.09 (4.63 - 15.68)	9.09 (4.63 - 15.68)	0.1272
12mos MMR (Measles, Mumps, Rubella)	81.31 (75.43 - 86.30)	12.62 (8.48 - 17.82)	6.07 (3.27 - 10.16)	69.29 (60.49 - 77.17)	18.90 (12.50 - 26.80)	11.81 (6.76 - 18.73)	0.0321
12mos Pneu-C-13 (Pneumococcal Conjugate 13)	79.44 (73.40 - 84.65)	10.75 (6.94 - 15.69)	9.81 (6.18 - 14.61)	68.50 (59.67 - 76.45)	18.90 (12.50 - 26.80)	12.60 (7.38 - 19.65)	0.0589
12mos Men-C-C (Meningococcal Conjugate C)	80.84 (74.92 - 85.89)	13.55 (9.27 - 18.88)	5.61 (2.93 - 9.59)	66.14 (57.21 - 74.30)	20.47 (13.83 - 28.54)	13.39 (8.00 - 20.56)	0.0063
15mos Var (Varicella)	64.00 (56.41 - 71.10)	24.57 (18.39 - 31.64)	11.43 (7.12 - 17.10)	52.53 (42.24 - 62.66)	24.24 (16.19 - 33.89)	23.23 (15.33 - 32.79)	0.0324
18mos DTaP-IPV-Hib (Diphtheria, Tetanus, Pertussis, Polio, Haemophilus influenzae type b)	66.67 (57.83 - 74.72)	17.83 (11.65 - 25.54)	15.50 (9.73 - 22.92)	58.65 (48.58 - 68.23)	24.04 (16.20 - 33.41)	17.31 (10.59 - 25.97)	0.4195

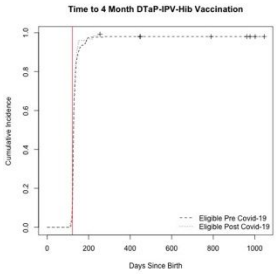
Table 3 – Median time to vaccination (and 95% confidence interval) for each of the routine childhood vaccinations pre-vs-post the start of COVID-19. Log-rank test p-values are presented for testing differences in each of the routine childhood vaccination cumulative incidence functions pre-vs-post COVID-19.

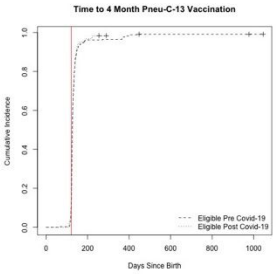
	Pre COVID-19					Post COVID-19					
	Number Eligible for Vaccination	Number Vaccinated	Median Time to Vaccination	Lower Limit 95% CI Median Time to Vaccination	Upper Limit 95% CI Median Time to Vaccination	Number Eligible for Vaccination	Number Vaccinated	Median Time to Vaccination	Lower Limit 95% CI Median Time to Vaccination	Upper Limit 95% CI Median Time to Vaccination	Log Rank Test P-value
2mos DTaP-IPV-Hib (Diphtheria, Tetanus, Pertussis, Polio, Haemophilus influenzae type b)	375	369	63	63	64	131	130	64	63	65	1.000
2mos Pneu-C-13 (Pneumococcal Conjugate 13)	374	364	63	63	64	131	130	64	63	65	0.900
4mos DTaP-IPV-Hib (Diphtheria, Tetanus, Pertussis, Polio, Haemophilus influenzae type b)	342	335	126	126	128	122	121	127	125	129	0.400
4mos Pneu-C-13 (Pneumococcal Conjugate 13)	338	335	126	126	127	122	120	127	125	129	0.700
6mos DTaP-IPV-Hib (Diphtheria, Tetanus, Pertussis, Polio, Haemophilus influenzae type b)	303	299	188	188	189	118	110	191	189	195	0.007
12mos MMR (Measles, Mumps, Rubella)	214	201	372	371	375	127	112	374	372	377	0.050
12mos Pneu-C-13 (Pneumococcal Conjugate 13)	205	193	374	372	377	124	111	375	372	377	0.200
12mos Men-C-C (Meningococc	214	202	373	372	377	127	110	377	374	381	0.007

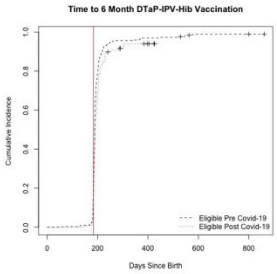
al Conjugate C)											
15mos Var (Varicella)	175	155	471	466	477	99	76	478	470	526	0.040
18mos DTaP-IPV-Hib (Diphtheria, Tetanus, Pertussis, Polio, Haemophilus influenzae type b)	121	109	561	556	568	101	86	567	560	580	0.400

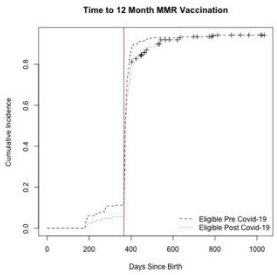

Time to 2 Month DTaP-IPV-Hib
Cumulative Incidence
Days Since Birth
Eligible Pre Covid-19
Eligible Post Covid-19

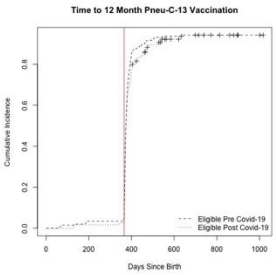

Time to 2 Month Pneu-C-13 Vaccination
Cumulative Incidence
Days Since Birth
Eligible Pre Covid-19
Eligible Post Covid-19

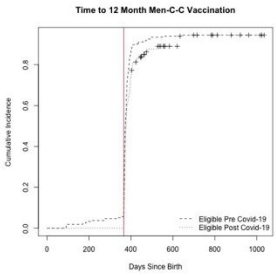

Time to 4 Month DTaP-IPV-Hib Vaccination
Cumulative Incidence
Days Since Birth
Eligible Pre Covid-19
Eligible Post Covid-19

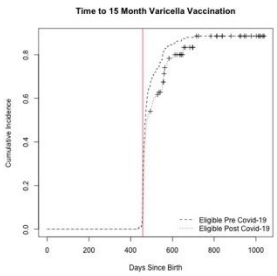

Time to 4 Month Pneu-C-13 Vaccination
Cumulative Incidence
Days Since Birth
Eligible Pre Covid-19
Eligible Post Covid-19


Time to 6 Month DTaP-IPV-Hib Vaccination
Cumulative Incidence
Days Since Birth
Eligible Pre Covid-19
Eligible Post Covid-19


Time to 12 Month MMR Vaccination
Cumulative Incidence
Days Since Birth
Eligible Pre Covid-19
Eligible Post Covid-19


Time to 12 Month Pneu-C-13 Vaccination
Cumulative Incidence
Days Since Birth
Eligible Pre Covid-19
Eligible Post Covid-19


Time to 12 Month Men-C-C Vaccination
Cumulative Incidence
Days Since Birth
Eligible Pre Covid-19
Eligible Post Covid-19


Time to 15 Month Varicella Vaccination
Cumulative Incidence
Days Since Birth
Eligible Pre Covid-19
Eligible Post Covid-19

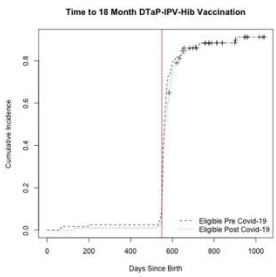

Time to 18 Month DTaP-IPV-Hib Vaccination
Cumulative Incidence
Days Since Birth
Eligible Pre Covid-19
Eligible Post Covid-19

Figure 1: Cumulative incidence functions for each of the 10 routine childhood vaccinations, pre-vs-post COVID-19. The dashed line represents vaccinations scheduled to fall in the pre-COVID-19 period; whereas, the dotted line indicates vaccinations scheduled to fall in the post-COVID-19 period. A vertical red line depicts the scheduled timing of each of the routine childhood vaccinations. The sub-plots in each of the six rows correspond to the 2-, 4-, 6-, 12-, 15-, and 18-month routine childhood vaccinations, respectively.

DISCUSSION

COVID-19 poses threats to public health and health care systems worldwide, with governments implementing multi-faceted restrictions to curb the spread of COVID-19 and lessen the burden on health care systems (6). Although these mitigation strategies are important, concerns have been raised about their unintended consequences, such as the disruption to the provision of routine primary care, including vaccine delivery. Immunization against vaccine-preventable illness is a cornerstone of primary care in Ontario. Adherence to recommended vaccination schedules, irrespective of pandemic restrictions, was emphasized by several key organizations including the Canadian Pediatrics Society, the National Advisory Committee on Immunization, and Public Health Ontario (7–9). Ours is the first study to examine childhood vaccination data in the time of COVID-19 from an Ontario primary care perspective.

Our data suggested that vaccine completion rates were largely unchanged pre-and post the onset of COVID-19 restrictions for children in the first six months of life. However, we found that vaccine completion rates at the 12-month, 15-month and 18-month ages were modestly lower in the post pandemic period. We observed that even prior to the pandemic, there was attrition in vaccination rates in these older age groups, though this seemed to be amplified post-COVID-19. While it is reassuring that many children do eventually "catch up", it may be clinically significant that there was an increase in the delayed vaccination rate (ranging from 5-15%) in the post COVID-19 period depending on the age group analyzed. In the event of an outbreak, these unvaccinated children may be at greater risk of morbidity from a vaccine-preventable illness (10).

The Public Health Agency of Canada (PHAC) routinely monitors childhood vaccination coverage in Canada through the childhood National Vaccination Coverage Survey (cNICS) and declares a national vaccination goal of 95% for each childhood vaccine (11). Our FHT vaccination rates seemed on par with cNICS's Ontario data for 2017 (11). Research from Alberta and Nova Scotia assessed timeliness of routine childhood vaccination and revealed that the 12 and 18 month vaccinations had the lowest proportion of children receiving timely doses (12,13). Our observations appeared to be consistent with these findings in both the pre-pandemic and post-pandemic periods.

Reasons for incomplete vaccine coverage in children, prior to the COVID-19 pandemic have received much attention in the literature (14,15). Our study was not designed to probe into specific factors that may account for reductions in childhood vaccination rates. Rather, we aimed to present what we know as the first Canadian dataset reporting early childhood vaccination rates during COVID-19. The observation that the 12-to-18-month age group had less than ideal vaccination rates both prior to and during COVID-19, as well as increased delayed vaccinations post COVID-19 suggests that this group may represent a high yield target for improving overall vaccination rates.

Some jurisdictions have reported declining early childhood vaccination rates as a result of COVID-19 (4,5), with New York specifically noting a rebound in vaccination rates after a proactive effort to encourage vaccinations (16). The literature suggests a combination of service provision and service utilization factors affected vaccine uptake rates during the pandemic (17). S*ervice provision factors* include the disruption or suspension of programs, workforce shortages due to COVID-19 related redeployments, provider illness, inadequate supply of PPE or infection prevention and control, and supply chain disruptions of vaccines due to production or border restrictions (17). In our clinical setting, we were fortunately unaffected by these barriers and were uninterrupted in our ability to offer and prioritize in-person visits for early childhood vaccinations. Therefore, our clinical environment may have represented one of several local "best case scenarios." This leads us to conclude that service utilization factors may have more of a

contributory role in our observed reduced vaccine uptake during the pandemic. By addressing *service utilization factors*, there may be ways to mitigate the potential of reduced vaccination rates in the context of COVID-19 and perhaps to improve rates overall (17). We should continue to emphasize timely vaccinations across all age groups. Given public fears of COVID-19 infection, and potential confusion regarding evolving public health messages, clear and proactive education directed toward parents becomes vital. Workflows that facilitate on time vaccinations can be implemented and may include the flagging of missing vaccinations on the CPP and automated identification of these patients in the EMR for call-back to book appointments.

We recognize that our study, like many retrospective chart reviews, has limitations. First, the inconsistency and potential for error during documentation in EMRs is well known (18). Clinicians have different templates and systems in which they like to document, further increasing the heterogeneity and difficulties in analyzing this type of data. At our two clinic sites, we mitigated this by enforcing a built-in vaccination entry system to document all vaccinations with all care providers. Another limitation may be the difficulty in establishing a clear division between COVID-19 and pre-COVID-19 as patients in family medicine are under continuous rather than episodic care. This limitation may affect our attempts to present a conclusive comparison between both time periods. Regardless, our intention with this study was to report our clinic's vaccination trends during this time of flux.

This retrospective chart review shows the rate of vaccination during COVID-19 in two settings where service-provision factors were not significantly changed; therefore, our data likely under-estimated the effect of the COVID-19 pandemic on vaccination rates and may not be representative of the broader context.

CONCLUSION

Our findings suggest that in our setting the COVID-19 pandemic has led to a modest deterioration in the uptake of routine childhood vaccines. Like the rest of Canada, our routine childhood vaccination rates are still suboptimal and its drivers are complicated even in non-pandemic circumstances. From our data, the lower rates in 12- to 18-month-old children represent a potentially high yield target for interventions. Improving vaccination rates will be important during COVID-19 as the potential of a developing cohort of children with less protection against vaccine-preventable illnesses could further burden an already strained public health system as Canada continues to fight against the transmission of COVID-19 and looks towards recovery.

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CONFLICTS OF INTEREST, FINANCIAL DISCLOSURES, GRANT FUNDING, etc.

No conflicts of interest to declare. No sources of funding.

Appendix 1: Ontario's Publicly Funded Immunization Schedules (19)

Publicly Funded Immunization Schedules for Ontario – January 2021

Publicly funded vaccines may be provided only to eligible individuals and must be free of charge

Routine Schedule: Children Starting Immunization in Infancy												
Vaccine \ Age	2 Months	4 Months	6 Months	1 Year Φ	15 Months	18 Months	4 Years	Grade 7	14 Years	24 Years	≥34 Years Ψ	65 Years
DTaP-IPV-Hib Diphtheria, Tetanus, Pertussis, Polio, *Haemophilus influenzae* type b	◆	◆	◆			◆						
Pneu-C-13 Pneumococcal Conjugate 13	◆	◆		◆								
Rot-5 Rotavirus	▲	▲	▲									
Men-C-C Meningococcal Conjugate C				◆								
MMR Measles, Mumps, Rubella				■								
Var Varicella					■							
MMRV Measles, Mumps, Rubella, Varicella							■					
Tdap-IPV Tetanus, diphtheria, pertussis, Polio							◆					
HB Hepatitis B								●				
Men-C-ACYW Meningococcal Conjugate ACYW-135								●				
HPV-9 Human Papillomavirus								●				
Tdap Tetanus, diphtheria, pertussis									◆	◆		
Td (booster) Tetanus, diphtheria											◆ Every 10 years	
HZ Herpes Zoster												❙
Pneu-P-23 Pneumococcal Polysaccharide 23												■
Inf Influenza				*Every year in the fall								

◆ - A single vaccine dose given by intramuscular injection

■ - A single vaccine dose given by subcutaneous injection

▲ - A single vaccine dose given by mouth

● - Provided through school-based immunization programs. Men-C-ACYW is a single dose; HB is a 2 dose series (see Table 6); HPV-9 is a 2 dose series (see Table 10). Each vaccine dose is given by intramuscular injection

Φ - Given no earlier than the 1st birthday, and prior to 16 months of age

Ψ - Once a dose of Tdap is given in adulthood (24 years of age), adults should receive Td boosters every 10 years thereafter

❙ - HZ is a 2 dose series (see Table 12) given by intramuscular injection

★ - Children 6 months to 8 years of age who have not previously received a dose of influenza vaccine require 2 doses given ≥4 weeks apart. Children who have previously received ≥1 dose of influenza vaccine should receive 1 dose per season thereafter

Note: A different schedule and/or additional doses may be needed for high risk individuals (see Table 3) or if doses of a vaccine series are missed (see appropriate Tables 4-24)

Appendix 2

Number of births in each month of the study. Number of vaccinations administered in each month, for each vaccination class.

Month-Year	Number Births	Number DTaP-IPV-Hib	Number Pneu-C-13	Number MMR	Number Men-C-C	Number Varicella	Total Number Vaccinations
18-Jan	16	NA	NA	NA	NA	NA	0
18-Feb	14	NA	NA	NA	NA	NA	0
18-Mar	13	13	13	0	0	0	26
18-Apr	20	13	13	0	0	0	26
18-May	14	25	25	0	3	0	53
18-Jun	16	28	26	0	0	0	54
18-Jul	13	38	25	0	1	0	64
18-Aug	14	47	35	0	2	0	84
18-Sep	16	31	21	0	0	0	52
18-Oct	20	49	34	0	1	0	84
18-Nov	12	45	30	1	0	0	76
18-Dec	12	45	31	0	2	0	78
19-Jan	16	37	37	11	12	0	97
19-Feb	12	51	43	12	11	0	117
19-Mar	13	43	43	15	14	0	115
19-Apr	12	41	38	22	19	11	131
19-May	13	48	45	17	13	10	133
19-Jun	16	37	37	17	16	9	116
19-Jul	12	48	43	17	22	15	145
19-Aug	25	43	37	17	14	4	115
19-Sep	23	54	41	16	16	16	143
19-Oct	19	67	58	17	16	15	173
19-Nov	13	53	47	15	17	11	143
19-Dec	10	62	43	11	8	9	133
20-Jan	15	75	60	18	16	28	197
20-Feb	19	60	36	12	14	14	136
20-Mar	16	52	38	11	10	7	118
20-Apr	22	59	36	8	9	8	120
20-May	21	52	39	11	12	7	121
20-Jun	15	64	59	17	17	12	169
20-Jul	18	69	50	13	12	9	153
20-Aug	16	62	50	21	21	14	168
20-Sep	NA	76	71	25	27	12	211
20-Oct	NA	65	47	17	12	15	156
20-Nov	NA	50	39	21	17	21	148