

**ПОПУЛЯЦИОННЫЙ ИММУНИТЕТ К ВАКЦИНОУПРАВЛЯЕМЫМ
ИНФЕКЦИЯМ (КОРИ, КРАСНУХЕ, ЭПИДЕМИЧЕСКОМУ
ПАРОТИТУ) У НАСЕЛЕНИЯ САНКТ-ПЕТЕРБУРГА И
ЛЕНИНГРАДСКОЙ ОБЛАСТИ**

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**HERD IMMUNITY TO VACCINE PREVENTABLE INFECTIONS IN SAINT
PETERSBURG AND THE LENINGRAD REGION: SEROLOGICAL
STATUS OF MEASLES, MUMPS, AND RUBELLA**

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Резюме

Введение. Специфическая профилактика кори, краснухи и эпидемического паротита явилась главной предпосылкой радикального снижения частоты этих инфекций в Российской Федерации. Наблюдающийся в последние годы рост доли серонегативных лиц привёл к увеличению заболеваемости корью, что напрямую связано с низким популяционным иммунитетом, который обеспечивает защиту населения только в условиях высокой плотности иммунизированных лиц и их равномерного распределения в популяции. Оценить число иммунизированных лиц возможно лишь при проведении сероэпидемиологического мониторинга популяционного иммунитета.

Цель исследования. Изучение уровня популяционного иммунитета населения Санкт-Петербурга и Ленинградской области к вирусам кори, краснухи и паротита.

Материалы и методы. В исследовании участвовали 6774 жителя региона (волонтёры) в возрасте от 1-го года до 70+ лет. Репрезентативность обследуемой когорты обеспечивалась Веб-приложением «Мониторинг популяционного иммунитета социально значимых инфекций», использованного на стадии регистрации волонтёров путём рандомизации и регулирования объёма выборки в возрастных группах. В ходе исследования участники заполняли анкету и сдавали пробы венозной крови для определения IgG антител к вирусам кори, краснухи и паротита методом ИФА с использованием тест-систем производства АО Вектор-Бест, РФ.

Результаты. В сентябре 2023 г. в Санкт-Петербурге и Ленинградской области популяционный иммунитет населения соответствовал критерию эпидемиологического благополучия только в отношении краснухи – во всех возрастных группах доля серонегативных лиц не превышала 15%, большинство волонтёров имели высокий уровень антител как после заболевания, так и после вакцинации. Для кори и паротита критерием эпидемиологического благополучия считается наличие не более 7%

серонегативных лиц. Достаточный уровень серопревалентности к вирусу кори выявлен только в старших возрастных группах (60 лет и старше), а к вирусу паротита не выявлен ни в одной возрастной группе. Средний уровень серопревалентности населения Санкт-Петербурга и Ленинградской области к вирусам кори, краснухи и паротита составил 81.4%, 95.5% и 78.4% соответственно. Проблемными возрастными группами с низкой серопревалентностью к вирусу кори (62,4-74,3%) оказались подростки (12-17 лет) и молодые взрослые (18-39 лет). Большинство серопозитивных лиц, вакцинированных от кори, имели низкие уровни антител; высокие уровни отмечены преимущественно у лиц старшего возраста, переболевших корью. Низкая серопревалентность к вирусу паротита чаще наблюдалась среди взрослых (около 70%) в возрасте от 18-ти до 49-ти лет. Распределение серопревалентности в зависимости от рода занятий было сравнительно однородным с некоторым преобладанием серопозитивности среди пенсионеров и школьников.

Заключение. Используемая в РФ система специфической профилактики вакциноуправляемых вирусных инфекций показала высокую эффективность и способствовала формированию популяционного иммунитета, позволившего в течение многих лет до минимального уровня снизить риск появления как спорадических, так и групповых заболеваний. В настоящее время серопревалентность населения Санкт-Петербурга и Ленинградской области к вирусам кори и эпидемического паротита недостаточна для обеспечения эпидемиологического благополучия и требует принятия соответствующих управленческих решений и проведения дополнительных профилактических мероприятий, направленных на повышение популяционного иммунитета к этим инфекциям.

Ключевые слова: Вакциноуправляемые инфекции, популяционный иммунитет, корь, краснуха, паротит, серопревалентность,

ИММУНИТЕТ К КОРИ, КРАСНУХЕ И ПАРОТИТУ
IMMUNITY TO MEASLES, RUBELLA AND MUMPS

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Abstract

Specific measles, mumps, and rubella prevention has been the main prerequisite for a striking decline in the incidence of such infections in Russia. An increase in the percentage of seronegative individuals observed in recent years resulted in higher measles incidence being directly related to low herd immunity that accounts for a population protection solely under conditions of a high density of immunized individuals and their uniform distribution in the population. The number of immunized individuals may be estimated only while conducting seroepidemiological monitoring of herd immunity. Objective of the study: to assess a level of herd immunity in the St. Petersburg and Leningrad Region population against measles, mumps, and rubella viruses. Materials and methods. There were enrolled 6,774 residents into the study: volunteers aged from 1 to 70+ years. The representativeness of the surveyed cohort was ensured by using the Web application "Monitoring of herd immunity against socially significant infections", used at the stage of volunteer enrollment, by randomization and regulation of the sample size in age groups. Participants filled out a questionnaire and agreed to provide venous blood samples to assess IgG antibody levels against measles, mumps, and rubella viruses by using ELISA. Results. In September 2023, in St. Petersburg and the Leningrad Region, herd immunity met the criterion for epidemiological well-being only with respect to rubella. In all age groups, the proportion of seronegative individuals did not exceed 15%, and most volunteers had high Ab levels, both after illness and vaccination. For measles and mumps, the criterion for epidemiological well-being is considered not to exceed more than 7% seronegative individuals. A sufficient level of measles seroprevalence was detected only in older age groups (≥ 60 years old). Sufficient mumps seroprevalence was not detected in any age group. The average population (St. Petersburg, Leningrad Region) seroprevalence magnitude for measles, rubella, and mumps viruses were 81.4%, 95.5%, and 78.4%, respectively. The problematic age groups with low measles seroprevalence (62.4–74.3%) were adolescents (12-17 yrs) and young adults (18-39 yrs). Most seropositive individuals vaccinated against measles had low Ab levels; high levels

were noted mainly in older measles convalescent individuals. Low mumps seroprevalence (~70%) was more often observed among adults aged 18 to 49 years. The distribution of seroprevalence in various occupational group was relatively uniform, with some predominance of seropositivity among pensioners and schoolchildren. Conclusion. The system of specific prophylaxis for vaccine-preventable viral infections used in Russia has shown high efficacy and contributed to the formation of herd immunity, which for many years allowed to lower a risk of both sporadic and group infections to minimal levels. Currently, measles and mumps seroprevalence in the local population is maintained at insufficient level to ensure epidemiological well-being. This necessitates making appropriate management decisions and conducting additional preventive measures aimed at enhancing relevant herd immunity.

Keywords: vaccine-preventable infections, herd immunity, measles, rubella, mumps, seroprevalence, antibodies, St. Petersburg, Leningrad Region, population, cohort study.

1 Introduction

Acute infectious diseases accompany an individual person throughout their life. Most often, they manifest as sporadic cases. Less often, local outbreaks in groups or limited areas occur. A sudden increase in the number of cases above the predicted level among the population of a certain area or region is classified as an 'epidemic', and if the population of large regions or continents is involved, it is customary to use the term 'pandemic' [50, 56]. A striking example of the evolution of the epidemic process is COVID-19, which began in 2020, soon developing into a pandemic that affected most countries globally. As of 06/04/2024, more than 775 million cases have been registered [68]. Currently, COVID-19 has transformed into a typical seasonal respiratory infection [47]. One of the reasons for this transformation has been the formation of herd immunity, and the use of a wide range of vaccines played a role.

Herd immunity as a protective factor for a susceptible population works only in conditions of a high proportion of immunized individuals and their uniform distribution in the population. Estimating the percentage of truly immune individuals in a population (both as a result of infection or vaccination) is a complex task. Analysis of morbidity based only on registration of laboratory-confirmed manifest forms of illness does not allow for a reliable assessment of post-infectious immunity in the population. The share of individuals with post-vaccination immunity may differ significantly from official vaccination data due to several factors: underestimation of actual population size (e.g., due to migratory processes); ineffectiveness of individual vaccine batches (e.g., due to non-adherence to storage or transportation conditions); or as a result of individuality in the formation of immunological memory in specific individuals.

These factors necessitate monitoring of herd immunity in different age groups living in all Russian administrative regions. The use of analytical methods and laboratory systems in this work allows for the prompt analysis of a large array of data. This provides a scientific basis for understanding the causes behind evolution of the epidemiological situation with respect to specific infections. Such

31 an approach can also clarify forecasts regarding expected epidemiological
32 conditions, events, and burdens. Vaccine-based prevention technologies have made
33 it possible to achieve outstanding success in reducing the spread of such highly
34 contagious infections as measles, mumps, and rubella. Nevertheless, monitoring of
35 ongoing, adequate implementation is a prerequisite for maintaining progress in
36 recent decades and reducing suffering.

37 Characteristic features of these infections are the airborne transmission
38 mechanism and an absence of pathogen-specific therapeutic choices. In global
39 practice, the trivalent vaccines M-M-P II and Priorix are primarily used for specific
40 prevention, forming effective specific immunity simultaneously to measles, mumps,
41 and rubella [26, 41]. In Russia, the three-component vaccine Vactrivor is used for
42 this purpose [16].

43 Specific prevention has been the main prerequisite for a radical
44 reduction in the measles incidence in recent decades to sporadic cases, mainly of
45 imported origin. However, some periods have seen fluctuations in incidence, for
46 example from 2012 to 2018. According to Rospotrebnadzor, 6 measles cases were
47 registered in the Leningrad Region in 2022, with 1 case in St. Petersburg. The
48 favorable situation persisted until 2023, when the number of measles cases began to
49 increase rapidly, and currently continues to increase, in all Russian regions.

50 Moreover, most cases are no longer associated with importation, and
51 diseases and/or outbreaks occur, including among the vaccinated population. In
52 2023, there was a trend towards an increase in measles cases in eight regions of the
53 Northwestern Federal District (NWFED): St. Petersburg; Leningrad Region;
54 Arkhangelsk Region; Murmansk Region; Kaliningrad Region; Vologda Region; the
55 Komi Republic; and the Republic of Karelia.

56 As of September 2023, 271 verified measles cases were registered (2
57 per 100,000 pop.). In 70% of cases, the disease developed among unvaccinated
58 individuals, and 5% of patients could not confirm or deny a history of vaccination.
59 In 10% of cases, the disease developed among those vaccinated once. In 15%,
60 occurrence was after revaccination. Most illnesses were associated in some way with

61 importation from other countries, mainly Tajikistan. In all cases, the measles virus
62 genotype D8 MeaNS 8248 was identified.

63 Rubella cases have not been registered in the Northwestern Federal
64 District since 2021, which can probably be explained by a high level of herd
65 immunity among the population.

66 Despite mumps vaccination within the framework of the national
67 schedule, manifest cases of this disease are still observed in the city and region. In
68 2022, 12 cases were detected (0.09 per 100,000 pop.), mainly in St. Petersburg, and
69 13 cases were already registered in the first 9 months of 2023. Mumps is often
70 observed in vaccinated individuals worldwide, which is apparently associated with
71 a decrease in the intensity of post-vaccination immunity according to time elapsed
72 after immunization [28, 34, 57]. Summarized data on the incidence of these
73 infections (measles, mumps, rubella), illustrating the information above, are shown
74 in Figure 1.

75 Thus, despite vaccination against these airborne transmissible
76 pathogens, cases of vaccine-preventable infections are still registered. The only
77 factor capable of preventing the spread of such pathogens is the formation of herd
78 specific immunity [2, 38, 53]. Clearly, progress in this area is impossible without an
79 assessment of the status and strength of herd immunity, including the possible
80 influences of age, region, and professional category [30, 40]. The aim of the study
81 was to assess herd immunity to measles, mumps, and rubella viruses in a cohort of
82 volunteers living in St. Petersburg and the Leningrad Region.

83 **2 Materials and Methods**

84 **2.1 Characteristics of the analyzed volunteer cohort**

85 A cross-sectional, randomized study was conducted under the
86 Rospotrebnadzor program 'Assessment of herd immunity to vaccine preventable and
87 other relevant infections in the St. Petersburg and Leningrad Region Population', as
88 approved by the local ethics committee of the Saint Petersburg Pasteur Institute. All
89 participants, or their legal representatives, were familiarized with the purpose and
90 methodology of the study and signed informed consent. Random selection of

91 volunteers for the study was carried out using a web application with a questionnaire.
92 The selected volunteers were stratified into nine age groups: 1-5 years; 6-11 years;
93 12-17 years; 18-29 years; 30-39 years; 40-49 years; 50-59 years; 60-69 years; and
94 70+ years. The size of a representative sample was calculated using a formula based
95 on the Moivre-Laplace limit theorem [8, 12]. The total number of volunteers in the
96 cohort surveyed was 6,774 people.

97 Child volunteers (1-17 years) made up 20.8% of the total number of
98 those surveyed and were divided into three groups: 1-5 years (5.4%); 6-11 years
99 (7.5%); and 12-17 years (7.9%) (Table 1). The proportions of volunteers in adult age
100 groups were approximately the same and differed in numbers by 1.5 – 2.5%. In total,
101 the cohort consisted of 1,789 men (26.4%) and 4,985 women (73.6%). Hence,
102 women participated in the study more actively (by a factor of 2.8). Representatives
103 of various fields of activity took part in the study (Table 2).

104 As follows from Table 2, the largest numbers of volunteers belonged to
105 the groups of pensioners and medical workers. The smallest was IT specialists. The
106 predominance of pensioners and medical workers in the cohort can be explained, to
107 a certain extent, by the greater social activity, and more responsible attitude to their
108 health, of volunteers in these two categories.

109 2.2 Research methods

110 During a wide information campaign, individuals who expressed a
111 desire to participate in the study filled out an online questionnaire with personal data
112 which was sent to the Web application for subsequent analysis. The collected
113 information included: full name; gender; age; area of residence; field of activity;
114 presence of chronic diseases; and contact information. Individuals who met the
115 inclusion criteria (absence of acute illness at the time of the study) were invited to
116 provide additional information and blood for subsequent laboratory testing in
117 person. The methodology for organizing and conducting the study has been
118 described earlier in detail [12].

119 At the blood collection point, the registrar and volunteer filled out an
120 extended questionnaire, including questions about medical history (measles, mumps,

121 rubella, other vaccine-preventable infections). Also recorded were vaccinations and
122 re-vaccinations against the listed infections (including vaccine names and dates of
123 administration). The information was taken from the vaccination certificate provided
124 by the volunteer, or clarified from other medical documentation.

125 In addition to the survey using a specially designed questionnaire, all
126 volunteers were tested for the presence of antibodies to the measles, mumps, and
127 rubella viruses.

128 Blood samples were taken from the ulnar vein into vacutainers containing
129 ethylenediaminetetraacetic acid solution (K₃EDTA). Vacutainers were centrifuged
130 at room temperature. Blood plasma was separated from cellular elements,
131 transferred to microtubes, and stored at 4°C until testing.

132 ELISA testing was performed using reagent kits manufactured by
133 Vector-Best (Russia) according to manufacturer instructions: "VectoMeasles-IgG"
134 for the presence and level of antibodies (Abs) to the measles virus; "VectoRubella-
135 IgG" for the presence and level of Abs to the rubella virus; and "VectoParotit-IgG"
136 for the presence of Abs to the mumps virus. The quantitative content of antibodies
137 to measles and rubella viruses was expressed in IU/ml. The study flow chart is shown
138 in Figure 2.

139 2.3 Statistical processing

140 Statistical processing was performed using methods of variation
141 statistics and the Excel 2011 package. The relationships between age and
142 seroprevalence levels were calculated using the Pearson method. Statistical
143 processing of proportions was performed using the method of A. Wald and J.
144 Wolfowitz [65], as modified by A. Agresti and B. A. Coull [23]. Calculation of the
145 statistical significance of differences in shares was performed using the z test [5].
146 When assessing diefferences in the compared indicators, a probability level was used
147 to estimate significance ($p \leq 0.05$, unless indicated otherwise).

148 3 Results

149 3.1 Herd immunity to the measles virus

150 The average measles seroprevalence in the volunteer cohort was 81.4%
151 (95% CI: 80.4–82.3). It was distributed unevenly across age groups, specifically:
152 with maximum values in those >60 years of age (94.8–96.2%); and with a smaller
153 share of seropositive volunteers in younger age groups from 12 to 49 years (<80%).
154 The differences were significant at $p \leq 0.05$. Seroprevalence in young children's
155 groups (1-5 years, 6-11 years) did not differ from the average cohort value (Fig. 3).

156 When analyzing seroprevalence, it is necessary to take into account
157 changes in the national measles vaccination strategy. A single vaccination was
158 introduced in 1968.

159 In other words, vaccinated individuals aged 40–55 were likely vaccinated in
160 childhood once. A full immunization program (2 vaccinations) was introduced in
161 1986, which correlates with those under 40 years of age. Persons over 55 years of
162 age were likely only vaccinated in adulthood according to epidemiological
163 indications. It was in adults, starting from 50 years of age, that we noted a
164 statistically significant increase in seroprevalence. In the absence of routine
165 childhood vaccination, this may indicate a previous infection. Low measles
166 seroprevalence among adults aged 18-39 may be associated with the socioeconomic
167 situation in the post-Soviet period. Particularly noteworthy is the high proportion of
168 seronegative individuals among children (18.4–25.7%), probably as a result of
169 medical exemptions and parental refusals to vaccinate.

170 When assessing seroprevalence depending on field of activity, no
171 significant differences were noted by overall professional group. However, the
172 highest seroprevalence level (95.9%; 95% CI: 94.6–96.9) was observed among
173 pensioners (differences with the final value of the indicator were significantly
174 higher, $p < 0.001$), most of whom probably acquired immunity to measles as a result
175 of a childhood infection. The lowest levels were observed among schoolchildren
176 (77.9%; 95% CI: 74.9–80.6) and students (66.7%; 95% CI: 60.1–72.7), which were
177 significantly lower than the final cohort value ($p < 0.05$). These data fully correlate
178 with the age distribution of seroprevalence described above.

179 In addition to seroprevalence, the study included a quantitative
180 assessment of anti-measles IgG levels in volunteers of different ages (Fig. 4).

181 The observed trends differed in both shape and direction. The
182 distribution of seronegative individuals (<0.18 IU/ml) was bell-shaped. The smallest
183 number of such individuals was detected among those aged ≥ 60 years. The share of
184 individuals with low anti-measles IgG levels (0.18–0.5 IU/ml) was the highest
185 among children and gradually decreased with advancing age category. It should be
186 noted that such dynamics are not accidental, as the correlation coefficient shows ($\rho =$
187 0.85 ; $p < 0.01$).

188 A negative trend was observed in relation to the average IgG level (0.5–
189 1.0 IU/ml). As in the previous group, the largest share of individuals with average
190 levels was detected among children. The smallest was seen among those aged ≥ 60
191 years ($\rho = -0.85$; $p < 0.01$). The distributions of seropositive individuals with high
192 (1.01–2.0 IU/ml) and very high (>2.0 IU/ml) IgG levels are interesting. In the group
193 with high levels, the trend changed from negative to positive, although with a low
194 determination coefficient ($\rho = 0.61$; insignificant at $p > 0.05$). The most interesting
195 finding was seen regarding the distribution of seropositivity with the highest anti-
196 measles IgG levels (Fig. 5). The regression curve remained almost at the same level
197 (4.9–5.7 IU/ml) in age groups from 1–3 years to 30–39 years, and then increased
198 almost exponentially to 69.8% (95% CI: 66.8–72.6).

199 Thus, low and medium anti-measles IgG levels were predominantly
200 detected in individuals under 50 years of age, while high Ab levels were detected in
201 individuals aged ≥ 50 years. It can be assumed that the higher share of seropositive
202 individuals with the maximum IgG concentration in older age groups is due to a
203 history of manifest infection.

204 The surveyed cohort was heterogeneous in terms of infectious and
205 vaccinal status. Overall, 4,746 individuals provided information about a history of
206 measles and vaccination in the questionnaire. After verification of questionnaire data
207 against medical records, 2,628 individuals for whom reliable information was

208 available (Supplementary Table 3S) were divided into 4 groups: 'sick, never
209 vaccinated' (SNV, n=105); 'sick, vaccinated' (SV, n=58);

210 'never sick, vaccinated' (NSV, n=2,061); and 'never sick, never vaccinated'
211 (NSNV, n=404). It is necessary to acknowledge that such a division is somewhat
212 arbitrary since information about vaccination was confirmed by medical records, yet
213 a history of illness or lack thereof was not documented by most volunteers.
214 Information on the relationship between history, the presence of measles
215 seropositivity, and anti-measles Ab levels was of interest (Fig. 5).

216 In the groups of volunteers who had had measles (SV, SNV), regardless
217 of vaccinal status, seroprevalence and Ab levels were generally higher than in the
218 groups who had not had measles (NSV, NSNV), also regardless of vaccination.

219 As expected, the highest share of seropositive individuals was found
220 among volunteers who had indicated a history of illness in the questionnaire,
221 regardless of vaccinal status (groups SNV, SV). In these groups, seroprevalence was
222 94.8–99.0% (Fig. 5), and the vast majority (~80%) had high Ab levels (≥ 1 IU/ml)
223 (Fig. 6).

224 In the groups with no official history of measles (NSNV, NSV),
225 seronegativity was about 22%. Seropositivity in these groups was quite high (~78%)
226 regardless of vaccinal status, although significantly lower than the value for those
227 with a measles history ($p < 0.001$). The share of individuals with high Ab levels (> 1
228 IU/ml) was significantly lower than that of those who had had measles. Regarding
229 high Ab level individuals: they were 44.0% among the unvaccinated (NSNV) (of
230 which 32.9% had Abs > 2 IU/ml); and they were 22.8% among those vaccinated
231 (NSV) (of which 10.1% had Abs > 2 IU/ml). These results are apparently explained
232 by the structure of these two groups. Half of the volunteers in the NSNV group were
233 over 50 years old. As shown earlier, seropositivity at this age is about 90% and
234 higher. This indicates childhood measles infection which the volunteer did not
235 remember, or did not know about. This is understandable, especially if the illness
236 was mild. In any case, if infection occurred, then post-infectious immunity was
237 formed, which is usually accompanied by high Ab levels. Unvaccinated individuals

238 have a significantly higher chance of getting measles than vaccinated people. This
239 is confirmed by the greater share of people with high Ab levels in the unvaccinated
240 group.

241 In the largest group, 'never sick, vaccinated' (NSV), the majority were
242 children and people under 60 years of age who were vaccinated according to the
243 national schedule. They would be expected to have post-vaccination immunity.
244 However, more than 20% of those in this group did not have anti-measles antibodies,
245 and only 28% of volunteers had high levels.

246 Of the total, 2,297 volunteers were vaccinated against measles. About
247 40% of individuals did not have a specific vaccine name listed on their certificate.
248 Approximately equal numbers of volunteers were vaccinated with measles vaccine
249 (28.6%; 95% CI: 26.8–30.5) and measles-mumps vaccine (22.0%; 95% CI: 20.4–
250 23.8). The total share of other vaccines (Priorix, M-M-R II, Vactrivor, etc.) was about
251 12% (Fig. 7).

252 Significant differences in vaccines were noted depending on volunteer
253 age. This is likely due to the domestic availability of various vaccines used at
254 different times (Fig. 8). Adult volunteers from 30 to 69 years old were combined
255 into one group due to an absence of significant differences.

256 Most children were vaccinated with two-component (measles, mumps)
257 or three-component (measles, mumps, rubella) vaccines. Regarding the latter, both
258 imported (Priorix, M-M-R II) and domestic (Vactrivor) preparations have been used.
259 The share of children vaccinated with monovalent measles vaccine was below 10%.

260 Most adult volunteers, especially the elderly, were vaccinated with a
261 monovalent measles vaccine. Vaccination with it increased proportionally with age:
262 from 29.1% (95% CI: 24.9–33.8) in the group '18–29 years old' to 47.8% (95% CI:
263 36.5–59.4) in the group ≥ 70 years. In adult volunteers aged 30–69 years, two- and
264 three-component vaccines were practically not used. About 10.1% (95% CI: 7.5–
265 13.5) of persons aged 18–29 years had been vaccinated with two-component
266 measles-mumps vaccine since 2002 (when it entered serial production). Among
267 volunteers aged ≥ 70 years, there were also persons vaccinated with measles-mumps

268 vaccine (17.5%; 95% CI: 10.0–28.0), probably during vaccination of the adult
269 population during periods of increased incidence in recent years.

270 When summarizing measles herd immunity among local volunteers (St.
271 Petersburg, Leningrad Region), it can be stated that the threshold level of immunity
272 sufficient to prevent epidemic spread of the pathogen ($\leq 7\%$ seronegative
273 individuals) has been achieved only in the age groups of 60 years and older. Among
274 adult volunteers under 50 years of age, seroprevalence did not reach 80%. In the
275 range 18-29 years old, the minimum values were noted (62.4%). It is noteworthy
276 that about 20% of children who should have been vaccinated according to the
277 national schedule did not have antibodies to the measles virus.

278 3.2 Herd immunity to the rubella virus

279 As noted earlier, the rubella situation in 2021–2022 was favorable.
280 There were no sporadic cases, let alone epidemic outbreaks, in St. Petersburg or the
281 Leningrad Region. Despite the fact that rubella is milder than other airborne
282 infections (COVID-19, influenza, measles), it is a significant public health concern
283 due to its teratogenic potential and association with autism [42]. Rubella is one of
284 the most common infections causing fetal abnormalities (congenital rubella
285 syndrome) in pregnant women.

286 The first live attenuated rubella vaccine was created by P. D. Parkman
287 and H. M. Meyer Jr. in 1966 [48]. Inclusion of the rubella vaccine in national
288 immunization schedules has increased vaccination coverage to 89.0% in most
289 developed countries. Russia is no exception, and rubella vaccination has been
290 included in the national schedule since 1997. Routine immunization occurs at
291 several points: children at 1 year old; children at 6 years old; and girls aged 13 years.
292 Additional immunization is performed for children aged 1 to 17 years: who have not
293 had rubella; who have not been vaccinated; or have been vaccinated only once.
294 Young women 18 to 25 years old may also receive vaccination if they have not had
295 rubella or been vaccinated previously.

296 The absence of rubella cases does not preclude large-scale studies of
297 herd immunity against vaccine-preventable infections. Vigilance regarding these

298 pathogens, including rubella, is an important prerequisite for maintaining
299 epidemiological well-being, without setbacks, in the country. The long-term use of
300 a live attenuated vaccine in Russia has resulted in a high level of herd immunity
301 (95.5%; 95% CI: 94.9–95.9) in the St. Petersburg and Leningrad Region population
302 (Fig. 9).

303 The highest rubella seroprevalence values were found in the subgroups
304 of elderly (60–69 yrs) and older (70⁺ years) people. The lowest were among those
305 middle-aged (30–39 yrs). Differences with the overall seroprevalence value were
306 significant ($p < 0.05$). Despite some seroprevalence differences among various age
307 groups, the average level of herd immunity exceeds 95%. Since the criterion for
308 epidemic well-being regarding rubella is the detection of $\leq 7\%$ seronegative
309 individuals, the situation in St. Petersburg and the Leningrad Region can be
310 considered favorable. This is confirmed by the absence of rubella cases in recent
311 years in the regions analyzed. As expected, given the high overall seroprevalence of
312 the population, differences by field of activity were not seen. Anti-rubella IgG levels
313 were determined in volunteers depending on age (Fig. 10).

314 The data reflect a complex, heterogeneous structure regarding the
315 distribution of anti-rubella Abs present in the population. The share of seronegative
316 individuals and those with minimal Ab levels was distributed relatively uniformly.
317 It was described by linear regression, with virtually no dependence on age. The
318 trends change with higher Ab levels, requiring a more complex approximation
319 described by 3rd degree polynomials. Significant heterogeneity in the results is
320 noteworthy, including opposing trends describing certain Ab concentration
321 distributions: 25–100 IU/ml (average) and >200 IU/ml (maximum).

322 Within the age intervals 6–11 yrs and 12–17 yrs, an increase in average
323 Ab levels, and a decrease in maximum levels, are observed. In the range 18–29 yrs,
324 there is a turning point in trends. By the age range 50–59 yrs, the largest share of
325 volunteers had Abs at maximum levels, and a statistically significant proportion of
326 seropositive individuals had only average levels. Considering that for both trends
327 the determination coefficient varies within a range (0.5–0.61), it can be considered

328 that this form of regression is not random. It likely reflects real processes, and
329 statistically significant features, of the quantitative Ab distribution.

330 Among volunteers of all age groups, the shares of individuals with
331 medium, high, or very high Ab levels were distributed evenly. No more than 7% of
332 volunteers had low Ab levels (10–25 IU/ml). Nevertheless, in children from 6 to 17
333 years old, high IgG levels were detected significantly less often than in children 1–
334 5 years old or adults ≥ 18 yrs.

335 As with measles, those volunteers (4219 people) who provided
336 information about their illness and vaccination in the questionnaire were divided into
337 four groups (Suppl. Table 8S). Depending on infectious and vaccinal status after
338 verification of their questionnaire data against medical records (2302 people), these
339 were: SNV (n=180); SV (n=43); NSNV (n=813); and NSV (n=1266).

340 The age distribution of volunteers by infectious and vaccinal status is
341 related to the national schedule, which has included rubella vaccination since 1998.
342 In this regard, only people under 25 years of age were routinely vaccinated against
343 rubella. People over 25 years of age, primarily women, may have received
344 unscheduled vaccination based on epidemiological indications. It can be assumed
345 that the groups of those who have had the disease (SNV, SV) should be mostly
346 represented by people aged ≥ 30 years. The NSV group is most likely to be children
347 and young people (18–29 years old). The NSNV group is volunteers of different
348 ages who were not vaccinated, either due to medical exemptions, refusal (children
349 and adults < 25 years), or because of age (people > 25 years). Such a classification is
350 largely arbitrary since the actual number of people who have had rubella may be
351 higher due to the prevalence of mild and asymptomatic cases. Furthermore, people
352 of any age may have received rubella vaccination based epidemiological measures,
353 especially women, for whom the presence of rubella constitutes a risk of developing
354 pre- and postnatal lesions in newborns [27, 33, 42].

355 Given the high overall rubella seroprevalence in the cohort (95.5%),
356 and its uniform distribution across age groups, one would not expect to find

357 significant differences in seroprevalence in volunteers of different infectious and
358 vaccinal status (Fig. 11, 12).

359 Although significant differences were not found between groups,
360 seroprevalence exceeded 95% among volunteers who had experienced rubella or
361 were vaccinated (SNV, SV, NSV), which is higher than the value for those who
362 denied a history of vaccination or illness (NSNV, 88.6%). As with measles, the vast
363 majority of volunteers who had had the disease (>80%) had high IgG levels (>100
364 IU/ml), including about 60% with levels higher than 200 IU/ml.

365 Despite the absence of a history (disease and/or vaccination) among
366 NSNV, the share of those with high antibody levels was also high, reaching almost
367 89%. This fact indicates that the share of people who had actually experienced
368 rubella is undoubtedly higher due to the prevalence of mild or asymptomatic cases,
369 which nevertheless leave a trace in the form of circulating IgG [16]. Furthermore,
370 among volunteers who had not had rubella, Ab levels were lower than in those who
371 had been ill: IgG exceeded 100 IU/ml in almost 60%, including about 30% with a
372 value higher than 200 IU/ml (Fig. 12).

373 Of the total cohort, only 1,368 volunteers provided medical
374 documentation with information on rubella vaccination. Vaccine name was not
375 indicated in the vaccination certificates of 37.7% of people (Fig. 13). Most
376 volunteers were vaccinated with a domestic monovalent rubella vaccine: 47.2%
377 (95% CI: 44.6–49.9). The usage share of three-component imported and domestic
378 vaccines ranged from 1.5% (M-M-R II) to 8.7% (Priorix).

379 Age differences were noted regarding vaccines used for rubella
380 vaccination. These are likely associated with the availability of specific vaccines in
381 different time periods (Fig. 14). Adult volunteers aged 30–49 years were combined
382 into one group due to an absence of significant differences.

383 Most volunteers in all age groups were vaccinated with domestic
384 monovalent rubella vaccine. The three-component Vactrivor (measles, mumps,
385 rubella) vaccine has been used in Russia since 2019 as part of the national
386 vaccination schedule. Hence, the maximum share of those vaccinated with Vactrivor

387 was noted among children aged 1–5 years (22.4%; 95% CI: 17.4–28.5). In other age
388 groups, it was apparently used for one-time revaccination in older children, as well
389 as vaccination according to epidemiological indications in adults aged 50–69 years.
390 The imported three-component vaccine Priorix was used for routine vaccination and
391 revaccination of children, as well as vaccination of adults according to
392 epidemiological indications, during the periods when it was available in Russia.

393 Thus, the conducted serological studies (Ab presence, levels) revealed
394 a high level of herd immunity, indicating that conditions in the region (St.
395 Petersburg, Leningrad Region) are close to the threshold beyond which the rubella
396 virus in the population is completely eliminated.

397 3.3 Herd immunity to the mumps virus

398 Mumps can be accompanied by numerous complications, the most
399 common of which is orchitis [62, 69, 71]. Less often, meningitis, nephritis,
400 polyneuropathy, pancreatitis, deafness, and other problems, can occur [25, 45, 60,
401 71]. The infection contributes to the formation of persistent immunity. In Russia,
402 planned vaccination of children (at the age of 12 months) began in 1980. In 2001,
403 mandatory revaccination of children at 6 years of age was introduced. Accordingly,
404 volunteers younger than about 45 years were subject to scheduled mumps
405 vaccination.

406 Our data shows that the overall seroprevalence in the local volunteer
407 cohort (St. Petersburg, Leningrad Region) was 78.4% (95% CI: 77.4–79.3) in
408 September 2023 (Fig. 15). Considering that the share of seronegative individuals
409 should not exceed 15% to ensure epidemiological well-being regarding mumps, it is
410 obvious that the level of herd immunity is insufficient to prevent the spread of
411 infection in the surveyed areas.

412 The distribution of mumps seroprevalence showed statistically significant age
413 differences relative to the average cohort value. A significantly higher ($p \leq 0.01$)
414 share of seropositive individuals was observed in children aged 6–11 years (probably
415 after revaccination at 6–7 yrs), as well as in the older groups (≥ 60 yrs) (likely post-
416 infectious immunity in unvaccinated individuals). In contrast, among young adult

417 and middle-aged volunteers (18–49 years), there was significantly lower
418 seroprevalence ($p \leq 0.0001$). This fact is to be expected since this interval includes
419 those vaccinated once at the age of 1 year (since 1980) before the introduction of
420 revaccination (in 2001).

421 The distribution of seroprevalence depending on occupation was
422 consistent with the age distribution. The highest values (~86%) were found among
423 schoolchildren and pensioners (children, elderly). The lowest (~70%) were among
424 medical workers, civil servants, and transportation workers (those middle-aged). In
425 all cases, the differences were significant at $p \leq 0.05$. For participants who provided
426 information about illness and vaccination by questionnaire ($n=4,527$), data were
427 verified against medical records when possible (Supp. Table 12S). Those with
428 documented infectious and vaccinal status ($n=2,346$) were divided into four groups:
429 SNV ($n=111$); SV ($n=25$); NSNV ($n=708$); and NSV ($n=1502$).

430 As with other vaccine-preventable infections, the groups with
431 volunteers who had

432 experienced symptomatic mumps were represented mainly by adults over 30
433 years of age. Some of the volunteers who had had the illness were also vaccinated,
434 likely due to epidemiological measures. The NSV group was represented mainly by
435 children and young people under 30 years of age. This is obviously related to the
436 initiation of mumps vaccination in Russia. Older people would have been vaccinated
437 for epidemiological reasons or in accordance with specific regional vaccination
438 programs.

439 When comparing mumps seroprevalence among volunteers with
440 different infectious and vaccinal status, the highest share of seropositive individuals
441 was observed in the groups who had experienced symptomatic mumps (regardless
442 of vaccination): SNV group – 91.0% (95% CI: 84.2–95.0); and SV group – 92%
443 (95% CI: 75.0–97.8). Seroprevalence among volunteers who indicated no history of
444 mumps (regardless of vaccination) was lower: NSV group – 80.2% (95% CI: 78.1–
445 82.2); and NSNV group – 73.9% (95% CI: 70.5–77.0) (Fig. 16). It is noteworthy

446 that volunteers who denied a history of illness or vaccination, were nevertheless
447 mostly seropositive for anti-mumps antibodies.

448 Medical documentation with information on mumps vaccination was
449 provided by 1,583 volunteers. However, it was impossible to determine official
450 vaccine name in 37.8% of cases (Fig. 17). Most were vaccinated with domestic
451 vaccines: a two-component measles-mumps vaccine (31.5%; 95% CI: 29.3–33.9); a
452 monovalent mumps vaccine (17.9%; 95% CI: 16.1–19.9); and/or the three-
453 component Vactrivor vaccine (4.1%; 95% CI: 3.2–5.2). The share of the two
454 imported, three-component (measles, mumps, rubella) vaccines (Priorix, M-M-R II)
455 did not exceed 9%.

456 Age differences regarding vaccines used for mumps vaccination were
457 noted. These are likely related to the availability of specific vaccines in different
458 time periods (Fig. 18). Adult volunteers aged 30–49 and 50–69 years were combined
459 due to an absence of significant differences.

460 Most child volunteers (45.7–50.5%), as well as those over 70 years old
461 (81.3%; 95% CI: 57.0–93.4), were vaccinated with the measles-mumps vaccine. The
462 new domestic three-component vaccine Vactrivor, introduced into practice in 2019,
463 was used to vaccinate children aged 1–5 years (22.4%; 95% CI 17.3–28.5) and 6–
464 11 years (3.8%; 95% CI 2.2–6.5%). In other age groups, only a few such vaccinated
465 individuals were noted. In contrast, those aged 18 to 69 years were vaccinated with
466 monovalent mumps vaccine (25.2–48.2%) or, to a lesser extent, mumps-measles
467 vaccine (5.8–32.1%). Regarding imported, three-component vaccines, Priorix was
468 used in certain young groups (6–11 yrs, 12–17 yrs). M-M-R II was used in isolated
469 cases in different age groups.

470 When summarizing our analysis of herd immunity to mumps, we note
471 that seroprevalence in the local population is close to the threshold for
472 epidemiological well-being ($\leq 15\%$ seronegative individuals) only for certain
473 groups: children aged 6–17 years and individuals in the oldest groups (≥ 60 yrs).

474 In the volunteer cohort, a separate group consisted of 'naive' individuals
475 who denied a history of illness or vaccination. They presumably should have had

476 neither post-infectious, nor post-vaccination, immunity. Nevertheless, for all
477 infections analyzed, high seroprevalence was found among those in the NSNV
478 (never sick, never vaccinated) group: measles virus – 78.5% (95% CI: 74.2–82.2);
479 mumps virus – 73.9% (95% CI: 70.5–77.0); and rubella virus – 88.6% (95% CI:
480 86.2–90.6).

481 Age analysis showed that seroprevalence for all infections was minimal
482 in children aged 1-5 years (37.5% for measles, 48.6% for mumps and 50.0% for
483 rubella), with an increase to maximum levels in individuals aged ≥ 70 years (90.3%
484 for mumps, 96.0% for rubella and 97.7% for measles) (Fig. 19). Setting aside that
485 some volunteers, or their parents, may have forgotten illness or vaccination, one
486 aspect becomes apparent. The revealed seroprevalence values indicate insufficient
487 laboratory diagnostics of vaccine-preventable infections. In reality, older volunteers
488 had not only experienced 'childhood' infections, they also had likely received a
489 natural booster effect through encounters with infected individuals. This is
490 confirmed by the fact that Ab levels were higher in older age groups than in children.

491 It is obvious that the dependence in this case is not linear, and the trend
492 can be described by two tangents. The first is $\text{tg}\alpha_1=6.8$ (steeper), wherein the level
493 of herd immunity is growing at a high rate due to an active transmission process.
494 Adaptive immunity is quickly formed (via childhood immunization or transmission).
495 The second is $\text{tg}\alpha_2=0.3$, wherein all (or almost all) of those in the oldest groups (>60
496 years) have already encountered the virus in their lives through vaccination or
497 illness. In result, the virus practically does not spread in this age group.

498 **4 Discussion**

499 Herd immunity is the central mechanism for protecting the population
500 from contagious infectious pathogens that tend to spread as epidemics. These
501 include airborne infections, often in childhood (measles, mumps, rubella, diphtheria,
502 whooping cough), as well as acute respiratory viral infections that are not strongly
503 age-specific (influenza, parainfluenza, respiratory syncytial virus, coronaviruses,
504 etc.) [31, 39, 44, 46, 63, 66]. It is also worth mentioning that a number of infections
505 have virtually disappeared in recent times, yet caused a number of deadly epidemics

506 in the Middle Ages [1, 64]. The outcome of all these pandemics was the formation
507 of specific immunity to the pathogen. This process is based on the ability of cellular
508 and humoral mechanisms to block the transmission of pathogens among the
509 population, wherein the prevalence of positive serological results (p) exceeds the
510 critical value of herd immunity (p_c), known as the herd immunity threshold [43, 51,
511 70]. According to researchers, achieving this threshold is realistic (at least for
512 measles, mumps, and rubella) provided that vaccination of different population
513 segments is properly organized [51, 67].

514 The measles virus is a highly contagious pathogen, the basic
515 reproduction number (R_0) for which is 9–18 [61]. This means that the target
516 vaccination coverage to achieve the protective immunization threshold should be
517 about 95% [29]. The criterion for epidemic well-being regarding measles is the
518 presence of no more than 7% seronegative individuals in the population. Our results
519 show that in St. Petersburg and the Leningrad Region, the measles seroprevalence
520 in the cohort as a whole was 81.4% (95% CI: 80.4–82.3), which is significantly
521 below the threshold. We also note statistically significant heterogeneity in the
522 cohort: the lowest seroprevalence was found among individuals aged 18–39 years
523 (62.4%; 95% CI: 59.0–65.7); and the highest was among those aged ≥ 70 years
524 (96.2%; 95% CI: 94.8–97.2). Similar heterogeneity was found in volunteers
525 depending on field of activity. Higher seroprevalence was noted among pensioners
526 and preschoolers (which corresponds to the age distribution). It was also noted in
527 health workers and educators, both of which are 'at risk' groups. Since 2014, they
528 are subject to vaccination until the age of 55 under certain conditions (no history of
529 vaccination or illness) [13,14].

530 High anti-measles Ab levels are most typical for older individuals:
531 about 80% of seropositive individuals aged ≥ 60 years had high (1–2 IU/ml), or very
532 high (>2 IU/ml), IgG levels. The opposite situation was noted in the group 'children
533 aged 1–17 yrs': the overwhelming majority had low or medium Ab levels (0.18–1.0
534 IU/ml).

535 Analysis of volunteer histories (measles vaccination, past illness)
536 showed that seroprevalence was mainly influenced by past illness, not vaccination.
537 Among those who had had measles, seroprevalence and Ab levels were higher than
538 among those who had not, regardless of vaccination. Our data on local herd
539 immunity (St. Petersburg, Leningrad Region) are consistent with earlier data from
540 other seroepidemiological studies conducted in various Russian regions. They also
541 noted low measles seroprevalence in children and in adults aged 18–40 years [4, 9,
542 10, 11, 17, 18].

543 It can be assumed that the revealed differences are due to a number of
544 medical and social factors. Mandatory single vaccination of children with a live
545 measles vaccine at the age of 1 year was launched in the USSR in 1968. In 1986,
546 revaccination of children before entering school (at the age of 6 or 7 years) was
547 introduced. Thus, subjects who have undergone a full course of measles vaccination
548 within the framework of the national schedule (vaccination, revaccination) can be
549 classified fairly reliably as persons under 40 years of age. Persons aged 40–55 years
550 were most likely vaccinated once. Those over 55 would have been vaccinated only
551 according to epidemiological indications. Interestingly, starting from the age of 50,
552 the share of measles-seropositive persons with high Ab levels steadily increases.

553 There is no doubt that in the period preceding the introduction of
554 mandatory vaccination, measles incidence was high, and people over 50 years of age
555 were highly likely to have had this infection. The higher seroprevalence in groups
556 over 50 years of age, as well as high Ab levels, indicate a long-term and even lifelong
557 existence of anti-infective immunity. It is believed that the measles vaccination
558 coverage among the adult population aged 18–35 is maintained at the regulated level
559 and is about 99% in Russia [13, 14]. Our data indicate that the real seroprevalence
560 of the population at this age is 60–70%. Data from Russian authors indicate that
561 during periods of increased measles incidence, people in age groups with a low herd
562 immunity are primarily involved in the epidemic process [18]. Also noteworthy is
563 the high share of seronegative individuals among children (18.4–25.7%). Data from
564 official registrations and individual researchers confirm the involvement of

565 unvaccinated individuals in the epidemic process: no more than 5–7% of those
566 infected are vaccinated against measles [3, 21].

567 Thus, our results confirm the fact that individuals who have had
568 manifest measles (usually older people) have higher immune protection than after
569 vaccination [54]. In addition, older individuals in conditions of high measles
570 incidence in the pre-vaccination period probably encountered the pathogen
571 repeatedly, which strengthened post-infectious immunity (booster effect) and
572 ensured high Ab levels. The immune response formed following the measles vaccine
573 is lower. In addition, the probability of a natural booster effect in vaccinated
574 individuals in conditions of reduced circulation of wild virus is low. This is
575 confirmed by low Ab levels in seropositive young individuals [35].

576 Rubella, like measles, is a vaccine-preventable infection and, despite
577 the existence of a family of specific vaccines, continues to cause up to 100,000 cases
578 of congenital rubella syndrome worldwide annually [39, 42, 59]. Its basic
579 reproduction number varies from 3–8, potentially up to 12 [49, 56]. It follows that
580 the required threshold of herd immunity in European countries is estimated to be 67–
581 87%, while in developing countries it can reach 90% [39, 51, 52]. Live attenuated
582 MMR vaccine is used worldwide for specific prevention of rubella; it is capable of
583 generating adaptive immunity simultaneously to three pathogens: measles, mumps,
584 and rubella [58].

585 Rubella immunization in Russia was introduced into the schedule by an
586 order of the Ministry of Health (dated 27.12.97, No. 375), later replaced by a
587 subsequent order (dated 30.09.2015, No. 683H). Accordingly, children are subject
588 to routine immunization at specific points: those aged 12 months; 6 years; and girls
589 aged 13 years. Additional rubella immunization includes: all children from 1 to 17
590 years who have not been ill, not been vaccinated, or vaccinated only once; as well
591 as young women aged 18–25 years who have not been ill or vaccinated previously
592 [15].

593 An assessment of rubella herd immunity showed that the overall cohort
594 had the necessary immune protection, regardless of age or occupation. The average

595 rubella seroprevalence was 95.5% (95% CI: 94.9–95.9). The highest level was
596 recorded among volunteers aged 50–70⁺ years (96.3–97.6%). The lowest was in the
597 age group 30–39 years (92.7%; 95% CI: 90.8–94.3). In other words, the level of herd
598 immunity reached the threshold for epidemic well-being ($\leq 7\%$ seronegative
599 individuals in the pop.) in almost all age groups. This is confirmed by the absence
600 of registered cases of rubella, or congenital rubella syndrome, in 2021–2023
601 locally (St. Petersburg, Leningrad Region).

602 Unlike measles, 60–70% of volunteers had high, or very high, anti-
603 rubella IgG levels, and the share of individuals with low Ab levels did not exceed
604 7%. However, in children aged 6–17 years, high IgG levels were detected
605 significantly less frequently than in children aged 1–5 years or adults. This situation,
606 noted by other authors [20], may be associated with a weakening of immunity 6–10
607 years after revaccination in the absence of a natural booster effect when encountering
608 wild rubella virus. It is interesting to note that in the group of volunteers who had
609 not been ill or vaccinated against rubella, the share of seropositive individuals was
610 high, 88.6% (95% CI: 86.2–90.7), although significantly lower than in the groups of
611 those who had been ill and vaccinated. In addition, those with full recoveries from
612 symptomatic infections had higher Ab levels. Specifically, in 50–60% of such
613 volunteers, IgG levels exceeded 200 IU/ml, as opposed to 29–33% of those who
614 without a history of manifest rubella.

615 When summarizing the assessment of herd rubella immunity in the
616 local population (St. Petersburg, Leningrad Region), as well as the data of other
617 domestic authors [7, 9, 11, 17, 18, 20], it is obvious that the existing practice of
618 routine vaccination has contributed to the formation of herd immunity sufficient to
619 interrupt viral spread.

620 This is reflected in the absence of manifest cases in recent years. Clearly, a
621 high level of herd immunity has been maintained, even in the absence of circulation
622 of the wild strain or natural booster effects through encounters. It is premature, of
623 course, to declare a complete victory over rubella, and the possibility of imported

624 cases cannot be ruled out. However, the risk of epidemic spread among local
625 residents can currently be considered low.

626 In uncomplicated cases, mumps occurs as a mild, self-limiting
627 infection, but there are also complicated cases with the addition of orchitis in boys,
628 as well as pancreatitis and even neurological complications [60, 69, 72, 73]. The
629 mumps virus is less contagious than the measles virus. Values for the basic
630 reproductive number, depending on regional characteristics, can vary from 4–7
631 (USA) to 11–14 (Great Britain) [36]. Before the introduction of mass vaccination,
632 illness was widespread globally. In some countries, up to 5–6% of the population
633 has experienced symptomatic forms [22]. A significant change in the
634 epidemiological situation occurred only after the introduction of specific vaccination
635 into clinical practice in 1967. This has enabled a many-fold reduction in mumps
636 prevalence globally [6, 37].

637 Contemporary mumps epidemiology and its features have been shaped
638 by routine prevention using a live attenuated vaccine. The introduction of vaccines
639 against the virus in Russia has contributed to a decrease in the frequency of clinical
640 mumps cases, primarily due to the formation of strong herd immunity [6]. In Russia,
641 two domestic vaccines based on the Leningrad-3 strain are used: a monovalent
642 mumps vaccine and a divalent (mumps-measles) vaccine. Two imported trivalent
643 (measles, mumps, rubella) vaccines, M-M-R II and Priorix, are also used. Regardless
644 of their origin, all of the listed vaccines create 90% immunity, which lasts up to 5–6
645 years after administration [16, 19, 24, 32]. The vaccination program against mumps
646 in Russia has undergone changes, which obviously has affected seroprevalence in
647 various age groups. Routine vaccination of the child population (at the age of 12
648 months) began in 1980. In the year 2000, the attenuated mumps virus content in the
649 vaccine was increased by 2-fold. In 2001, due to an identified decrease in immunity,
650 mandatory booster revaccination of children at 6 years of age (before school) was
651 introduced into the national vaccination schedule.

652 Taking into account that the average value of the basic reproductive
653 number (R_0) varies within 4.5, it is possible to calculate the threshold level of mumps

654 herd immunity (R_i), which was 77.7%, using the formula $(1-(1/R_0)*100)$. In St.
655 Petersburg and the Leningrad Region, the average cohort value of R_i was 78.4%
656 (95% CI: 77.4–79.3). The highest R_i values were noted among children aged 6–11
657 years (88.0%; 95% CI: 84.9–90.6) and those ≥ 50 years (88.2%; 95% CI: 86.0–90.0);
658 differences with the average cohort value were significant ($p < 0.001$). The least
659 protected were middle-aged adults aged 18–49 years, among whom seronegativity
660 reached 30%. They were likely vaccinated once before the introduction of
661 revaccination in 2001.

662 The distribution of mumps seroprevalence by field of activity
663 corresponded with age. The highest seropositivity values were found among
664 schoolchildren and pensioners (children and the elderly). The lowest was among
665 medical workers, civil servants, and transportation workers (middle-aged people).
666 In all cases, the differences were significant ($p \leq 0.05$). As with other vaccine-
667 preventable infections, analysis of infectious history and vaccinal status showed that
668 the highest share of seropositive individuals was noted in groups of volunteers who
669 had experienced symptomatic mumps, regardless of vaccination: 87.6–91.0%.

670 Thus, the threshold for epidemic well-being with respect to mumps
671 ($\leq 15\%$ seronegative individuals) corresponded to the level of herd immunity only
672 among children aged 6–17 years and those > 60 years. The rest of the population,
673 including preschool children and adults aged 18 to 59, are not sufficiently protected
674 from mumps. As such, they can be involved in epidemiological processes.

675 Analysis of volunteer groups who cannot document, or recall, a history
676 of vaccination or illness (i.e., should not have had significant humoral immunity)
677 shows that there has been insufficient laboratory diagnostics of vaccine-preventable
678 infections. Latent and asymptomatic forms (measles, mumps, rubella) have very
679 likely been overlooked in the past. Seropositivity for these pathogens was noted in
680 all age groups. It increased with age, reaching maximum levels in those aged 70+
681 (90.3% for mumps, 96.0% for rubella and 97.7% for measles). Many of the older
682 adult volunteers were born in, or have lived through, the pre-vaccination period.
683 Many have had these 'childhood' infections, as well as the opportunity to receive a

684 natural 'booster effect' in conditions of high morbidity (through contact with infected
685 individuals).

686 In Russia, live attenuated vaccines are used for specific prevention of
687 these pathogens in the form of monovalent, two-component (measles, mumps), and
688 three-component preparations (measles, mumps, rubella). All available vaccines are
689 safe, effective, and can be equally used within the framework of immunization
690 programs. However, the general trend in vaccination development globally has been
691 a transition to combination vaccines with an increasing number of components. In
692 2019, the first domestic three-component vaccine, Vactrivor (measles, mumps,
693 rubella) [19], was registered in Russia. Earlier, the foreign vaccines Priorix and M-
694 M-R II were used as three-component vaccines. Multicomponent vaccines are
695 predominantly used for routine vaccination of children. Monovalent vaccines are
696 used for vaccination (and revaccination) of adults according to epidemiological
697 indications, depending on which pathogen is of public health concern.

698 5 Conclusions

699 1. Currently, herd immunity to 'childhood' infections in the local
700 population (St. Petersburg, Leningrad Region) ensures epidemiological well-being
701 only with respect to rubella. This is confirmed by the long-term absence of cases of
702 acute infection or congenital rubella. An unfavorable situation is noted with the level
703 of herd immunity to measles and mumps, which corresponds to the situation noted
704 in other Russian regions.

705 2. The highest share of susceptible individuals was found among young and
706 middle-aged groups. These volunteers typically: have not experienced symptomatic
707 cases of these infections; were vaccinated according to an incompletely established
708 vaccination schedule; and have not experienced a natural booster effect (due to
709 reduced circulation of wild viral strains). The aforementioned factors contribute to a
710 fading of post-vaccination immunity.

711 3. The least susceptible to these 'childhood' illnesses are individuals
712 over 50 years of age who have experienced infection (symptomatically or
713 asymptotically). They have developed post-infectious immunity (with high Ab

714 levels) and also received a natural booster effect in the pre-vaccination period in
715 conditions of high morbidity.

716 **4.** The situation with post-vaccination immunity to measles requires
717 additional analysis. Seroprevalence levels in certain age groups, including children,
718 are insufficient to ensure epidemiological well-being. Currently, outbreaks
719 associated with imported cases of infection are being registered in Russian regions,
720 with subsequent formation of foci among unvaccinated residents

РИСУНКИ

Figure 1. Annual incidence dynamics of measles, mumps, and rubella in the local population (2010 to 2023).

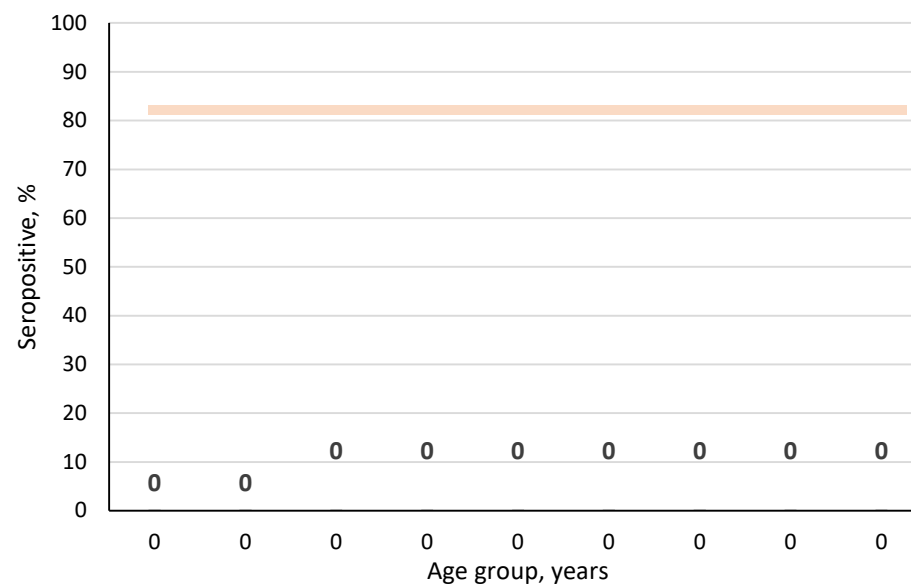


Figure 2. Study flow chart.

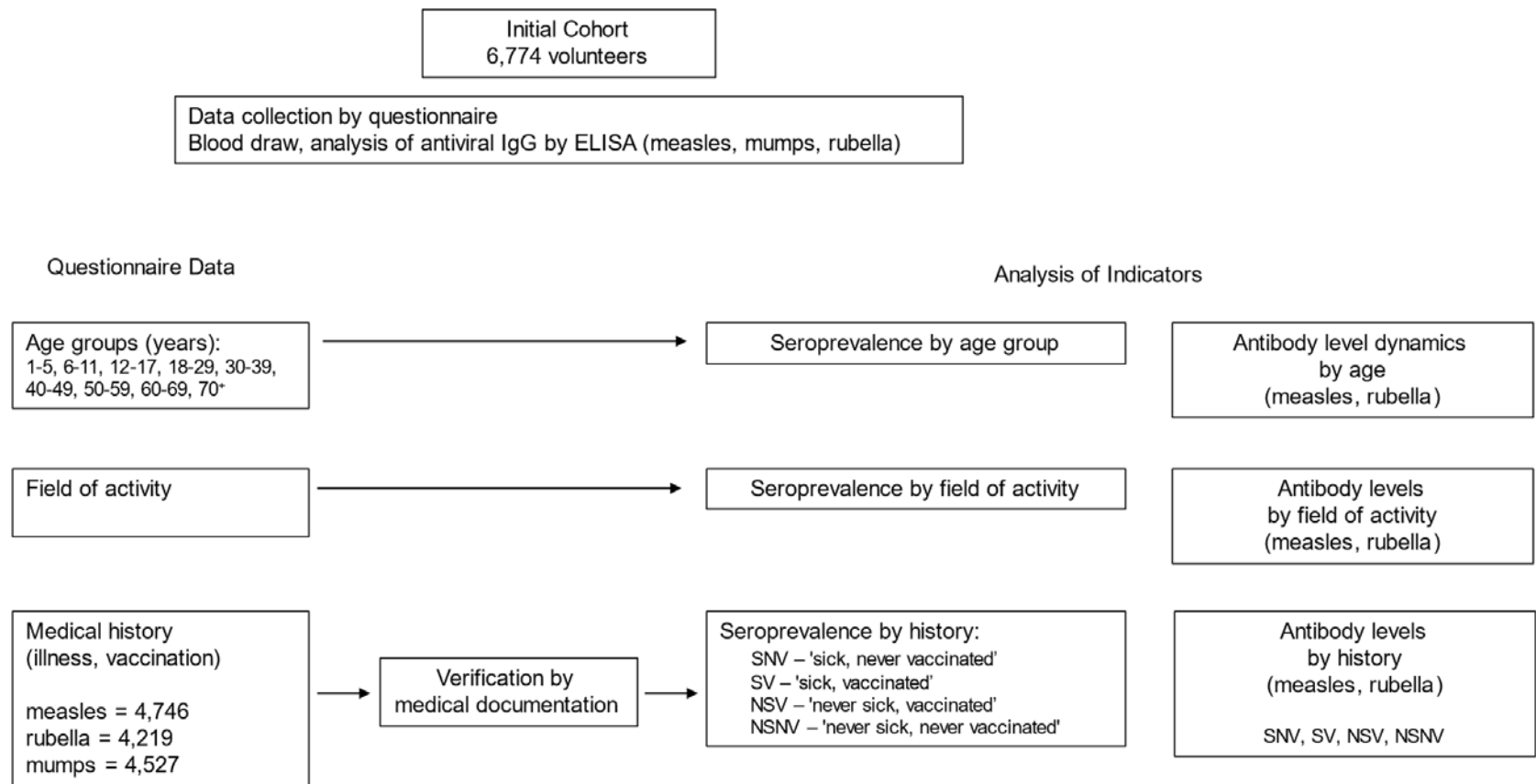


Figure 3. Measles seroprevalence (IgG presence) by age group. Note: vertical black lines are confidence intervals; horizontal translucent band is the 95% confidence interval of the final value for the entire sample (81.4%; 95% CI: 80.4–82.3). Numerical values and statistical significance indicators are given in Supplementary Table 1S.

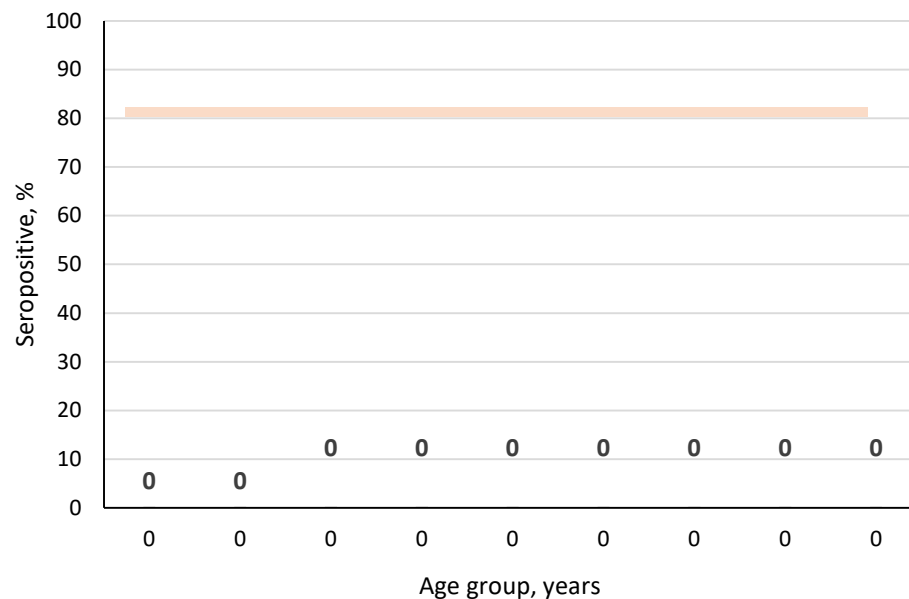


Figure 4. Trends in the quantitative distribution of anti-measles IgG levels by age group. Numerical values are shown in the upper left: regression equations (trend lines in corresponding colors); determination coefficients (R^2); Spearman correlation coefficients (ρ); p values. Quantitative Ab levels are in IU/ml. Vertical black lines are 95% confidence intervals. Numerical values and statistical significance indicators are given in Supplementary Table 2S.

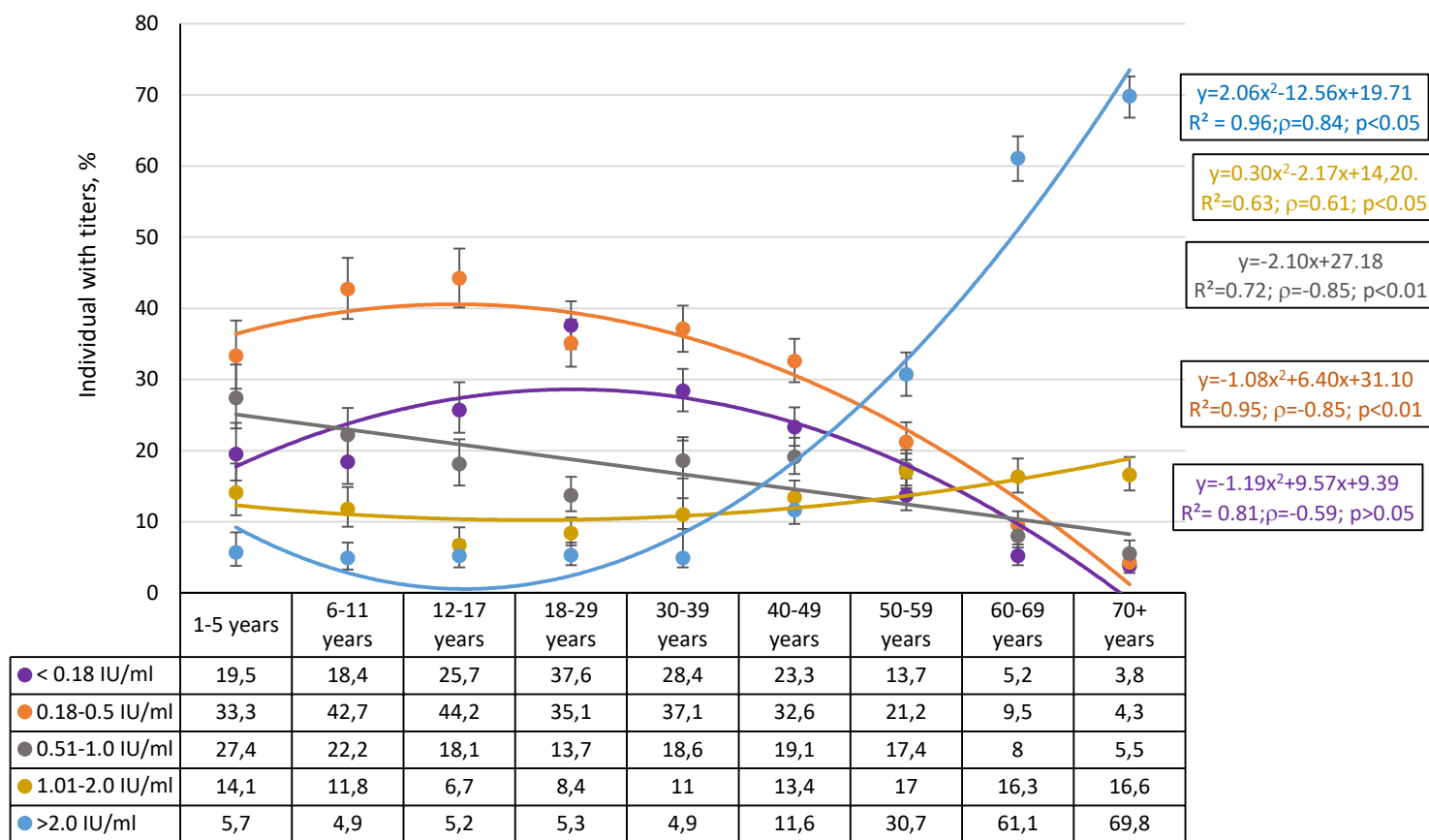


Figure 5. Measles seroprevalence by infectious and vaccinal status. Legend: SNV – 'sick, never vaccinated'; SV – 'sick, vaccinated'; NSV – 'never sick, vaccinated'; NSNV – 'never sick, never vaccinated'. Numerical values and statistical significance indicators are given in Supplementary Table 4S.

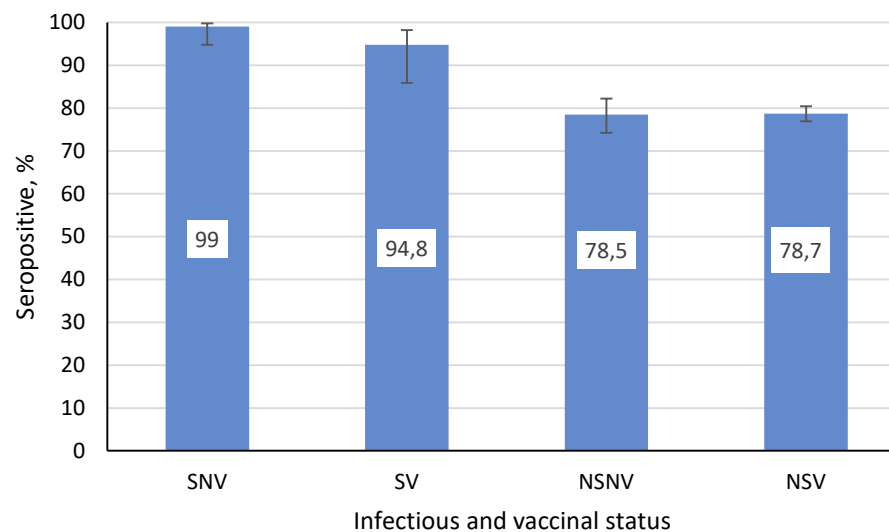


Figure 6. Anti-measles IgG levels by infectious and vaccinal status. Legend: SNV – 'sick, never vaccinated'; SV –'sick, vaccinated'; NSV – 'never sick, vaccinated'; NSNV – 'never sick, never vaccinated'. Numerical values and statistical significance indicators are given in Supplementary Table 4S.

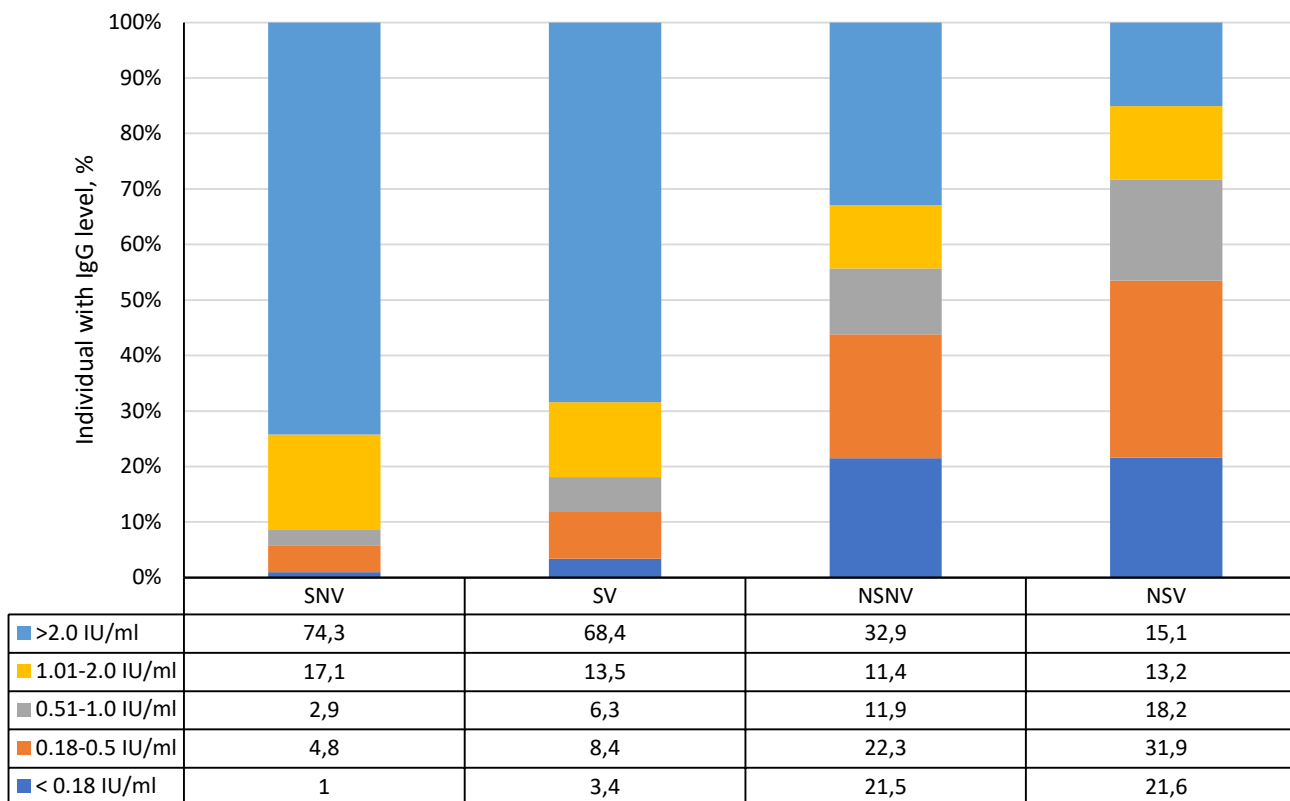


Figure 7. Structure of preparations used for measles vaccination (St. Petersburg, Leningrad Region). Numerical values and statistical significance indicators are given in Supplementary Table 5S.

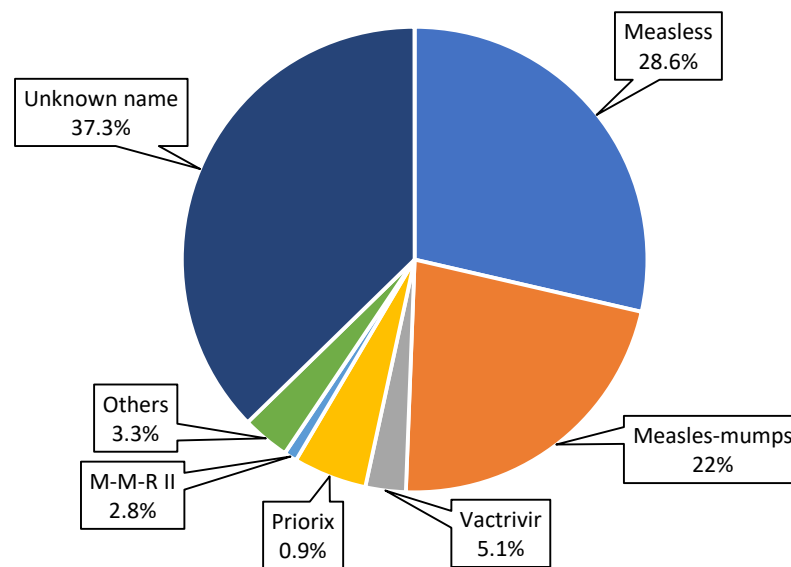


Figure 8. Preparations used for measles vaccination, by age group. Numerical values and statistical significance indicators are given in Supplementary Table 5S.

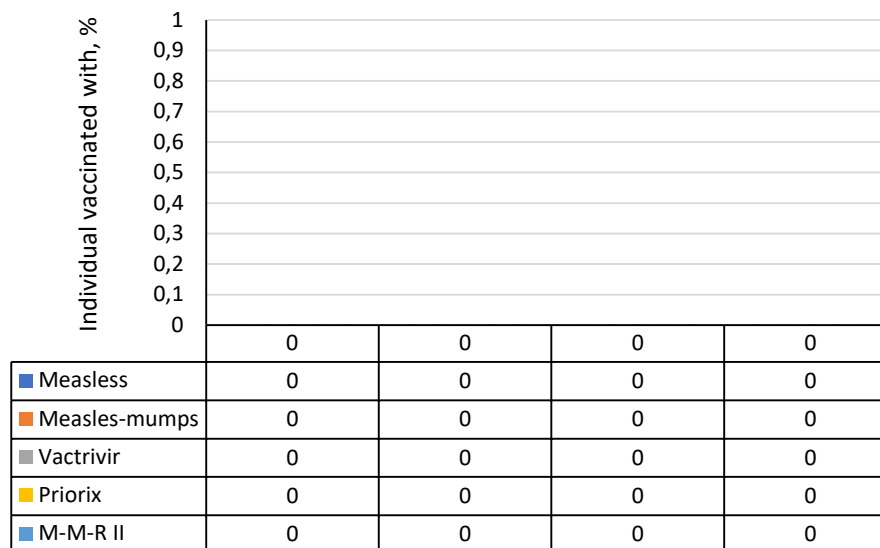


Figure 9. Rubella seroprevalence (IgG presence) by age group. Notes: vertical black lines are 95% confidence intervals; horizontal translucent stripe is the 95% confidence interval of the final value for the entire sample (95.5%; 95% CI: 94.9–95.9). Numerical values and statistical significance indicators are given in Supplementary Table 6S.

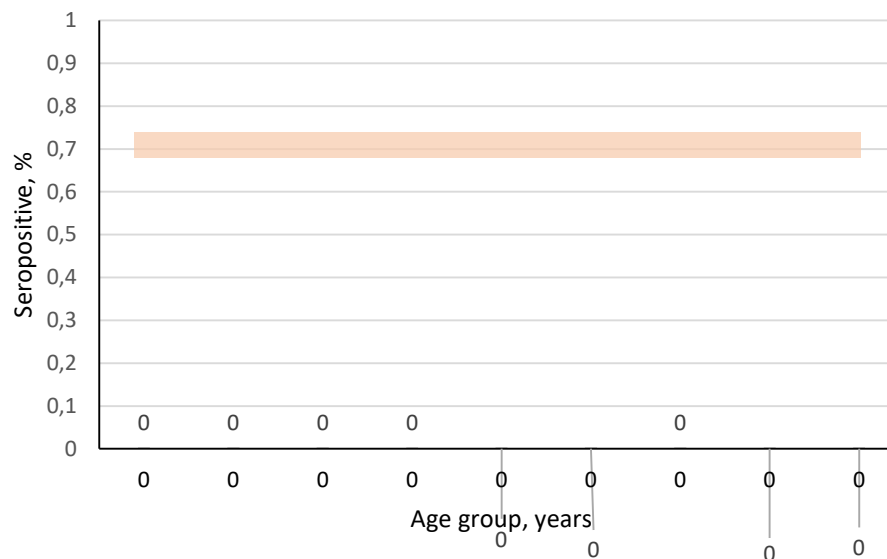


Figure 10. Trends in the quantitative distribution of anti-rubella IgG levels by age group. Numerical values are shown in the upper left: regression equations (trend lines in corresponding colors); determination coefficients (R^2); Spearman correlation coefficients (ρ); p values. Quantitative Ab levels are in IU/ml. Vertical black lines are 95% confidence intervals. Numerical values and statistical significance indicators are given in Supplementary Table 7S.

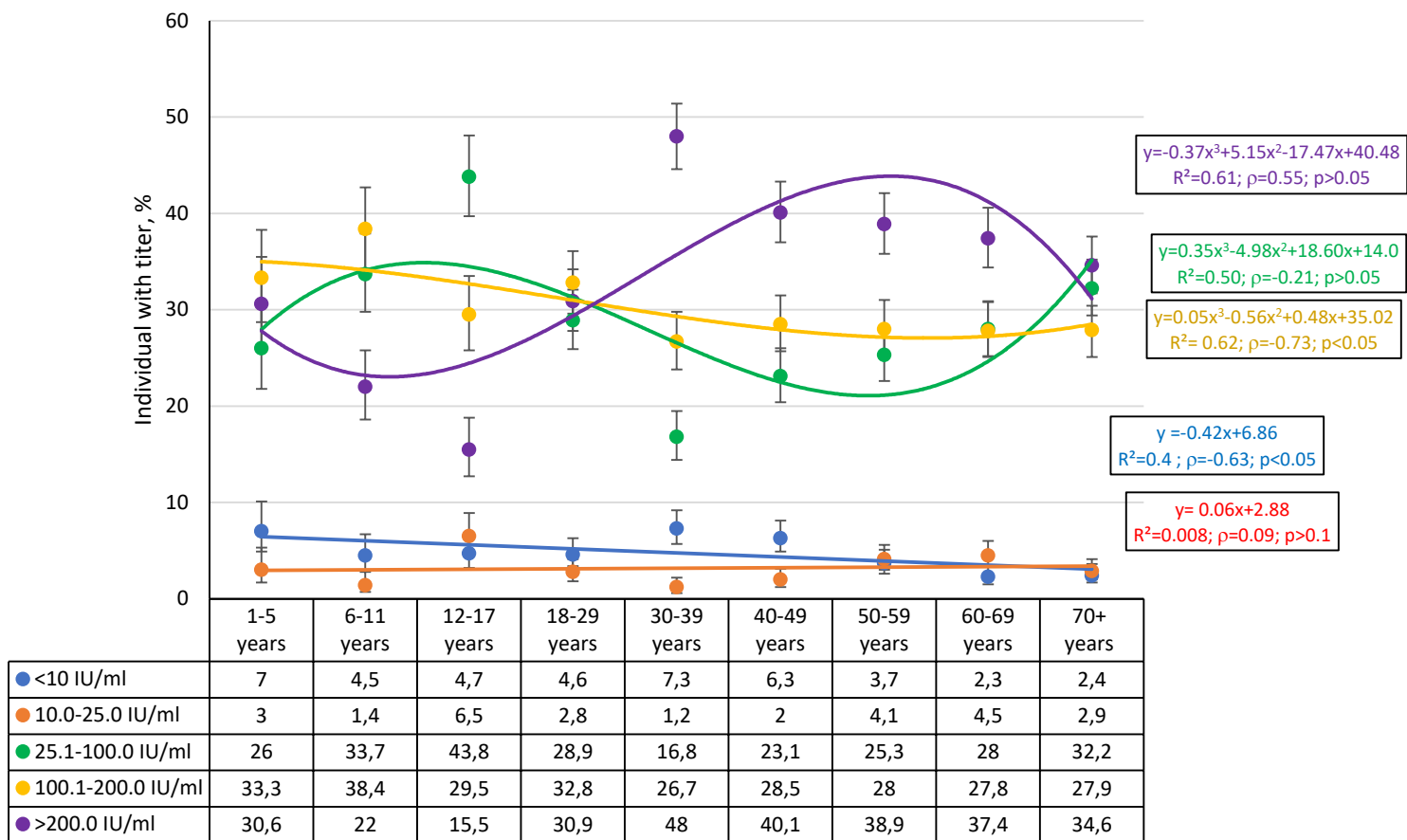


Figure 11. Rubella seroprevalence by infectious and vaccinal status. Legend: SNV – 'sick, never vaccinated'; SV – 'sick, vaccinated'; NSV – 'never sick, vaccinated'; NSNV – 'never sick, never vaccinated'. Vertical black bars are 95% confidence intervals. Numerical values and statistical significance indicators are given in Supplementary Table 9S.

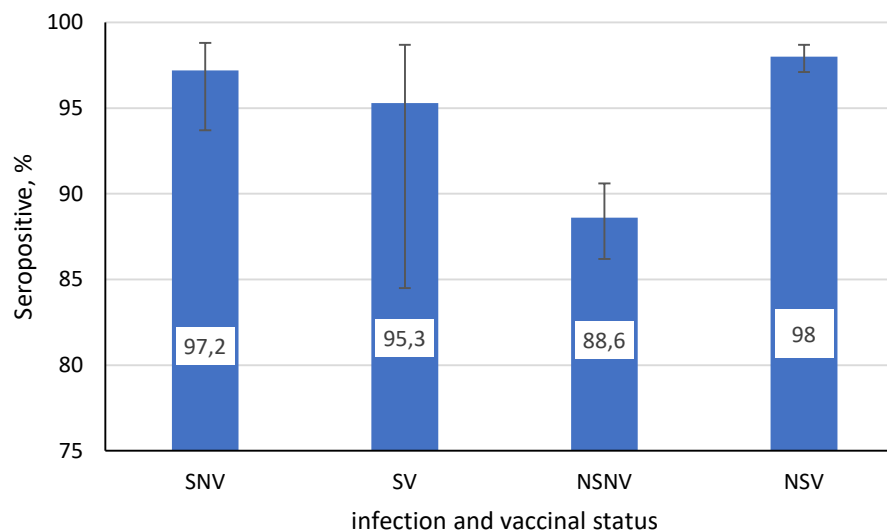


Figure 12. Anti-rubella IgG levels by infectious and vaccinal status. Legend: SNV – 'sick, never vaccinated'; SV – 'sick, vaccinated'; NSV – 'never sick, vaccinated'; NSNV – 'never sick, never vaccinated'. Numerical values and statistical significance indicators are presented in Supplementary Table 9S.

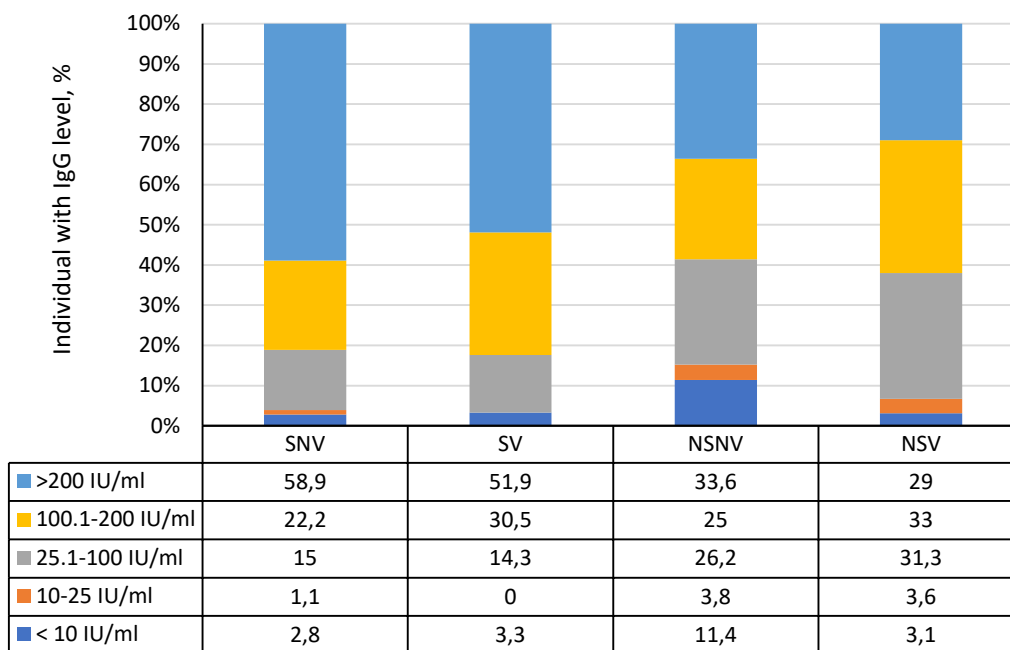


Figure 13. Structure of preparations used for rubella vaccination. Numerical values and statistical significance indicators are given in Supplementary Table 10S.

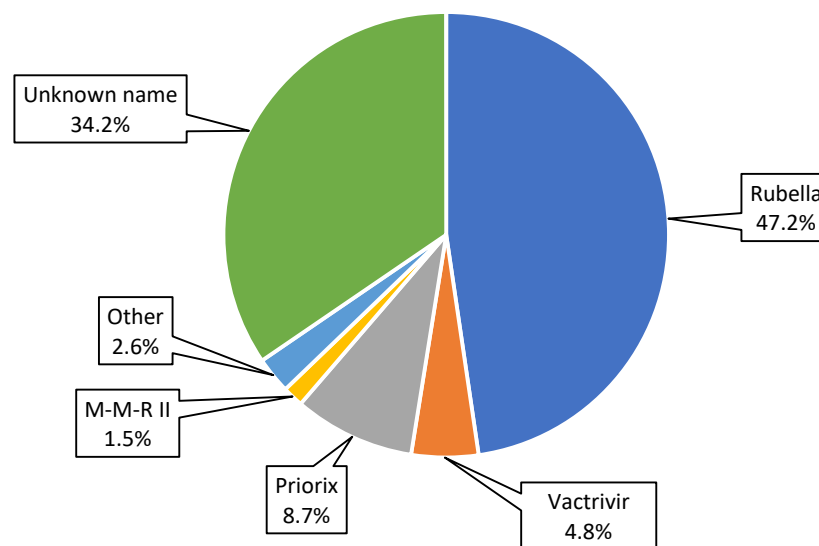


Figure 14. Preparations used for rubella vaccination, by age group. Note: vertical black lines are 95% confidence intervals. Numerical values and statistical significance indicators are given in Supplementary Table 10S.

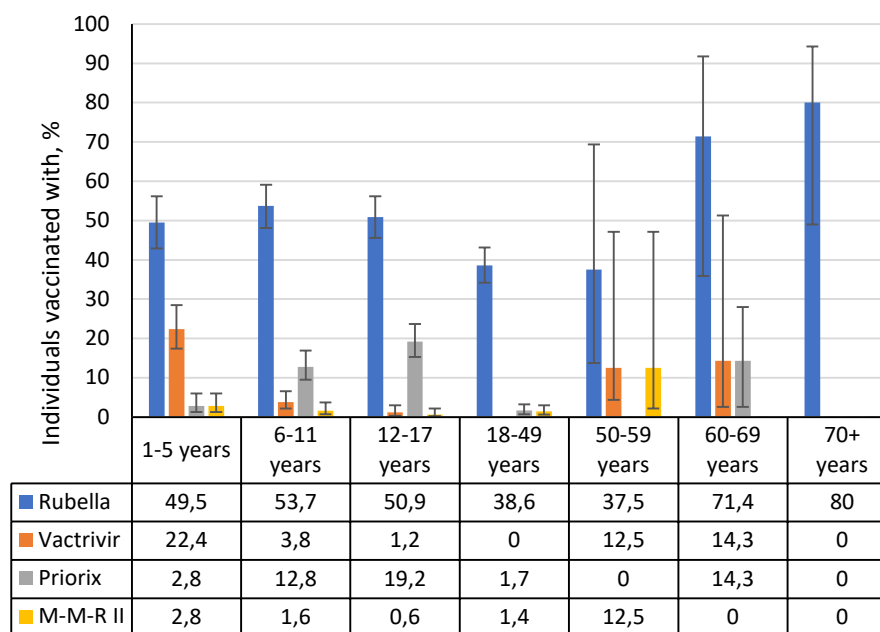


Figure 15. Mumps seroprevalence, by age group. Note: vertical black lines are 95% confidence intervals; horizontal translucent bar is the 95% confidence interval of the final value for the entire sample (78.4%; 95% CI: 77.4–79.3). Numerical values and statistical significance indicators are presented in Supplementary Table 11S.

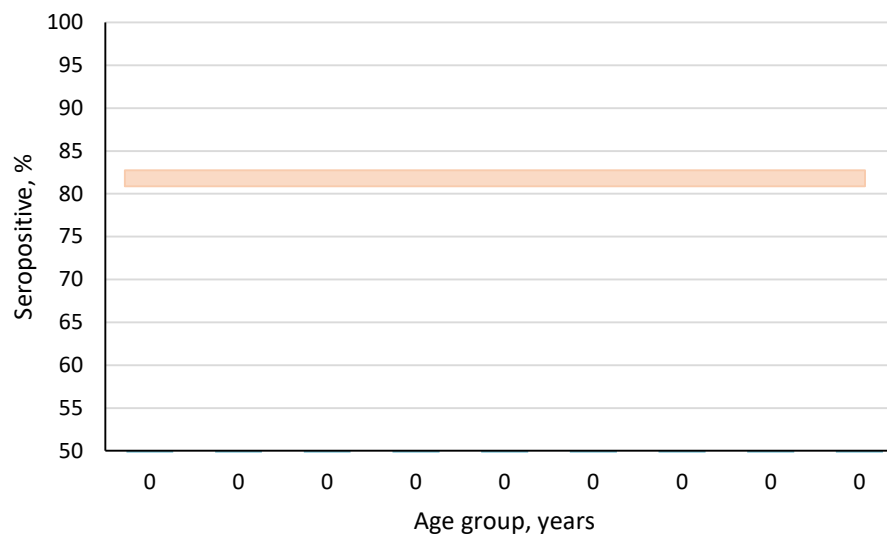


Figure 16. Mumps seroprevalence by infectious and vaccinal status. Legend: SNV – 'sick, never vaccinated'; SV – 'sick, vaccinated'; NSV – 'never sick, vaccinated'; NSNV – 'never sick, never vaccinated'. Note: vertical black lines are 95% confidence intervals.

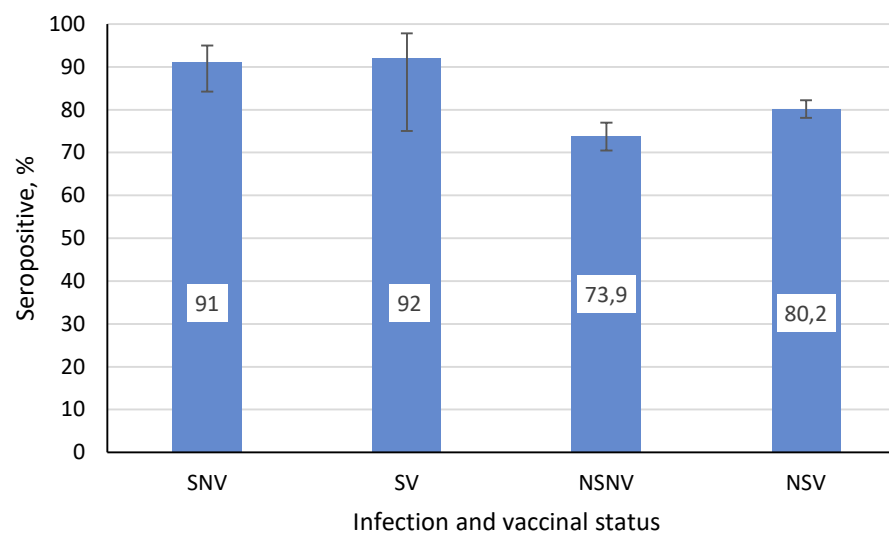


Figure 17. Structure of preparations used for mumps vaccination.

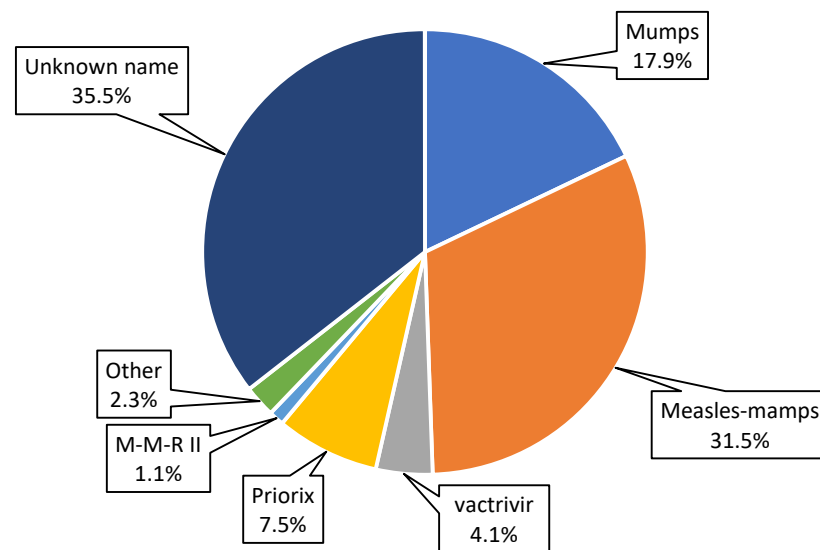


Figure 18. Preparations used for mumps vaccination, by age group. Note: vertical black lines are 95% confidence intervals. Numerical values and statistical significance indicators are given in Supplementary Table 13S.

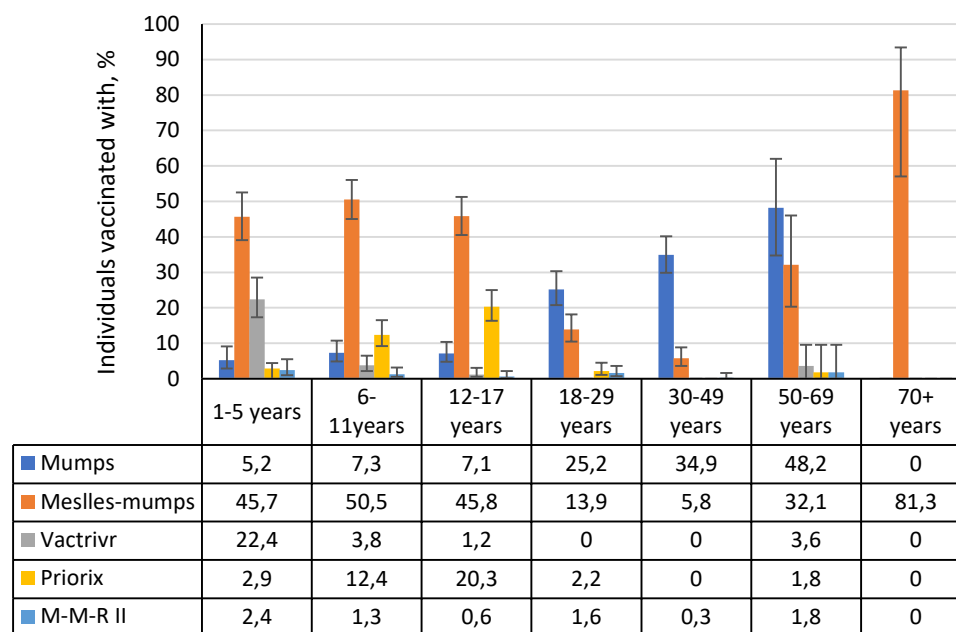
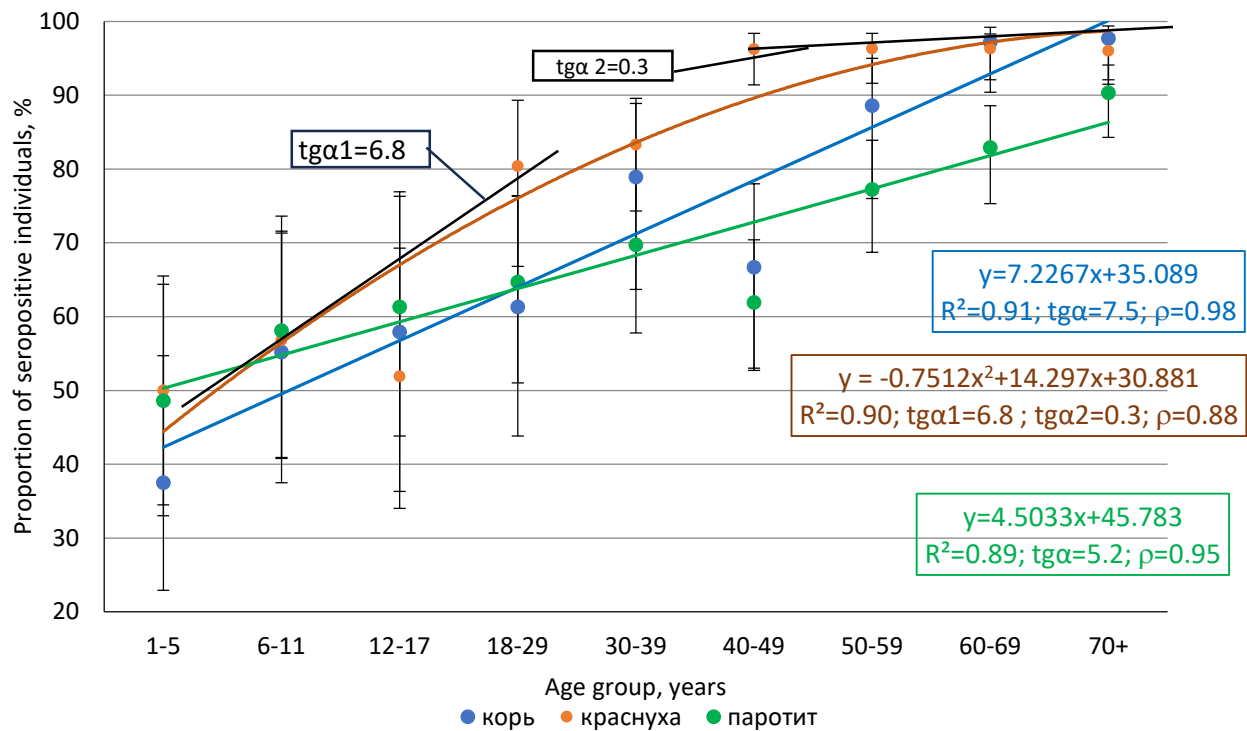


Figure 19. Seroprevalence among 'naive' volunteers (never sick, never vaccinated) for vaccine-preventable infectious pathogens. Since the rubella trendline was described by a 2nd degree polynomial, tangents to the curve were calculated for the youngest and oldest categories: $tg\alpha_1$ – slope of the youngest interval (aged 1–11 years), representing rate-of-increase in seropositivity in children; and $tg\alpha_2$ – slope of the oldest interval (aged ≥ 60 years). Trends for measles and mumps were straight lines. As such, their $tg\alpha$ values reflect evenly increasing seropositivity across age groups. Spearman correlation coefficients (ρ) are shown. For statistical significance, all at $p < 0.05$. Numerical values and statistical significance indicators are given in Supplementary Table 14S.

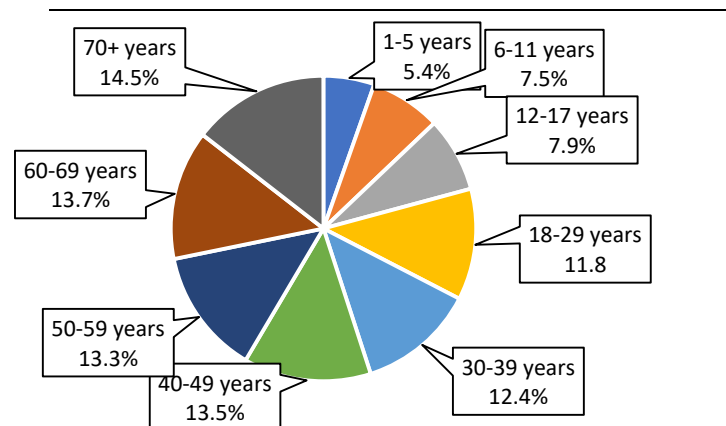


легенда на русском языке

ТАБЛИЦЫ

Table 1. Age structure of the volunteer cohort (St. Petersburg, Leningrad region).

| Age, years | N, persons | Share, % (95% CI) |
|-------------|------------|-------------------|
| 1-5 years | 369 | 5.4 (1.3-9.0) |
| 6-11 years | 510 | 7.5 (6.9-8.2) |
| 12-17 years | 536 | 7.9 (7.3-8.6) |
| 18-29 years | 796 | 11.8 (11.0-12.5) |
| 30-39 years | 838 | 12.4 (11.6-13.2) |
| 40-49 years | 915 | 13.5 (12.7-13.4) |



| | | |
|----------------|------|----------------------|
| 50-59 years | 900 | 13.3 (12.5- 14.1) |
| 60-69 years | 930 | 13.7(12.9- 14.6) |
| 70+ years | 980 | 14.5 (13.6- 15.3) |
| Total | 6774 | 6774 |

Note: 70+ designates volunteers aged ≥ 70 years.

Table 2. Distribution of volunteers by field of activity.

| Field of activity | Volunteers, N | Share, % | Confidence Interval (95%) |
|---------------------------|------------------|-------------|---------------------------------|
| Healthcare | 1366 | 20,2 | 19.2 – 21.1 |
| Pensioner | 1157 | 17,1 | 16.2 – 18.0 |
| Schoolars | 815 | 12 | 11.3 – 12.8 |
| Education | 592 | 8,7 | 8.1 – 9.4 |
| Office worker | 563 | 8,3 | 7.7 – 9.0 |
| Preschooler | 433 | 6,4 | 5.8 – 7.0 |
| Other | 292 | 4,3 | 3.8 – 4.8 |
| Industry | 269 | 4 | 3.5 – 4.5 |
| State-military service | 262 | 3,9 | 3.4 – 4.4 |
| Unemployed | 252 | 3,7 | 3.3 – 4.2 |
| Student | 213 | 3,1 | 2.8 – 3.6 |
| Business | 158 | 2,3 | 2.0 – 2.7 |

| | | | |
|---------------------------|------|-----|-----------|
| Research | 117 | 1,7 | 1.4 – 2.1 |
| The Arts | 101 | 1,5 | 1.2 – 1.8 |
| Transportation | 100 | 1,5 | 1.2 – 1.8 |
| Information tech. (IT) | 84 | 1,2 | 1.0 – 1.5 |
| Total | 6774 | 100 | - |

Table 1S. Measles seroprevalence by age group (St. Petersburg, Leningrad Region).

| Age group, years | Number of volunteers, N | IgG ⁺ | | |
|------------------|-------------------------|------------------|------|---------------|
| | | n | % | 95% C. I. |
| 1-5 | 369 | 297 | 80.5 | 76.1 – 84.2 |
| 6-11 | 510 | 416 | 81.6 | 78.0 – 84.7 |
| 12-17 | 536 | 398 | 74.3 | 70.4 – 77.8 * |
| 18-29 | 796 | 497 | 62.4 | 59.0 – 65.7 * |
| 30-39 | 838 | 600 | 71.6 | 68.5 – 74.5 * |
| 40-49 | 915 | 702 | 76.7 | 73.9 – 79.3 * |
| 50-59 | 900 | 777 | 86.3 | 83.9 – 88.4 # |
| 60-69 | 930 | 882 | 94.8 | 93.2 – 96.1 # |
| 70 ⁺ | 980 | 943 | 96.2 | 94.8 – 97.2 # |
| Total: | 6774 | 5512 | 81.4 | 80.4 – 82.3 |

Notes: n – number of seropositive volunteers; 70⁺ – persons aged ≥ 70 years; # value significantly higher than the cohort value ($p < 0.05$); * value significantly lower than the final result ($p < 0.05$); 95% CI - 95% confidence interval.

Table 2S. Anti-measles IgG levels by age group (St. Petersburg, Leningrad Region).

| Age group, years | N | Anti-measles IgG level (concentration interval), IU/ml | | | | | | | | | | | | | | |
|------------------|-----|--|------|-------------|----------|------|-------------|----------|------|-------------|----------|------|-------------|------|------|------------|
| | | <0.18 | | | 0.18-0.5 | | | 0.51-1.0 | | | 1.01-2.0 | | | >2.0 | | |
| | | n | % | 95% C. I. | n | % | 95% C. I. | n | % | 95% C. I. | n | % | 95% C. I. | n | % | 95% C. I. |
| 1-5 | 369 | 72 | 19.5 | 15.8 - 23.9 | 123 | 33.3 | 28.7 - 38.3 | 101 | 27.4 | 23.1 - 32.1 | 52 | 14.1 | 10.9 - 18.0 | 21 | 5.7 | 3.8 - 8.5 |
| 6-11 | 510 | 94 | 18.4 | 15.3 - 22.0 | 218 | 42.7 | 38.5 - 47.1 | 113 | 22.2 | 18.8 - 26.0 | 60 | 11.8 | 9.3 - 14.9 | 25 | 4.9 | 3.3 - 7.1 |
| 12-17 | 536 | 138 | 25.7 | 22.2 - 29.6 | 237 | 44.2 | 40.1 - 48.4 | 97 | 18.1 | 15.1 - 21.6 | 36 | 6.7 | 4.9 - 9.2 | 28 | 5.2 | 3.6 - 7.4 |
| 18-29 | 796 | 299 | 37.6 | 34.3 - 41.0 | 279 | 35.1 | 31.8 - 38.4 | 109 | 13.7 | 11.5 - 16.3 | 67 | 8.4 | 6.7 - 10.6 | 42 | 5.3 | 3.9 - 7.1 |
| 30-39 | 838 | 238 | 28.4 | 25.5 - 31.5 | 311 | 37.1 | 33.9 - 40.4 | 156 | 18.6 | 16.1 - 21.4 | 92 | 11.0 | 9.0 - 13.3 | 41 | 4.9 | 3.6 - 6.6 |
| 40-49 | 915 | 213 | 23.3 | 20.7 - 26.1 | 298 | 32.6 | 29.6 - 35.7 | 175 | 19.1 | 16.7 - 21.8 | 12 | 1.3 | 11.4 - 15.8 | 106 | 11.6 | 9.7 - 13.8 |

| | | | | | | | | | | | | | | | | |
|--------|-----|-----|------|-------------|-----|------|-------------|-----|------|-------------|----|----|-------------|-----|------|-------------|
| 50-59 | 900 | 123 | 13.7 | 11.6 - 16.1 | 191 | 21.2 | 18.7 - 24.0 | 157 | 17.4 | 15.1 - 20.1 | 15 | 17 | 14.7 - 19.6 | 276 | 30.7 | 27.7 - 33.8 |
| 60-69 | 930 | 48 | 5.2 | 3.9 - 6.8 | 88 | 9.5 | 7.7 - 11.5 | 74 | 8 | 6.4 - 9.9 | 15 | 16 | 14.1 - 18.9 | 568 | 61.1 | 57.9 - 64.2 |
| 70+ | 980 | 37 | 3.8 | 2.8 - 5.2 | 42 | 4.3 | 3.2 - 5.7 | 54 | 5.5 | 4.2 - 7.1 | 16 | 16 | 14.4 - 19.1 | 684 | 69.8 | 66.8 - 72.6 |
| Total: | 677 | 126 | 18.6 | 17.7 - 19.6 | 178 | 26.4 | 25.3 - 27.4 | 103 | 15.3 | 14.5 - 16.2 | 89 | 13 | 12.5 - 14.1 | 179 | 26.4 | 25.4 - 27.5 |

Note: N – number of volunteers in the age group; n – number of volunteers within the specified IgG range; % – n as a percentage of N (by age subgroup); 95% CI – confidence interval

Table 3S. Volunteer infectious and vaccinal status regarding measles (St. Petersburg, Leningrad Region).

| Age group, years | SNV | | | SV | | | NSNV | | | NSV | | |
|---------------------|-----|-----|------------|----|------|------------|------|------|-------------|-----|------|-------------|
| | n | % | 95% C. I. | n | % | 95% C. I. | n | % | 95% C. I. | n | % | 95% C. I. |
| 1-17 | 1 | 1.0 | 0.2 - 5.2 | 1 | 1.7 | 0.3 - 9.1 | 80 | 19.8 | 16.2 - 24.0 | 878 | 42.6 | 40.5 - 44.7 |
| 1-5 | 0 | 0.0 | 0.0 - 0.0 | 0 | 0.0 | 0.0 - 0.0 | 32 | 7.9 | 5.7 - 11.0 | 218 | 10.6 | 9.3 - 12.0 |
| 6-11 | 0 | 0.0 | 0.0 - 0.0 | 1 | 1.7 | 0.3 - 9.1 | 29 | 7.2 | 5.0 - 10.1 | 323 | 15.7 | 14.2 - 17.3 |
| 12-17 | 1 | 1.0 | 0.2 - 5.2 | 0 | 0.0 | 0.0 - 0.0 | 19 | 4.7 | 3.0 - 7.2 | 337 | 16.4 | 14.8 - 18.0 |
| 18-29 | 0 | 0.0 | 0.0 - 0.0 | 2 | 3.4 | 1.0 - 11.7 | 31 | 7.7 | 5.5 - 10.7 | 359 | 17.4 | 15.8 - 19.1 |
| 30-39 | 3 | 2.9 | 1.0 - 8.1 | 7 | 12.1 | 6.0 - 22.9 | 38 | 9.4 | 6.9 - 12.6 | 297 | 14.4 | 13.0 - 16.0 |
| 40-49 | 6 | 5.7 | 2.6 - 11.9 | 9 | 15.5 | 8.4 - 26.9 | 51 | 12.6 | 9.7 - 16.2 | 258 | 12.5 | 11.2 - 14.0 |

| Age group, years | SNV | | | SV | | | NSNV | | | NSV | | |
|---------------------|-----|-------|-------------|----|-------|-------------|------|-------|-------------|------|-------|-----------|
| | n | % | 95% C. I. | n | % | 95% C. I. | n | % | 95% C. I. | n | % | 95% C. I. |
| 50-59 | 16 | 15.2 | 9.6 - 23.3 | 13 | 22.4 | 13.6 - 34.7 | 44 | 10.9 | 8.2 - 14.3 | 153 | 7.4 | 6.4 - 8.6 |
| 60-69 | 38 | 36.2 | 27.6 - 45.7 | 16 | 27.6 | 17.8 - 40.2 | 72 | 17.8 | 14.4 - 21.9 | 75 | 3.6 | 2.9 - 4.5 |
| 70+ | 41 | 39.0 | 30.3 - 48.6 | 10 | 17.2 | 9.6 - 28.9 | 88 | 21.8 | 18.0 - 26.1 | 41 | 2.0 | 1.5 - 2.7 |
| Total: | 105 | 100.0 | | 58 | 100.0 | | 404 | 100.0 | | 2061 | 100.0 | |

Notes: n – number of volunteers in the specified age group with the established history; % – as percentage of the entire history group (total of all ages); 95% CI – 95% confidence interval. History: SNV – 'sick, never vaccinated'; SV – 'sick, vaccinated'; NSV – 'never sick, vaccinated'; NSNV – 'never sick, never vaccinated' (naive).

Table 4S. Anti-measles IgG levels by infectious and vaccinal status (St. Petersburg, Leningrad Region).

| Hist ory | N | Anti-measles IgG level (concentration interval), IU/ml | | | | | | | | | | | | | | | | | |
|-------------|------|--|------|-------------|----------|------|-------------|----------|------|-------------|----------|------|-------------|------|------|-------------|-------------|------|-------------|
| | | <0.18 | | | 0.18-0.5 | | | 0.51-1.0 | | | 1.01-2.0 | | | >2.0 | | | 0.18 ↔ >2.0 | | |
| | | n | % | 95% C. I. | n | % | 95% C. I. | n | % | 95% C. I. | n | % | 95% C. I. | n | % | 95% C. I. | n | % | 95% C. I. |
| SNV | 105 | 1 | 1.0 | 0.2 - 5.2 | 5 | 4.8 | 2.1 - 10.7 | 3 | 2.9 | 1.0 - 8.1 | 18 | 17.1 | 11.1 - 25.5 | 78 | 74.3 | 65.2 - 81.7 | 104 | 99.0 | 94.8 - 99.8 |
| SV | 58 | 3 | 5.2 | 1.8 - 14.1 | 7 | 12.1 | 6.0 - 22.9 | 5 | 8.6 | 3.7 - 18.6 | 11 | 19.0 | 10.9 - 30.9 | 32 | 55.2 | 42.5 - 67.3 | 55 | 94.8 | 85.9 - 98.2 |
| NSNV | 404 | 87 | 21.5 | 17.8 - 25.8 | 90 | 22.3 | 18.5 - 26.6 | 48 | 11.9 | 9.1 - 15.4 | 46 | 11.4 | 8.6 - 14.9 | 13 | 32.3 | 28.5 - 37.6 | 317 | 78.5 | 74.2 - 82.2 |
| NSV | 2061 | 439 | 21.3 | 19.6 - 23.1 | 760 | 36.9 | 34.8 - 39.0 | 392 | 19.0 | 17.4 - 20.8 | 262 | 12.7 | 11.3 - 14.2 | 208 | 10.1 | 8.9 - 11.5 | 1622 | 78.7 | 76.9 - 80.4 |

Note: N – number of volunteers with known history; n – number of volunteers within the specified IgG range; % – n as a percentage of N (by history subgroup); 95% CI – 95% confidence interval. History: SNV – 'sick, never vaccinated'; SV – 'sick, vaccinated'; NSV – 'never sick, vaccinated'; NSNV – 'never sick, never vaccinated' (naive).

Table 5S. Vaccines used for measles vaccination by age group (St. Petersburg, Leningrad Region).

| Age group, years | Vaccinated, N | Measles vaccine (Microgen) | | | Measles-mumps vaccine (Microgen) | | | Priorix (Glaxo Smith Kline) | | | M-M-R II (Merck Sharp & Dohme) | | | Vactrivor (Microgen) | | | Unnamed and other | | |
|------------------|---------------|----------------------------|------|-------------|----------------------------------|------|-------------|-----------------------------|-----|-------------|--------------------------------|-----|------------|----------------------|-----|------------|-------------------|------|-------------|
| | | n | % | 95% C. I. | n | % | 95% C. I. | n | % | 95% C. I. | n | % | 95% C. I. | n | % | 95% C. I. | n | % | 95% C. I. |
| 1-17 | 886 | 76 | 8.6 | 6.9 - 10.6 | 416 | 47 | 43.7 - 50.2 | 107 | 12 | 10.1 - 14.4 | 13 | 1.5 | 0.9 - 2.5 | 62 | 7 | 5.5 - 8.9 | 212 | 23.9 | 21.2 - 26.9 |
| 18-29 | 395 | 115 | 29 | 24.9 - 33.8 | 40 | 10 | 7.5 - 13.5 | 8 | 2 | 1.0 - 3.9 | 5 | 1.3 | 0.5 - 2.9 | 1 | 0.3 | 0.0 - 1.4 | 226 | 57.2 | 52.2-62.1 |
| 30-69 | 947 | 433 | 46 | 42.5 - 49 | 38 | 4 | 2.8 - 5.5 | 1 | 0.1 | 0 - 0.6 | 2 | 0.2 | 0.03 - 0.8 | 2 | 0.2 | 0.03 - 0.8 | 471 | 49.7 | 46.5 - 53.0 |
| 70+ | 69 | 33 | 48 | 36.5 - 59.4 | 12 | 17 | 10.2 - 28.0 | 0 | 0 | 0.0 - 0.0 | 0 | 0 | 0.0 - 0.0 | 0 | 0 | 0.0 - 0.0 | 24 | 34.8 | 23.7 - 47.2 |
| Total: | 2297 | 657 | 28.6 | 26.8 - 30.5 | 506 | 22.0 | 20.4 - 23.8 | 116 | 5.1 | 4.2 - 6.0 | 20 | 0.9 | 0.6 - 1.3 | 65 | 2.8 | 2.2 - 3.6 | 933 | 40.6 | 38.6 - 42.6 |

Notes: n – number of volunteers vaccinated with the specified vaccine; % – of N in the age group; 95% CI – 95% confidence interval.

Table 6S. Rubella seroprevalence by age group (St. Petersburg, Leningrad Region).

| Age group, years | Number of volunteers, N | IgG ⁺ | | |
|------------------|-------------------------|------------------|------|---------------|
| | | n | % | 95% C. I. |
| 1-5 | 369 | 343 | 93.0 | 89.9 - 95.1 |
| 6-11 | 510 | 487 | 95.5 | 93.3 - 97.0 |
| 12-17 | 536 | 511 | 95.3 | 93.2 - 96.8 |
| 18-29 | 796 | 759 | 95.4 | 93.7 - 96.6 |
| 30-39 | 838 | 777 | 92.7 | 90.8 - 94.3 * |
| 40-49 | 915 | 857 | 93.7 | 91.9 - 95.1 |
| 50-59 | 900 | 867 | 96.3 | 94.9 - 97.4 |
| 60-69 | 930 | 909 | 97.7 | 96.6 - 98.5 # |
| 70 ⁺ | 980 | 956 | 97.6 | 96.4 - 98.3 # |
| Total: | 6774 | 6466 | 95.5 | 94.9 - 95.9 |

Notes: n – number of seropositive volunteers; # value significantly higher than the cohort value ($p<0.05$); * value significantly lower than the final result ($p<0.05$); 95% CI – 95% confidence interval.

Table 7S. Anti-rubella IgG levels by age group (St. Petersburg, Leningrad Region).

| Age group, years | N | Anti-rubella IgG level (concentration interval), IU/ml | | | | | | | | | | | | | | |
|------------------|-----|--|----|------------|-----------|-----|-----------|------------|-----|-------------|-------------|-----|-------------|--------|-----|-------------|
| | | <10 | | | 10.0-25.0 | | | 25.1-100.0 | | | 100.1-200.0 | | | >200.0 | | |
| | | n | % | 95% C. I. | n | % | 95% C. I. | n | % | 95% C. I. | n | % | 95% C. I. | n | % | 95% C. I. |
| 1-5 | 369 | 26 | 7 | 4.9 - 10.1 | 11 | 3 | 1.7 - 5.3 | 96 | 26 | 21.8 - 30.7 | 123 | 33. | 28.7 - 38.3 | 113 | 30. | 26.1 - 35.5 |
| 6-11 | 510 | 23 | 4. | 3.0 - 6.7 | 7 | 1.4 | 0.7 - 2.8 | 172 | 33. | 29.8 - 37.9 | 196 | 38. | 34.3 - 42.7 | 112 | 22 | 18.6 - 25.8 |
| 12-17 | 536 | 25 | 4. | 3.2 - 6.8 | 35 | 6.5 | 4.7 - 8.9 | 235 | 43. | 39.7 - 48.1 | 158 | 29. | 25.8 - 33.5 | 83 | 15. | 12.7 - 18.8 |
| 18-29 | 796 | 37 | 4. | 3.4 - 6.3 | 22 | 2.8 | 1.8 - 4.1 | 230 | 28. | 25.9 - 32.1 | 261 | 32. | 29.6 - 36.1 | 246 | 30. | 27.8 - 34.2 |
| 30-39 | 838 | 61 | 7. | 5.7 - 9.2 | 10 | 1.2 | 0.6 - 2.2 | 141 | 16. | 14.4 - 19.5 | 224 | 26. | 23.8 - 29.8 | 402 | 48 | 44.6 - 51.4 |
| 40-49 | 915 | 58 | 6. | 4.9 - 8.1 | 18 | 2 | 1.2 - 3.1 | 211 | 23. | 20.4 - 25.9 | 261 | 28. | 25.7 - 31.5 | 367 | 40. | 37.0 - 43.3 |

| | | | | | | | | | | | | | | | | |
|--------|-----|----|---------|-----------|----|-----|--------------|-----|----------|----------------|-----|----------|----------------|-----|----------|----------------|
| 50-59 | 900 | 33 | 3. 7 | 2.6 - 5.1 | 37 | 4.1 | 3.0 - 5.6 | 228 | 25. 3 | 22.6 - 28.3 | 252 | 28 | 25.2 - 31.0 | 350 | 38. 9 | 35.8 - 42.1 |
| 60-69 | 930 | 21 | 2. 3 | 1.5 - 3.4 | 42 | 4.5 | 3.4 - 6.0 | 260 | 28 | 25.2 - 30.9 | 259 | 27. 8 | 25.1 - 30.8 | 348 | 37. 4 | 34.4 - 40.6 |
| 70+ | 980 | 24 | 2. 4 | 1.7 - 3.6 | 28 | 2.9 | 2.0 - 4.1 | 316 | 32. 2 | 29.4 - 35.2 | 273 | 27. 9 | 25.1 - 30.7 | 339 | 34. 6 | 31.7 - 37.6 |
| Total: | 677 | 30 | 4. 5 | 4.1 - 5.1 | 21 | 3.1 | 2.7 - 3.5 | 188 | 27. 9 | 26.8 - 29.0 | 200 | 29. 6 | 28.6 - 30.7 | 236 | 34. 8 | 33.7 - 36.0 |

Note: N – number of volunteers in the age group; n – number of volunteers within the specified IgG range; % – n as a percentage of N (by age subgroup); 95% CI – 95% confidence interval.

Table 8S. Volunteer infectious and vaccinal status regarding rubella (St. Petersburg, Leningrad Region).

| Age group, years | SNV | | | SV | | | NSNV | | | NSV | | |
|------------------|-----|-------|-------------|----|-------|-------------|------|-------|-------------|------|-------|-------------|
| | n | % | 95% C. I. | n | % | 95% C. I. | n | % | 95% C. I. | n | % | 95% C. I. |
| 1-17 | 0 | 0.0 | 0.0 - 0.0 | 6 | 14.0 | 6.6 - 27.3 | 100 | 12.3 | 10.2 - 14.7 | 848 | 67.0 | 64.3 - 69.5 |
| 1-5 | 0 | 0.0 | 0.0 - 0.0 | 0 | 0.0 | 0.0 - 0.0 | 36 | 4.4 | 3.2 - 6.1 | 213 | 16.8 | 14.9 - 19.0 |
| 6-11 | 0 | 0.0 | 0.0 - 0.0 | 0 | 0.0 | 0.0 - 0.0 | 37 | 4.6 | 3.3 - 6.2 | 312 | 24.6 | 22.3 - 27.1 |
| 12-17 | 0 | 0.0 | 0.0 - 0.0 | 6 | 14.0 | 6.6 - 27.3 | 27 | 3.3 | 2.3 - 4.8 | 323 | 25.5 | 23.2 - 28.0 |
| 18-29 | 22 | 12.2 | 8.2 - 17.8 | 16 | 37.2 | 24.4 - 52.1 | 46 | 5.7 | 4.3 - 7.5 | 262 | 20.7 | 18.6 - 23.0 |
| 30-39 | 47 | 26.1 | 20.2 - 33.0 | 13 | 30.2 | 18.6 - 45.1 | 90 | 11.1 | 9.1 - 13.4 | 111 | 8.8 | 7.3 - 10.5 |
| 40-49 | 36 | 20.0 | 14.8 - 26.4 | 4 | 9.3 | 3.7 - 21.6 | 132 | 16.2 | 13.9 - 18.9 | 28 | 2.2 | 1.5 - 3.2 |
| 50-59 | 28 | 15.6 | 11.0 - 21.6 | 2 | 4.7 | 1.3 - 15.5 | 134 | 16.5 | 14.1 - 19.2 | 6 | 0.5 | 0.2 - 1.0 |
| 60-69 | 25 | 13.9 | 9.6 - 19.7 | 1 | 2.3 | 0.4 - 12.1 | 161 | 19.8 | 17.2 - 22.7 | 4 | 0.3 | 0.1 - 0.8 |
| 70+ | 22 | 12.2 | 8.2 - 17.8 | 1 | 2.3 | 0.4 - 12.1 | 150 | 18.5 | 15.9 - 21.3 | 7 | 0.6 | 0.3 - 1.1 |
| Total: | 180 | 100.0 | | 43 | 100.0 | | 813 | 100.0 | | 1266 | 100.0 | |

Notes: n – number of volunteers in the specified age group with the established history; % – as percentage of the entire history group (total of all ages); 95% CI – 95% confidence interval. History: SNV – 'sick, never vaccinated'; SV – 'sick, vaccinated'; NSV – 'never sick, vaccinated'; NSNV – 'never sick, never vaccinated' (naive).

Table 9S. Anti-rubella IgG levels by infectious and vaccinal status (St. Petersburg, Leningrad Region).

| History | N | Anti-rubella IgG level (concentration interval), IU/ml | | | | | | | | | | | | | | | | | | |
|---------|------|--|------|------------|-------|-----|-----------|----------|------|-------------|-----------|------|-------------|------|------|-------------|-----------|------|-------------|--|
| | | <10 | | | 10-25 | | | 25.1-100 | | | 100.1-200 | | | >200 | | | 10 ↔ >200 | | | |
| | | n | % | 95% C. I. | n | % | 95% C. I. | n | % | 95% C. I. | n | % | 95% C. I. | n | % | 95% C. I. | n | % | 95% C. I. | |
| SNV | 180 | 5 | 2.8 | 1.2 - 6.3 | 2 | 1.1 | 0.3 - 4.0 | 27 | 15.0 | 10.5 - 20.9 | 40 | 22.2 | 16.8 - 28.8 | 106 | 58.9 | 51.6 - 65.8 | 175 | 97.2 | 93.7 - 98.8 | |
| SV | 43 | 2 | 4.7 | 1.3 - 15.5 | 0 | 0.0 | 0.0 - 0.0 | 3 | 7.0 | 2.4 - 18.6 | 12 | 27.9 | 16.7 - 42.7 | 26 | 60.5 | 45.6 - 73.6 | 41 | 95.3 | 84.5 - 98.7 | |
| NSNV | 813 | 93 | 11.4 | 9.4 - 13.8 | 31 | 3.8 | 2.7 - 5.4 | 213 | 26.2 | 23.3 - 29.3 | 203 | 25.0 | 22.1 - 28.1 | 273 | 33.6 | 30.4 - 36.9 | 720 | 88.6 | 86.2 - 90.6 | |
| NSV | 1266 | 25 | 2.0 | 1.3 - 2.9 | 39 | 3.1 | 2.3 - 4.2 | 445 | 35.2 | 32.6 - 37.8 | 438 | 34.6 | 32.0 - 37.3 | 319 | 25.2 | 22.9 - 27.7 | 1241 | 98.0 | 97.1 - 98.7 | |

Notes: N – number of volunteers with known history; n – number of volunteers within the specified IgG range; % – n as a percentage of N (by history subgroup); 95% CI – 95% confidence interval. History: SNV – 'sick, never vaccinated'; SV – 'sick, vaccinated'; NSV – 'never sick, vaccinated'; NSNV – 'never sick, never vaccinated' (naive).

Table 10S. Vaccines used for rubella vaccination by age group (St. Petersburg, Leningrad Region).

| Age group, years | Vaccinated, N | Anti-rubella vaccine (Microgen) | | | Vactrivor (Microgen) | | | Priorix (Glaxo Smith Kline) | | | M-M-R II (Merck Sharp & Dohme) | | | Unnamed and other | | |
|------------------|---------------|---------------------------------|------|-------------|----------------------|------|-------------|-----------------------------|------|-------------|--------------------------------|------|------------|-------------------|------|-------------|
| | | n | % | 95% C. I. | n | % | 95% C. I. | n | % | 95% C. I. | n | % | 95% C. I. | n | % | 95% C. I. |
| 1-5 | 214 | 106 | 49.5 | 42.9 - 56.2 | 48 | 22.4 | 17.4 - 28.5 | 6 | 2.8 | 1.3 - 6.0 | 6 | 2.8 | 1.3 - 6.0 | 48 | 22.4 | 17.0 - 28.6 |
| 6-11 | 313 | 168 | 53.7 | 48.1 - 59.1 | 12 | 3.8 | 2.2 - 6.6 | 40 | 12.8 | 9.5 - 16.9 | 5 | 1.6 | 0.7 - 3.7 | 88 | 28.1 | 23.2 - 33.5 |
| 12-17 | 334 | 170 | 50.9 | 45.6 - 56.2 | 4 | 1.2 | 0.5 - 3.0 | 64 | 19.2 | 15.3 - 23.7 | 2 | 0.6 | 0.2 - 2.2 | 94 | 28.1 | 23.4 - 33.3 |
| 18-49 | 482 | 186 | 38.6 | 34.2 - 43.1 | 0 | 0 | 0 - 0.6 | 8 | 1.7 | 0.7 - 3.2 | 7 | 1.5 | 0.6 - 3 | 281 | 58.3 | 53.8 - 62.7 |
| 50-59 | 8 | 3 | 37.5 | 13.7 - 69.4 | 1 | 12.5 | 2.2 - 47.1 | 0 | 0 | 0.0 - 0.0 | 1 | 12.5 | 2.2 - 47.1 | 3 | 37.5 | 8.5 - 75.5 |
| 60-69 | 7 | 5 | 71.4 | 35.9 - 91.8 | 1 | 14.3 | 2.6 - 51.3 | 1 | 14.3 | 2.6 - 51.3 | 0 | 0 | 0.0 - 0.0 | 0 | 0 | 0 |

| | | | | | | | | | | | | | | | | |
|--------|------|-----|------|----------------|----|-----|--------------|-----|-----|---------------|----|-----|--------------|-----|------|----------------|
| 70+ | 10 | 8 | 80 | 49.0 - 94.3 | 0 | 0 | 0.0 - 0.0 | 0 | 0 | 0.0 - 0.0 | 0 | 0 | 0.0 - 0.0 | 2 | 20 | 2.5 - 55.6 |
| Total: | 1368 | 646 | 47.2 | 44.6 - 49.9 | 66 | 4.8 | 3.8 - 6.1 | 119 | 8.7 | 7.3 - 10.3 | 21 | 1.5 | 1.0 - 2.3 | 516 | 37.7 | 35.1 - 40.4 |

Notes: N – number of vaccinated volunteers in the age group; n – number of volunteers vaccinated with the specified vaccine; % – of N in the age group; 95% CI – 95% confidence interval.

Table 11S. Mumps seroprevalence by age group (St. Petersburg, Leningrad Region).

| Age group, years | Number of volunteers, N | IgG ⁺ | | |
|------------------|-------------------------|------------------|------|---------------|
| | | n | % | 95% C. I. |
| 1-5 | 369 | 278 | 75.3 | 70.7 - 79.5 |
| 6-11 | 510 | 449 | 88 | 84.9 - 90.6 # |
| 12-17 | 536 | 440 | 82.1 | 78.6 - 85.1 |
| 18-29 | 796 | 555 | 69.7 | 66.4 - 72.8 * |
| 30-39 | 838 | 616 | 73.5 | 70.4 - 76.4 * |
| 40-49 | 915 | 637 | 69.6 | 66.6 - 72.5 * |
| 50-59 | 900 | 699 | 77.7 | 74.8 - 80.3 |
| 60-69 | 930 | 771 | 82.9 | 80.3 - 85.2 # |
| 70 ⁺ | 980 | 864 | 88.2 | 86.0 - 90.0 # |
| Total: | 6774 | 5309 | 78.4 | 77.4 - 79.3 |

Notes: n – number of seropositive volunteers; 70⁺ – persons aged ≥ 70 years; # value significantly higher than the cohort value ($p < 0.05$); * value significantly lower than the final result ($p < 0.05$); 95% CI – 95% confidence interval.

Table 12S. Volunteer infectious and vaccinal status regarding mumps (St. Petersburg, Leningrad Region).

| Age group, years | SNV | | | SV | | | NSNV | | | NSV | | |
|---------------------|-----|-------|-------------|----|-------|-------------|------|-------|-------------|------|-------|-------------|
| | n | % | 95% C. I. | n | % | 95% C. I. | n | % | 95% C. I. | n | % | 95% C. I. |
| 1-17 | 0 | 0.0 | 0.0 - 0.0 | 1 | 4.0 | 0.7 - 19.5 | 97 | 13.7 | 11.4 - 16.4 | 846 | 56.3 | 53.8 - 58.8 |
| 1-5 | 0 | 0.0 | 0.0 - 0.0 | 0 | 0.0 | 0.0 - 0.0 | 35 | 4.9 | 3.6 - 6.8 | 209 | 13.9 | 12.3 - 15.8 |
| 6-11 | 0 | 0.0 | 0.0 - 0.0 | 0 | 0.0 | 0.0 - 0.0 | 31 | 4.4 | 3.1 - 6.1 | 314 | 20.9 | 18.9 - 23.0 |
| 12-17 | 0 | 0.0 | 0.0 - 0.0 | 1 | 4.0 | 0.7 - 19.5 | 31 | 4.4 | 3.1 - 6.1 | 323 | 21.5 | 19.5 - 23.7 |
| 18-29 | 0 | 0.0 | 0.0 - 0.0 | 1 | 4.0 | 0.7 - 19.5 | 51 | 7.2 | 5.5 - 9.3 | 299 | 19.9 | 18.0 - 22.0 |
| 30-39 | 7 | 6.3 | 3.1 - 12.4 | 4 | 16.0 | 6.4 - 34.7 | 66 | 9.3 | 7.4 - 11.7 | 205 | 13.6 | 12.0 - 15.5 |
| 40-49 | 11 | 9.9 | 5.6 - 16.9 | 9 | 36.0 | 20.2 - 55.5 | 113 | 16.0 | 13.4 - 18.8 | 101 | 6.7 | 5.6 - 8.1 |
| 50-59 | 19 | 17.1 | 11.2 - 25.2 | 7 | 28.0 | 14.3 - 47.6 | 114 | 16.1 | 13.6 - 19.0 | 25 | 1.7 | 1.1 - 2.4 |
| 60-69 | 45 | 40.5 | 31.9 - 49.8 | 3 | 12.0 | 4.2 - 30.0 | 123 | 17.4 | 14.8 - 20.3 | 13 | 0.9 | 0.5 - 1.5 |
| 70+ | 29 | 26.1 | 18.9 - 35.0 | 0 | 0.0 | 0.0 - 0.0 | 144 | 20.3 | 17.5 - 23.5 | 13 | 0.9 | 0.5 - 1.5 |
| Total: | 111 | 100.0 | | 25 | 100.0 | | 708 | 100.0 | | 1502 | 100.0 | |

Notes: n – number of volunteers in the specified age group with the established history; % – as percentage of the entire history group (total of all ages); 95% CI – 95% confidence interval. History: SNV – 'sick, never vaccinated'; SV – 'sick, vaccinated'; NSV – 'never sick, vaccinated'; NSNV – 'never sick, never vaccinated' (naive).

Table 13S. Vaccines used for mumps vaccination by age group (St. Petersburg, Leningrad Region).

| Age group, years | Vaccinated, N | Measles-mumps vaccine (Microgen) | | | Priorix (Glaxo Smith Kline) | | | M-M-R II (Merck Sharp & Dohme) | | | Vactrivor (Microgen) | | | Mumps vaccine (Microgen) | | | Unnamed and other | | |
|------------------|---------------|----------------------------------|------|-------------|-----------------------------|------|-------------|--------------------------------|-----|------------|----------------------|------|-------------|--------------------------|------|-------------|-------------------|------|-------------|
| | | n | % | 95% C. I. | n | % | 95% C. I. | n | % | 95% C. I. | n | % | 95% C. I. | n | % | 95% C. I. | n | % | 95% C. I. |
| 1-5 | 210 | 96 | 45.7 | 39.1 - 52.5 | 6 | 2.9 | 1.3 - 6.1 | 5 | 2.4 | 1.0 - 5.5 | 47 | 22.4 | 17.3 - 28.5 | 11 | 5.2 | 2.9 - 9.1 | 45 | 21.4 | 16.1 - 27.6 |
| 6-11 | 315 | 159 | 50.5 | 45.0 - 56.0 | 39 | 12.4 | 9.2 - 16.5 | 4 | 1.3 | 0.5 - 3.2 | 12 | 3.8 | 2.2 - 6.5 | 23 | 7.3 | 4.9 - 10.7 | 78 | 24.8 | 20.1 - 29.9 |
| 12-17 | 325 | 149 | 45.8 | 40.5 - 51.3 | 66 | 20.3 | 16.3 - 25.0 | 2 | 0.6 | 0.2 - 2.2 | 4 | 1.2 | 0.5 - 3.1 | 23 | 7.1 | 4.8 - 10.4 | 81 | 24.9 | 20.3 - 30 |
| 18-29 | 317 | 44 | 13.9 | 10.5 - 18.1 | 7 | 2.2 | 1.1 - 4.5 | 5 | 1.6 | 0.7 - 3.6 | 0 | 0 | 0.0 - 0.0 | 80 | 25.2 | 20.8 - 30.3 | 18 | 5.7 | 51.5 - 62.6 |
| 30-49 | 344 | 20 | 5.8 | 3.6 - 8.8 | 0 | 0 | 0 | 1 | 0.3 | 0.01 - 1.6 | 0 | 0 | 0 | 12 | 3.5 | 29.9 - 40.2 | 20 | 5.9 | 53.6 - 64.3 |
| 50-69 | 56 | 18 | 32.1 | 20.3 - 46 | 1 | 1.8 | 0.05 - 9.6 | 1 | 1.8 | 0.05 - 9.6 | 2 | 3.6 | 0.4 - 12.3 | 27 | 48.2 | 34.7 - 62 | 7 | 12.5 | 5.2 - 24.1 |

| | | | | | | | | | | | | | | | | | | | | | | |
|--------|------|---------|----------|--------------|--------|---------|----|-----------|----|---------|------------|---------|-----|------------|------------|----------|----|--------------|--------|----------|-------------|---|
| 70+ | 16 | 13 | 81 .3 | 57.0 93.4 | - 0 | 0 | 0 | 0.0 - 0.0 | 0 | 0 | 0.0 0.0 | - 0 | 0 | 0 | 0.0 0.0 | - 0 | 0 | 0.0 0.0 | - 3 | 18 .8 | 4.1 45.7 | - |
| Total: | 1583 | 49 9 | 31 .5 | 29.3 33.9 | - 9 | 11 5 | 7. | 6.3 - 8.9 | 18 | 1. 1 | 0.7 1.8 | - 65 | 4.1 | 3.2 5.2 | - 4 | 28 .9 | 17 | 16.1 19.9 | - 8 | 59 .8 | 37 40.2 | - |

Notes: N – number of vaccinated volunteers in the age group; n – number of volunteers vaccinated with the specified vaccine; % – of N in the age group; 95% CI – 95% confidence interval.

Table 14S. Seroprevalence among 'naive' NSNV volunteers (never sick, never vaccinated) to causative pathogens of vaccine-preventable infections (St. Petersburg, Leningrad Region).

| Age group, years | Measles | | | | Rubella | | | | Mumps | | | |
|------------------|---------|-----|------|-------------|---------|-----|------|-------------|-------|-----|------|-------------|
| | N | n | % | 95% C. I. | N | n | % | 95% C. I. | N | n | % | 95% C. I. |
| 1-5 | 32 | 12 | 37.5 | 22.9 - 54.7 | 36 | 18 | 50.0 | 34.5 - 65.5 | 35 | 17 | 48.6 | 33.0 - 64.4 |
| 6-11 | 29 | 16 | 55.2 | 37.5 - 71.6 | 37 | 21 | 56.8 | 40.9 - 71.3 | 31 | 18 | 58.1 | 40.8 - 73.6 |
| 12-17 | 19 | 11 | 57.9 | 36.3 - 76.9 | 27 | 14 | 51.9 | 34.0 - 69.3 | 31 | 19 | 61.3 | 43.8 - 76.3 |
| 18-29 | 31 | 19 | 61.3 | 43.8 - 76.3 | 46 | 37 | 80.4 | 66.8 - 89.3 | 51 | 33 | 64.7 | 51.0 - 76.4 |
| 30-39 | 38 | 30 | 78.9 | 63.7 - 88.9 | 90 | 75 | 83.3 | 74.3 - 89.6 | 66 | 46 | 69.7 | 57.8 - 79.4 |
| 40-49 | 51 | 34 | 66.7 | 53.0 - 78.0 | 132 | 127 | 96.2 | 91.4 - 98.4 | 113 | 70 | 61.9 | 52.7 - 70.4 |
| 50-59 | 44 | 39 | 88.6 | 76.0 - 95.0 | 134 | 129 | 96.3 | 91.6 - 98.4 | 114 | 88 | 77.2 | 68.7 - 83.9 |
| 60-69 | 72 | 70 | 97.2 | 90.4 - 99.2 | 161 | 155 | 96.3 | 92.1 - 98.3 | 123 | 102 | 82.9 | 75.3 - 88.6 |
| 70 ⁺ | 88 | 86 | 97.7 | 92.1 - 99.4 | 150 | 144 | 96.0 | 91.5 - 98.2 | 144 | 130 | 90.3 | 84.3 - 94.1 |
| Total: | 404 | 317 | 78.5 | 74.2 - 82.2 | 813 | 720 | 88.6 | 86.2 - 90.6 | 708 | 523 | 73.9 | 70.5 - 77.0 |

N – number of NSNV volunteers; n – number of individuals seropositive for Abs to the specified infection; % – n as a percentage of N; 95% CI – 95% confidence interval.

РИСУНКИ

Figure 1. Annual incidence dynamics of measles, mumps, and rubella in the local population (2010 to 2023).

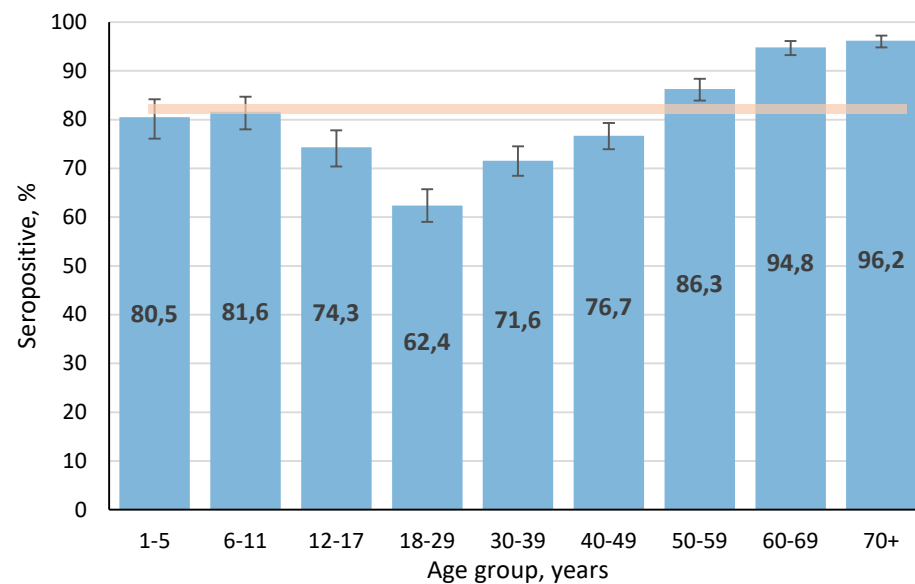


Figure 2. Study flow chart.

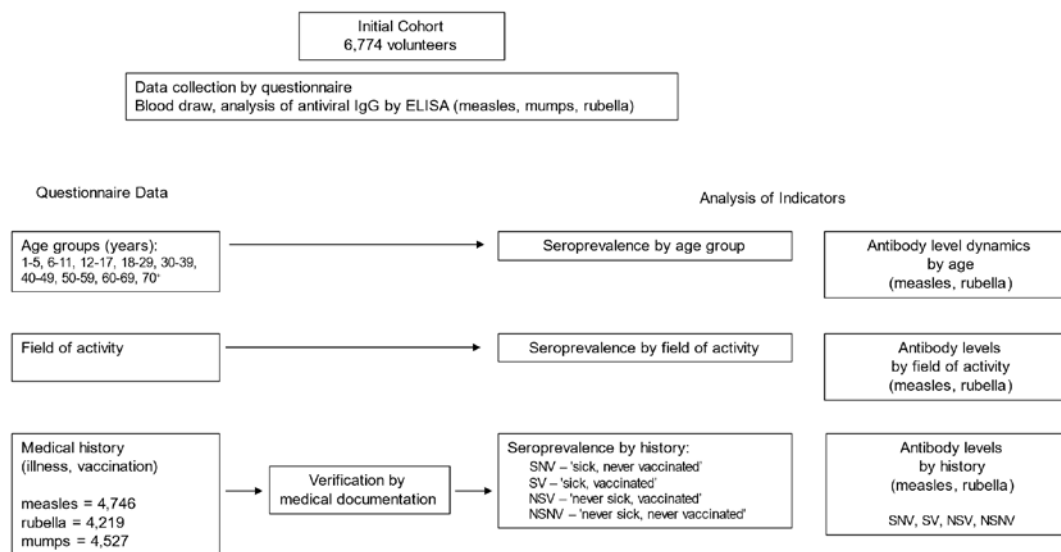


Figure 3. Measles seroprevalence (IgG presence) by age group. Note: vertical black lines are confidence intervals; horizontal translucent band is the 95% confidence interval of the final value for the entire sample (81.4%; 95% CI: 80.4–82.3). Numerical values and statistical significance indicators are given in Supplementary Table 1S.

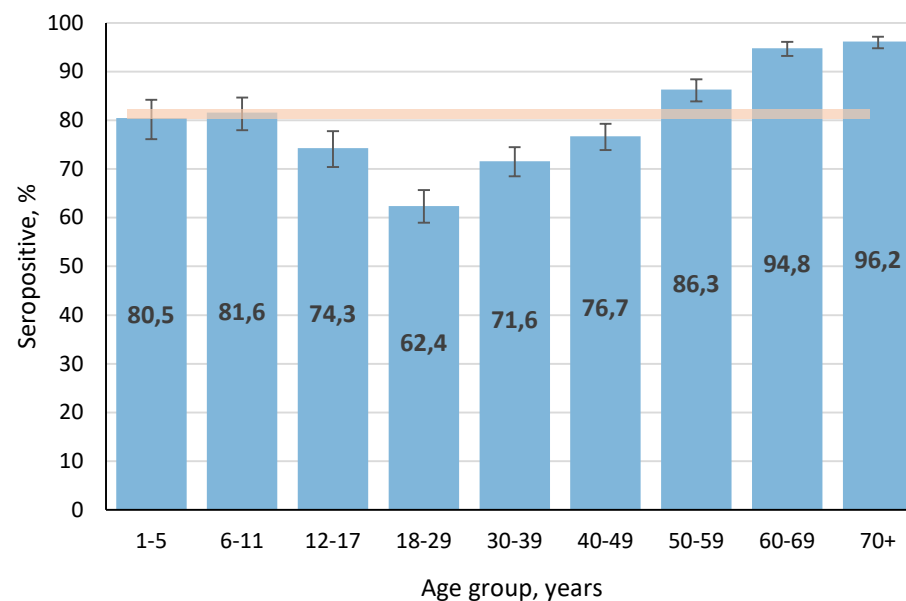


Figure 4. Trends in the quantitative distribution of anti-measles IgG levels by age group. Numerical values are shown in the upper left: regression equations (trend lines in corresponding colors); determination coefficients (R^2); Spearman correlation coefficients (ρ); p values. Quantitative Ab levels are in IU/ml. Vertical black lines are 95% confidence intervals. Numerical values and statistical significance indicators are given in Supplementary Table 2S.

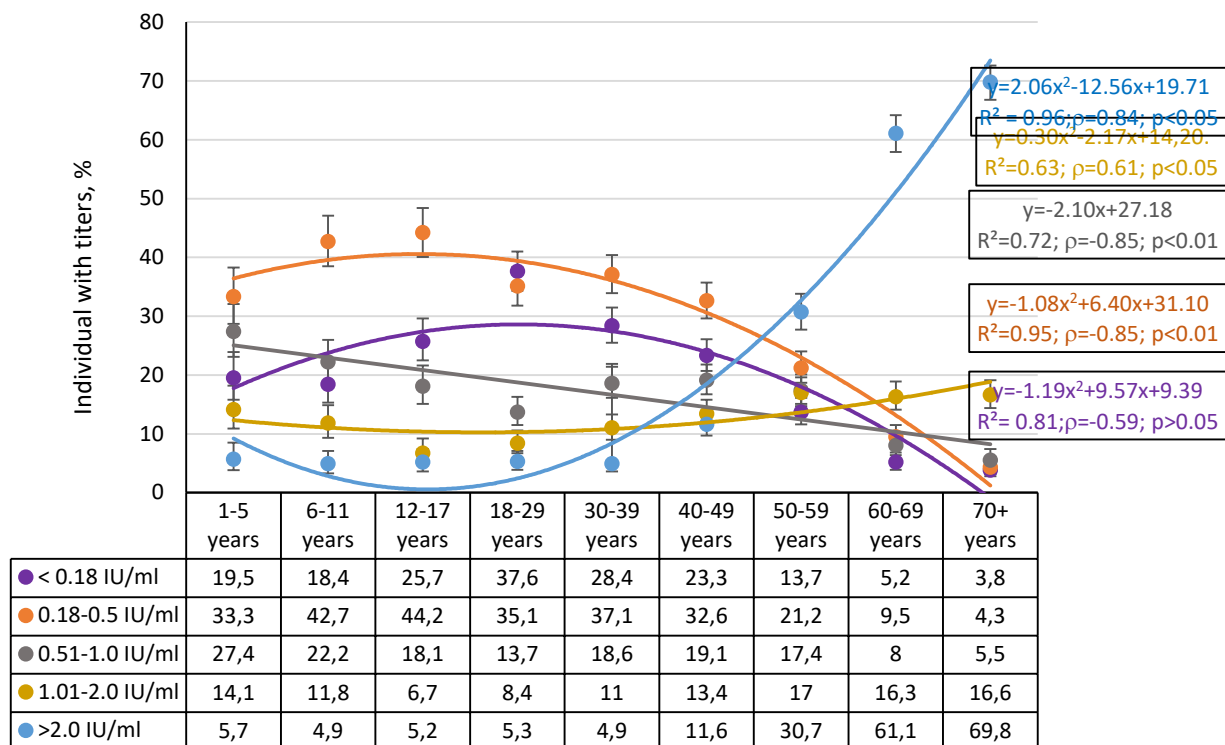


Figure 5. Measles seroprevalence by infectious and vaccinal status. Legend: SNV – 'sick, never vaccinated'; SV – 'sick, vaccinated'; NSV – 'never sick, vaccinated'; NSNV – 'never sick, never vaccinated'. Numerical values and statistical significance indicators are given in Supplementary Table 4S.

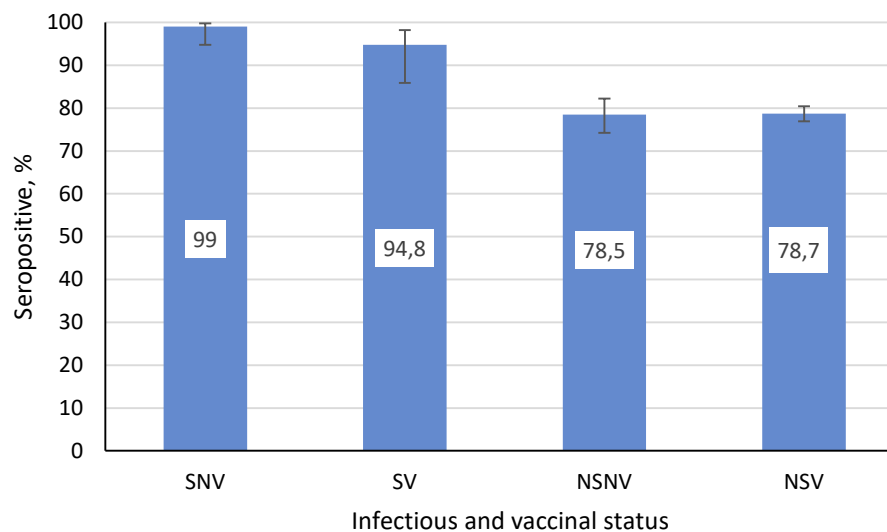


Figure 6. Anti-measles IgG levels by infectious and vaccinal status. Legend: SNV – 'sick, never vaccinated'; SV – 'sick, vaccinated'; NSV – 'never sick, vaccinated'; NSNV – 'never sick, never vaccinated'. Numerical values and statistical significance indicators are given in Supplementary Table 4S.

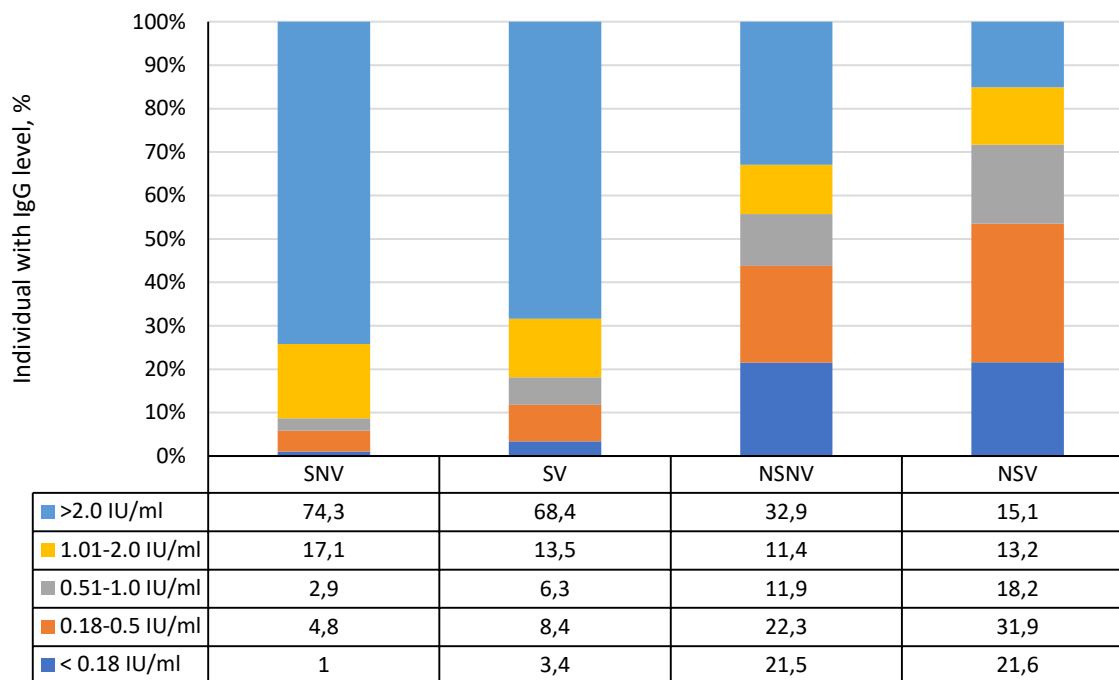


Figure 7. Structure of preparations used for measles vaccination (St. Petersburg, Leningrad Region). Numerical values and statistical significance indicators are given in Supplementary Table 5S.

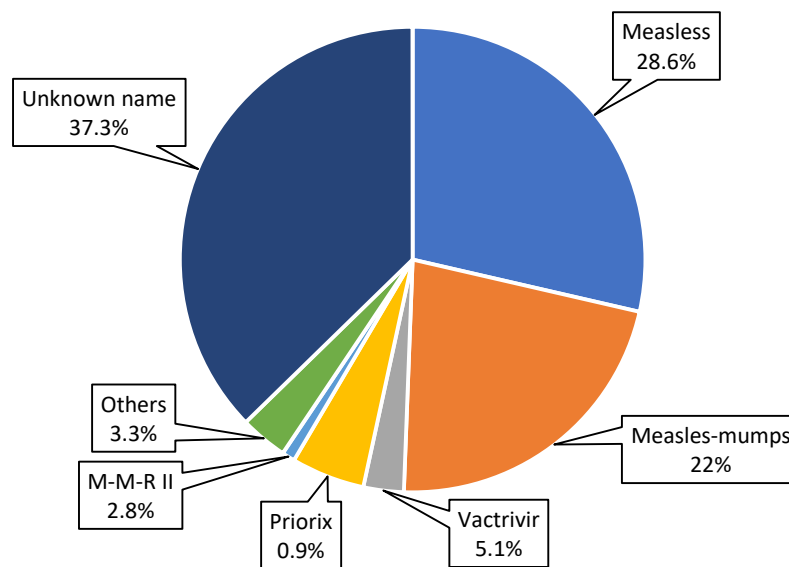


Figure 8. Preparations used for measles vaccination, by age group. Numerical values and statistical significance indicators are given in Supplementary Table 5S.

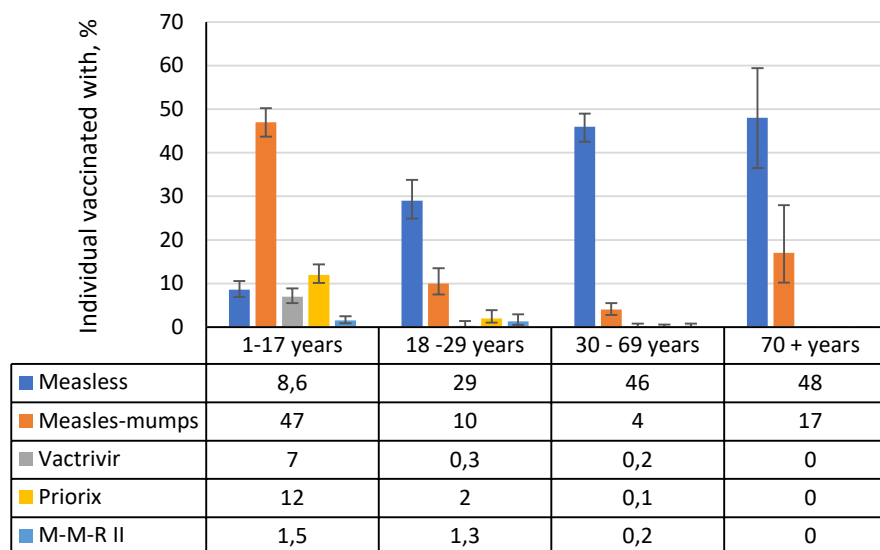


Figure 9. Rubella seroprevalence (IgG presence) by age group. Notes: vertical black lines are 95% confidence intervals; horizontal translucent stripe is the 95% confidence interval of the final value for the entire sample (95.5%; 95% CI: 94.9–95.9). Numerical values and statistical significance indicators are given in Supplementary Table 6S.

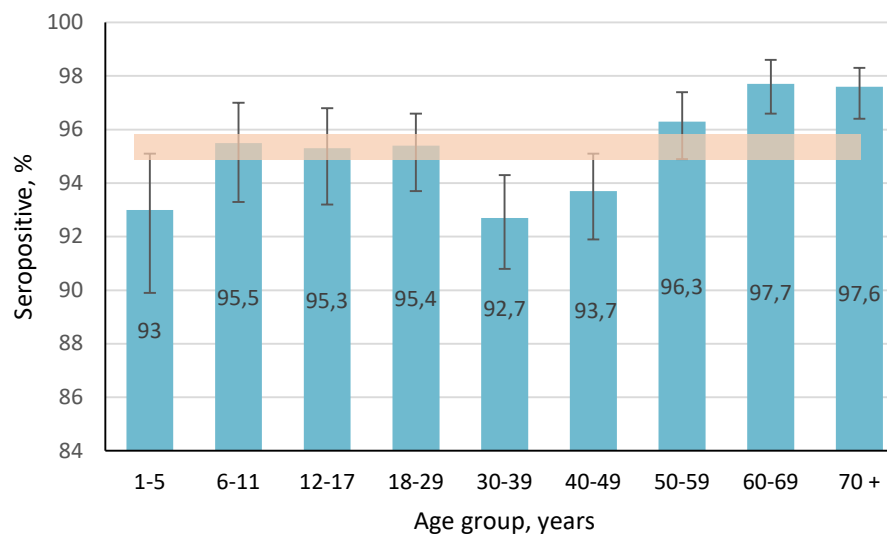


Figure 10. Trends in the quantitative distribution of anti-rubella IgG levels by age group. Numerical values are shown in the upper left: regression equations (trend lines in corresponding colors); determination coefficients (R^2); Spearman correlation coefficients (ρ); p values. Quantitative Ab levels are in IU/ml. Vertical black lines are 95% confidence intervals. Numerical values and statistical significance indicators are given in Supplementary Table 7S.

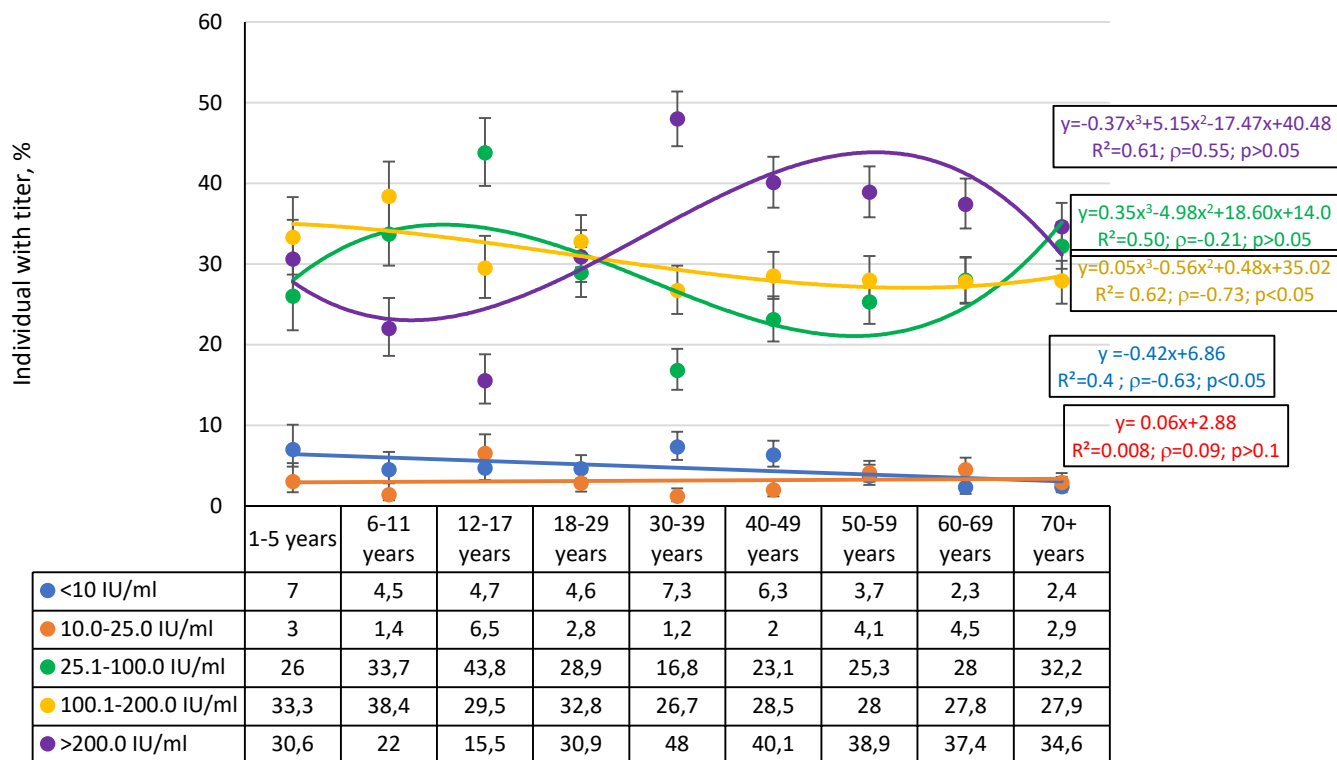


Figure 11. Rubella seroprevalence by infectious and vaccinal status. Legend: SNV – 'sick, never vaccinated'; SV – 'sick, vaccinated'; NSV – 'never sick, vaccinated'; NSNV – 'never sick, never vaccinated'. Vertical black bars are 95% confidence intervals. Numerical values and statistical significance indicators are given in Supplementary Table 9S.

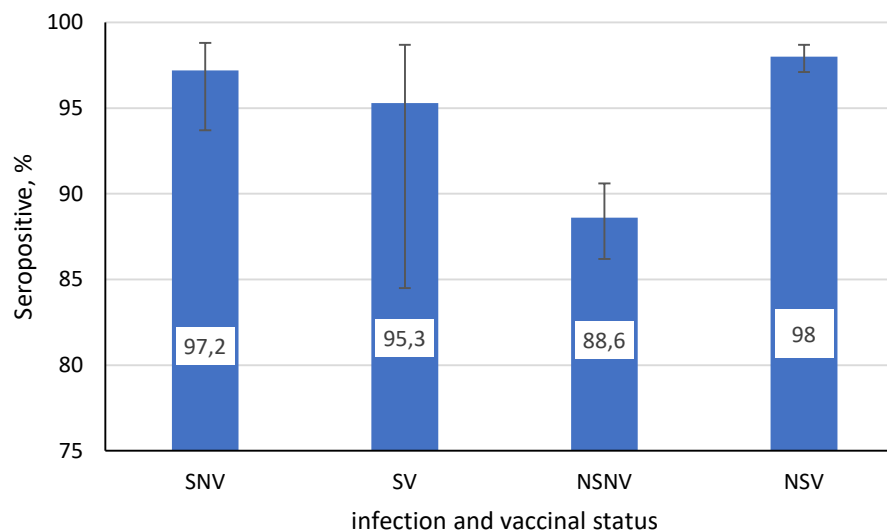


Figure 12. Anti-rubella IgG levels by infectious and vaccinal status. Legend: SNV – 'sick, never vaccinated'; SV – 'sick, vaccinated'; NSV – 'never sick, vaccinated'; NSNV – 'never sick, never vaccinated'. Numerical values and statistical significance indicators are presented in Supplementary Table 9S.

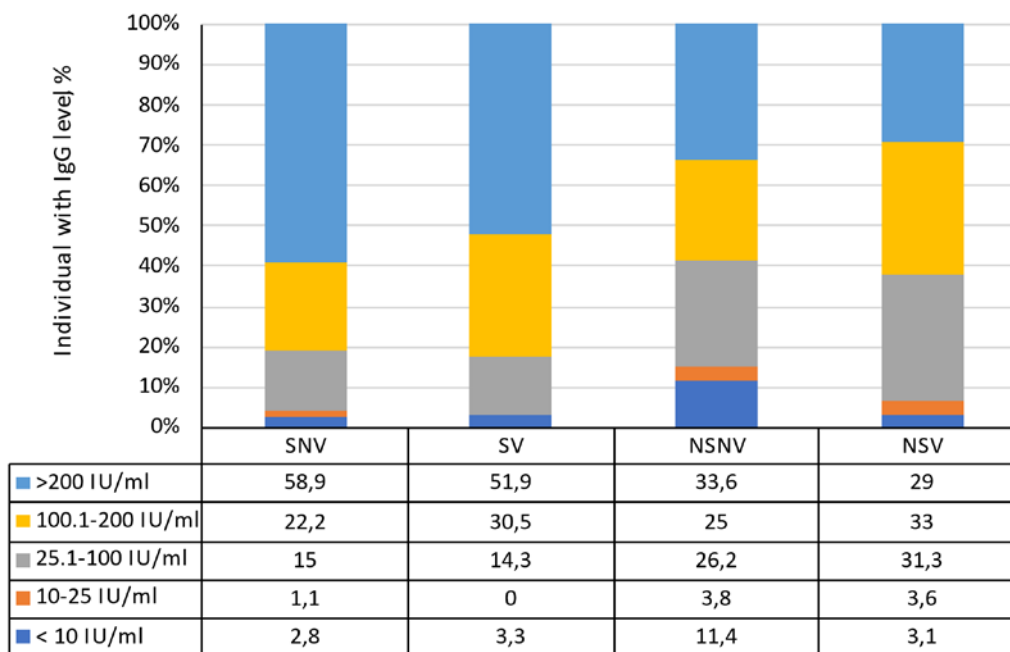


Figure 13. Structure of preparations used for rubella vaccination. Numerical values and statistical significance indicators are given in Supplementary Table 10S.

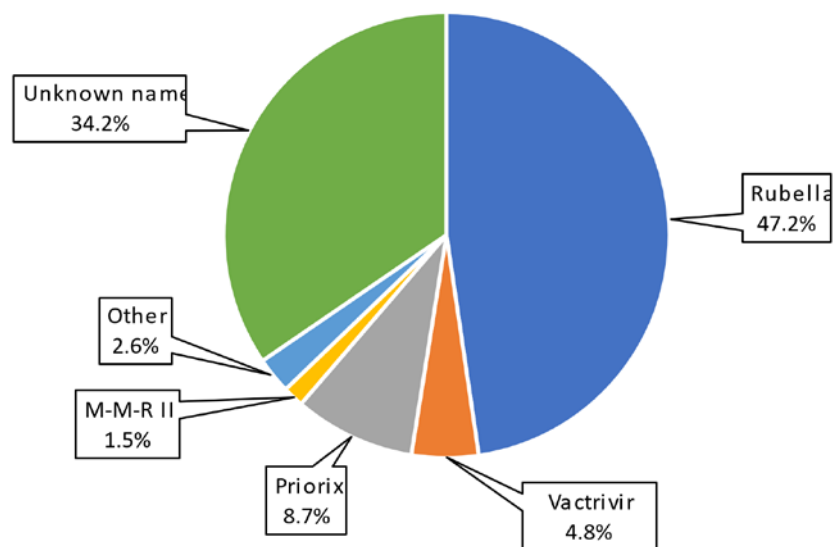


Figure 14. Preparations used for rubella vaccination, by age group. Note: vertical black lines are 95% confidence intervals. Numerical values and statistical significance indicators are given in Supplementary Table 10S.

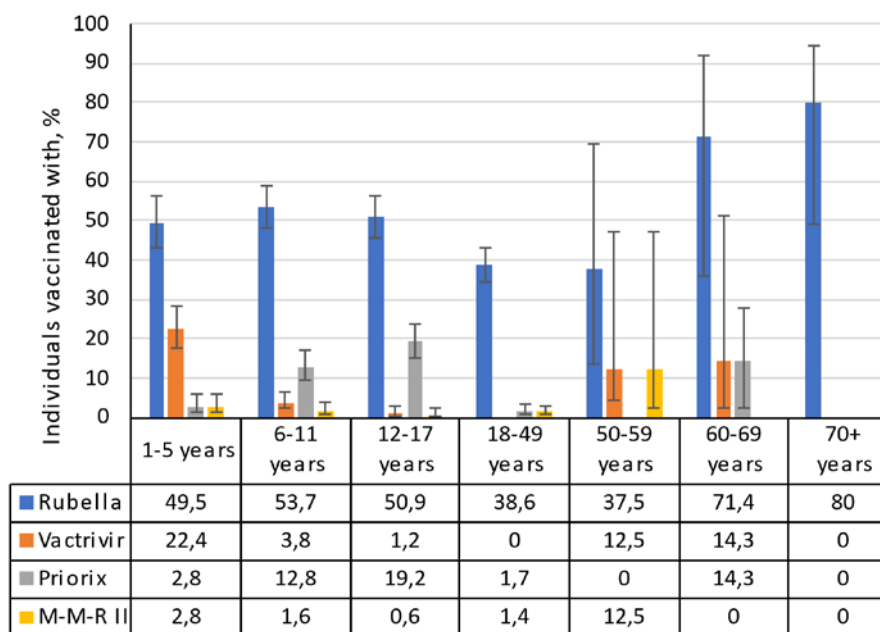


Figure 15. Mumps seroprevalence, by age group. Note: vertical black lines are 95% confidence intervals; horizontal translucent bar is the 95% confidence interval of the final value for the entire sample (78.4%; 95% CI: 77.4–79.3). Numerical values and statistical significance indicators are presented in Supplementary Table 11S.

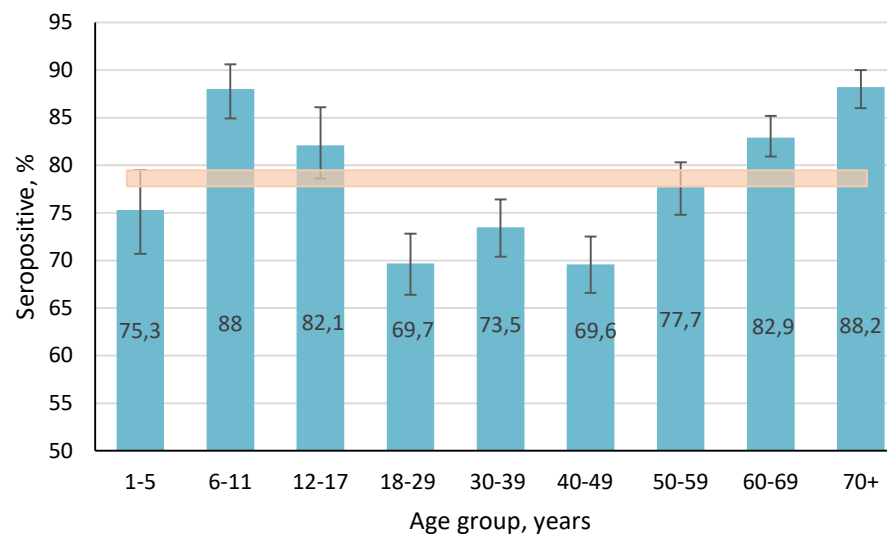


Figure 16. Mumps seroprevalence by infectious and vaccinal status. Legend: SNV – 'sick, never vaccinated'; SV – 'sick, vaccinated'; NSV – 'never sick, vaccinated'; NSNV – 'never sick, never vaccinated'. Note: vertical black lines are 95% confidence intervals.

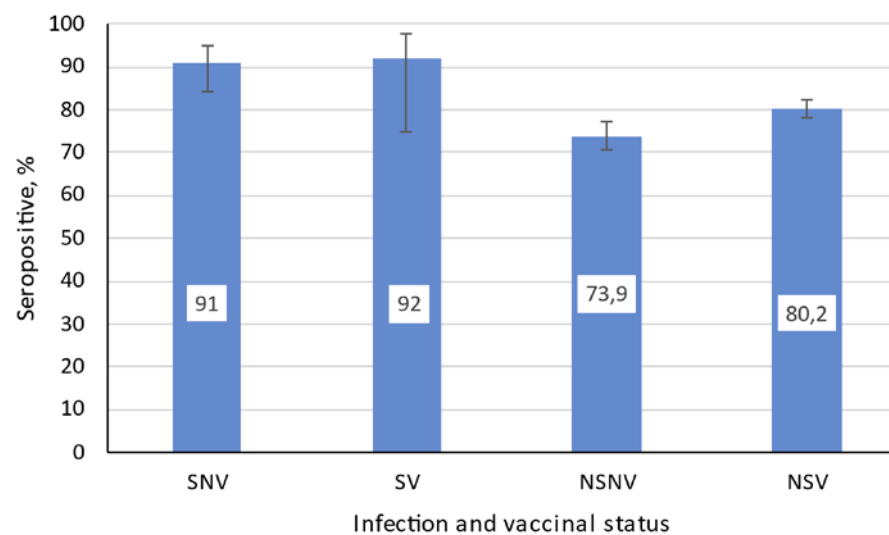


Figure 17. Structure of preparations used for mumps vaccination.

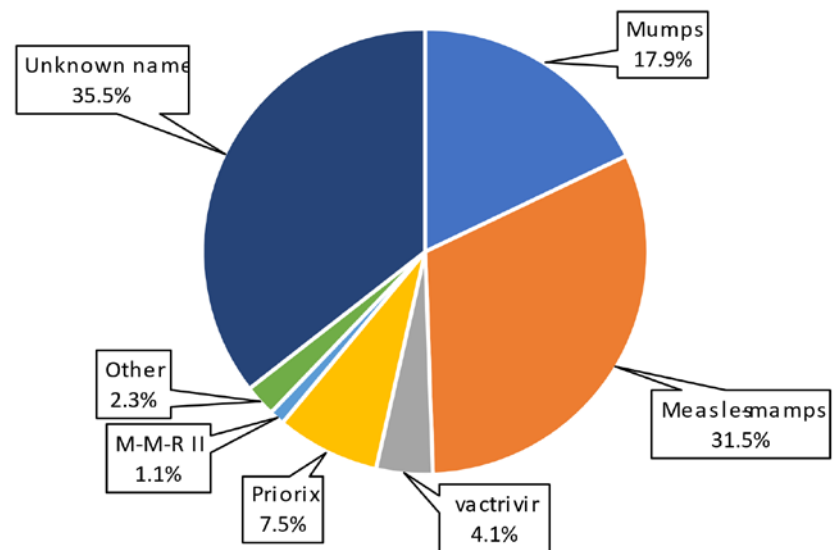


Figure 18. Preparations used for mumps vaccination, by age group. Note: vertical black lines are 95% confidence intervals. Numerical values and statistical significance indicators are given in Supplementary Table 13S.

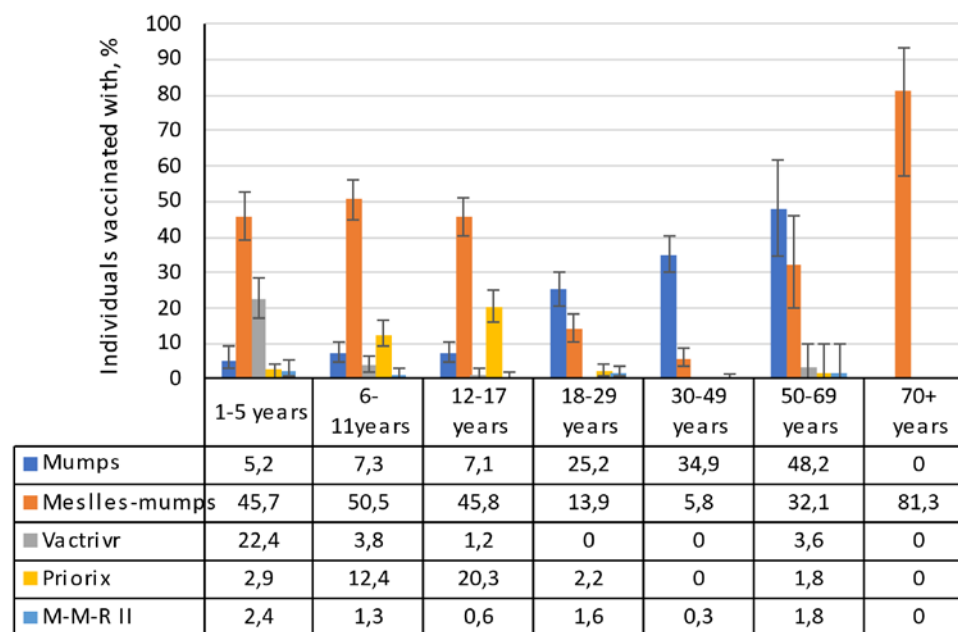
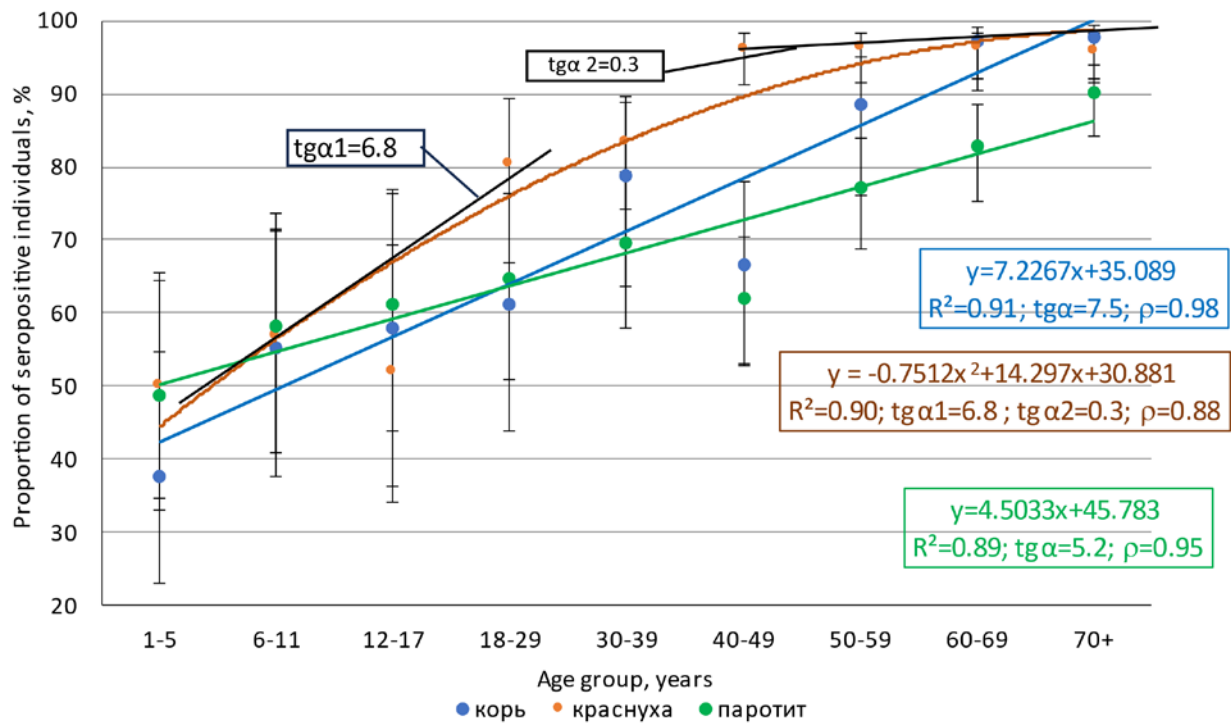


Figure 19. Seroprevalence among 'naive' volunteers (never sick, never vaccinated) for vaccine-preventable infectious pathogens. Since the rubella trendline was described by a 2nd degree polynomial, tangents to the curve were calculated for the youngest and oldest categories: $tg\alpha_1$ – slope of the youngest interval (aged 1–11 years), representing rate-of-increase in seropositivity in children; and $tg\alpha_2$ – slope of the oldest interval (aged ≥ 60 years). Trends for measles and mumps were straight lines. As such, their $tg\alpha$ values reflect evenly increasing seropositivity across age groups. Spearman correlation coefficients (ρ) are shown. For statistical significance, all at $p < 0.05$. Numerical values and statistical significance indicators are given in Supplementary Table 14S.



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Блок 3. Метаданные статьи

ПОПУЛЯЦИОННЫЙ ИММУНИТЕТ К ВАКЦИНОУПРАВЛЯЕМЫМ
ИНФЕКЦИЯМ (КОРИ, КРАСНУХЕ, ЭПИДЕМИЧЕСКОМУ ПАРОТИТУ) У
НАСЕЛЕНИЯ САНКТ-ПЕТЕРБУРГА И ЛЕНИНГРАДСКОЙ ОБЛАСТИ
HERD IMMUNITY TO VACCINE PREVENTABLE INFECTIONS IN SAINT
PETERSBURG AND THE LENINGRAD REGION: SEROLOGICAL STATUS
OF MEASLES, MUMPS, AND RUBELLA

Сокращенное название статьи для верхнего колонтитула:

ИММУНИТЕТ К КОРИ, КРАСНУХЕ И ПАРОТИТУ
IMMUNITY TO MEASLES, RUBELLA AND MUMPS

Ключевые слова: Вакциноуправляемые инфекции, популяционный иммунитет, корь, краснуха, паротит, серопревалентность, антитела, Санкт-Петербург, Ленинградская область, население, когортное исследование.

Keywords: vaccine preventable infections, herd immunity, measles, rubella, mumps, seroprevalence, antibodies, St. Petersburg, Leningrad Region, population, cohort study

Оригинальная статья.

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