Vaccine 41 (2023) 7226–7233

Contents lists available at ScienceDirect

Vaccine

journal homepage: www.elsevier.com/locate/vaccine

Childhood vaccination coverage and regional differences in Swiss birth cohorts 2012–2021: Are we on track?

Simeon J. Zürcher [a,*], Andri Signorell [a], Anja Léchot-Huser [b], Christoph Aebi [c,1], Carola A. Huber [a,d,1]

[a] Department of Health Sciences, Helsana Group, Zürich, Switzerland
[b] Pediatric Medical Center, Seeland Group, Biel, Switzerland
[c] Department of Pediatrics, Inselspital, Bern University Hospital, University of Bern, Switzerland
[d] Institute of Primary Care, University of Zurich, University Hospital Zurich, Switzerland

ARTICLE INFO

Keywords:
Child
Coverage
Geographical differences
Surveillance
Switzerland
Vaccination
Vaccination schedule
Vaccination timeliness

ABSTRACT

Aims: Many western countries are challenged by delayed and insufficient vaccination coverage rates in children, and thus missing WHO coverage targets. This study aimed to estimate vaccination coverage and timeliness in Swiss children over a decade. Furthermore, we evaluated the impact of COVID-19, regional variations, and the adherence to the amended vaccination schedule in 2019.

Methods: Retrospective observational study with Swiss health insurance claims data including birth cohorts 2012–2021 of children continuously observed until ages 13, 25, and 48 months respectively. We used population-weighted proportions and time-to-event analyses to describe coverage and timeliness of diphtheria/tetanus/pertussis/poliomyelitis/haemophilus influenzae type b (DTaP-IPV-Hib), measles/mumps/rubella (MMR), hepatitis B (HBV), pneumococcal (PCV), and meningococcal (MCV) vaccinations according to the national schedule. The potential impact of COVID-19 and vaccination schedule adherence were evaluated descriptively. Logistic regression was used to investigate regional factors potentially associated with non-vaccination.

Results: 120,073 children, representing between 12 and 17 % of all Swiss children born in corresponding years, were included. Coverage remained stable or improved over the years. The 2019 amendment of the national immunization schedule was associated with an increase of ~10 % points in full coverage in Swiss children for DTaP-IPV-Hib, MMR and HBV despite the concurrent COVID-19 pandemic. Nonetheless, full vaccination coverage remained below 90 % with many vaccination series being delayed or not completed. The comparison across the different vaccines revealed large differences in coverage. Moreover, we observed large regional differences in non-vaccination with children living in rural and German-speaking areas more likely to be entirely unvaccinated.

Conclusion: Full vaccination coverage in Swiss children is still below 90 % with many vaccinations administered delayed. Given regional differences, missed or delayed booster vaccinations, and differences in vaccine-specific acceptability, more effort may be needed to achieve national vaccination targets.

1. Introduction

While public health institutions strive to eliminate or control vaccine-preventable diseases (VPD), many western countries including Switzerland are challenged by insufficient and delayed vaccinations in paediatric populations [1,2]. In consequence, outbreaks of VPD still regularly occur potentially leading to hospitalizations, disability, fatal illnesses and death [3–5]. To prevent VPD in those most vulnerable and achieve an optimal population protection, vaccination schedules start shortly after birth. Low coverage and delays undermine the success of vaccination programmes [6,7]. Although, vaccines are known as one of the most significant public health interventions in the last century - shown to be safe, strongly effective in reducing morbidity and mortality, cost-effective and associated with numerous indirect benefits [5,8–10] -

* Corresponding author at: Department of Health Sciences, Helsana Group, PO Box, 8081 Zürich, Switzerland.
E-mail address: simeon.zuercher@helsana.ch (S.J. Zürcher).
[1] Christoph Aebi and Carola A. Huber contributed equally to this publication (shared last authorship).

https://doi.org/10.1016/j.vaccine.2023.10.043
Received 25 July 2023; Received in revised form 13 October 2023; Accepted 15 October 2023
Available online 27 October 2023

setbacks in vaccination programs are not uncommon. For instance, countries free of endemic measles have re-established transmissions and the eradication of poliomyelitis has still not been achieved [4,11]. In addition, interruptions of vaccine supply have become increasingly frequent in recent years as the worldwide demand challenges the manufacturers' production capacities [12]. Therefore, achieving and maintaining high levels of vaccine coverage remain a complex, multifaceted, and continuous challenge for vaccine stakeholders [2,7].

Globally, childhood vaccination coverage rates have plateaued at 86 % in 2019 for the third diphtheria, tetanus and pertussis vaccination – which is an important marker for vaccination coverage - with a considerable decline to 81 % in 2021 [13]. Missed vaccinations, lower coverage rates and an increase in vaccine scepticism associated with the COVID-19 pandemic raised some new concerns of health authorities [13–15]. However, even before the pandemic, many European Union member states experienced stagnations or even a decline in coverage in the period 2009–2017 [2]. In contrast, a few existing findings from Switzerland indicated coverage improvements in children over the last 20 years, however, with conflicting results regarding the coverage rates achieved [1,6,16–18]. For example, the Swiss National Vaccination Coverage Survey (SNVCS) - a cross-sectional study aimed at regularly monitoring coverage of children aged 2, 8, and 16 years within three-year periods at the cantonal and national level - finds substantially higher coverage rates than studies using a large database of health insurance claims data (2006–2016) [1,6,16]. SNVCS used either simple random sampling or two-stage cluster sampling of children at the cantonal level. Families of selected children are contacted by letter/mail and reminded by phone to submit a copy of the child's vaccination record. Post-stratification weighting (sex, nationality, and urbanisation) for each canton was used to account for different characteristic distributions in the study population [17,19].

In absence of central registries (as in Switzerland), vaccination surveillance can be difficult to perform, and estimation approaches vary by data sources. Thus, it is valuable to consider results from different sources. Health claims data are a suitable complement [20,21] to provide timely and reliable information, including information on temporal trends, adherence to vaccination schedules, and vaccination timeliness. Therefore, these data may add critical information that supports the progress of the vaccination program in Switzerland.

Following up on previous claims-based studies [1,6], we analysed vaccinations for children aged ≤4 years across birth cohorts 2012–2021. In this study we aimed, first to estimate the vaccination coverage in Switzerland, second to evaluate vaccination timeliness and third to describe potential regional variations. Furthermore, we focused on describing the adherence to amended vaccination schedules and to describe the potential impact of the COVID-19 pandemic.

2. Methods

2.1. Study design and data source

This is a retrospective observational study using mandatory health insurance claims from the Helsana Group covering all Swiss cantons and representing approximately 15 % of the Swiss population. All Swiss residents are obligated to be enrolled in a basic health insurance, which is provided by health insurers on private market, but regulated by federal authorities. The basic insurance is obliged to offer basic insurance to every resident of Switzerland and to cover necessary medical treatments including the vaccinations analysed in this study. Parents can choose different deductibles for their insurance (Helsana; 0 or 500 CHF), but most (>99 %) choose deductibles of 0 CHF for their children. This means that, except of a shared co-payment of 10 %, paediatric treatments are covered by the insurance. We used data from January 1, 2012 to March 31, 2023 of the entire paediatric collective ≤48 months of age meeting the eligibility criteria defined below. According to national vaccination schedule of the Swiss Federal Office of Public Health (FOPH) [22] all recommended basic and supplementary vaccines for this age group were included (Table 1).

In Switzerland, health care is organised at the cantonal level. Until the age of four, paediatricians and general practitioners in the outpatient setting are responsible for vaccine administration. Vaccinations are voluntary in Switzerland and therefore a personal decision. Depending on canton, children are mostly eligible for kindergarten at the age of four. In some cases, school medical examinations and vaccinations are provided already in the kindergarten, which may be not directly reimbursed by the health insurance. Therefore, Swiss health claims data may not appropriately cover vaccinations for children of age four or older. Because there is no central registry and electronic records are not available nationwide, vaccinations are usually documented by paper cards and surveillance data cannot be recorded directly. Vaccination data can be lacking or incomplete if the paper cards are lost or not brought to the doctor's visit.

2.2. Study population

All children insured with Helsana since birth, born between January 1, 2012 and December 31, 2021, and insured for at least 13 months were included. The observation period lasted from birth until the earliest of (a) the end of the insurance contract (change of health insurance, moving abroad, death), (b) the completion of the fourth year of life, or (c) March 31, 2023. We mainly analysed the 2012–2021 birth cohorts separately and further grouped individuals by their observation periods of 13, 25, and 48 months (e.g., to evaluate the number of administered vaccinations until the completion of a certain age of the birth cohort 2020). Accordingly, the individual observation time varied from at least 13 up to 48 months depending on birth cohort and observation time.

2.3. Swiss vaccination schedule

The Swiss vaccination schedule is reviewed regularly and published annually by the FOPH and the Federal Vaccination Commission (EKIF) [22]. The schedule distinguishes between recommended basic (essential for individual and public health) and recommended supplementary vaccinations (optimal individual protection). The vaccination schedule is in accordance with the preventive health examinations for children recommended by the Swiss Paediatric Society [23].

Relevant amendments were implemented in 2019 for children aged ≤24 months (Table 1 for an overview). The amendments concerned mainly a simplification from a "3 + 1" to a "2 + 1" scheme for the pentavalent/hexavalent vaccines, the earlier timing of measles-mumps-rubella (MMR), and the addition of further basic vaccinations. Basic vaccinations across the entire study period included diphtheria, tetanus, acellular pertussis, poliomyelitis, and haemophilus influenzae type b (DTaP-IPV-Hib), and MMR. Hepatitis B (HBV) was recommended with priority to individuals aged 11–15 year until 2018 and changed to infant vaccination (DTaP-IPV-Hib-HBV) in 2019. The added pneumococcal vaccine (PCV) changed to a basic vaccine in 2019. The meningococcal vaccine (MCV) remained a supplementary vaccine, but with further serogroups added (ACWY instead of C).

Special recommendations apply for certain risk groups such as premature infants (defined as low birth weight <1500 g or born <32 pregnancy week). We defined full vaccination coverage for single vaccines (e.g., DTaP-IPV-Hib) as receiving all scheduled doses according to the Swiss schedule at 25 months of age. Age-appropriate administration was defined as 30 days prior or after the recommended age [1].

2.4. Variables

Regional variables included the a) Swiss canton of origin, b) geographic region (urban, intermediate, rural), and c) language region (German, French, Italian) [24]. The influence of the COVID-19 pandemic was displayed as time period 2020–2021. We assumed that

Table 1
Swiss vaccination schedule including amendments from 2012 to 2021 for children aged ≤24 months.

Vaccination	Year	Scheduled months								
		2 mo.	3 mo.	4 mo.	6 mo.	9 mo.	12 mo.	12-15 mos.	15-24 mos.	24 mo.
Diphtheria, tetanus, pertussis, poliomyelitis, and haemophilus influenzae type b (DTaP-IPV-Hib)	2019-2021	B1	a	B2			B3			
	2012-2018	B1	a	B2	B3				B4	
Measles, mumps, rubella (MMR)	2019-2021[b]					B1	B2			
	2012-2018[c]						B1		B2	
Hepatitis B (HBV)	2019-2021	B1	a	B2			B3			
	2012-2018[d]	S1	a	S2	S3				S4	
Streptococcus pneumoniae (PCV)	2019-2021	B1	a	B2			B3			
	2012-2018	S1	a	S2			S3			
Meningococcus ACWY (MCV)	2019-2021									S1
Meningococcus C	2012-2018							S1		

Abbreviations: B1–B4, recommended basic vaccinations and dose number; S1–S3, recommended supplementary vaccinations and dose number.
[a]Indication-based additional vaccinations (e.g. premature birth).
[b]If indicated, the first dose can be administered earlier (e.g., measles outbreak). If the first dose is administered between 6 and 8 months, a total of 3 MMR vaccine doses are recommended.
[c]If indicated, the first dose can be administered between 6 and 9 months.
[d]Recommendation primarily for individuals aged between 11 and 15 years of age. However, administration also possible earlier.

an effect would be reflected in a change in coverage or timeliness for vaccine doses administered during the pandemic. For instance, vaccinations in the cohorts 2020/2021 and scheduled doses during the pandemic for the cohort 2019 (e.g., the third doses of DTaP-IPV-Hib, HBV, or PCV at 12 months of age).

2.5. Statistical analyses

We mainly focussed on the results at 25 months of age to allow for a comparison with other studies [2,25,26]. Therefore, study population characteristics were shown for the cohort observed at least 25 months. We calculated percentages (using the survey package in R [27]) with corresponding 95 % confidence intervals (95 % CI) to describe non-vaccination and vaccination coverage at 13, 25, and 48 months of age by birth cohort for each vaccination separately. Inverse Kaplan Meier curves were used to describe months until vaccination to determine adherence to the age-appropriate recommendations (vaccination timeliness) during the first 25 months of age. We considered a larger time window of 36 months for MCV, as administration of MCV ACWY (recommended from 2019) is licensed starting at 24 months of age. These analyses consisted of all subjects included and irrespective of whether they experienced the event "vaccination" or not (right censoring). To extrapolate our estimates to the Swiss population, analyses were weighted based on the demographic distribution of the analytical samples (individuals observed at least 13, 25 and 48 months) relative to the Swiss population. Children were weighted by year according to their sex and canton of residence at 12 months of age. The distribution of the Swiss population was provided by the Federal Statistical Office (residence statistics) [28]. Weighted and unweighted estimates were compared to detect differences. Regional variations in non-vaccination (defined as proportion entirely unvaccinated until 25 months of age) are shown descriptively. Multivariate logistic regression was used to assess associations between non-vaccination and sex, geographic region, and language region. Statistical analyses were conducted in R (version 4.2.1).

2.6. Ethical considerations

According to national regulations including the Human Research Act and Swiss federal Law on data protection (article 22) formal ethical approval was not required because the data were retrospective, pre-existing, and anonymous.

3. Results

3.1. Cohort characteristics

A total of 120,073 children over all birth cohorts were included (Table 2). The sample size of children observed at least 13 months varied from n = 10,051 to n = 15,026 by birth cohorts. This corresponds to approximately 12–17 percent of all Swiss children born in the corresponding years. The distribution of characteristics for those observed at least 25 months remained approximately the same across birth cohorts with an almost equal sex ratio and a majority with urban and German language region origin.

3.2. DTP-IPV-Hib

Coverage for the primary series with the pentavalent vaccine at 13 and 25 months, respectively, was high (>90 %) and relatively stable in all birth cohorts (irrespective of COVID-19), but with considerably lower coverage for the subsequent booster doses (Fig. 1A, Table S1A). In the 2018 birth cohort a large decrease of the fourth dose coverage resulted from the amended 2019 schedule (reduction from four to three doses). Full coverage with 3 doses (2 + 1 schedule, 2019–2021) was ~67 % and ~85 % at 13 and 25 months respectively (Table S1A). This left a substantial proportion of children incompletely protected after age 13 months. Full vaccination coverage increased by 14 % points (2017: 71 %; 2019: 85 %) at 25 months of age after the implementation of the amended 2019 vaccination schedule. Fig. 2A–D shows that most children were vaccinated on time, but with an increasing delay when comparing priming with booster doses. >10 %, 14 % and 19 % of the first, second and third DTaP-IPV-Hib doses, respectively were

Table 2
Characteristics of study population by birth cohorts (unweighted).

	Total	Cohort 2012	Cohort 2013	Cohort 2014	Cohort 2015	Cohort 2016	Cohort 2017	Cohort 2018	Cohort 2019[a]	Cohort 2020[a]	Cohort 2021[a]
Cohort size											
Observed ≥13 months	120,073	11,196	10,944	11,328	12,013	10,874	10,051	11,522	12,697	14,422	15,026
Observed ≥25 months	97,573	9800	9414	9894	10,365	10,058	9488	10,926	11,969	13,576	2083
Observed ≥48 months	62,462	7527	8186	8019	9005	8991	8566	9814	2354	0	0
Characteristics of cohort observed ≥25 months											
Sex, n (%)											
Female	47,356 (48.5 %)	4774 (48.7 %)	4551 (48.3 %)	4749 (48.0 %)	5058 (48.8 %)	4929 (49.0 %)	4560 (48.1 %)	5290 (48.4 %)	5862 (49.0 %)	6579 (48.5 %)	1004 (48.2 %)
Geographic region, n (%)											
Urban	68,049 (69.7 %)	6784 (69.2 %)	6574 (69.8 %)	6962 (70.4 %)	7310 (70.5 %)	7112 (70.7 %)	6688 (70.5 %)	7688 (70.4 %)	8281 (69.2 %)	9236 (68.0 %)	1414 (67.9 %)
Intermediate	18,045 (18.5 %)	1802 (18.4 %)	1737 (18.5 %)	1794 (18.1 %)	1875 (18.1 %)	1818 (18.1 %)	1710 (18.0 %)	2041 (18.7 %)	2235 (18.7 %)	2614 (19.3 %)	419 (20.1 %)
Rural	11,476 (11.8 %)	1213 (12.4 %)	1101 (11.7 %)	1138 (11.5 %)	1180 (11.4 %)	1128 (11.2 %)	1090 (11.5 %)	1197 (11.0 %)	1453 (12.1 %)	1726 (12.7 %)	250 (12.0 %)
Language region, n (%)											
German	69,494 (71.2 %)	7068 (72.1 %)	6755 (71.8 %)	7046 (71.2 %)	7368 (71.1 %)	7262 (72.2 %)	6852 (72.2 %)	7784 (71.2 %)	8499 (71.0 %)	9384 (69.1 %)	1476 (70.9 %)
French	23,809 (24.4 %)	2194 (22.4 %)	2116 (22.5 %)	2353 (23.8 %)	2559 (24.7 %)	2397 (23.8 %)	2247 (23.7 %)	2713 (24.8 %)	3021 (25.2 %)	3671 (27.0 %)	538 (25.8 %)
Italian	4267 (4.4 %)	537 (5.5 %)	541 (5.7 %)	495 (5.0 %)	438 (4.2 %)	399 (4.0 %)	389 (4.1 %)	429 (3.9 %)	449 (3.8 %)	521 (3.8 %)	69 (3.3 %)

[a] Few or no observations for cohorts 2019, 2020 and 2021 at 25 or 48 months respectively since study end was defined as March 31, 2023.

administered delayed (Fig. S5).

3.3. MMR

Coverage at 25 months ranged between 85 % (2017) and 91 % (2013) for the first and 67 % (2017) and 80 % (2020/2021) for the second doses (full coverage, Fig. 1B and Table S1B). The uptake of the second dose improved from about ~70 % before 2019 to ~80 % in the birth cohorts 2020/2021, which reflects the highest full coverage observed during the COVID-19 pandemic. Additionally, we observed large catch-up effects after 25 months of age in some birth cohorts (up to 10 % of children received the second MMR vaccination until 48 months, Table S1B). However, for recent years (2019–2021) we observed poor adherence to the 2019 vaccination schedule (Fig. 2E–F). Accordingly, we found that 63 % of the second MMR doses, administered during COVID-19 in cohorts 2019–2021, were delayed (Fig. S5).

3.4. HBV

HBV coverage at 25 months of age showed large gaps between the two priming and the booster dose (Fig. 1C). In the cohorts 2019–2020, primarily affected by the amendments in the vaccination schedule (change of HBV from adolescent to infant vaccination in 2019) coverage but also timeliness (Fig. S2A–D) improved, with, however, full coverage not exceeded 76 % (2021). We observed a reduction in the proportion of delayed doses after 2019 (Fig. S5).

3.5. PCV

PCV vaccination coverage increased over the years, with full vaccination coverage of ~82 % (2019–2021), ranging from 65 to 77 % between 2012 and 2017, and being at the highest with 83 % (2019) after the introduction of the amended vaccination schedule (Fig. 1D). Also, vaccination timeliness improved after the schedule implementation (Fig. S2E–G, Fig. S5). For example, the proportion of children with delayed first doses was 15 % between 2012 and 2017 and decreased to 10 % between 2019 and 2021.

3.6. MCV

Meningococcal vaccination remained a supplementary vaccination during the study period and showed consistently low coverage at 25 months (Fig. S1). Coverage peaked in 2016 (72 %) and decreased to <60 % in recent years. However, Fig. S3 shows that approximately an additional 20 % of children receive the MCV vaccination after 25 months of age. Accordingly, timeliness was generally poor with 44 % and 35 % of the priming MCV dose administered delayed before and after the implementation of the amended vaccination schedule (Fig. S5).

Further details including vaccination coverage at 13, 25 and 48 months of age with corresponding 95 % CIs are shown in Supplementary Tables 1A–1E. The comparison of population weighted with unweighted estimates revealed only marginal differences and are therefore not shown (<1 %).

3.7. Regional differences and correlates of non-vaccination

The percentage of entirely unvaccinated children across all birth cohorts varied largely from <5 % to >10 % by Swiss cantons (Fig. S4). The multivariate regression analysis (Table S2) showed that rural (OR 2.15; 95 % CI, 1.97–2.34) and intermediate (OR 1.46; 95 % CI, 1.34–1.58) regions (versus urban), and the German-speaking region (versus French (OR 0.83; 95 % CI, 0.77–0.90) and Italian (OR 0.82; 95 % CI, 0.69–0.96)) were significantly associated with an increased probability of non-vaccination.

4. Discussion

In this large retrospective study using health insurance claims data we examined vaccination coverage and timeliness, the potential impact of COVID-19, adherence to vaccination schedule amendments, and regional variations in Swiss children aged ≤4 years. Despite the COVID-19 pandemic, we mostly found stable or increasing trends in coverage over time for those aged 25 months. However, we found that after a relatively high coverage for priming doses, booster vaccinations were often missed or substantially delayed. Full coverage was below 90 %, indicating that the vaccination targets according to the FOPH have not

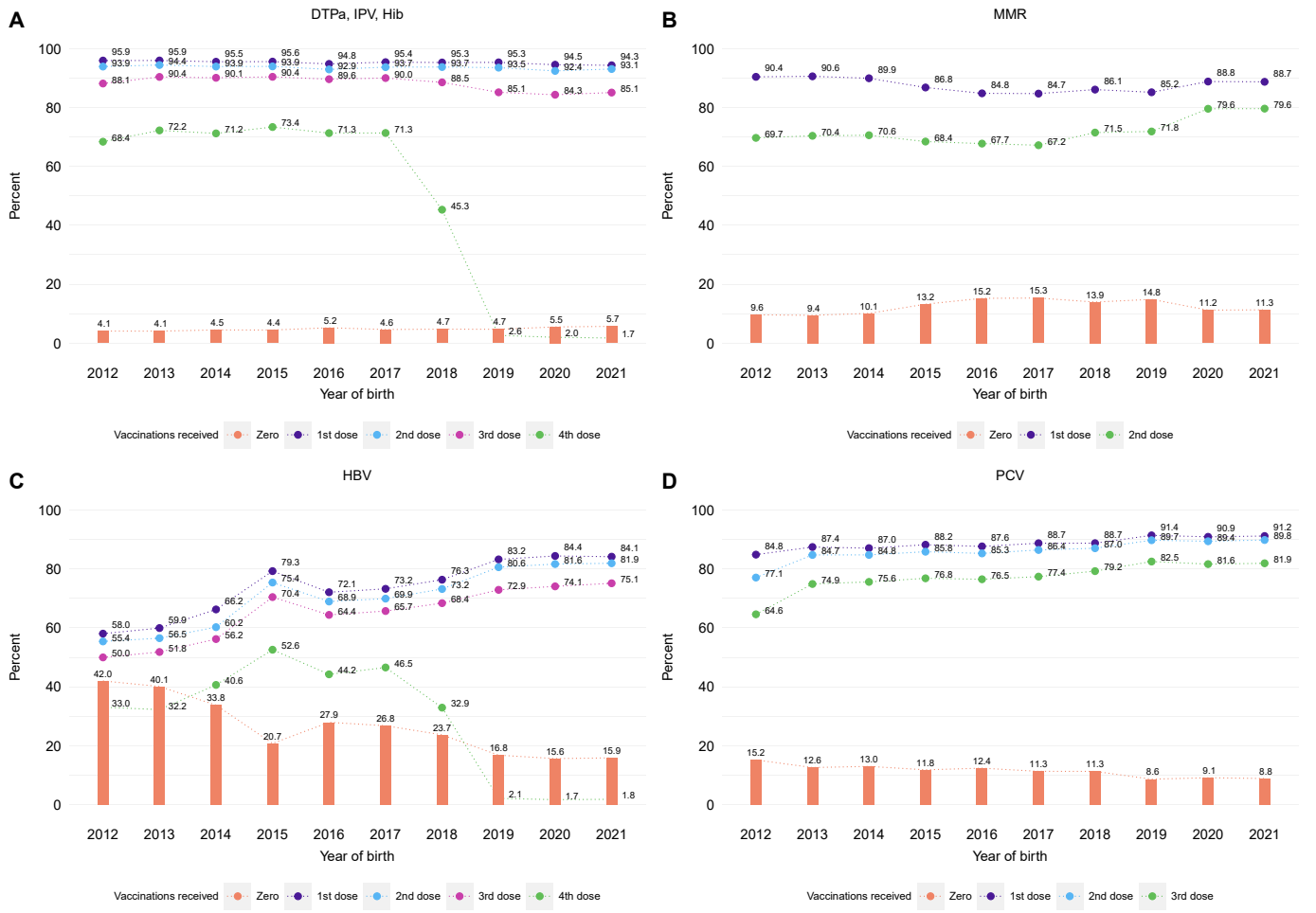

Fig. 1. Vaccination coverage for different vaccinations by birth cohorts 2012–2021 at 25 months of age. The dots show the percentage of children that received a certain vaccination dose. The bottom bars show the percentage of completely unvaccinated children with the corresponding vaccinations. Note: coverage was similar (difference <0.1 %) for each of the individual vaccination doses in A or B and are therefore shown together. Up-to-date vaccination at 24 months according to the Swiss vaccination schedule included 4 doses of diphtheria, tetanus, pertussis, poliomyelitis, and haemophilus influenzae type b (DTaP-IPV-Hib), and hepatitis B (HBV) until 2018 and was reduced to 3 doses in 2019. The steep drop in 2018 of the fourths doses in A/C was expected due to schedule changes. Recommended doses remained the same for measles, mumps and rubella (MMR) and pneumococcal vaccination (PCV).

yet been met for any vaccination in Switzerland (e.g., 95 % MMR or Hib coverage at 24 months [29,30]). The amended vaccination schedule was quickly adopted, and we observed good adherence (except for MMR and MCV). The amendments were associated with improvements in full coverage and a better vaccination timeliness (e.g., >10 percentage point increase of full DTaP-IPV-Hib coverage). Our data further suggest that uptake varies widely by vaccine type, which could indicate differential parental acceptance [31,32]. Among vaccines that have long been recommended as basic vaccinations (DTaP-IPV-Hib, MMR), MMR particularly, showed low coverage and substantial delays. Lastly, we found prominent regional differences in non-vaccination, which may indicate that larger efforts may be needed in some Swiss regions to improve vaccination coverage.

In line with previous studies [1,6,16], we found an improvement in vaccination coverage over the years in Swiss children. However, our results diverge from the national monitoring SNVCS [16] with coverage estimates that are mostly and consistently lower. For example, SNVCS found coverage of about 87–94 % for the second MMR and ≥95 % for the third doses of DTaP-IPV-Hib in children aged 25–36 months [16]. In contrast, we found estimates that are about 10 percentage points lower at 25 months in corresponding years, even when considering the catch-up effects until the age of 48 months. Comparable estimates were only found for HBV, which were in a similar range. We assume that these discrepancies may be explained with methodological differences. The data used for this study was based on health insurance claims. Although, we assume that invoices have mostly been submitted for reimbursement (due to high costs for vaccinations and preventive examinations generally covered by the insurance), we cannot exclude underreporting. On the other hand, the SNVCS is limited by a non-response of about 23 % in recent years, which may lead to an overestimation. It was shown that participants in SNVCS tend to differ from non-participants [17,19], with the possibility that those who refuse participation may have less positive attitudes toward vaccines.

Compared with overall estimates for Europe, we found consistently lower estimates in all cohorts for most vaccinations, except for PCV and Hib [2,26]. Interestingly, we found similar estimates between 2012 and 2019 compared with Germany for some vaccinations and years (full coverage of MMR and DTaP-IPV of 69–80 % and 78–81 % respectively at 24 months in Germany) [25].

Delayed or missed vaccinations result in inadequate protection when individuals are most vulnerable and carries the risk of never completing the vaccination course [7,31]. Despite from the mostly low but improving coverage and the suboptimal vaccination timeliness, we found the following overall picture that was striking. First, the proportion of missed booster doses, after a relatively high coverage of primary vaccine doses, was remarkable, with about 9 % of children having started but never completed the different vaccination series in recent years (2019–2021). This issue is well known and has been shown

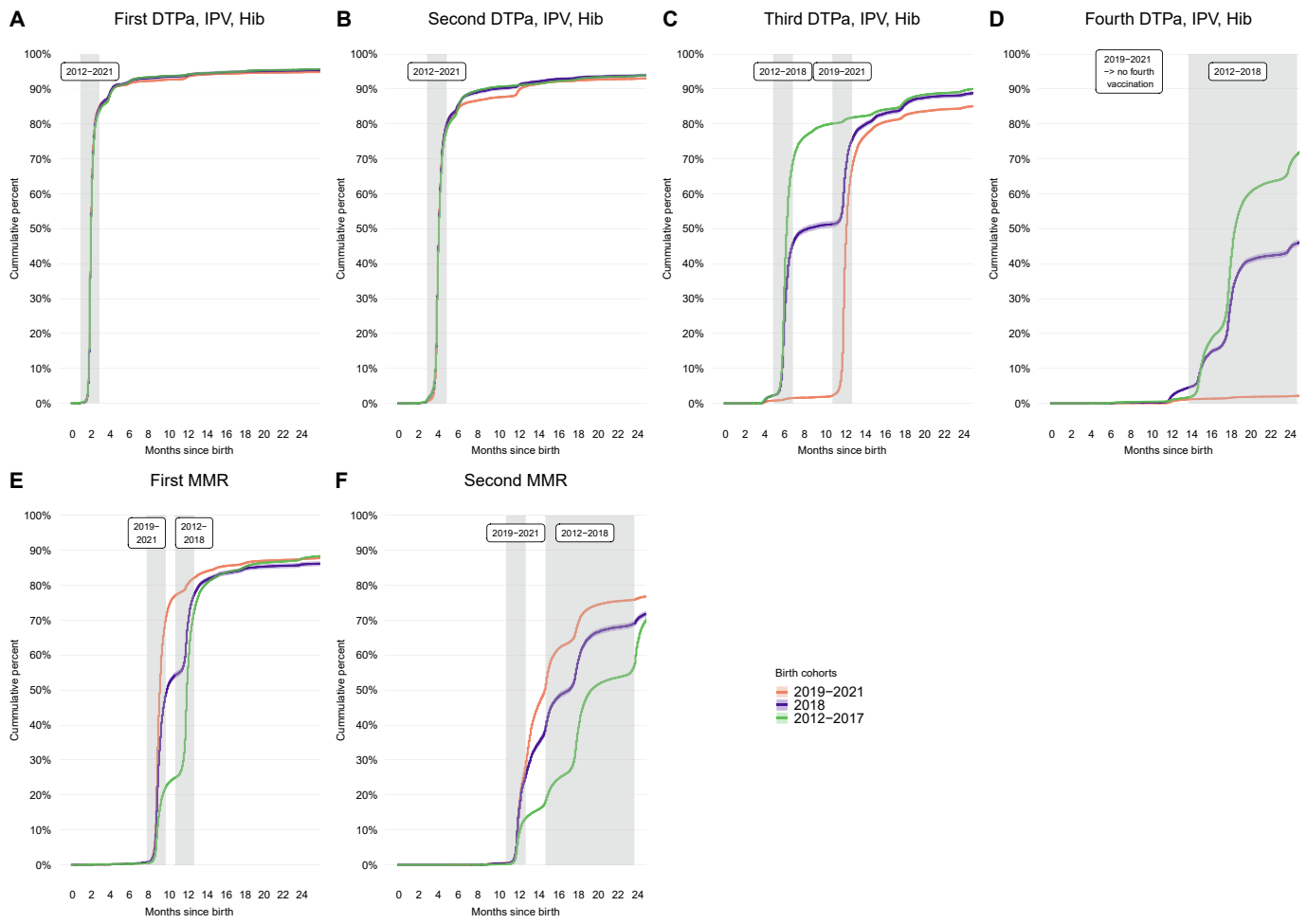

Fig. 2. Vaccination timeliness for diphtheria, tetanus, pertussis, poliomyelitis, and haemophilus influenzae type b (DTaP-IPV-Hib) and measles, mumps and rubella (MMR) vaccinations by birth cohorts until 25 months of age. Shown are months from birth to 1st, 2nd, 3rd, and 4th vaccination by birth cohorts. The gray shaded areas indicate the period for age-appropriate administration (±30 days) according to the 2012–2018 and the 2019–2021 vaccination schedules.

previously in Switzerland [1,6,19], but also in many other countries [31,33]. Evidence shows that timely booster doses are necessary for a sufficient protection, which is particularly relevant for the "2 + 1" schedule from age 1 year onward [34]. Second, the comparison across vaccination types (Fig. 1) showed a relevant proportion of children who received some but not all recommended basic vaccinations (selective vaccinations), which likely reflects differences in parental acceptance [31,35]. Among the vaccines recommended as basic vaccinations since more than a decade, MMR showed a much lower coverage that DTaP-IPV-Hib, which is in line with previous studies [18,25,33]. For instance, about 9 % of children who received at least one dose of DTaP-IPV-Hib was entirely unvaccinated with MMR at 25 months of age (data not shown). The belief that MMR vaccine can cause serious side effects is still widespread [32]. Third, delays were common and affected booster doses more importantly than primary vaccination series. These delays are well known to be associated with an extending period at risk for VPD. Furthermore, delays complicate the timing of follow-up vaccinations and often lead to incomplete vaccination series [7,31,33].

Although this study did not allow the analysis of the causes of missed or delayed doses, it is unlikely that these results are solely explained by a restricted access to vaccinations. Health care in Switzerland is known to be of high quality and is generally considered to be well accessible as the mandatory basic insurance covers necessary treatment costs and there is a high density of health care providers [36]. It was previously shown that most Swiss children show sufficient doctor visits until the age of 24 months to complete the recommended vaccinations [6]. However, there are also possible barriers that may have contributed to missed or delayed vaccinations such practical issues (e.g., inconvenient timing, lack of time, transportation issues) [35]. Also, there are currently no reminder-recall systems available at a national level that may support vaccination uptake (see practical implications). Beside these barriers, delayed or missed vaccinations may be indicative of parental vaccination hesitancy [31,32,35]. Evidence for parental hesitancy may be supported by the non-vaccination proportion ranging from 5 to 15 % by geographic region or selective vaccination patterns [31].

In contrast to many other countries [13–15], we mainly observed stable or even increasing coverage rates and no further vaccination delays during COVID-19. These results are comparable with recent data from SNVCS [16] and are in line with observations from Germany [25].

In addition, our study indicates that the amended vaccination schedule 2019 was immediately adopted with overall good adherence for most vaccines. We mainly observed an increasing trend regarding the full coverage in the range of 3–25 percentage points after the amended schedule was implemented. Vaccinations newly added to the basic recommendations (HBV, PCV) further increased in temporal association with the amended vaccination schedule, however, not yet reaching the levels for DTaP-IPV-Hib. Exceptions were the MCV and MMR vaccinations. In cohorts 2019–2021, the second dose of MMR was given later than the recommended 12 months of age in most children. One main reason could be the hesitancy to administer 3 vaccines concurrently at the 12-month visit, with MMR being the one most likely to be deferred [32,35]. Furthermore, MCV is still administered at a very low rate with

large delays. More efforts may be needed to increase MCV uptake.

Lastly, the large regional variations in vaccination coverage found in our study were already shown previously. Our results are consistent with previous studies showing cantonal differences and higher vaccination coverage in the French and Italian language regions compared to the German language region [1,16,17]. In addition, children from French- and Italian-speaking regions tend to be vaccinated earlier [19]. These differences may be explained by individual factors (e.g., social influences, confidence in vaccination, logistical barriers) and differences in pediatric care, which may vary by region [32,35,36].

4.1. Practical implications

Monitoring is key to detect eventual disruptions, monitor vaccination schedule adherence and to understand regional differences. This can provide information about the success of vaccination programs and help to adjust strategies as needed. Like many other countries, Switzerland does not run a nation-wide vaccination registry and surveillance is manly based on one source (SNVCS) [17]. While SNVCS provides valuable information, claims data are a beneficial and cost-effective supplement the regular monitoring. This approach has been shown to be well suited and is already in use in countries such as Germany [20,21,25]. In addition, it provides accurate and timely data including information on timeliness and regional differences. Furthermore, comprehensive personal electronic health records still need to be implemented in Switzerland. On the one hand, electronic records could provide further data and on the other hand help to increase the vaccination coverage and timeliness - for example through digital technologies that incorporate digital reminders [7,37].

4.2. Strengths and limitations

Strength of this study are the large sample size covering about 12–17 % of children born between 2012 and 2021 in Switzerland (considering children observed $\geq$13 months). Our study provides in depth knowledge regarding vaccinations over a decade, adherence to adapted vaccination schedules, and regional variations that provide important insights regarding the progress towards reaching national coverage targets. Although, we used weighting procedures and our internal analyses showed that characteristics such as the sex ratio is comparable to those of the general population, our data source may not be entirely representative to the Swiss general population. Although, our study may underestimate the real coverage rate, our results valuably complement the vaccination monitoring in Switzerland. Underestimating may have arisen from missed vaccinations due to invoices not sent for reimbursement by parents or vaccinations administered during a hospital stay (not covered by our data). However, we assume that both cases were relatively rare since most vaccinations (and associated doctor visits) are fully reimbursed (except a shared co-payment of 10 %) by health insurances and hospital stays of >2 month occurred very seldom (<0.1 %). In addition, we were unable to analyse preterm infants, for whom special recommendations were applied [22].

5. Conclusion

This study provides important findings that may support the vaccination surveillance in Switzerland. Although the study showed an overall improvement from 2012 to 2021 in vaccination coverage and timeliness for children aged $\leq$4 years, with a neglectable untoward influence of the COVID-19 pandemic, full vaccination coverage in Swiss children was still under 90 % with many vaccinations missed or administered delayed. Importantly, the amended vaccination schedule 2019 (e.g., change from 3 + 1 to a 2 + 1 schedule) was immediately adopted with full-vaccination coverage rates mainly increased in temporal association. Given regional differences, missed booster vaccinations, and differences in vaccine-specific acceptability, more effort may be needed to achieve national vaccination targets.

6. Author contributions

SJZ and AS conceived and designed the study. SJZ and AS conducted the statistical analyses. SJZ wrote the first draft of the manuscript. All authors contributed to data interpretation, manuscript revisions and approved the final version of the manuscript.

7. Ethical approval

Not required.

8. Funding

No funding.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Data availability

Individual data cannot be made fully available because the study is based on claims data of the Helsana Group. Data can be shared on the reasonable request from Carola Huber (carola.huber@helsana.ch).

Appendix A. Supplementary material

Supplementary data to this article can be found online at https://doi.org/10.1016/j.vaccine.2023.10.043.

References

[1] Schneider R, Reinau D, Schur N, Blozik E, Früh M, Signorell A, et al. Coverage rates and timeliness of nationally recommended vaccinations in Swiss preschool children: a descriptive analysis using claims data. Vaccine 2020;38(6):1551–8. https://doi.org/10.1016/j.vaccine.2019.11.057.
[2] Bechini A, Boccalini S, Ninci A, Zanobini P, Sartor G, Bonaccorsi G, et al. Childhood vaccination coverage in Europe: impact of different public health policies. Expert Rev Vaccines 2019;18(7):693–701. https://doi.org/10.1080/14760584.2019.1639502.
[3] Leong WY. Measles cases hit record high in Europe in 2018. J Travel Med 2018;25(1). https://doi.org/10.1093/jtm/tay080.
[4] Durrheim DN. Measles eradication-retreating is not an option. Lancet Infect Dis 2020;20(6):e138–41. https://doi.org/10.1016/S1473-3099(20)30052-9.
[5] Rodrigues CMC, Plotkin SA. Impact of vaccines; health, economic and social perspectives. Front Microbiol 2020;11:1526. https://doi.org/10.3389/fmicb.2020.01526.
[6] Bielicki JA, Achermann R, Berger C. In touch but not up-to-date: ambulatory visits and vaccination status in a cohort of young Swiss children. Vaccine 2013;31(46):5375–80. https://doi.org/10.1016/j.vaccine.2013.09.025.
[7] Guerra FA. Delays in immunization have potentially serious health consequences. Paediatr Drugs 2007;9(3):143–8. https://doi.org/10.2165/00148581-200709030-00002.
[8] van Wijhe M, McDonald SA, de Melker HE, Postma MJ, Wallinga J. Effect of vaccination programmes on mortality burden among children and young adults in the Netherlands during the 20th century: a historical analysis. Lancet Infect Dis 2016;16(5):592–8. https://doi.org/10.1016/S1473-3099(16)00027-X.
[9] Ehreth J. The global value of vaccination. Vaccine 2003;21(7):596–600. https://doi.org/10.1016/S0264-410X(02)00623-0.
[10] Mina MJ. Measles, immune suppression and vaccination: direct and indirect nonspecific vaccine benefits. J Infect 2017;74:S10–7. https://doi.org/10.1016/S0163-4453(17)30185-8.
[11] Chumakov K, Ehrenfeld E, Agol VI, Wimmer E. Polio eradication at the crossroads. Lancet Glob Health 2021;9(8):e1172–5. https://doi.org/10.1016/S2214-109X(21)00205-9.
[12] Pasté M, Stoffel M, Bardone C, Baron-Papillon F, Czwarno A, Galbraith H, et al. Addressing vaccine supply challenges in Europe: expert industry perspective and recommendations. Health Policy 2022;126(1):35–42. https://doi.org/10.1016/j.healthpol.2021.11.006.
[13] World Health Organization. COVID-19 pandemic fuels largest continued backslide in vaccinations in three decades. [Accessed June 13, 2023]; Available from: https:

//www.who.int/news/item/15-07-2022-covid-19-pandemic-fuels-largest-continued-backslide-in-vaccinations-in-three-decades.
[14] Lassi ZS, Naseem R, Salam RA, Siddiqui F, Das JK. The impact of the COVID-19 pandemic on immunization campaigns and programs: a systematic review. Int J Environ Res Public Health 2021;18(3). https://doi.org/10.3390/ijerph18030988.
[15] Causey K, Fullman N, Sorensen RJD, Galles NC, Zheng P, Aravkin A, et al. Estimating global and regional disruptions to routine childhood vaccine coverage during the COVID-19 pandemic in 2020: a modelling study. Lancet 2021;398 (10299):522–34. https://doi.org/10.1016/S0140-6736(21)01337-4.
[16] Swiss Federal Office of Public Health. Durchimpfung bei 2-jährigen Kindern in der Schweiz, Erhebungsperioden 1999–2003, 2005–2007, 2008–2010, 2011–2013, 2014–2016, 2017–2019 und 2020—2022. [Accessed June 10, 2023]; Available from: https://www.bag.admin.ch/bag/de/home/gesund-leben/gesundheitsfoerderung-und-praevention/impfungen-prophylaxe/informationen-fachleute-gesundheitspersonal/durchimpfung.html.
[17] Lang P, Zimmermann H, Piller U, Steffen R, Hatz C. The Swiss National Vaccination Coverage Survey, 2005–2007. Public Health Rep 2011;126(Suppl. 2):97–108. https://doi.org/10.1177/00333549111260S212.
[18] Merle T, Jeannot E. Surveillance of vaccination coverage in 5–6- and 13–14-years-old schoolchildren in Geneva. Arch Pediatr 2020;27(6):292–6. https://doi.org/10.1016/j.arcped.2020.06.009.
[19] Baroutsou V, Wymann M, Zens K, Sinniger P, Fehr J, Lang P. National and regional variations in timely adherence to recommended measles vaccination scheme in 2-years old in Switzerland, 2005–2019. Vaccine 2022;40(22):3055–63. https://doi.org/10.1016/j.vaccine.2022.04.008.
[20] Kalies H, Redel R, Varga R, Tauscher M, von Kries R. Vaccination coverage in children can be estimated from health insurance data. BMC Public Health 2008;8: 82. https://doi.org/10.1186/1471-2458-8-82.
[21] Rieck T, Feig M, Eckmanns T, Benzler J, Siedler A, Wichmann O. Vaccination coverage among children in Germany estimated by analysis of health insurance claims data. Hum Vaccin Immunother 2014;10(2):476–84. https://doi.org/10.4161/hv.26986.
[22] Swiss Federal Office of Public Health. Swiss Vaccination Schedules (DE, FR, IT). [Accessed February 25, 2023]; Available from: https://www.bag.admin.ch/bag/de/home/gesund-leben/gesundheitsfoerderung-und-praevention/impfungen-prophylaxe/schweizerischer-impfplan.html.
[23] Ambühl D, Bächler A, Baumann T, Jenni O, Leuchter Ha-Vinh R, Lips U et al. Checklisten für die Vorsorgeuntersuchungen Checklisten nach den Empfehlungen der Schweizerischen Gesellschaft für Pädiatrie (4. Auflage 2011). [Accessed April 25, 2023]; Available from: https://www.paediatrieschweiz.ch/unterlagen/.
[24] Federal Statistical Office. Raumgliederung der Schweiz: Gemeindetypologie und Stadt/Land-Typologie 2012. [Accessed October 03, 2023]; Available from: https://www.bfs.admin.ch/bfs/de/home/statistiken/querschnittsthemen/raeumliche-analysen/raeumliche-gliederungen/raeumliche-typologien.html.
[25] Rieck T, Feig M, Siedler A. Impfquoten von Kinderschutzimpfungen in Deutschland; aktuelle Ergebnisse aus der RKI-Impfsurveillance. Epid Bull Robert Koch Institut 2022;48.
[26] United Nations Children's Fund. Immunisation 2011–2021 Europe (UNICEF Data Ware House). [Accessed March 20, 2023]; Available from: https://data.unicef.org/resources/data_explorer/unicef_f/.
[27] Lumley T. Analysis of complex survey samples. J Stat Soft 2004;9(8):1–19. 10.18637/jss.v009.i08.
[28] Federal Statistical Office. STAT-TAB – interaktive Tabellen (BFS); Ständige und nichtständige Wohnbevölkerung nach Kanton, Geschlecht, Zivilstand und Alter, 2010–2022. [Accessed October 10, 2023]; Available from: https://www.pxweb.bfs.admin.ch/pxweb/de/px-x-0102010000_102/-/px-x-0102010000_102.px/.
[29] Swiss Federal Office of Public Health and Federal Vaccination Commission. Empfehlungen zur Prävention von Masern, Mumps und Röteln. [Accessed March 30, 2023]; Available from: https://www.bag.admin.ch/dam/bag/de/dokumente/mt/i-und-b/richtlinien-empfehlungen/neue-empfehlungen-2019/praevention-masern-mumps-roeteln.pdf.download.pdf/praevention-masern-mumps-roeteln-de.pdf.
[30] Swiss Federal Office of Public Health. Aktionsplan: Nationale Strategie zu Impfungen. [Accessed October 10, 2023]; Available from: https://www.bag.admin.ch/dam/bag/de/dokumente/mt/i-und-i/nsi/aktionsplan-nsi.pdf.download.pdf/aktionsplan-nsi.pdf.
[31] Newcomer SR, Glanz JM, Daley MF. Beyond vaccination coverage: population-based measurement of early childhood immunization schedule adherence. Acad Pediatr 2023;23(1):24–34. https://doi.org/10.1016/j.acap.2022.08.003.
[32] Novilla MLB, Goates MC, Redelfs AH, Quenzer M, Novilla LKB, Leffler T, et al. Why parents say no to having their children vaccinated against measles: a systematic review of the social determinants of parental perceptions on MMR vaccine hesitancy. Vaccines (Basel) 2023;11(5). https://doi.org/10.3390/vaccines11050926.
[33] Bailly A-C, Gras P, Lienhardt J-F, Requillart J-C, Vié-le-Sage F, Martinot A, et al. Timeliness of vaccination in infants followed by primary-care pediatricians in France. Hum Vaccin Immunother 2018;14(4):1018–23. https://doi.org/10.1080/21645515.2017.1409318.
[34] Heath PT, McVernon J. The UK Hib vaccine experience. Arch Dis Child 2002;86(6): 396–9. https://doi.org/10.1136/adc.86.6.396.
[35] Smith LE, Amlôt R, Weinman J, Yiend J, Rubin GJ. A systematic review of factors affecting vaccine uptake in young children. Vaccine 2017;35(45):6059–69. https://doi.org/10.1016/j.vaccine.2017.09.046.
[36] Jenni OG, Sennhauser FH. Child health care in Switzerland. J Pediatr 2016;177S: S203–12. https://doi.org/10.1016/j.jpeds.2016.04.056.
[37] Balzarini F, Frascella B, Oradini-Alacreu A, Gaetti G, Lopalco PL, Edelstein M, et al. Does the use of personal electronic health records increase vaccine uptake? A systematic review. Vaccine 2020;38(38):5966–78. https://doi.org/10.1016/j.vaccine.2020.05.083.