Towards elimination: measles susceptibility in Australia and 17 European countries


Objective To evaluate age-specific measles susceptibility in Australia and 17 European countries.

Methods As part of the European Sero-Epidemiology Network 2 (ESEN2), 18 countries collected large national serum banks between 1996 and 2004. These banks were tested for measles IgG and the results converted to a common unitage to enable valid intercountry comparisons. Historical vaccination and disease incidence data were also collected. Age-stratified population susceptibility levels were compared to WHO European Region targets for measles elimination of < 15% in those aged 2–4 years, < 10% in 5–9-year-olds and < 5% in older age groups.

Findings Seven countries (Czech Republic, Hungary, Luxembourg, Spain, Slovakia, Slovenia and Sweden) met or came very close to the elimination targets. Four countries (Australia, Israel, Lithuania and Malta) had susceptibility levels above WHO targets in some older age groups indicating possible gaps in protection. Seven countries (Belgium, Bulgaria, Cyprus, England and Wales, Ireland, Latvia and Romania) were deemed to be at risk of epidemics as a result of high susceptibility in children and also, in some cases, adults.

Conclusion Although all countries now implement a two-dose measles vaccination schedule, if the WHO European Region target of measles elimination by 2010 is to be achieved higher routine coverage as well as vaccination campaigns in some older age cohorts are needed in some countries. Without these improvements, continued measles transmission and outbreaks are expected in Europe.


Introduction

Live attenuated measles vaccines have been available since the early 1960s and are now in use worldwide. They have the potential to achieve highly effective measles control and elimination, as observed in the Americas.1

In 1998, the WHO European Region agreed to eliminate measles in Europe by 2007.2 By 2002, the incidence of measles in Europe was estimated to be below 5 per 100 000 and a strategic plan was developed which outlined an approach for achieving elimination by the revised year of 2010.3–5

The approach focused on each member state delivering two doses of measles vaccine through the routine programme at very high (> 95%) coverage, undertaking catch-up campaigns to address older susceptible cohorts, strengthening surveillance through case-based reporting and laboratory confirmation

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of suspect cases, and improving communication about the benefits and risks of vaccination.

To measure progress towards elimination and to identify populations for vaccination campaigns, age-group specific susceptibility targets were established. These targets were based on an effective reproduction number less than one, and hence elimination.6,7 These age-specific susceptibility levels could be estimated from high-quality historical vaccine coverage data (but only in populations with no measles transmission) or from population serological surveillance data.8 Progress towards elimination can also be assessed from age-specific incidence data, but this is less useful when close to elimination because it is possible for susceptible age cohorts to go unnoticed for many years. Outbreaks in older susceptible cohorts have occurred in Europe in recent years and are serious because of the greater morbidity caused by the disease in older individuals.9,10

The size of outbreaks generated by imported measles cases can also be used to determine the effective reproductive number if cases are confirmed and extensive investigation to identify all cases in a cluster is performed.7

In many countries, high-quality historical vaccine coverage and disease incidence data are not available so serological surveillance is an essential part of assessing population immunity. Even in countries with good vaccine coverage and disease incidence, data serological surveillance can help identify older susceptible cohorts and also problems with vaccine effectiveness. Although serological surveillance has clear potential, in the past it has been difficult to compare countries because they have used different methods for testing serum antibody levels.

To obtain standardized serological data, countries participated in the measles work-package of the European Sero-Epidemiology Network 2 (ESSEN2).11 The ESSEN2 project was a continuation of the original ESSEN project with the same purpose of coordinating and harmonizing serological surveillance in Europe.5,12,13

The measles component of the original project included seven countries, and identified four with a low risk of outbreaks (England and Wales, Finland, France and the Netherlands) and three with an intermediate/high risk of measles outbreaks (Denmark, Germany and Italy). Germany and Italy have since experienced outbreaks, highlighting the importance of seroepidemiological surveys and the need for targeted action based on the results.14,15

In this paper, the results from measles serological surveillance in participating countries, as well as data on measles vaccine coverage and disease incidence, are presented and compared to the WHO European Region elimination targets. The results are used to identify susceptible cohorts to help inform future vaccination strategies as well as to identify discordance with routine coverage estimates suggesting possible problems with vaccine effectiveness or coverage data.

Methods

Serum bank collection

Each participating country was required to test a serum bank representative of the general population in their country using their usual measles assay for measuring antimeasles IgG antibody. ESEN project guidelines recommended that approximately 100 sera be tested in each 1-year age band of those <20 years of age and 200 in each 5-year age band in those aged ≥20 years. Although it was preferable that countries collected and tested the bank during the ESSEN2 study (2001–2003), some countries had already collected and tested such banks between 1996 and 2000. Each country obtained ethical approval from the appropriate national authorities for the serum collections.

Vaccine programme, coverage and measles incidence

A questionnaire was distributed to each country and completed in 2001/2002 to obtain information on current and historical measles vaccine programme organization, vaccine coverage estimates by age since 1970 and measles incidence by age group (clinical notifications and laboratory confirmations) since 1970. This information was subsequently updated in 2006 using data from the WHO centralized information system for infectious diseases (CISID).16

Standardization and reference assay

A standardization panel of 151 sera was prepared by the measles, mumps and rubella (MMR) vaccine reference centre (Robert Koch Institute, Berlin, Germany) and tested by each participating country at the same time as the serum bank. Each country was required to use the same measles assay for testing the panel as used for testing the national serum bank. Standardization equations were obtained by regression of local results against the reference centre and were used to convert the titres of the national serum bank to the unitage of the reference centre (ESSEN2 units). Further details of the standardization methodology, including the back-standardization method used for countries that had already tested their national serum bank, are given by Kafatos.17 Details of the measles assays used by the participating countries and the selection of the standardization equations are given by Tischer.18 The assay of the reference laboratory to which results were standardized was the enzyme immunoassay (EIA, Enzygnost, Dade Behring). The equivocal range for this assay was 0.15–0.35 IU/ml. After standardization, the results were classified as negative, equivocal or positive using these cut-offs. Comparisons of panel results obtained by this EIA and by the gold standard plaque neutralization test suggested that the equivocal titres could be regarded as positive.16

Data analysis

The proportion seropositive or equivocal (antimeasles antibody concentration >0.15 IU/ml) was calculated in each age group along with 95% exact confidence interval and plotted to form a seroprofile. Reported first-dose vaccine coverage at 24 months for each age group was added along with an indication of the number of doses and type of measles vaccine scheduled for each age group. Second-dose vaccine coverage was not generally available and is therefore not shown.

The proportion seronegative in each country by age was compared to the WHO elimination targets of ≤15% in those aged 2–4 years, <10% in those aged 5–9 years and ≤5% in those aged 10–19, 20–39 and 40+ years. Countries were grouped into those with low susceptibility to outbreaks (WHO elimination targets met for 2–4 year-old and 5–9 year-old age groups and at least two of the three older age groups), intermediate susceptibility (targets missed in two of the following age groups: 10–19, 20–39 or 40+), and higher susceptibility (targets missed in either
Table 1. Year and number of samples collected in national serum banks of participating countries

<table>
<thead>
<tr>
<th>Country or area</th>
<th>Type of sample</th>
<th>Year of collection</th>
<th>Age range collected (years)</th>
<th>No. samples aged &lt; 20 years</th>
<th>No. samples aged ≥ 20 years</th>
</tr>
</thead>
<tbody>
<tr>
<td>Australia</td>
<td>Residual</td>
<td>2002</td>
<td>1–34</td>
<td>2496</td>
<td>1278</td>
</tr>
<tr>
<td>Belgium</td>
<td>Residual</td>
<td>2002/2003</td>
<td>1–60+</td>
<td>1953</td>
<td>1421</td>
</tr>
<tr>
<td>Bulgaria</td>
<td>Residual</td>
<td>2001–2004</td>
<td>1–60+</td>
<td>969</td>
<td>697</td>
</tr>
<tr>
<td>Cyprus</td>
<td>Residual/Population</td>
<td>2003</td>
<td>1–50</td>
<td>1901</td>
<td>1000</td>
</tr>
<tr>
<td>Czech Republic</td>
<td>Population</td>
<td>2001</td>
<td>1–60+</td>
<td>1695</td>
<td>1318</td>
</tr>
<tr>
<td>England and Wales</td>
<td>Residual</td>
<td>2000</td>
<td>1–60+</td>
<td>1814</td>
<td>1756</td>
</tr>
<tr>
<td>Hungary</td>
<td>Residual</td>
<td>2003</td>
<td>1–60+</td>
<td>2014</td>
<td>1476</td>
</tr>
<tr>
<td>Ireland</td>
<td>Residual</td>
<td>2003</td>
<td>1–60+</td>
<td>1214</td>
<td>1376</td>
</tr>
<tr>
<td>Israel</td>
<td>Residual</td>
<td>1998</td>
<td>1–60+</td>
<td>1866</td>
<td>1484</td>
</tr>
<tr>
<td>Latvia</td>
<td>Population</td>
<td>2003</td>
<td>1–60+</td>
<td>1594</td>
<td>1432</td>
</tr>
<tr>
<td>Lithuania</td>
<td>Residual</td>
<td>2003</td>
<td>1–60+</td>
<td>1872</td>
<td>1480</td>
</tr>
<tr>
<td>Luxembourg</td>
<td>Population</td>
<td>2000/2001</td>
<td>4–60+</td>
<td>1381</td>
<td>1298</td>
</tr>
<tr>
<td>Malta</td>
<td>Residual</td>
<td>2003</td>
<td>1–60+</td>
<td>820</td>
<td>1047</td>
</tr>
<tr>
<td>Romania</td>
<td>Residual</td>
<td>2002</td>
<td>1–60+</td>
<td>2304</td>
<td>1535</td>
</tr>
<tr>
<td>Slovakia</td>
<td>Population</td>
<td>2002</td>
<td>1–60+</td>
<td>2080</td>
<td>1560</td>
</tr>
<tr>
<td>Spain</td>
<td>Population</td>
<td>1996</td>
<td>2–39</td>
<td>1926</td>
<td>1679</td>
</tr>
<tr>
<td>Sweden</td>
<td>Population</td>
<td>1996/1997</td>
<td>a</td>
<td>994</td>
<td>398</td>
</tr>
</tbody>
</table>

* Sera collected from 2, 5, 8, 10, 14, 17, 20–34 and 65+ age groups.

2–4 or 5–9 year-old age groups). More emphasis is placed on the younger age groups because of increased spread of disease in the young and also because this is likely to reflect recent problems in vaccine coverage.

**Results**

**Serum bank collection**

Australia and seventeen countries in the WHO European Region undertook testing for measles IgG antibodies of serum banks collected between 1996 and 2004 (Table 1). Serum banks were obtained either through residual sera collected during routine laboratory testing (11 of 18 countries), by population-based random sampling (6 of 18), or a combination of these two methods (1 of 18). Sera were collected from all age groups, were evenly distributed between males and females, and were geographically representative of each country. Although using residual sera raises the possibility of bias it is unlikely that for measles immunity this would be large. Not all countries met the sample size targets with numbers too small for evaluation (n < 75) in under 2-year-olds in three countries (Bulgaria, the Czech Republic and Malta). In Spain, there was no sampling in under 2-year-olds, and in Luxembourg there was no sampling in under 4-year-olds and only 37 samples from 4-year-olds.

**Vaccine programme, coverage and measles incidence**

Routine measles vaccination has been in place for two or more decades in all the participating countries. All countries have now adopted a two-dose MMR vaccine schedule (Table 2). The first country to introduce a two-dose schedule was Slovenia in 1974 and the last was Spain in 1996. Most countries moved from one measles dose to a two-dose MMR vaccine schedule. In England and Wales and Romania large catch-up campaigns in older children were also performed when the MMR vaccine was introduced. More emphasis is placed on the younger age groups because of increased spread of disease in the young and also because this is likely to reflect recent problems in vaccine coverage.

**Seroprophiles and comparisons to WHO age-specific targets for measles susceptibility**

Measles seroprofiles, first-dose measles vaccine coverage and the vaccine(s) recommended for each age cohort for the 18 countries are available from the ESEN2 pages of the Health Protection Agency website: http://www.hpa.org.uk/esen2. These seroprofiles can be used to help identify susceptible age cohorts in each country that may have arisen through low vaccine coverage, poor effectiveness of the vaccine or a reduction in measles transmission in unvaccinated cohorts. The seroprofiles show that the proportion seropositive or equivocal increases from age 1–3 years in most countries, reflecting vaccine administration. In the older prevaccination cohorts (typically aged over 35 years), high seroprevalence is generated through natural exposure, whereas in the younger cohorts seroprevalence should reflect mostly vaccination. In the age cohorts not scheduled for more than one dose, reported vaccine coverage agrees approximately with measles seroprevalence in all countries, with the exceptions of Bulgaria, Latvia and Romania where reported official age-specific coverage is much higher than the proportion seropositive.
Table 2. Measles vaccination policies, reported incidence in 2001 and year of previous major outbreak

<table>
<thead>
<tr>
<th>Country or area</th>
<th>Year of introduction</th>
<th>Year two-dose MMR vaccine introduced</th>
<th>Age of vaccination in 2001</th>
<th>Mean first dose coverage 1997–2001 (%)</th>
<th>2001 reported measles incidence (per 100 000)</th>
<th>Year incidence last exceeded 20 per 100 000</th>
</tr>
</thead>
<tbody>
<tr>
<td>Australia</td>
<td>1975</td>
<td>1993</td>
<td>12</td>
<td>91</td>
<td>0.7&lt;sup&gt;a&lt;/sup&gt;</td>
<td>1994</td>
</tr>
<tr>
<td>Belgium</td>
<td>1985</td>
<td>1994</td>
<td>15</td>
<td>80</td>
<td>N/A</td>
<td>1997</td>
</tr>
<tr>
<td>Bulgaria</td>
<td>1969</td>
<td>2001</td>
<td>13</td>
<td>93</td>
<td>0.1&lt;sup&gt;a&lt;/sup&gt;</td>
<td>1992</td>
</tr>
<tr>
<td>Cyprus</td>
<td>1974</td>
<td>1989</td>
<td>13–15</td>
<td>88</td>
<td>0&lt;sup&gt;a&lt;/sup&gt;</td>
<td>1983</td>
</tr>
<tr>
<td>Czech Republic</td>
<td>1969</td>
<td>1987</td>
<td>15</td>
<td>96</td>
<td>0.1&lt;sup&gt;a&lt;/sup&gt;</td>
<td>1990</td>
</tr>
<tr>
<td>England and Wales</td>
<td>1968</td>
<td>1995</td>
<td>12–15</td>
<td>88</td>
<td>0.1&lt;sup&gt;a&lt;/sup&gt;</td>
<td>1994</td>
</tr>
<tr>
<td>Hungary</td>
<td>1974</td>
<td>1991</td>
<td>15</td>
<td>100</td>
<td>0.2&lt;sup&gt;a&lt;/sup&gt;</td>
<td>1989</td>
</tr>
<tr>
<td>Ireland</td>
<td>1985</td>
<td>1992</td>
<td>15</td>
<td>77</td>
<td>6.3&lt;sup&gt;a&lt;/sup&gt;</td>
<td>2000</td>
</tr>
<tr>
<td>Israel</td>
<td>1967</td>
<td>1994</td>
<td>12</td>
<td>94</td>
<td>0.3&lt;sup&gt;a&lt;/sup&gt;</td>
<td>1994</td>
</tr>
<tr>
<td>Latvia</td>
<td>1968</td>
<td>2002</td>
<td>15</td>
<td>97</td>
<td>&lt;0.1&lt;sup&gt;a&lt;/sup&gt;</td>
<td>1987</td>
</tr>
<tr>
<td>Lithuania</td>
<td>1966</td>
<td>1998</td>
<td>15</td>
<td>97</td>
<td>0.2&lt;sup&gt;a&lt;/sup&gt;</td>
<td>1987</td>
</tr>
<tr>
<td>Luxembourg</td>
<td>1986&lt;sup&gt;a&lt;/sup&gt;</td>
<td>1994</td>
<td>15–18</td>
<td>91</td>
<td>1.6&lt;sup&gt;a&lt;/sup&gt;</td>
<td>1987</td>
</tr>
<tr>
<td>Malta</td>
<td>1983</td>
<td>1992</td>
<td>15</td>
<td>90</td>
<td>0.5&lt;sup&gt;a&lt;/sup&gt;</td>
<td>1986</td>
</tr>
<tr>
<td>Romania</td>
<td>1979</td>
<td>2005</td>
<td>12–15</td>
<td>98</td>
<td>&lt;0.1&lt;sup&gt;a&lt;/sup&gt;</td>
<td>1998</td>
</tr>
<tr>
<td>Slovakia</td>
<td>1969</td>
<td>1992</td>
<td>14</td>
<td>99</td>
<td>0&lt;sup&gt;a&lt;/sup&gt;</td>
<td>1984</td>
</tr>
<tr>
<td>Slovenia</td>
<td>1968</td>
<td>1990</td>
<td>12–18</td>
<td>92</td>
<td>0&lt;sup&gt;a&lt;/sup&gt;</td>
<td>1995</td>
</tr>
<tr>
<td>Spain</td>
<td>1978</td>
<td>1996</td>
<td>12–15</td>
<td>94</td>
<td>0.1&lt;sup&gt;a&lt;/sup&gt;</td>
<td>1995</td>
</tr>
<tr>
<td>Sweden</td>
<td>1971</td>
<td>1982</td>
<td>18</td>
<td>94</td>
<td>&lt;0.1&lt;sup&gt;a&lt;/sup&gt;</td>
<td>1983</td>
</tr>
</tbody>
</table>

MMR, measles, mumps and rubella; N/A, not available.
<sup>a</sup> Notifications.
<sup>b</sup> Laboratory confirmations.
<sup>c</sup> Age in 2002.
<sup>d</sup> First year of routine MMR vaccine, measles vaccine used previously.

Discussion

This paper provides an overview of measles seroepidemiology in Australia and a large number of countries throughout Europe for the period 1996–2004. The results of the ESEN2 project and those of the earlier ESEN project, provide invaluable information about progress towards the WHO measles elimination target for 2010 in the WHO European Region.<sup>1</sup>

The results of the serological surveys illustrate the heterogeneity of measles control in the region. This reflects the wide range in current and historical measles vaccine policy and vaccine coverage. Three groups of countries can be distinguished. Seven countries (the Czech Republic, Hungary, Luxembourg, Slovakia, Slovenia, Spain and Sweden) have age-specific susceptibility levels congruent with having achieved or approaching measles elimination. All these countries have had two-dose measles vaccine programmes from the 1970s onwards with very high reported first-dose measles vaccine coverage (mostly > 95%) for at least the previous five years. The notable exception is Spain, which only implemented a second dose in 1996 at the time the serosurvey was undertaken. Reflecting this high population immunity, all these countries except Spain had very low reported measles incidence with an average incidence from notifications of less than 4/100 000/year and incidence from confirmed cases (where available) of < 0.5/100 000/year in the decade before the serosurveys. In Spain, the population immunity comes from both vaccination and disease. To ensure measles elimination is achieved in 2010, it will be critical that these countries maintain very high routine coverage (> 95%) with two doses of measles vaccine.

In four countries (Australia, Israel, Lithuania and Malta), the proportion susceptible had reached the WHO susceptibility targets in children under 10 years of age, but was above the target for adolescents and young adults. These countries have employed routine two-dose measles programmes since the early...
It is of concern that in seven (Belgium, Bulgaria, Cyprus, England and Wales, Ireland, Latvia and Romania) of the 18 countries, there is high susceptibility in several age groups, including young children. In Belgium, Cyprus, Ireland and England and Wales, first-dose measles vaccine coverage in the five years up to 2001 was below 90%. This has led to the proportion of children susceptible to measles exceeding the WHO susceptibility targets. This lower coverage has only been a recent phenomenon in England and Wales, and to some extent in Ireland (which also has high susceptibility in adults), reflecting the impact of parental concern on the safety of MMR vaccine on uptake.\(^{21}\) The decreased coverage in England and Wales can also be seen in the reduced seropositivity in children compared to the ESEN 1996 survey.\(^{4}\) Since these ESEN2 surveys, outbreaks in England and Wales have been reported in young children.\(^{23}\) In Belgium and Cyprus, in addition to high susceptibility in young children, a significant proportion of adolescents remain susceptible to measles reflecting lower historical measles vaccine uptake.

In Bulgaria and Latvia, there is evidence of susceptible age groups in both young children and young adults, and only in young children in Romania. This disagrees with the officially reported measles coverage data, which in each case is > 90% in the last five years. In Latvia, MMR vaccine coverage estimates agree with the observed rubella seroprofiles,\(^{24}\) suggesting that the reported vaccine coverage is accurate and that there may either be a problem with the vaccine, the samples or the standardization process. If there was a problem with the standardization then this would need to be age specific because the oldest age cohorts showed high levels of antibody; also, samples were tested immediately upon collection and the testing of the standardization panel was satisfactory. The affected cohorts received the Leningrad strain of measles vaccine during the 1980s and 1990s. If the problem is the vaccine and true seroprevalence is as low as reported then it is surprising that large outbreaks have not already occurred. However, large outbreaks in older populations that had been highly vaccinated with the Leningrad strain have been reported from neighbouring countries, such as Ukraine.\(^{25}\) The discrepancy requires further study.

In Bulgaria, the discrepancy between vaccine coverage and seroprevalence is smaller and more consistent across age groups, including vaccinated adults. This could represent a possible problem with sample storage or with the assay, but this seems unlikely because seroprevalence is high in the oldest age groups and the standardization panel results were good. A large outbreak in 1992 in children and young adults suggests that routine vaccine coverage could be underestimated\(^{26}\) and that significant pools of susceptibles may exist, but recent incidence has been very low with no cases reported in 2002–2004 and no indigenous spread following an imported case from China in 2005.\(^{27}\)

In Romania, the low susceptibility in the adolescent and adult age groups presumably reflects the impact of the 1998 catch-up campaign that targeted 7–18 year-olds and after which the reported incidence of measles was very low. However, levels of susceptibility are particularly high in the younger (< 8 years) age groups, and the discrepancy with reported routine vaccine coverage suggests that it is lower than reported. Indeed Romania recently reported a large, national outbreak, which particularly affected younger age groups from marginalized populations.\(^{18,28}\)

To achieve elimination, all these higher susceptibility countries will need to strengthen their routine measles programmes to achieve > 95% with both
Hacia la eliminación: vulnerabilidad al sarampión en Australia y en 17 países europeos

Objetivo: Evaluar la vulnerabilidad específica de la edad al sarampión en Australia y en 17 países europeos.

Métodos: Como parte de la Red Europea de Seroepidemiología 2 (ESEN2), 18 países crearon grandes serotecas nacionales entre 1996 y 2004. A través de estas serotecas, se logró recoger datos sobre anticuerpos IgG contra el sarampión en Australia y 17 países europeos. Se realizaron análisis comparativos en interpaíses y se recogieron también datos sobre el historial de vacunación para permitir comparaciones válidas interpaíses. Se propuso una proporción de 5% en los grupos de más edad como meta de eliminación de la red de protección. Los países se clasificaron en cuatro grupos: aquellos que alcanzaron las metas de eliminación o se acercaban mucho a ellas, aquellos que habían superado la meta y aquellos que mostraban déficits de protección. Los análisis se realizaron con la ayuda de programas estadísticos y se calcularon tasas de mortalidad por sarampión y por otras enfermedades virales. Se estableció un ajuste de dosis y se propuso una estrategia de vacunación para evitar la propagación del virus.

Resultados: Siete países (Republika Checa, Hungría, Luxemburgo, España, Eslovaquia, Eslovenia y Suecia) habían alcanzado las metas de eliminación o se acercaban mucho a ellas. Cuatro países (Australia, Israel, Lituania y Malta) habían superado la meta y cuatro países (Bélgica, Bulgaria, Chipre, Inglaterra y Gales, Irlanda, Letonia y Rumania) habían mostrado déficits de protección. Los análisis se realizaron con la ayuda de programas estadísticos y se calcularon tasas de mortalidad por sarampión y por otras enfermedades virales. Se estableció un ajuste de dosis y se propuso una estrategia de vacunación para evitar la propagación del virus.

Conclusión: Aunque todos los países aplican hoy día una pauta de vacunación antisuampiónica de dos dosis, para alcanzar la meta de la Región de Europa de la OMS de eliminar el sarampión...
for 2010 algunos países deberán garantizar una mayor cobertura sistemática, y llevar a cabo además campañas de vacunación centradas en algunas cohortes de más edad. Sin esas mejoras, cabe prever que continuarán en Europa la transmisión y los brotes de sarampión.
Measles susceptibility in Australia and Europe

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