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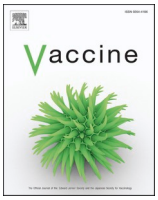

Immunity against vaccine-preventable diseases among pregnant employees in Germany. A situation analysis before the introduction of the Measles Protection Act

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ABSTRACT

Background: Immunization against vaccine-preventable diseases prior to pregnancy is an important measure of primary prevention both for the mother and the unborn child. We analyzed immunity rates against measles, mumps, rubella, varicella, and pertussis in pregnant employees in Germany prior to significant changes in legal conditions in 2020, to provide a basis of comparison for future research.

Methods: We analyzed occupational-medical routine data in three collectives of pregnant women with an occupational risk of infection in the years 2018 and 2019: 1: hospital staff with regular access to an in-house company physician (n = 148); 2: employees in childcare with regular access to external occupational-health services (n = 139); 3: teachers with no regular access to occupational healthcare (n = 285). Immune status was assessed by a physician based on vaccination certificates, laboratory results, and medical documentation on prior infections. We compared immunity rates against measles, rubella, varicella, and pertussis as well as full immunity against all targeted vaccine-preventable diseases.

Results: Altogether, n = 572 pregnant women were included in our study. Of these women, 96.5 % were immune to rubella, 95.8 % to varicella, 88.3 % to measles, 82.7 % to mumps, and 67.8 % to pertussis. Only 56.2 % of the women had full immunity against all targeted vaccine-preventable diseases. Collective 1 showed the highest immunity rates against measles and pertussis as well as the highest rate of full immunity against all targeted vaccine-preventable diseases. The immunity rates against rubella and varicella did not differ significantly between the collectives. With the exception of rubella, the lowest immunity rates during pregnancy were found in Collective 3.

Conclusion: We found pregnancy-relevant immunity gaps in all our study groups with significant differences between the collectives. Considering the potentially devastating consequences of infections during pregnancy, all medical professionals and health-policy makers should be involved in an increased effort to improve vaccination rates prior to pregnancy.

1. Introduction

There are several infectious diseases, such as measles, rubella, or varicella, that can pose a risk during pregnancy. Some of these diseases can harm the unborn child and cause lifelong impairment or disability; others can lead to severe complications for the mother or the newborn

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[1]. Therefore, providing the best possible protection for both the mother and the unborn child is a matter of societal concern.

1.1. Regulations for occupational-medical consultations in Germany

In Germany, employees with an occupational risk of infection are entitled to a regular preventive occupational-medical consultation during which their individual immune status is examined [2,3].

Employees are considered as subjected to an occupational risk of infection if their risk of contracting a communicable disease in their workplace exceeds the risk of contracting this disease in their daily lives. Thus, an occupational risk of infection can be found in workplaces such as hospitals, where medical staff is in regular, close contact to sick people, or childcare facilities, where teachers and childcare workers are exposed to childhood diseases because of their regular and often close contact to many children. The exact occupational fields of activity that entail a mandatory occupational-medical consultation (OMC) or a mandatory offer of such a consultation are specified by the German Ordinance on Preventive Occupational Health Care [2]. During OMCs, the employees are offered advice on their occupational risks as well as voluntary tests and measures by an occupational physician. It can be assumed that many employees accept these offers, as it has been shown that vaccination gaps are higher during first consultations than during subsequent appointments [4]. However, in their study on employees in preschool childcare, Goertz et al. were able to demonstrate that, even in subsequent consultations, full immunization coverage could not be reached, with some vaccination gaps still nearing or even exceeding 20 % (e.g. measles: 19.2 %, rubella: 21.8 %) [4].

Apart from the German Ordinance on Preventive Occupational Health Care, pregnant employees are entitled to an OMC on the legal basis of the German Maternity Protection Act in order to provide an assessment of their workplace infection risk, as § 10 of this Act compels employers to "assess [for each activity] the hazards in terms of their nature, duration and magnitude to which a pregnant or breastfeeding woman or her child is or may be exposed" [5].

1.2. Prevention gaps during pregnancy

As many of the pregnancy-relevant infections, such as measles, rubella, or varicella, are vaccine-preventable, immunization can be an effective measure of primary prevention, but only if full immunization against the disease is reached before pregnancy. This condition is due to two reasons: on the one hand, live vaccinations (such as measles, mumps, and rubella) are contraindicated during pregnancy [6], and on the other hand, many pregnant women will only make their condition known after eight to twelve weeks of pregnancy. Until then, there are usually no specific preventive measures in a woman's social and occupational environment. As such, without adequate immunization before pregnancy, there is a kind of prevention gap, and that prevention gap occurs during a very vulnerable phase of embryonic development. As the standards and specifications of the German Maternity Protection Act for pregnant women will only be implemented once the employer is informed of the pregnancy, this prevention gap becomes particularly relevant if the pregnant woman has an occupational risk of infection.

1.3. Immunity rates in the German population

Infection prevention for vulnerable groups, like pregnant employees, is still lacking in Germany. Despite all measures taken before 2020, Germany has not been able to achieve a measles-vaccination coverage high enough to pave the way for the elimination of measles. According to the World Health Organization (WHO), a threshold of 95 % vaccination coverage must be reached or crossed to eradicate the disease [7]. A large-scale survey including more than 3,500 German children that was conducted as a part of the official health-monitoring performed by the Robert Koch Institute (RKI) in the years 2014 to 2017 (KiGGS, wave 2) reported a measles-vaccination coverage of 93.6 %. A second vaccination against mumps was only documented for 92.3 % of the children examined (3–17 years), 93.1 % were vaccinated twice against rubella, and only 50.9 % were vaccinated twice against varicella. Of children aged 7 to 17 years, 78.9 % had received a baseline immunization against pertussis plus at least one booster vaccination [8]. The German Health Interview and Examination Survey for Adults (DEGS1) with 8,151 participants (November 2008 to December 2011) found a seroprevalence of anti-measles IgG antibodies of less than 90 % in adults born in or after 1965, whereas it had exceeded 97 % in adults born before that year. The same study also found insufficient immunity rates to mumps (84.2 %) and rubella (94.0 %) among German adults [9].

1.4. Change of legal and regulatory conditions in Germany since 2020

As Germany has thus also been falling short of the 95 % goal for measles, especially in younger generations, the German Standing Committee on Vaccination (STIKO) of the RKI updated its recommendations on measles, mumps, rubella, and varicella vaccinations for employees with an occupational risk of infection in January 2020. Since then, two vaccinations against measles and mumps are required instead of only one (for adults born after the year 1970) to achieve full immunization [10,11].

Furthermore, in March 2020, measles vaccinations (or proving individual immunity against measles as an alternative) were declared compulsory for children in day care, kindergarten, and school as well as for certain occupational groups by the Introduction of the Measles Protection Act [12]. The occupational groups concerned comprise employees at community facilities (such as nurseries, daycare facilities, and schools); employees at medical facilities (such as hospitals, outpatient clinics, or medical offices); and personnel working in shared accommodations (such as refugee accommodations or children's homes) [13]. Since this legislation and change of official recommendations explicitly aims at increasing vaccination coverage and pushing it beyond the 95 % threshold, it is important to record vaccination rates before its enforcement – especially for vulnerable groups like pregnant employees with an occupational risk of infection which may benefit not only from better protection against measles, but also from higher immunization coverage against other vaccine-preventable diseases that might follow in its wake (due to, for example, the usage of combination vaccines).

Last but not least, the SARS-CoV-2 pandemic as well as the control measures subsequently taken by authorities may have altered individuals' perception of and stance towards active immunization.

1.5. Aim of the study: Providing a basis of comparison for future investigation

Since all relevant events having taken place in or since the year 2020 (the SARS-CoV-2 pandemic, the update of STIKO vaccination guidelines, and the implementation of the Measles Protection Act), they can be expected to influence vaccination coverage in Germany – especially concerning measles, but most likely also concerning other diseases such as mumps, rubella, and varicella. They may even have an impact on immunization rates in general. The aim of our study was therefore to perform a situation analysis of immunity to measles, mumps, rubella, varicella, and pertussis among the vulnerable group of pregnant employees before the aforementioned changes took place in order to provide a basis of comparison for future investigation.

2. Materials and methods

In our cross-sectional study, we examined three collectives of pregnant employees. Each collective belonged to a different occupational group in childcare or health services which was entitled to regular occupational-medical consultations for all employees (regardless of pregnancy status) [2,3]. Employees were eligible for inclusion in our

study if they were both entitled to regular OMCs due to an occupational risk of infection and were pregnant at the time of the consultation. Our collectives were provided with varying levels of access to occupational-health services. We collected data from the years 2018 and 2019 due to the aforementioned changes in legal and regulatory conditions which went into effect in 2020. If there were employees with more than one check-up during this two–year period, we only included data from the most recent consultation.

Collective 1 (C1) consisted of 147 pregnant employees of the University Hospital of Erlangen and one pregnant employee of *Friedrich-Alexander-Universität Erlangen-Nürnberg* (FAU). The one pregnant employee of FAU was included alongside the 146 hospital employees as she was entitled to the same regular OMC because she performed occupational activities in a research facility listed in the German Ordinance on Preventive Occupational Health Care [2]. Occupational-health services were provided by an in-house company physician. The mean age was 31.1 years (range: 23–43 years), and the women were seen at 11.7 weeks of pregnancy on average (range: 5–29 weeks of pregnancy).

Collective 2 (C2) was comprised of 139 pregnant employees at childcare facilities with access to external occupational-health services provided by the *B·A·D Gesundheitszentrum* in Erlangen. The women's mean age was 30.2 years (range: 19–46 years) and the mean week of pregnancy at consultation was 9.1 (range: 4–30).

In Collective 3 (C3), we included 285 pregnant teachers in Northern Bavaria, who were not offered any regular occupational-health services during the survey period, although they were legally entitled to regular OMCs. The mean age in this group was 31.9 years (range: 23–41 years), and consultation took place at 13.7 weeks of pregnancy on average (range: 5–32).

For each pregnant woman, we recorded age and week of pregnancy at consultation; place of work; occupational-risk profile (contact with children or patients of different age groups); and immune status regarding measles, mumps, rubella, varicella, and pertussis.

All women included were born after 1970, which means that there was the general indication for vaccination against measles and mumps for all participants of our study (according to the guidelines of the German Standing Committee on Vaccination (STIKO). In case of rubella, there was the general recommendation for two vaccinations for all participants independent of a woman's age [14].

Immune status was assessed by a physician on the basis of vaccination certificates, laboratory results, and medical documentation of prior infections. The criteria for the assumption of immunity are specified in Table 1. If all recommended vaccinations were complete and reliably documented in a vaccination certificate, immunity was assumed and no further steps were taken. Otherwise, IgG-antibody tests were recommended and carried out if deemed appropriate and consented to by the pregnant employee. If there was pre-existing documentation on positive IgG-antibody titres, this was accepted as proof of immunity as well (with the exemption of mumps and pertussis). Self-reported vaccinations, self-reported laboratory results, or earlier infections without documentation were not accepted as evidence of immunity. An exception was made for self-reported infections of varicella (chicken pox) in view of the very clear clinical picture combined with the disease's high prevalence among German children during the relevant timeframe [15,16]. The physician's decision about full immunization was consistently based on the guidelines published by STIKO [14]. Immunity to mumps was included in our study, but was not compared between the three collectives, as there were major methodological differences between the collectives regarding the assessment of mumps immune status: In C1, a positive serology in laboratory tests (mumps-IgG positive) was accepted as proof of immunity to mumps, whereas in C2 and C3, mumps antibody titres were not used to decide on mumps immunity at all, based on the assumption that no protective mumps IgG-antibody titre is defined [1]. Thus, in C2 and C3, women with insufficient mumps immunization were considered vulnerable to the mumps disease even if a positive mumps IgG-antibody titre was documented.

Table 1
Criteria for the assumption of immunity.

	Immunity was assumed if at least one of the following criteria was met:
Measles	• 2 vaccinations* • 1 vaccination during adulthood*,† • Positive serology in laboratory tests (Measles-IgG positive) • Medical documentation of a prior measles infection * If at least two vaccinations during childhood or at least one vaccination during adulthood (18 years or older) are documented in the vaccination certificate, immunity can be assumed even if the IgG-antibody titer is negative or only marginally increased [1]. †This does not apply to Collective 1.
Rubella	• 2 vaccinations* • Positive serology in laboratory tests (Rubella-IgG positive) • Medical documentation of a prior rubella infection * If at least two vaccinations are documented in the vaccination certificate, immunity can be assumed even if the IgG-antibody titer is negative or only marginally increased [1].
Varicella	• 2 vaccinations • Positive serology in laboratory tests (Varicella-IgG positive) • Medical documentation of a prior varicella infection • Self-reported prior varicella infection
Pertussis	• At least one vaccination against pertussis within the past ten years
Mumps	• 2 vaccinations* • 1 vaccination during adulthood* • Medical documentation of a prior mumps infection • **Only in Collective 1:** Positive serology in laboratory tests (Mumps-IgG positive) * If at least two vaccinations during childhood or at least one vaccination during adulthood (18 years or older) are documented in the vaccination certificate, immunity can be assumed even if the IgG-antibody titer is negative or only marginally increased [1].

For statistical analysis, we used Microsoft Excel (Version 2211, Microsoft, USA) and IBM SPSS Statistics (Version 26, IBM, USA). Descriptive data is given as absolute values with percent values in parentheses or as a mean with the standard deviation and range in brackets. If data for any variable could not be obtained for all women, the variable was calculated based on the actual number of available data sets. Comparative statistics were performed by Kruskal-Wallis-test and binary logistic regression; p-values, odds ratios (OR), and 95 %-confidence intervals (in brackets) were also calculated. The significance level was set at 5 %. We compared Collectives 1, 2, and 3 regarding immunity rates against measles, rubella, varicella, and pertussis as well as full immunity against all targeted vaccine-preventable diseases. In a second step, we combined data from Collectives 1 and 2 (collectives with regular OMCs) and compared it to C3 (collective without regular OMCs). The variables "age" and "collective" were included in the binary logistic regression model.

All procedures in our study were performed in compliance with relevant laws and institutional guidelines and have been approved by the ethics committee of Friedrich-Alexander-Universität Erlangen-Nürnberg (reference number: 23-92-Br; date: March 27, 2023).

3. Results

Altogether, n = 572 pregnant women were included in our study. The details on demographic and occupational characteristics are presented in Table 2. Of these 572 women, 96.5 % were immune to rubella, 95.8 % to varicella, 88.3 % to measles, 82.7 % to mumps, and 67.8 % to pertussis. Only 56.2 % of the women had full immunity against all of the aforementioned diseases.

The comparison of immunity rates within the individual collectives by binary logistic regression rendered the following results: C1 showed the highest immunity rates against measles ($p < 0.001$; OR: 14.070 [3.359–58.927]) and pertussis ($p = 0.002$; OR: 2.080 [1.306–3.313]) as

Table 2
Demographic and occupational characteristics of collectives 1, 2, and 3.

	Collective 1	Collective 2	Collective 3
n	148	139	285
Occupational group	Hospital staff	Employees in childcare	Teachers
Place of employment	University Hospital Erlangen: 147 (99.3 %) - Medical departments: 137 (93 %) - Institutes: 5 (3 %) - Pharmacy: 2 (1 %) - Administration: 3 (2 %) Friedrich-Alexander-Universität: Research center for animal studies: 1 (0.7 %)	*(n = 137)* - Daycare: 39 (28 %) - Kindergarten: 68 (50 %) - Daycare and kindergarten: 19 (14 %) - Daycare center for schoolchildren: 4 (3 %) - Other: 7 (5 %)	- Elementary school (*Grundschule*): 118 (41 %) - Elementary and secondary school (type 1) (*Grund- u. Mittelschule*): 11 (4 %) - Secondary school (type 1: *Mittelschule*): 28 (10 %) - Secondary school (type 2: *Realschule*): 27 (10 %) - Secondary school (type 3: *Gymnasium*): 26 (9 %) - School for children with special needs (*Förderschule*): 54 (19 %) - Trade or vocational school (*Berufs(fach-)schule*): 11 (4 %) - Other (e.g. Schools for the sick (Schule für Kranke)): 10 (4 %)
Occupational-health services	Regular access to an in-house company physician	Regular access to external occupational-health services	No regular access to occupational-health services during the survey period[‡]
Age at occupational-medical consultation (years)	31.1 ± 4.0 [23 – 43]	30.2 ± 5.0 [19 – 46]	31.9 ± 3.1 [23 – 41] *(n = 284)*
Week of pregnancy at occupational-medical consultation	11.7 ± 5.4 [5 –29] *(n = 132)*	9.1 ± 4.3 [4 –30]	13.7 ± 5.1 [5 –32] *(n = 281)*
Contact with children in the workplace	70 (47 %)	139 (100 %)	285 (100 %)
Contact with pre-school children in the workplace	62 (42 %)	132 (95 %)	140 (49 %)
Contact with children aged < 3 years in the workplace	36 (24 %)	58 (42 %)	–
Contact with patients	127 (86 %)	–	–

[‡] Since conducting this study, the Occupational-Medical Institute for Schools (*Arbeitsmedizinisches Institut für Schulen*, AMIS-Bayern) was founded at the Bavarian Office for Health and Food Safety (*Bayerisches Landesamt für Gesundheit und Lebensmittelsicherheit*, LGL) by order of the Bavarian State Ministry of Health and Care and the Bavarian State Ministry of Education. AMIS-Bayern provides occupational-medical advice for the principals and employees of state-run schools (especially in cases of pregnancy).

well as the highest rate of full immunity against all diseases included in the comparison (measles, rubella, varicella, pertussis; $p < 0.001$; OR: 2.506 [1.608–3.905]). The participants from C2 were significantly more likely to have immunity against measles than their counterparts in C3. With the exception of rubella, C3 showed the poorest immunity rates during pregnancy and the lowest rate of full immunity against the diseases included in the comparison. The percentage of participants immune to varicella and the percentage immune to rubella did not differ significantly between the collectives (varicella: $p = 0.371$ for C1 and $p = 0.340$ for C2 when compared to C3; rubella: $p = 0.331$ for C1 and $p = 0.071$ for C2 when compared to C3). Younger age (<32 years) was a significant predictor for a higher probability of immunity against measles and for a higher probability of full immunity against the diseases included in the comparison in the binary logistic regression model. Table 3 provides an overview of immunity rates within the individual collectives. A comparison of immunity rates between Collectives 1, 2, and 3 is shown in Fig. 1.

By combining Collectives 1 and 2 (C1+2), we merged data from women who belonged to different occupational fields (medicine and childcare), but who all had regular access to occupational-health services (in contrast to the teachers in C3, who had no such access). The participants in C1+2 were more likely to be immune to measles ($p < 0.001$; OR: 4.795 [2.429–9.467]); they showed a higher immunity rate against pertussis (non-significant, $p = 0.069$), and they were more likely to have full immunity against measles, rubella, varicella and pertussis ($p = 0.001$; OR: 1.787 [1.265–2.526]). There were almost no differences in immunity rates against rubella and varicella between Collectives 1+2 and 3 (rubella: $p = 0.709$; varicella: $p = 0.963$). Fig. 2 shows a comparison of the immunity rates in C1+2 and C3. Higher age (≥32 years) correlated with a lower likelihood of immunity against measles ($p < 0.001$; OR: 0.332 [0.183–0.601] and a lower likelihood of full immunity against the diseases included in the comparison ($p = 0.043$; OR: 0.701 [0.496–0.989]).

The three collectives differed significantly in age and week of pregnancy at the time of occupational-medical consultation (Kruskal-Wallis test; age: $p < 0.001$, week of pregnancy: $p < 0.001$) (see Table 2). The women in C3 showed the highest age (31.9 years) and highest week of pregnancy (13.7 weeks). C1 was on average somewhat younger with a mean age of 31.1 years and was seen earlier by the occupational physician at a mean 11.7 weeks of pregnancy. The youngest study group was C2 with a mean age of 30.2 years, having reached a mean 9.1 weeks of pregnancy at consultation. This means a difference of more than two and a half weeks less compared to C1 and of more than four and a half

Table 3
Immunity rates.

Immunity rates	Collective 1 (n = 148)	Collective 2 (n = 139)	Collective 3 (n = 285)	Collective 1+2 (n = 287)
Measles	98.5 % *(n = 134)*	93.3 % *(n = 135)*	81.1 %	95.9 % *(n = 269)*
Rubella	98.6 % *(n = 142)*	92.7 % *(n = 137)*	97.2 %	95.7 % *(n = 279)*
Varicella	93.9 %	97.8 % *(n = 136)*	95.8 %	95.8 % *(n = 284)*
Pertussis	79.1 %	63.7 % *(n = 135)*	63.9 %	71.7 % *(n = 283)*
Mumps	94.6 % *(n = 130)*	85.2 % *(n = 135)*	76.1 %	No combination of data because of methodological differences between Collectives 1 and 2
Full immunity against measles, rubella, varicella, and pertussis	73.8 % *(n = 141)*	60.0 % *(n = 135)*	51.9 %	67.0 % *(n = 276)*

If data for any variable could not be obtained for all women, the variable was calculated based on the actual number of available data sets (given in italicized parentheses).

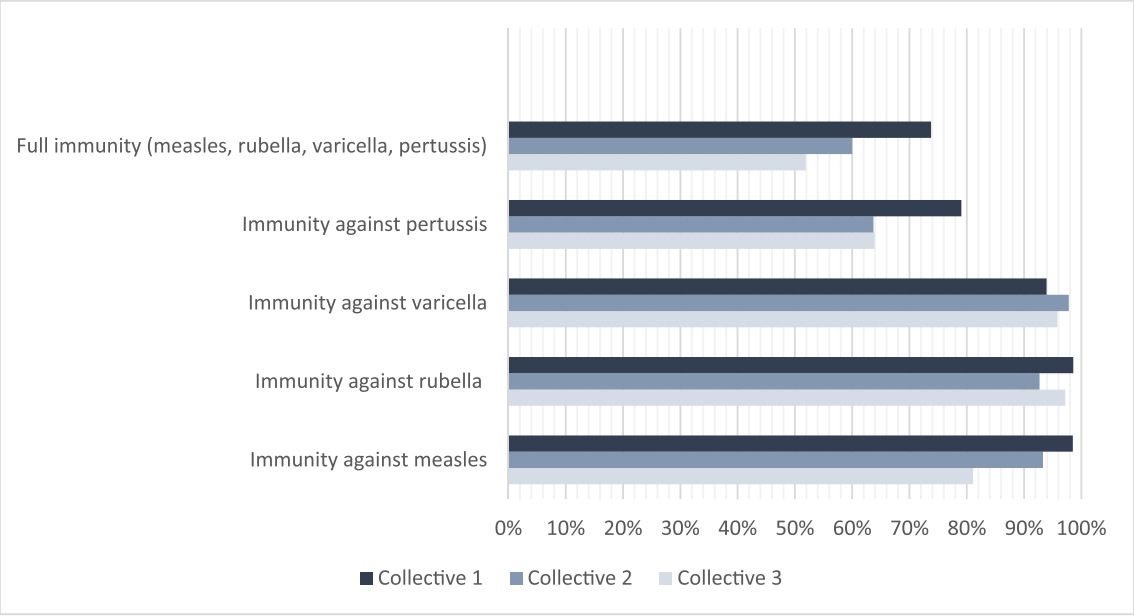

Fig. 1. Comparison of immunity rates between Collectives 1, 2, and 3.

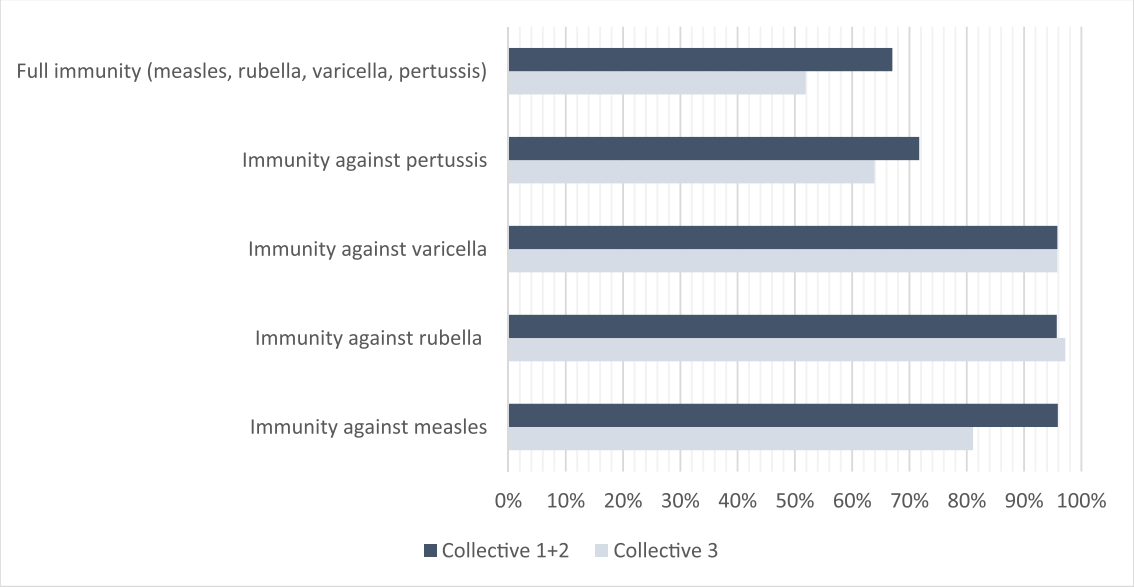

Fig. 2. Comparison of immunity rates between Collectives 1 + 2 and 3.

weeks less compared to C3.

4. Discussion

4.1. Immunity rates found in comparable studies

Overall, we found high rates of immunity against rubella (96.5 %) and varicella (95.8 %), which correspond to the immunity rates reported in a systematic review by Kofahl et al. on employees in childcare and comparison groups from 2020 (rubella: 89.8–98.7 %, varicella: 93.6–100 %). Immunity to measles proved to be lower in our study group (88.3 %) than in the systematic review (91.3–91.7 %), whereas precisely the opposite was true for pertussis (study group: 67.8 %; review: 14.3–45.8 %) [17]. Wutzler et al. described a similar varicella seropositivity rate of 96.3 % in women of childbearing age (18–39 years) [16], whereas a cross-sectional study among medical students by Schmid et al. (2004) found very low rates of documented immunity to vaccine-preventable diseases (pertussis: 2 %, measles: 32 %, mumps: 24 %, rubella: 25 %) [18]. A cross-sectional multicenter health survey at German and Hungarian universities found basic/booster immunization to pertussis in 39.0 % / 43.6 % of Hungarian and 15.8 % / 60.5 % of German medical students [19]. A higher vaccination-based immunity in German children aged 3 to 17 years is reported by the German KiGGS study, with vaccination-based immunity rates of 92.3 % for mumps, 93.1 % for rubella, 50.9 % for varicella, and 78.9 % for pertussis (7–17 years) [8].

4.2. Strengths and limitations of the present study

However, these studies neither addressed the same occupational groups as our study nor did they exclusively include pregnant women. Even though the review by Kofahl et al. [17] centers on employees in

childcare, our findings are only partially comparable with the immunity rates reported in the review, as in the DEGS1 study [20] included in the review, both vaccination certificates and self-reported vaccinations were relied upon to assess the vaccination status of participants, whereas, in our study, self-reported immunization was not accepted as proof of immunity. We thus eliminated the risk of a recall bias which must be considered an important confounding factor in many other studies dealing with immunity rates.

Studies evaluating immunity rates in pregnant women, especially those with an occupational risk of infection, are scarce in Germany and in Europe. This is a drawback, since the beginning of pregnancy is a highly decisive point in time where immunity is concerned: Live vaccines are contraindicated during pregnancy [6], and any existing immunity gaps regarding measles, mumps, rubella, or varicella therefore remain unchanged until the end of the pregnancy. As a result, the number of pregnant women with corresponding immunity gaps during pregnancy found in our study is tantamount to the number of women who have not been reached or convinced by vaccination recommendations in time.

Nevertheless, there are some limitations that should be kept in mind when interpreting the results of our study. We were not able to collect comprehensive data on some factors that might have influenced vaccination coverage and immunity, such as the number of previous pregnancies and the number of previous OMCs. In C3, participants were offered an OMC on the basis of a research project. Therefore, it is likely that not all schools and pregnant teachers have been reached and informed about this offer, so it is possible that our sample is not representative of all Bavarian teachers. Finally, we did not gather information on the individual reasons that led to the observed immunity gaps, which would have been valuable for contextualizing our findings and drawing the right conclusions for appropriate preventive measures.

4.3. Incidence rates and outbreaks of communicable diseases in Germany from 2014 to 2019

The incidence of rubella in Germany ranged from 0.03/100,000 to 0.05/100,000 in the years 2014 to 2016 and remained stable at 0.02/100,000 from 2017 to 2019. Outbreaks were reported for every year since 2014 except 2018, with 2 to 9 persons concerned, most of them children who contracted the disease within their family or childcare facility.

The incidence of measles in Germany varied between 0.4/100,000 and 1.1/100,000 in the years 2014 to 2019. The documented number of measles outbreaks was 73 for 2018 and 65 for 2019, with more than 300 persons concerned, respectively. Most of the cases were due to transmissions within families and community or medical facilities. Some outbreaks could be traced back to contagions in public transport, and one outbreak in 2019 was documented as imported from Ukraine.

For mumps, an incidence between 0.6/100,000 and 1.0/100,000 was reported for Germany in the years 2014 to 2019, with the highest age-specific incidences being found in children under 10 years.

For varicella, there were incidences between 24.7/100,000 and 30/100,000 from 2014 to 2019, with the highest age-specific incidences in the age group under 10 years. In most years since 2014, there were more than 1000 disease outbreaks with 4,000 to over 5,000 cases, predominantly in childcare and community facilities with most persons concerned being children [21,22,23,24,25,26].

Fortunately, varicella shows a high frequency of natural infection with the wild virus for women of childbearing age [15,16]. Nevertheless, like for measles, the contagion index is nearly 100 % [27,28], which means that almost everybody without immunization who encounters a sick person will become infected, too. Considering the risk of serious complications for the fetus or infant if the mother falls ill with a vaccine-preventable disease during pregnancy, such as congenital rubella syndrome or congenital varicella syndrome, subacute sclerosing panencephalitis from a measles infection, or severe pertussis infections that may be fatal to newborns [1,29,30], even low rates of immunity gaps during pregnancy require additional preventive efforts.

4.4. Differences in immunity rates between collectives 1, 2, and 3

By comparing the three collectives, we were able to demonstrate that there are significant differences in immunity rates during pregnancy between different socioeconomic groups in Germany. As C1 showed the highest immunity rates during pregnancy (apart from varicella), it must be assumed that there are factors which have led to more comprehensive immunization prior to pregnancy in this group. Such factors may include differences in age structure, socioeconomic status, the number of preceding pregnancies, or the medical training most of the women in C1 had undergone [20,31,32]. Another reason might be a varying quality of general and gynecological care in our individual collectives. The recommendations for vaccinations were based on the STIKO guidelines and were therefore identical for all three collectives, except for the fact that the employees in C1 were only considered to be fully vaccinated against measles if they had received two vaccinations (while in C2 and C3, one vaccination during adulthood was accepted). Thus, the vaccination recommendations for C1 were more comprehensive and vaccinations probably offered more frequently than in C2 and C3. This difference underscores the fact that the varying levels of access to occupational-medical services must be considered as well. The regular occupational-medical consultations on immunity and infections in C1 might have enhanced risk awareness, encouraging the women to complete their immunization on time, prior to becoming pregnant. With an in-house company physician, trust between employee and occupational physician might have been more solid than in the case of external occupational-health services (as in C2), which might have had a positive impact on immunity rates.

Interestingly, we did not see these differences for immunity against varicella and rubella. The reason for this might be found in the high rates of natural infection with the wild-type varicella virus among the age groups considered, which might have rendered active varicella immunization unnecessary [15,16]. For rubella, it is widely known that there is a risk of serious complications if the disease is contracted during pregnancy. This assumption is supported by the fact that, among the infections relevant to our study, only immunity against rubella was explicitly mentioned in the German maternal health passport until 2020 [33,34]. It is possible that vaccinations against rubella were therefore generally recommended earlier and more frequently than vaccinations against other diseases that can pose a risk during pregnancy.

4.5. Public perception of and stance towards active immunization in Germany

As described in the introduction, official and large-scale studies in the German population [8,9] have shown insufficient vaccination coverage for all vaccine-preventable diseases targeted by this study. Despite all measures taken before the implementation of the Measles Protection Act, Germany has not been able to reach the WHO goal of 95 % immunization coverage for measles, which might be due to different reasons. On the one hand, the willingness to be vaccinated among medical students and among participants of a large-scale, representative survey among more than 5,000 German adults was shown to be influenced by their own perceived risk and their knowledge about the respective disease [31,35]. Therefore, providing people with easily comprehensible information on vaccinations, diseases, and their potential consequences might help to increase immunization rates. On the other hand, Diehl and Hunkler reported that there seems to be a group of 5 % of parents who are clearly hesitant to vaccinations and openly opposed to vaccination recommendations by STIKO [36]. These findings are consistent with the large-scale, representative survey mentioned above which found 4 % of participants defining themselves as reluctant or opposed to vaccinations [31]. This hesitation might be connected to a

distrust in official authorities and the government who encourage vaccinations, as in the German "*Querdenken*" movement [36,37]. It is unclear whether this last group can be reached by objective arguments.

4.6. Possible consequences of mandatory vaccinations

Vaccination hesitancy and resistance may be used as justification for implementing the Measles Protection Act to increase immunization coverage. However, the enforcement of vaccinations by authorities might just as well achieve the exact opposite result, causing even more reluctance and skepticism. This problem is aggravated by the fact that there is no single vaccination against measles. It is only available in combination with either mumps and rubella or mumps, rubella, and varicella. As a result, it is often claimed that a mandatory measles vaccination virtually results in mandatory mumps and rubella vaccinations as well, which even increases distrust and opposition in some people. On the other hand, this regulation might lead to an improved vaccination coverage of mumps, rubella, and even varicella.

What is more, the important role played by active immunization and by further containment and control measures imposed by German authorities during the SARS-CoV-2 pandemic may have influenced people's stance towards vaccinations in one direction or the other. Graeber et al. demonstrated that the perception of mandatory vaccinations is ambivalent in the German population and that half of German residents reject the idea of mandatory vaccinations against COVID-19 [38].

The combination of all these factors following in the wake of enforcing a legal obligation for vaccinations are likely to influence vaccination coverage in Germany not only for measles, but for other diseases as well, the exact impact and final result of which being very difficult to predict.

5. Conclusions

We found pregnancy-relevant immunity gaps in all three collectives of our study group. Although all women had regular access to medical consultation on immunization by family doctors and gynecologists, there were significant differences in immunity rates between the collectives.

In light of the potentially devastating consequences of infections during pregnancy, full immunization coverage should be the goal for all women, independent of their occupational risk of infection. The Measles Protection Act must be seen as a means to an end; however, German health-policy makers would be well-advised to simultaneously put an increased effort into earlier, better, and more comprehensive advice on immunization to raise risk awareness and willingness to get vaccinated in all citizens, but especially in women prior to pregnancy.

To this end, all medical professionals charged with the medical treatment and care of women and girls should be involved in an interdisciplinary effort to improve vaccination rates. Consequently, occupational-medical consultations on immunity should not be limited to women with an occupational risk of infection, but rather extended to all women seen during occupational-medical check-ups.

CRediT authorship contribution statement

Anna Wolfschmidt-Fietkau: Writing – original draft, Methodology, Investigation, Formal analysis, Data curation, Conceptualization. **Ruediger S. Goertz:** Conceptualization, Data curation, Writing – review & editing. **Stephanie Goertzen:** Writing – review & editing, Data curation, Conceptualization. **Klaus Schmid:** Writing – review & editing, Conceptualization. **Marie Seidling:** Writing – review & editing, Investigation. **Elsa Gherman:** Writing – review & editing, Investigation. **Uta Ochmann:** Writing – review & editing, Methodology. **Hans Drexler:** Writing – review & editing, Supervision, Conceptualization.

Declaration of competing interest

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Data availability

The data that has been used is confidential.

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