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Gaps in knowledge about the vaccine coverage of immunocompromised children: a scoping review

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ABSTRACT

Immunocompromised children are at increased risk of severe illness from vaccine-preventable infections. However, inadequate vaccine coverage remains a concern. This scoping review sought to determine the current state of knowledge regarding vaccine coverage of immunocompromised children. Bibliographic databases were searched for primary research from any year. Data were analyzed quantitatively and narratively. Ninety-seven studies met inclusion criteria. The most commonly studied vaccines were pneumococcal ($n = 46$), influenza ($n = 44$), diphtheria/tetanus/pertussis/poliomyelitis/*Haemophilus influenzae* type B/hepatitis B-containing ($n = 36$), and measles- and/or mumps- and/or rubella-containing ($n = 29$). Immunocompromising conditions studied included cancer/stem cell transplants ($n = 24$), solid organ transplants ($n = 23$), sickle cell disease ($n = 21$), immunosuppressive therapy ($n = 14$), human immunodeficiency virus ($n = 12$), splenectomy ($n = 4$), and primary immunodeficiency ($n = 2$). As more children are treated with immunosuppressive therapies, it is critical to identify whether they are being appropriately vaccinated for age and condition. We identified gaps in the current state of knowledge for specific vaccine types in specific immunocompromised populations.

Introduction

Appropriate vaccination of immunocompromised children is critical, given that they have impaired immune systems due to conditions, illnesses, medical treatments, or medications that suppress their immune function.[1,2] These children are more susceptible to infections and at higher risk of developing severe or complicated infections.[2] For example, among solid organ transplant recipients, vaccine-preventable infections have been shown to cause significant morbidity and mortality, resulting in hospitalization rates up to 87 times higher than the general population.[3] Optimizing vaccine coverage in this vulnerable population is of utmost importance as it is the best way to prevent severe and complicated infection and even death from vaccine-preventable diseases.[2]

Although routinely used live and inactivated vaccines are both safe and effective for the vast majority of children, this is not always the case for immunocompromised children who have impaired immune systems due to conditions, illnesses, medical treatments, or medications that suppress their immune function.[1,2] The goal of vaccination in this population is to maximize the benefits while minimizing harm, since some vaccines may not be as safe or effective.[4,5] Thus, the individual's underlying condition, disease progression, and timing of the vaccinations must be considered when health-care providers are weighing the risks versus the benefits of providing these children particular vaccines.[4] The reason why the child may be immunocompromised may affect vaccination requirements in different ways. Solid organ transplant recipients will remain on lifelong immunosuppression following transplant;

therefore, vaccination should be optimized prior to transplantation and as early in the course of disease as possible when the maximum immune response would be expected and administration of live vaccines may be safe.[4,6–8] In contrast, other immunocompromising conditions such as cancer or HIV may result in temporary immunosuppression, allowing for live vaccines to only be safely administered once the child in no longer considered to be immunocompromised.[4,9]

Despite known risks for vaccine-preventable infections, inadequate vaccine coverage has been identified as a concern for immunocompromised children.[6] In addition, immunocompromising conditions have become more prevalent as immunosuppressive therapies are being used for an increasing range of medical conditions and the life expectancy for patients with these conditions is increasing.[2] Thus, assessment of vaccine coverage among children with immunocompromising conditions is important.[4,10] The purpose of this scoping review was to determine the current state of knowledge regarding vaccine coverage of children who are immunocompromised by mapping out the characteristics of the existing literature, in order to identify gaps in the existing research.

Methods

A scoping review was conducted in order to examine the extent, range, and nature of knowledge about vaccine coverage in this clinical population, as well as to identify research gaps. The review was guided by Arksey and O'Malley's framework,[11]

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which includes five stages: (1) identifying the research question, (2) identifying relevant studies, (3) selecting relevant studies, (4) charting the data, and (5) collating, summarizing, and reporting results. The optional sixth stage of expert consultation was employed to identify any missing relevant literature. An unpublished review protocol is available upon request.

Study inclusion/exclusion criteria

The inclusion criteria were comprised of the following Population, Intervention, Comparison, and Outcome (PICO) criteria: (1) Population: all children from birth to 18 y of age who have an immunocompromising condition of any kind; (2) Intervention: vaccination with any active vaccine; (3) Comparison: studies with and without comparison groups were included; (4) Outcome: vaccine coverage, defined as the proportion of eligible children in the study population who received the vaccine(s) being investigated.[12] No limits were placed on study design or publication date. Primary research in the English language from any income country, and with extractable data were included. In order to identify potential publication bias, both published and unpublished research were included. Abstracts that met the study inclusion criteria were included. Reviews, case reports, editorials, letters and comments were excluded.

Search strategy

A research librarian searched the following databases for literature from any year: MEDLINE, Embase, Cochrane Library, CINAHL, ProQuest Dissertations and Theses Global, Scopus, and Web of Science Core Collection, which includes the Conference Proceedings Science Citation Index. Terms representing immunization/vaccination were combined with terms representing being immunocompromised or conditions or medications that might contribute to being immunocompromised. Reference lists of included studies and excluded review articles were also chain searched for relevant citations. The initial search was conducted May 15, 2019, with an updated search run on April 21, 2020.

Study selection

Two independent reviewers (AP, HT) conducted Level 1 (title/abstract) and Level 2 (full-text) screening based on the predetermined inclusion criteria using Covidence, a scoping review software platform.[13] Discrepancies were resolved by reaching a consensus through discussion and consulting a third reviewer (SM) when consensus could not be reached. We consulted with our clinical expert (CB) to verify that our included articles captured all key literature known to them.

Data collection/extraction

Two authors (AP and HT) developed, pilot tested, and revised the data extraction form in Google sheets. Data were extracted by one reviewer (AP) and verified by a second reviewer (HT). The following general data were extracted: record identification, title, author, year of publication, and country. Methodological elements were also extracted, including study design, aim, setting, sampling procedures, sample size, vaccine(s) and doses assessed, data collection methods, and comparison groups. Additional information about the population were extracted, including age range and the immunocompromising condition.

Quality appraisal

Two independent reviewers (AP and HT) appraised the quality of the evidence of all the included studies using the Mixed Methods Appraisal Tool (MMAT), version 2018.[14] The MMAT was chosen *a priori*, as the literature search allowed for inclusion of all research methodologies. In the case of discrepancies, a discussion occurred between the two reviewers until consensus was reached. A third reviewer was consulted when consensus was not reached. Studies were categorized into scores of 0.5–3.5 (low quality) and 4–5 (high quality).

Data analysis

A numerical analysis of the extracted variables was conducted to describe and quantify the following characteristics of the included articles: General characteristics such as geographic region, income of country, year of publication, and type of publication; study design, study aim; quality score; population characteristics such as immunocompromising condition, age, comparison group; sample size; and vaccine types, vaccine coverage, timepoints of measurement of coverage, and data source. A narrative synthesis and tabulation of these findings was prepared.

Results

In total, 4542 records were retrieved through database searching and chain searching. After removal of duplicates and screening, 97 studies met our inclusion criteria (see Figure 1). A summary of the characteristics of included studies is presented in Table 1.

Vaccine types

Vaccine coverage was studied for many different vaccines (see Table 1). Several studies measured the vaccine coverage of all vaccines in the relevant vaccine guidelines or routine schedules ($n = 24$). Of these studies, 16 also reported coverage results for certain individual vaccines. Of the studies that examined specific vaccines, pneumococcal ($n = 46$) and influenza ($n = 44$) vaccines were the most commonly studied. Additional vaccines studied included measles- and/or mumps- and/or rubella (M/M/R)-containing ($n = 29$), varicella ($n = 23$), diphtheria- and/or tetanus- and/or pertussis- and/or poliomyelitis- and/or *Haemophilus influenzae* type B- and/or hepatitis B (D/T/P/Polio/Hib/Hep B)-containing ($n = 36$), meningococcal ($n = 25$), human papillomavirus (HPV) ($n = 19$), Bacillus Calmette-Guérin (BCG) ($n = 10$), hepatitis A ($n = 11$), rotavirus ($n = 2$), typhoid fever ($n = 1$), and yellow fever ($n = 1$) vaccines. One study did not state which vaccine types were studied.
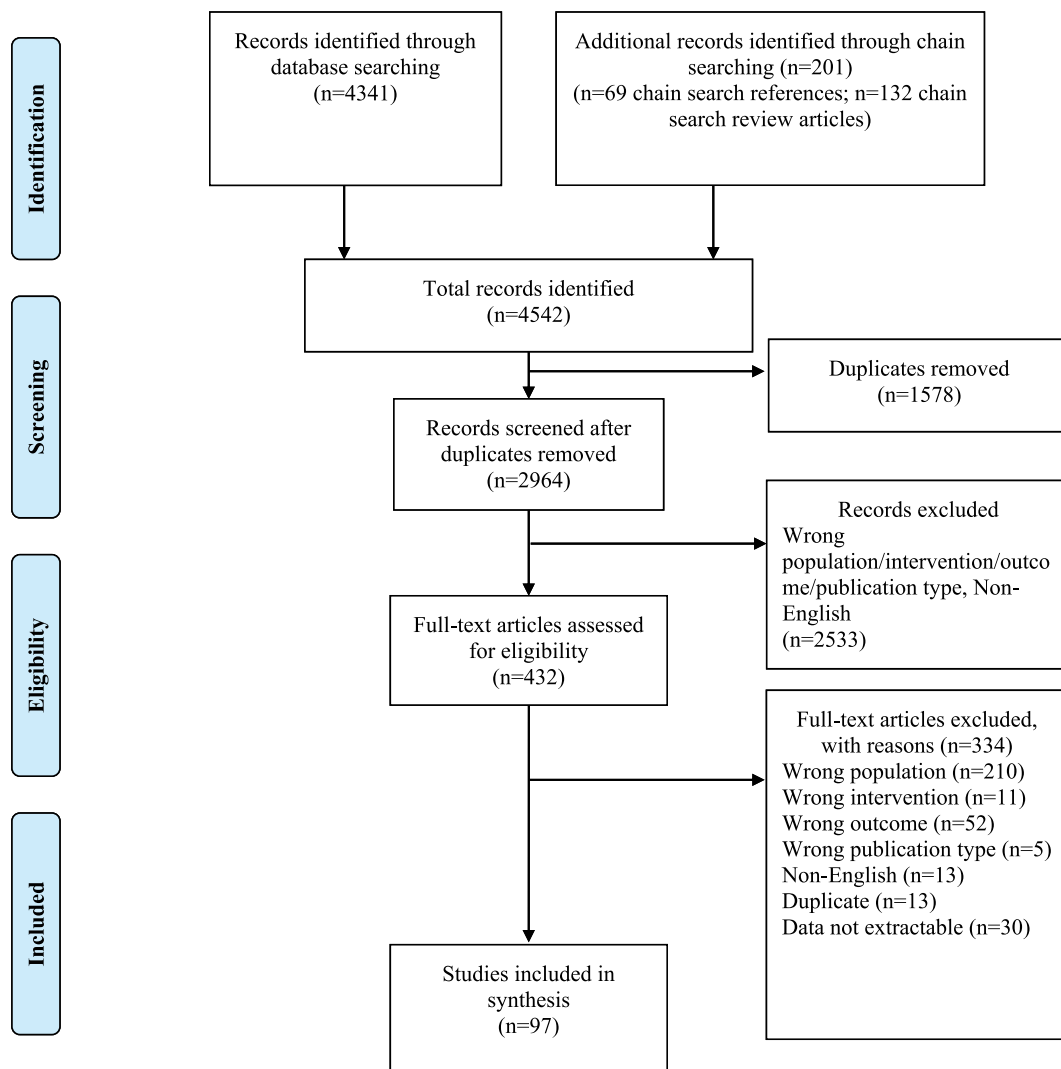
Figure 1. PRISMA flow diagram.

Study characteristics

The majority of the studies were of cross-sectional design (*n* = 46). Others were of retrospective cohort (*n* = 19), prospective cohort interventional (*n* = 16), prospective cohort observational (*n* = 11), case–control (*n* = 4), or randomized controlled trial (*n* = 1) designs. Among most of the vaccine types, the cross-sectional design was most commonly used (Table 3). Retrospective cohort design (*n* = 14) was common among studies measuring pneumococcal vaccine coverage, and interventional prospective cohort design (*n* = 12) was common among studies measuring influenza vaccine coverage.

The most common method of determining the vaccine coverage of immunocompromised children was by reviewing the medical record or chart (*n* = 25). A variety of other data sources were used, including caregiver or patient questionnaire (*n* = 18), hospital unit questionnaire (*n* = 1), electronic medical records (*n* = 5), vaccination database or registry (*n* = 7), caregiver interview (*n* = 1), and physician obtained data (*n* = 2). There were 25 studies that used mixed data sources and 13 studies did not describe the data source used. Identified data sources were used broadly across vaccine types (Table 4).

There were studies with sample sizes under 25 (*n* = 9), between 25 and 50 (*n* = 14), between 51 and 100 (*n* = 24), and between 101 and 200 (*n* = 18). There were 28 studies with sample sizes greater than 200. The largest sample size consisted of 54,809 immunocompromised children. Five studies did not specify their sample size. Small sample sizes (<100 participants) were common among all vaccines studied, though the frequently studied vaccines (influenza and pneumococcal) had a greater number of studies with larger sample sizes (Table 5).

The distribution of age ranges studied varied across the studies. There were studies that included children from 0 to 4 y (*n* = 48), 5 to 11 y (*n* = 55), and 12 to 18 y (*n* = 50). However, several studies did not provide the age range of the population studied (*n* = 29).

Some studies compared the vaccine coverage of the immunocompromised population to a non-immunocompromised population (*n* = 24). Others compared to a population with the same immunocompromised condition with different characteristics, such as age, gender, or cohort year (*n* = 23). Three studies had a comparison group consisting of a population with a different immunocompromising condition. There were 50 studies that did not include a comparison group.

Table 1. Frequency of study characteristics of included studies ($N = 97$).[a]

Characteristics	Number of articles	% of articles
Year of Publication		
2015–2020	50	52
2011–2014	27	28
2000–2010	18	19
<2000	2	2
Publication Type		
Journal article	67	69
Abstract	30	31
Immunocompromising Condition		
Cancer/stem cell transplant	24	25
Solid organ transplant	23	24
Sickle cell disease	21	22
HIV	12	12
Immunosuppressive therapy for a chronic condition	14	14
Splenectomy	4	4
Primary immunodeficiency	2	2
Unspecified	3	3
Age Range of Children		
0–4 y	48	49
5–11 y	55	57
12–18 y	50	52
Not stated	29	30
Vaccine Type		
Immunization guidelines/routine schedules	24	25
Measles- and/or mumps- and/or rubella-containing	29	30
Varicella	23	24
Diphtheria- and/or tetanus- and/or pertussis- and/or poliomyelitis- and/or *Haemophilus influenzae* type B- and/or hepatitis B-containing	36	37
Meningococcal	25	26
Pneumococcal	46	47
Rotavirus	2	2
Influenza	44	45
Human papillomavirus	19	20
Bacillus Calmette–Guérin	10	10
Hepatitis A	11	11
Typhoid fever	1	1
Yellow fever	1	1
Not stated	1	1
Timepoints of Vaccine Coverage Measurement[b]		
Pretreatment	20	30
Posttreatment	25	37
During treatment	21	31
Unspecified	6	9
Geographic Region		
North America	48	49
Europe	33	34
Africa	6	6
Latin America/Caribbean	6	6
Oceania	3	3
Middle East	2	2
Income of Country		
High-income	84	87
Upper-middle-income	10	10
Lower-middle-income	2	2
Low-income	4	4
Study Design		
Cross-sectional	46	47
Retrospective cohort	19	20
Prospective cohort interventional	16	16
Prospective cohort observational	11	11
Case-control	4	4
Randomized controlled trial	1	1
Vaccine Coverage Data Source		
Medical record/chart	25	26
Caregiver/parent questionnaire	18	19
Hospital unit questionnaire	1	1
Electronic medical record	5	5
Database or registry	7	7
Caregiver interview	1	1
		(Continued)

Table 1. (Continued).

Characteristics	Number of articles	% of articles
Physician-obtained data	2	2
Mixed data sources	25	26
Not stated	13	13
Sample Size		
<25	9	9
25–50	14	14
51–100	24	25
101–200	18	19
>200	28	29
Not stated	5	5
Comparison Group		
Non-immunocompromised	24	25
Same immunocompromised condition	23	24
Different immunocompromised condition	3	3
No comparison group	50	52
Quality Score		
High	34	35
Low	63	65

[a]Totals may not equal 100% due to non-mutually exclusive categories.
[b]Frequency calculated using the 67 studies relevant to this variable.

The studies included 67 peer-reviewed journal articles and 30 published abstracts. There were 34 studies that had a high-quality score (4–5 out of 5) and 63 studies that had a low-quality score (0.5–3.5 out of 5). Studies were commonly scored lower due to insufficient detail provided in the methods, such as when studies measured multiple variables besides vaccination coverage. Many of the studies were published between 2015 and 2020 ($n = 50$). Fewer studies were published from 2011 to 2014 ($n = 27$), and 2000 to 2010 ($n = 18$). Only two studies were published before the year 2000.

Country of origin

The 97 studies primarily came from the United States of America ($n = 46$) and Europe ($n = 33$). Six studies were from Africa and 6 were from Latin America/the Caribbean. Few studies were from Australia ($n = 3$), Canada ($n = 2$), or the Middle East ($n = 2$). The studies were also categorized according to country income level, as defined by The World Bank.[15] The majority of the studies were conducted in high-income countries ($n = 84$). Fewer studies were from upper-middle-income ($n = 10$), lower-middle-income ($n = 2$), and low-income ($n = 4$) countries.

The vaccine types studied in each geographic region are provided in Table 2. Many of the studies from North America and Europe measured the coverage of M/M/R-containing ($n = 19$), D/T/P/Polio/Hib/Hep B-containing ($n = 27$), meningococcal ($n = 23$), pneumococcal ($n = 39$), influenza ($n = 41$), and HPV ($n = 19$) vaccines. Fewer studies measured the coverage of the varicella vaccine ($n = 17$). Only two studies measured the coverage of the rotavirus vaccine, one in North America and one in Europe. BCG vaccine coverage was not studied in North America but was included in three studies from Europe. The three studies from Oceania (all from Australia) presented estimates for coverage of M/M/R-containing ($n = 1$), varicella ($n = 3$), D/T/P/Polio/Hib/Hep B-containing ($n = 1$), influenza ($n = 1$), and pneumococcal ($n = 1$) vaccines.

Table 2. Vaccine types and geographic regions.[a]

Vaccine type	Geographic region					
	North America	Europe	Oceania	Latin American and the Caribbean	Africa	Middle East
M/M/R-containing[b]	n = 8	n = 11	n = 1	n = 4	n = 3	n = 2
Varicella	n = 8	n = 9	n = 3	n = 2	n = 0	n = 0
D/T/P/Polio/Hib/Hep B-containing[c]	n = 14	n = 13	n = 1	n = 2	n = 4	n = 2
Meningococcal	n = 12	n = 11	n = 0	n = 1	n = 1	n = 0
Pneumococcal	n = 22	n = 17	n = 1	n = 3	n = 3	n = 0
Rotavirus	n = 1	n = 1	n = 0	n = 0	n = 0	n = 0
Influenza	n = 17	n = 24	n = 1	n = 1	n = 1	n = 0
HPV[d]	n = 12	n = 7	n = 0	n = 0	n = 0	n = 0
BCG[e]	n = 0	n = 3	n = 0	n = 2	n = 3	n = 2
Hepatitis A	n = 7	n = 3	n = 0	n = 1	n = 0	n = 0
Typhoid fever	n = 0	n = 0	n = 0	n = 0	n = 1	n = 0
Yellow fever	n = 0	n = 0	n = 0	n = 0	n = 1	n = 0

[a]The darker colored cells indicate areas that were more commonly studied.
[b]Measles- and/or mumps- and/or rubella-containing.
[c]Diphtheria- and/or tetanus- and/or pertussis- and/or poliomyelitis- and/or *Haemophilus influenzae type B-* and/or hepatitis B-containing.
[d]Human papillomavirus.
[e]Bacillus Calmette–Guérin.

Table 3. Vaccine types and study designs.[a]

Vaccine type	Study design					
	Retrospective cohort	Prospective cohort: interventional	Prospective cohort: observational	Cross-sectional	Case-control	Randomized controlled trial
M/M/R- containing[b]	n = 7	n = 2	n = 2	n = 17	n = 1	n = 0
Varicella	n = 5	n = 2	n = 1	n = 14	n = 1	n = 0
D/T/P/Polio/Hib/Hep B-containing[c]	n = 10	n = 1	n = 3	n = 21	n = 1	n = 0
Meningococcal	n = 7	n = 1	n = 1	n = 13	n = 2	n = 1
Pneumococcal	n = 14	n = 5	n = 3	n = 21	n = 3	n = 0
Rotavirus	n = 2	n = 0	n = 0	n = 0	n = 0	n = 0
Influenza	n = 6	n = 12	n = 4	n = 21	n = 1	n = 1
HPV[d]	n = 5	n = 1	n = 0	n = 12	n = 1	n = 0
BCG[e]	n = 2	n = 0	n = 2	n = 6	n = 0	n = 0
Hepatitis A	n = 4	n = 2	n = 0	n = 4	n = 1	n = 0
Typhoid fever	n = 1	n = 0	n = 0	n = 0	n = 0	n = 0
Yellow fever	n = 1	n = 0	n = 0	n = 0	n = 0	n = 0

[a]The darker colored cells indicate areas that were more commonly studied.
[b]Measles- and/or mumps- and/or rubella-containing.
[c]Diphtheria- and/or tetanus- and/or pertussis- and/or poliomyelitis- and/or *Haemophilus influenzae type B-* and/or hepatitis B-containing.
[d]Human papillomavirus.
[e]Bacillus Calmette–Guérin.

Table 4. Vaccine types and data sources.[a]

Vaccine type	Data Source								
	Medical record/chart	Electronic medical record	Database/ registry	Caregiver/patient questionnaire	Hospital unit questionnaire	Caregiver interview	Physician-obtained	Mixed	Unspecified
M/M/R-containing[b]	n = 14	n = 2	n = 0	n = 3	n = 0	n = 0	n = 0	n = 7	n = 3
Varicella	n = 11	n = 2	n = 0	n = 1	n = 0	n = 0	n = 0	n = 7	n = 2
D/T/P/Polio/Hib/Hep B-containing[c]	n = 12	n = 3	n = 1	n = 3	n = 0	n = 1	n = 1	n = 11	n = 3
Meningococcal	n = 8	n = 3	n = 1	n = 2	n = 0	n = 0	n = 1	n = 7	n = 2
Pneumococcal	n = 17	n = 3	n = 3	n = 5	n = 1	n = 0	n = 2	n = 13	n = 3
Rotavirus	n = 0	n = 0	n = 0	n = 1	n = 0	n = 0	n = 0	n = 0	n = 1
Influenza	n = 5	n = 4	n = 4	n = 9	n = 1	n = 0	n = 1	n = 13	n = 6
HPV[d]	n = 3	n = 2	n = 1	n = 7	n = 0	n = 0	n = 0	n = 5	n = 1
BCG[e]	n = 2	n = 1	n = 0	n = 2	n = 0	n = 1	n = 0	n = 3	n = 1
Hepatitis A	n = 3	n = 2	n = 0	n = 0	n = 0	n = 0	n = 1	n = 4	n = 1
Typhoid fever	n = 1	n = 0	n = 0	n = 0	n = 0	n = 0	n = 0	n = 0	n = 0
Yellow fever	n = 1	n = 0	n = 0	n = 0	n = 0	n = 0	n = 0	n = 0	n = 0

[a]The darker colored cells indicate areas that were more commonly studied.
[b]Measles- and/or mumps- and/or rubella-containing.
[c]Diphtheria- and/or tetanus- and/or pertussis- and/or poliomyelitis- and/or *Haemophilus influenzae type B-* and/or hepatitis B-containing.
[d]Human papillomavirus.
[e]Bacillus Calmette–Guérin.

Table 5. Vaccine types and sample sizes.[a]

Vaccine type	Sample size					
	<25	25–50	51–100	101–200	>200	Not stated
M/M/R-containing[b]	n = 3	n = 8	n = 9	n = 2	n = 7	n = 0
Varicella	n = 2	n = 6	n = 9	n = 1	n = 5	n = 0
D/T/P/Polio/Hib/Hep B—containing[c]	n = 2	n = 8	n = 10	n = 5	n = 9	n = 1
Meningococcal	n = 2	n = 6	n = 6	n = 2	n = 7	n = 1
Pneumococcal	n = 5	n = 8	n = 11	n = 11	n = 9	n = 1
Rotavirus	n = 0	n = 1	n = 0	n = 0	n = 1	n = 0
Influenza	n = 4	n = 6	n = 11	n = 8	n = 12	n = 3
HPV[d]	n = 2	n = 3	n = 3	n = 2	n = 8	n = 1
BCG[e]	n = 0	n = 3	n = 3	n = 1	n = 3	n = 0
Hepatitis A	n = 2	n = 1	n = 5	n = 0	n = 2	n = 1
Typhoid fever	n = 0	n = 0	n = 1	n = 0	n = 0	n = 0
Yellow fever	n = 0	n = 0	n = 1	n = 0	n = 0	n = 0

[a]The darker colored cells indicate areas that were more commonly studied.
[b]Measles- and/or mumps- and/or rubella-containing.
[c]Diphtheria- and/or tetanus- and/or pertussis- and/or poliomyelitis- and/or *Haemophilus influenzae type B*- and/or hepatitis B-containing.
[d]Human papillomavirus.
[e]Bacillus Calmette–Guérin.

As with high-income countries, the vaccines most commonly studied in upper-middle, lower-middle, and low-income countries included M/M/R-containing (n = 9), D/T/P/Polio/Hib/Hep B-containing (n = 8), and pneumococcal (n = 6) vaccines. The BCG vaccine was more commonly studied in these countries (n = 7); typhoid fever (n = 1) and yellow fever (n = 1) vaccines were only studied in Africa. The HPV and rotavirus vaccines were not studied in these regions at all.

Vaccine coverage by immunocompromising condition

The included studies reported on a variety of immunocompromising conditions, including cancer/stem cell transplant, solid organ transplant, sickle cell disease, HIV, immunosuppressive therapy, splenectomy, primary immunodeficiency, and unspecified immunosuppression (disease/treatment not specified). The types of vaccines studied for each condition are summarized in Table 6. Vaccine coverage estimates for each condition are provided in Table 7; although some studies reported either/both vaccine initiation (≥1 dose) and vaccine series completion, and/or pre- and post-intervention coverage, only series completion and pre-intervention results are included in the table.

Cancer/stem cell transplant

Twenty-four articles (including six abstracts) reporting on vaccine coverage among children with cancer or stem cell recipients were retrieved. Study publication dates ranged from 2006 to 2020. Target populations included children who had completed treatment (n = 15) and those undergoing treatment (n = 6), with only one study reporting on pre-treatment vaccine coverage. One study did not specify the timepoint of coverage measurement. Most of the studies were completed in high-income countries (n = 23), including the USA (n = 14), Italy (n = 2), Australia (n = 2), Greece, Canada, Spain, the UK, and Germany (n = 1 per country). The remaining study was completed in Brazil (upper-middle-income country). No studies were completed in lower-middle or low-income countries.

The studies reported on influenza (n = 11), HPV (n = 9), M/M/R-containing (n = 5), varicella (n = 5), D/T/P/Polio/Hib/ HepB-containing (n = 5), pneumococcal (n = 2), meningococcal (n = 2), and hepatitis A (n = 2) vaccine coverage. Eight studies reported on more than one vaccine type. For commonly studied vaccines, reported coverage estimates ranged broadly. For influenza, vaccine coverage estimates ranged from 3.4% to 87.1%; HPV coverage estimates ranged from 0%-27.3%, M/M/R-containing estimates ranged from 2.1%-90.9%. Coverage for all other vaccines studied was below 55%.

Solid Organ Transplant

Twenty-three studies (including nine abstracts) conducted among solid organ transplant recipients met the eligibility criteria. Studies were mainly published between 2007 and 2019, with one study from 1994. Studies most commonly reported pre-transplant vaccine status (n = 15), with four reporting post-transplant coverage, and three not specifying timepoint. A total of ten studies focused on liver transplant patients, six on kidney transplant and the remaining on multiple transplant types. Studies were conducted in the USA (n = 12), Iran (n = 2), Austria, Italy, the UK, Greece, Switzerland, Israel and Brazil (n = 1 per country). One study was conducted across four European countries (Germany, Italy, Turkey, and the UK).

Studies reported on pneumococcal (n = 14), D/T/P/Polio/ Hib/Hep B-containing (n = 13), M/M/R-containing (n = 13), varicella (n = 12), influenza (n = 8), meningococcal (n = 7), hepatitis A (n = 6), HPV (n = 5), and BCG (n = 5) vaccines. For pre-transplant candidates, the reported coverage range for studied vaccines was >70%, except for HPV (reported coverage 27.3–90%) and BCG (reported coverage 97–100%).

Sickle Cell Disease

Twenty-one studies (including four abstracts) reported on vaccine coverage among children with sickle cell disease. Study publication dates ranged from 2008 to 2020, though most were published after 2015. The majority of studies were completed in high or upper-middle-income countries (n = 18), with two in low-income countries, and one mixed. Studies were completed in the USA (n = 11), Italy (n = 2), France, Brazil, Jamaica, the UK, Spain, Uganda, Burkina Faso (n = 1 for

Table 6. Immunocompromising conditions and vaccine Types.[a]

Immunocompromising condition	Vaccine type											
	M/M/R- containing[b]	Varicella	D/T/P/Polio/Hib/Hep B-containing[c]	Meningococcal	Pneumococcal	Rotavirus	Influenza	HPV[d]	BCG[e]	Hepatitis A	Typhoid fever	Yellow fever
Cancer/Stem Cell Transplant	n = 5	n = 5	n = 5	n = 2	n = 2	n = 0	n = 11	n = 9	n = 0	n = 2	n = 0	n = 0
Solid Organ Transplant	n = 13	n = 12	n = 13	n = 7	n = 14	n = 1	n = 8	n = 5	n = 5	n = 6	n = 0	n = 0
Sickle Cell Disease	n = 2	n = 1	n = 5	n = 7	n = 16	n = 0	n = 10	n = 0	n = 1	n = 3	n = 1	n = 1
HIV	n = 5	n = 1	n = 7	n = 2	n = 2	n = 0	n = 6	n = 2	n = 4	n = 0	n = 0	n = 0
Other Immunosuppressive Therapy	n = 3	n = 3	n = 3	n = 4	n = 7	n = 1	n = 9	n = 3	n = 0	n = 0	n = 0	n = 0
Splenectomy	n = 0	n = 0	n = 3	n = 3	n = 4	n = 0	n = 1	n = 0	n = 0	n = 0	n = 0	n = 0
Primary Immunodeficiency	n = 1	n = 1	n = 0	n = 0	n = 1	n = 0	n = 1	n = 0	n = 0	n = 0	n = 0	n = 0
Unspecified	n = 0	n = 0	n = 0	n = 0	n = 0	n = 0	n = 3	n = 0	n = 0	n = 0	n = 0	n = 0

[a] The darker colored cells indicate areas that were more commonly studied.
[b] Measles- and/or mumps- and/or rubella-containing.
[c] Diphtheria- and/or tetanus- and/or pertussis- and/or poliomyelitis- and/or Haemophilus influenzae type B- and/or hepatitis - containing.
[d] Human papillomavirus..
[e] Bacillus Calmette–Guérin.

each). One study reported on participants in both the USA and Nigeria.

Studies reported on a wide range of vaccines, including pneumococcal ($n = 16$), influenza ($n = 10$), meningococcal ($n = 7$), D/T/P/Polio/Hib/HepB-containing ($n = 5$), hepatitis A ($n = 3$), M/M/R-containing ($n = 2$), varicella ($n = 1$), BCG ($n = 1$), typhoid fever ($n = 1$), and yellow fever ($n = 1$). The majority of studies ($n = 13$) reported on coverage for more than one type of vaccine. Reported pneumococcal vaccine coverage ranged from 0% to 97.5%; influenza and meningococcal coverage ranged from 0% to 90% and 25% to 90.2%, respectively.

HIV

A total of 12 studies (including three abstracts) that met the inclusion criteria reported on vaccine coverage among children with HIV. Studies were mainly published between 2006 and 2018, with one study published in 2000. Seven studies were from high-income countries (Italy [$n = 4$], UK [$n = 2$], USA [$n = 1$]), two from upper-middle-income (mixed from Brazil, Mexico, Argentina, Peru, Jamaica [$n = 2$]), and three from low-income countries (Niger [$n = 1$], Zambia [$n = 1$], and Malawi [$n = 1$]).

Studies reported on vaccine coverage for D/T/P/Polio/Hib/HepB-containing ($n = 7$), influenza ($n = 6$), M/M/R-containing ($n = 5$), BCG ($n = 4$), meningococcal ($n = 2$), pneumococcal ($n = 2$), HPV ($n = 2$), and varicella ($n = 1$). Most of the studies ($n = 9$) reported on more than one vaccine. As with the other conditions, coverage estimates for the commonly studied vaccines ranged broadly. Reported vaccine coverage for D/T/P/Polio/Hib/HepB-containing ranged from 7.0% to 97.9%, influenza from 10% to 82%.

Immunosuppressive therapy

Fourteen studies (half of which were abstracts) described vaccine coverage in children undergoing immunosuppressive therapy. Studies were published between 2010 and 2020. Target populations included patients with inflammatory bowel disease ($n = 7$), juvenile idiopathic arthritis ($n = 2$), rheumatic disease ($n = 2$), autoimmune hepatitis ($n = 1$), chronic renal disease ($n = 1$), systemic lupus erythematosus ($n = 1$), or general use of immunosuppressive therapy ($n = 2$). All studies were completed in high- or upper-middle-income countries: USA ($n = 5$), Poland ($n = 2$), Canada, Australia, Germany, Greece, Portugal, Switzerland (n = 1 for each) and one study conducted across eight European countries.

Vaccine coverage for influenza ($n = 9$), pneumococcal ($n = 7$), meningococcal ($n = 4$), varicella ($n = 3$), D/T/P/Polio/Hib/HepB-containing ($n = 3$), HPV ($n = 3$), and M/M/R-containing ($n = 3$) vaccines were reported, with seven studies reporting on more than one vaccine type. Reported influenza vaccine coverage ranged from 1.7% to 84.3%, while coverage reported for pneumococcal and meningococcal vaccines was less than 45% in all included studies.

Splenectomy

A total of four studies examining vaccine coverage in children with splenectomy met the inclusion criteria, published between 1998 and 2019. Three studies addressed vaccine coverage post-splenectomy, while one presented coverage among children

Table 7. Complete vaccine coverage, by immunocompromising condition.[a]

Complete vaccine coverage by immunocompromising condition and vaccine type, %(n)

Study	As per guideline[b]	M/M/R- containing[c]	Varicella	D/T/P/Polio/Hib/Hep B-containing[d]	Meningococcal	Pneumococcal	Rotavirus	Influenza	HPV[e]	BCG[f]	Hepatitis A
Cancer/Stem Cell Transplant											
Pretreatment	81.3 (48)[50]	93.2 (55)[50]	64.4 (38)[50]	96.6 (57)[50]							
Undergoing/ posttreatment	6 (14),[55] 9.8 (5),[44] 9 (9),[56] 30–40,[9,57] 44.9 (40),[58] 47.5 (28),[50] 88 (30)[59]	2.1 (5),[55] 35.3 (18),[44] 40 (36),[58] 81.1–90.9 (18–20)[60]	2.5 (6),[55] 13 (6),[61] 15 (13),[58] 21.4 (11)[44]	0–0.4 (0–1),[55] 12–54 (11–48),[58] 21.6– 54.9 (11–28)[44]	1.3 (3),[55] 39 (35),[58] 47.5 (24)[44]	1.7–5.5 (4–13),[55] 17.6–21.6 (9–11)[44]		3.4 (8),[55] 20.5 (42),[9,51] 25.8 (36),[62] 39.2 (20),[44] 40 ,[9,63] 54.8 (263),[9,64] 66.1–70.3 (184–267),[9,53] 74.9 (140),[9,65] 87.1 (122)[41]	0 (0),[55] 12.6–25.5 (30–66),[66] 13.5 (133),[67] 18.3 (42),[68] 20.9 (72),[69] 27.3 (14)[44]	0 (0),[44] 2.5 (6)[55]	
Unspecified time point								6.3–33.3 (1–6)[p45]			
Solid Organ Transplant											
Pre-transplant	8.7 (14),[70] 27.6 (24),[71] 29 (5),[72] 32 (13),[73] 33 (6),[74] 47 (14),[54] 80,[9,h46] 86.4 (57)[75]	28–36 ,[l76] 44 (11),[9,l77] 55.5 (50),[l78] 57.4 (54),[l79] 58 (58),[l80] 60 (18),[l54] 71.7–93.5 (33–43),[l81] 75 (31),[l73] 75 ,[k,l71] 82.1–84.9 (206–213),[l70] 89,[l82] 100 [g,h46]	0 (0),[9,77] 17.9–36.3 ,[l76] 10.8 (5),[81] 20 (6),[54] 37.2 (35),[79] 58 (24),[l73] 58.9 (119),[70] 62 ,[k,71] 88,[82] 100 [g,h46]	14–43 (6–19),[l77] 15–84 ,[l76] 50–84,[82] 57.2–87.8 (52–59),[78] 58–85 (68–85),[80] 63.0–97.8 (29–45),[81] 70–75 ,[k,71] 70.5–88.6 (177–202),[70] 73–100,[g,h46] 71–89 (29–36),[l73] 92 (59),[83] 100 (30)[54]	0 ,[l76] 11 (5),[l73] 33 (10),[l54] 47.9 (81),[70] 75–100,[g,h46] 94[51]	0 (0),[9,77] 0–6 ,[l76] 0–100,[g,h46] 10.8 (5),[81] 30–44 ,[k,71] 39 (16),[l73] 42.0 (73),[70] 63[51], 73 (22),[54] 84 (54)[83]	50 (21)[l73]	23 (7),[54] 72 (46),[83] 100 [9,h46]	27.3 (9),[70] 65 ,[k,71] 90[82]	97 (97),[80] 97.8 (88),[78] 100 (46),[81] 100 (13)[70]	8 (2),[77] 42 (17),[l73] 54 ,[k71] 50–100,[9,h46] 68,[82] 91 (29)[83]
Post-transplant	76.0–100 (35–46)[81]		10.8 (5)[81]	50.0–97.8 (23–45)[l81]		10.8 (5),[81] 15 (9),[l42] 44 (40),[84] 25 (9)[m86]		57.1 (8),[85] 67 (125),[43] 77 (45)[l42]		100 (46)[81]	
Unspecified/ Combined time point	80 (27)[m86]	80 (27)[m86]	100 [m86]	45–71 (15–24)[m86]	82 (28)[m86]			33.3 (5),[87] 35.3 (77),[88] 55– 59 (6–13)[m86]	12.5[m86]	80 (27)[m86]	
Sickle Cell Disease	19.5 (16),[89] 46.2 (48),[55] 69.8 (44),[90] 85 (17)[91]	20–100 ,[9,l92] 92.3 (96)[52]	49 (27)[l90]	37–100 ,[9,92] 56 (14),[93] 84.6–91.3 (88–95)[52]	25–77,[9,94] 47.5 (29) ,[k,90] 56 (14),[93] 56 ,[9,92] 59 (115),[47] 60 (19),[95] 86.8–90.2[96]	0 (0),[97] 0–23 ,[9,92] 8–48 (5–30) ,[k,90] 25,[g98] 40–73,[48] 44.7–72.5,[47] 47.4 (768),[9,99] 52.7– 64.3,[9100] 54.8 (57),[52] 53–60,[9,94] 56 (14),[93] 80,[g101] 73.3–96.8 (23–30),[95] 85 (17),[91] 88 (23),[97] 91.0–94.8 (286–271),[102] 97.5[103]		0 (0),[97] 8 (2),[93] 17 (11),[k,90] 26,[9101] 45 ,[9,104] 50 (10),[91] 52 (56),[9,94] 60,[103] 63.7 (205),[105] 90 (26)[97]		100 [92]	15 (3),[91] 25 (16)[l90]
HIV											

(Continued)

Table 7. (Continued).

Study	Complete vaccine coverage by immunocompromising condition and vaccine type, %(n)										
	As per guideline[b]	M/M/R- containing[c]	Varicella	D/T/P/Polio/Hib/Hep B-containing[d]	Meningococcal	Pneumococcal	Rotavirus	Influenza	HPV[e]	BCG[f]	Hepatitis A
	38 (12),[106] 68 (61)[107]	32 (6),[108] 67.0 (32);[109] 68.1 (258);[110] 70.1 (96);[111] 87.1 (165)[112]	15[k][108]	7.0 (8),[109] 26.9–42.9[o],[49] 43.5– 74.5;[110] 55.5– 80.3 (76–110);[111] 68 (21);[106] 74 (14);[108] 91.4–97.9 (174–186)[112]	30.2–38.6[o],[49] 68 (13)[108]	25 (10);[k42] 50[k108]		10–40,[p45] 48 (15);[106] 69.4 (25);[113] 72 (29);[k42] 82 (28)[114]	40;[k108] 56(17)[106]	52 (16);[106] ; 70.4 (273);[110] 100 (190);[112] 100 (257)[109]	
Immunosuppressive Therapy for a Chronic Condition											
	10.4 (25),[115] 18 (9);[116] 49 (26);[117] 98 (118)[118]	86 (43);[116] 89.3 (384);[119] 92 (300)[120]	18.4 (79),[119] 31–66,[o116] 74 (87)[120]	67–86,[o116] 81.9–99.3 (352– 427);[119] 89 (290)[120]	9.4 (5);[117] 13–76;[o116] 23.5 (101)[119]	0–20.9,[121] 3.7–94.3 (4–100);[122] 7.0 (11),[g123] 7.8 (38);[124] 18.6 (80);[119] 26.4 (14);[117] 30 (36);[118] 42 (21)[116]	1.9 (8)[119]	1.7 (1),[117] 7.8 (38);[124] 26.7 (4);[85] 46 (41);[87] 57.1 (8);[85] 62.9 (202);[88] 74 (89);[118] 78–80,[g125] 84.3 (130)[123]	5.9 (22)[119]		
Splenectomy				37.5 (3)[g,126] 41 (37)[127]	31.3 (5)[g,126] 51 (46)[127]	44.4 (8)[g,126]; 72 (65);[127] 100 (4)[128]		18.8 (3)[lg 01]			
Primary Immunodeficiency	77–82[o129]		66[o129]			31–40[o129]		10–36.4[p45]			
Unspecified Immunocompromising Condition								3.9 (2,115);[130] 45.5– 48.1[p,131] 61.3 (434, 377)[132]			

[a]Reported coverage for additional vaccines studied for sickle cell disease: typhoid fever, 26%;[91] yellow fever, 100%.[91] See supplemental material for more detail.

[b]Reported up-to-date as per referenced guidelines or infectious disease physician recommendations.

[c]Measles- and/or mumps- and/or rubella-containing; for studies that considered components of the vaccine separately, coverage is presented as a range.

[d]Diphtheria- and/or tetanus- and/or pertussis- and/or poliomyelitis- and/or Haemophilus influenzae type B- and/or hepatitis B-containing; for studies that considered components of the vaccine separately, coverage is presented as a range.

[e]Human papillomavirus.

[f]Bacillus Calmette–Guérin.

[g]Vaccination coverage from study's pre-intervention phase or intervention control group.

[h]Vaccine coverage reported as interquartile range.

[i]Hib coverage not included as only 1 child in study was eligible due to changing guidelines.

[j]Reports coverage at time of evaluation and at time of transplant. Evaluation coverage reported here.

[k]Coverage numbers for individual vaccines estimated from figure.

[l]Gives coverage for different age at transplant, provided as range here.

[m]Booster coverage.

[n]Overall coverage reported here; authors also provide estimates by age range.

[o]Reported coverage as per age, unknown n.

[p]Range represents vaccine coverage reporting on a range of years.

with idiopathic thrombocytopenia purpura (pre-splenectomy). Studies were completed in high-income countries, including the USA ($n = 2$), Switzerland ($n = 1$), and the Netherlands ($n = 1$).

All four studies examined vaccine coverage for pneumococcal vaccines, three also reported on D/T/P/Polio/Hib/HepB-containing and meningococcal vaccine coverage, and one additionally included influenza vaccine coverage. Pneumococcal vaccine coverage ranged from 44.4% to 100% in the included studies. Coverage for all other vaccines fell below 51%.

Primary Immunodeficiency

Only two studies examining vaccine coverage among children with primary immunodeficiency were retrieved, published in 2006 and 2019. Both were conducted in high-income countries (Australia and Italy). One study included a number of vaccines (M/M/R-containing, varicella, and pneumococcal vaccines), while the other focused on influenza vaccine coverage. Other than the M/M/R-containing vaccine (reported range 77–82%), all vaccine coverage levels were below 66%.

Unspecified

Three studies reported on vaccine coverage among children with unspecified immunosuppression, two were published in 2012 and one in 2016. Two studies were completed in the UK and one in the USA. All three studies focused exclusively on influenza vaccine coverage, with reported estimates ranging from 3.9% to 61.3%.

Discussion

We identified 97 studies that measured vaccine coverage in immunocompromised populations of children, 30 of which were abstracts. There was variability in the characteristics of the studies, such as the vaccine type, geographic location, immunocompromising condition, and vaccination data source.

The vaccine types studied varied by geographic region, with most studies occurring in high-income countries in North America and Europe. Variations in vaccine coverage considerations between these regions are likely related to differing vaccination priorities and schedules. For example, BCG vaccine coverage was not studied in North America, but was measured in areas in Europe in which there is a higher risk of tuberculosis and BCG is routinely recommended.[16] Although some studies reported on M/M/R-containing vaccine coverage, this should remain a focus for future studies, as measles is a reemerging concern in high-income countries.[17] The limited number of studies from Australia is surprising given the volume of research coming out of Australia related to vaccine coverage and determinants of uptake.[18] Therefore, clinicians and vaccine program administrators in Australia lack local evidence regarding which vaccines may have inadequate vaccine coverage in their immunocompromised populations. Given the difference in vaccine schedules and policies, additional country-specific coverage analysis is important.

Vaccines studied in lower-middle and low-income countries included typhoid fever, yellow fever, and BCG. These likely differed from those studied in North American and European countries due to the risk associated with these diseases in these geographic locations.[19–24] The HPV vaccine and rotavirus vaccines were not studied at all, which may be attributed to a lack of resources deeming this vaccine a lower priority for a resource-limited country. Future research on these two vaccines is important, given the high burden of HPV-associated cancers[25] and diarrhea-related morbidity and death[26,27] in low-resource settings.

Some vaccine types were studied extensively in certain immunocompromised populations, while others were studied minimally or not at all. Coverage for pneumococcal and influenza vaccines were the most commonly studied; these vaccine types were addressed for all studied conditions, with the exception of the unspecified immunosuppression group. The seasonal inactivated influenza vaccine is recommended for all immunocompromised populations, according to both Canadian and American immunization advisory committees.[4,28,29] Future research should expand focus on vaccines other than influenza and pneumococcal vaccines in order to provide broader understanding of vaccine coverage in these populations. Specific recommendations for each immunocompromised group are provided below.

Influenza vaccines were commonly studied in children with cancer and stem cell transplant recipients. People receiving cancer treatment are identified as a population at high-risk for influenza-related complications and hospitalization.[30] Additionally, a number of studies also included HPV vaccine in these populations. The HPV vaccine is especially important for childhood cancer survivors, as they have a higher risk than the general population for health complications, such as subsequent malignancies caused by HPV.[31,32] However, certain vaccines have not been as extensively studied in this population, such as meningococcal and pneumococcal vaccines. Future research should focus on determining if children with cancer and/or stem cell transplants are being adequately vaccinated to protect them from these diseases.

Among solid organ transplant recipients, pneumococcal, D/T/P/Polio/Hib/HepB-containing, M/M/R-containing and varicella vaccines were commonly studied. As live vaccines are generally contraindicated after solid organ transplant, it is critical to optimize vaccination with live vaccines prior to transplant.[4,33] Accordingly, most of the studies retrieved focused on pre-transplant vaccination status. While the use of live vaccines is generally not recommended after solid organ transplant, ongoing vaccination with inactivated vaccines can be given once a child is on baseline immunosuppression, which is usually about 6 months after transplant.[4,6] With this in consideration, it is important to evaluate whether these children are adequately vaccinated according to recommended schedules both before and after transplantation. As guidelines on the use of live vaccines post-transplant continue to evolve,[34] it will be important to continue monitoring live vaccine coverage in these patients.

Children with sickle cell disease and those who have had a splenectomy are at increased risk of developing certain infections with encapsulated bacteria, such pneumococcus, meningococcus, and *Haemophilus influenzae* type B.[35,36] Vaccination against these organisms is particularly important due to the higher risk of severe sepsis, meningitis, and pneumonia when

infected with these organisms.[29,37] Accordingly, coverage studies in these populations focused on these vaccines.

Pneumococcal vaccines were commonly studied in children with sickle cell disease. As pneumonia is a leading cause of death in infants and children with sickle cell disease,[36] studies of pneumococcal vaccines are particularly important in this population.[29,38] However, there appears to be a lack of research in the vaccine coverage of M/M/R-containing, varicella, rotavirus, and HPV vaccines in children with sickle cell disease, so future research may be focused on these particular vaccines.

Studies from North America suggest that annual vaccination with the inactivated influenza vaccine is recommended among children who have received a splenectomy, to prevent severe and complicated influenza infection, as well as to reduce the risk of severe secondary bacterial infection.[6,38] Despite this high importance, we identified only one study measuring influenza vaccine coverage in this population. Therefore, this is an area in which future research is warranted.

The vaccines that were studied in children with HIV varied. D/T/P/Polio/Hib/Hep B-containing and influenza vaccines were most common. This may be because immunization guidelines for individuals with HIV vary depending on the course of the illness and degree of immunosuppression. There is also variability in the vaccines studied in low- versus high-income countries, which reflect the vaccines routinely provided in those settings. Inactivated vaccines can be administered at any time, although are ideally administered at a time of low immune suppression when response will be improved. Routinely used live vaccines, such as M/M/R; varicella; and rotavirus, can be administered early in the disease course or after immune recovery with treatment.[4,29] Other live vaccines, such as BCG, typhoid fever, and live influenza vaccines are not necessarily recommended.[4,29] Thus, it is understandable why typhoid fever and yellow fever vaccines coverage were not studied, whereas it might be important for future research to focus on vaccine coverage for rotavirus vaccine.

For other populations that were on immunosuppressive therapy, influenza and pneumococcal vaccines were commonly studied. These vaccines are routinely recommended to individuals with chronic conditions who are on immunosuppressive therapy.[4,6,28] If possible, individuals should be vaccinated before commencing immunosuppressive therapy. Fortunately, chronic conditions such as inflammatory bowel disease are less common in children under 2 y of age, so often the majority of live vaccines will have been completed prior to the onset of disease and immunosuppressive therapy.[39] Once receiving immunosuppressive therapy, live vaccines are generally contraindicated.[4,29] Aside from influenza and pneumococcal vaccines, all other commonly recommended vaccines were less frequently studied in this population, so these vaccines may be considered in further research.

Primary immunodeficiencies encompass a large variety of conditions, which include inherited disorders that result in defects in antibody production, complement deficiencies, or other aspects of cell-mediated immunity.[4,29] For these individuals, other methods of protection against infection may be utilized, such as with replacement immune globulin or pathogen-specific immune globulin preparations. However, vaccination is still recommended whenever possible.[4,6] While all inactivated vaccines should

be given, specialist consultation is usually required to determine if or when administration of live vaccines is recommended.[4,6,8] As few vaccine types were studied in this population, this is clearly an area where more vaccine coverage research is needed to determine if these vulnerable children are being optimally protected against vaccine-preventable diseases.

Included studies were evaluated for quality using the MMAT. This review included both published and unpublished literature, as well as conference abstracts, in order to identify publication bias resulting from exclusion of unpublished works. This likely resulted in overall lower quality scores than may have been realized with only peer-reviewed articles. As many of the studies received a low-quality score, there is room for high-quality research to be conducted on this topic. To achieve a higher quality score, studies need to provide a more detailed description of the methods followed and gather vaccine coverage data from more accurate sources.

Variability in study design, data source, and sample size pose a challenge for drawing summary conclusions. Almost half the included studies used a cross-sectional design. Most intervention studies used a prospective cohort design; only one intervention study was designed as a randomized controlled trial, which is not surprising, given the ethical issues of using randomized controlled trials in this context. Vaccine coverage data sources ranged from more accurate sources, including charts, electronic medical records, and vaccination databases or registries, to less accurate sources, such parent/guardian self-report through questionnaires or interviews.[40] Parent recall typically overestimates vaccine coverage, erroneously identifying children as up-to-date.[40] The majority of studies had small sample sizes. The exception was influenza vaccine, in which most studies had larger samples. In order to provide evidence to vaccine program administrators and clinicians, more studies should be conducted using validated data sources and large sample sizes. The move toward use of administrative health data analysis will facilitate this, providing growing evidence to guide clinical practice in this area. While the results from each study may be useful for a particular setting and/or population, it was difficult to synthesize vaccine coverage results due to variations in methodologies and reporting.

An important area for future investigation is a review of barriers to vaccination in children with immunocompromising conditions and/or the effectiveness of interventions. Although these issues were not the focus of this review, a few barriers that were frequently stated by authors are noteworthy. These include concerns about the safety and effectiveness of vaccines and lack of information about the vaccines.[41–43] Strategies to help improve vaccination may include increased education[44–49] and development of vaccination policies specific to immunocompromised populations.[50–52] Health-care providers should also consistently incorporate the review of vaccine records into their practice.[46,52–54] Work should also be done to reduce barriers to vaccination, such as cost and accessibility.

Limitations

There were a few limitations to this review. Although we contacted authors of published abstracts to determine if a full-text publication was available, we did not contact authors when

limited information was available in the full-text study report. Another limitation was the exclusion of articles that were not published in the English language (*n* = 13). Only primary research was included and relevant websites were not searched for additional citations. However, the search included worldwide publications, unpublished literature, and did not limit literature by methodology or year of publication.

Conclusion

To our knowledge, this is the first scoping review to comprehensively review the body of literature on vaccine coverage of immunocompromised children. This topic has gained more interest in recent years, as evidenced by the increasing amount of research conducted beyond the early 2000s. It is expected that this trend will continue as more children are being treated with immunosuppressive therapies and children with immunocompromising conditions are living longer, more functional lives. We have identified several substantial knowledge gaps with respect to vaccine coverage in immunocompromised children that should be used to guide future research in this important area. One specific area in which research should be focused is a systematic or scoping review of barriers to vaccination among immunocompromised populations, as this could facilitate development of meaningful interventions to improve appropriate vaccine coverage among this vulnerable population. These findings are critical to inform public health policy and practice surrounding the vaccination of immunocompromised children.

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No potential conflicts of interest were disclosed.

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