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Citation for published version (APA):

Document license:
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DOI:
10.1016/j.vaccine.2018.08.008

Document status and date:
Published: 01/10/2018

Document Version:
Publisher’s PDF, also known as Version of Record (includes final page, issue and volume numbers)

Please check the document version of this publication:

• A submitted manuscript is the version of the article upon submission and before peer-review. There can be important differences between the submitted version and the official published version of record. People interested in the research are advised to contact the author for the final version of the publication, or visit the DOI to the publisher’s website.
• The final author version and the galley proof are versions of the publication after peer review.
• The final published version features the final layout of the paper including the volume, issue and page numbers.

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Narcolepsy and adjuvanted pandemic influenza A (H1N1) 2009 vaccines – Multi-country assessment

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A R T I C L E   I N F O

Article history:
Received 19 December 2017
Received in revised form 25 July 2018
Accepted 2 August 2018
Available online 16 August 2018

A B S T R A C T

Background: In 2010, a safety signal was detected for narcolepsy following vaccination with Pandemrix, an ASO3-adjuvanted monovalent pandemic H1N1 influenza (pH1N1) vaccine. To further assess a possible association and inform policy on future use of adjuvants, we conducted a multi-country study of narcolepsy and adjuvanted pH1N1 vaccines.

Methods: We used electronic health databases to conduct a dynamic retrospective cohort study to assess narcolepsy incidence rates (IR) before and during pH1N1 virus circulation, and after pH1N1 vaccination.
1. Introduction

In fall 2009, large-scale vaccination campaigns were implemented globally in response to the influenza A (H1N1) pandemic (pH1N1). Different inactivated monovalent vaccines were used; the United States used unadjuvanted vaccines, whereas in Europe, MF59–Focetria, Novartis Vaccines and Diagnostics) and AS03–adjuvanted (Pandemrix, GSK biologicals) vaccines were mostly used. In Canada, AS03–adjuvanted Arepanrix (ID Biomedical Corp., a subsidiary of GSK Biologicals) was used. Arepanrix and Pandemrix had similar pH1N1 antigens and used the same AS03 adjuvant; however, there were slight differences in the manufacturing processes for the two vaccines. In August 2010, case reports from Sweden and Finland emerged describing narcolepsy in children following vaccination with Pandemrix [1–6].

Narcolepsy is a chronic debilitating sleep disorder with a suspected autoimmune etiology. Genetic predisposition also appears to play a role; narcolepsy with cataplexy (with hypocretin deficiency) is highly associated with HLA-DQB1 *06:02, while narcolepsy without cataplexy (and normal hypocretin levels) is less associated with HLA-DQB1 *06:02, but still more so than in the general population. Narcolepsy/cataplexy is characterized by excessive daytime sleepiness (EDS), cataplexy, sleep paralysis, hypnagogic hallucinations and fragmented nighttime sleep. Symptoms often emerge gradually and may initially be non-specific [7–10]. The insidious onset can result in diagnostic delays of months to years, making it challenging to study exposures that might cause or contribute to disease occurrence [11].

Several European studies were initiated to rapidly evaluate the possible association between Pandemrix-AS03 and narcolepsy [1,2,4,5,12–18]. These studies are summarized in reviews by Verstraeten et al. [19], Sturkenboom [20] and Sarkanen et al. [21]. Several studies showed an increased risk, but results were variable within and across studies and subject to methodological challenges due to narcolepsy epidemiology and increased awareness about the association. Most studies focused on Pandemrix-AS03 and data were limited on other adjuvanted pH1N1 vaccines, including Arepanrix-AS03 and Focetria-MF59 [22,23].

To better understand the relationship between narcolepsy and different adjuvanted pH1N1 vaccines, we organized an international research network, including study sites within and outside of Europe, where adjuvanted vaccines were used and little or no substantial concerns were raised about an association with narcolepsy in local media. Drawing on the expertise of clinicians, research scientists and public health officials within the network, we implemented the Systematic Observational Method for Narcolepsy and Influenza Immunization Assessment (SOMNIA) study.

2. Methods

2.1. Study site selection

We used a stepwise process to identify, recruit, and select participating study sites for incidence rates and case-control analyses. First, we identified countries that used adjuvanted 2009 pH1N1 vaccines using information obtained from the World Health Organization and from the two vaccine manufacturers. We excluded countries where compensation programs for narcolepsy associated with pH1N1 vaccination existed because we believed this could potentially bias case ascertainment with vaccinated cases potentially being evaluated sooner or differently than non-vaccinated cases. Finland, Norway and Sweden were excluded from the case-control study on this basis. In addition, Finland and Sweden had been signaling countries. Of note Sweden, as a signaling country was included in the incidence rate study to provide a reference comparison, but data from Sweden were not pooled in the incidence rate analysis. Working with national, regional and local health officials, academics, and sleep centers, we assessed whether potential study sites had acceptable availability and accessibility of vaccination and outcome data. Israel, South Korea and Cuba, were excluded because of lack of exposure information. Brazil was eliminated because obtaining timely administrative approvals was not feasible. Finally, we engaged in discussions with prospective investigators to gauge willingness and ability to participate in the incidence rate or case-control studies and confirm existence of acceptable data and data systems to participate using the common study protocol. After completing these steps and obtaining the necessary clearances we included the final set of countries in our analysis.

All sites used the same protocol, the same data collection materials and common analytics, but sites could implement the protocol based upon their local processes and health care structure. For quality control, the study coordination team verified implementation of the protocol with all sites during monthly calls. The data management team further verified all the data and discussed potential biases with the sites. Sites were responsible for verification of their results and decisions on inclusion of the data and could access remotely the secure data sharing environment. These distributed data management procedures have been previously described [24].

2.2. Narcolepsy incidence rates analysis

We estimated narcolepsy incidence rates (IR) at ten study sites (in seven countries) using population-based electronic health record databases from general practitioners (GP) (Spain [Valencia...
<table>
<thead>
<tr>
<th>Study site (vaccines)</th>
<th>IR Data source</th>
<th>Codes and algorithms</th>
<th>Case-control or case-coverage Data source</th>
<th>Case identification</th>
<th>Controls source</th>
<th>pH1N1 vaccine exposure</th>
</tr>
</thead>
<tbody>
<tr>
<td>Europe</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Switzerland</td>
<td>SIDIAP general practitioners’ database</td>
<td>ICD-10 code G47.4</td>
<td>Matched in same hospital of case, no consent required</td>
<td>SIDIAP database, no consent required</td>
<td>General practitioner (CP) medical record</td>
<td></td>
</tr>
<tr>
<td>Spain, Catalonia</td>
<td>SIDIAP general practitioners’ database</td>
<td>ICD-9CM codes 347.3 with Manual validation</td>
<td>Identified from 24 sleep centers and electronic registries (inpatient and outpatient databases)</td>
<td>SIA general practitioners’ database, no consent required</td>
<td>Obtained from electronic registry</td>
<td></td>
</tr>
<tr>
<td>Spain, Valencia</td>
<td>SIA regional general practitioners’ databases</td>
<td>ICD-9CM codes 347.3 with Manual validation</td>
<td>Identified from 24 sleep centers and electronic registries (inpatient and outpatient databases)</td>
<td>SIA general practitioners’ database, no consent required</td>
<td>Obtained from electronic registry</td>
<td></td>
</tr>
</tbody>
</table>
| The Netherlands      | IPCI general practitioners’ databases | Free text narcolepsy & MSLT, cases manually validated | Four sleep centers (academic and non-university hospitals). Consent required | IPCI general practitioners’ database, no consent required | 1. Electronic medical GP records for all patients  
2. For cases also from vaccination card and public health agency to estimate completeness in GP records |
| The United Kingdom   | THIN general practitioners’ databases | Read codes F27.00; F270.00; F271.00; F27z.00 | Identified from 24 sleep centers and electronic registries (inpatient and outpatient databases) | Matched from ICES provincial database of all residents with health insurance, no consent required | 1. Primary care physician (PCP), family physicians’ and pediatricians’ charts;  
2. Public health unit records (electronic databases, and physician billing claims data) |
| Denmark              | Danish Civil Registration System covering the Northern and Central Region of Jutland in Denmark linked to Danish National Patient Register | ICD-10 code G47.4, inpatient, ambulatory care and emergency room diagnosis | Identified from 24 sleep centers and electronic registries (inpatient and outpatient databases) | SIA general practitioners’ database, no consent required | Obtained from electronic registry |
| Sweden               | Patient register at the National board of health, Population from population register at Statistics Sweden | ICD-10 code G47.4, diagnosis in and outpatient | Identified from 24 sleep centers and electronic registries (inpatient and outpatient databases) | SIA general practitioners’ database, no consent required | Obtained from electronic registry |
| South America        |                |                     |                                          |                     |                |                   |
| Argentina            |                |                     |                                          |                     |                |                   |
| North America (Canada) |                |                     |                                          |                     |                |                   |
| North America (Canada) |                |                     |                                          |                     |                |                   |
| Manitoba             |                |                     |                                          |                     |                |                   |

*MSLT = Multiple Sleep Latency Test*
Study populations included individuals registered in the database for at least one year prior to follow-up. Follow-up started at the beginning of the study period (January 1, 2003) or the date of registration and ended at the earliest of the following: death, the patient moving, the end of the study period (December 31, 2013) or outcome occurrence. Cases were captured in these databases by identifying individuals with newly diagnosed narcolepsy with or without cataplexy. (Database codes and algorithms are shown in Table 1). In GP databases in the Netherlands and from records of sleep medicine specialists in Valencia, case finding algorithms were validated using the Brighton Collaboration case definition criteria for narcolepsy [25]. In other sites, we required both diagnostic codes for narcolepsy along with reimbursement claims for a multiple sleep latency test (MSLT) to reduce the risk of false positives. We calculated IRs by year and month and categorized them into three periods: (1) pre-pH1N1, (2) during wild-type pH1N1 virus circulation until the start of pH1N1 vaccination (country specific), and (3) from the start of pH1N1 vaccination through the end of the study in December 2013. Periods of wild-type pH1N1 virus circulation and vaccination varied by sites. We stratified IRs by age and sex and pooled aggregated person-time and case counts for further analysis. IR data from Sweden were analyzed separately since Sweden had been a priori identified as a signaling country, and hence, served as a comparator for other sites in our IR analysis [26,29]. We estimated incidence rate ratios (IRR), comparing the two latter periods to the pre-pH1N1 period, using Poisson regression.

2.3. Case-control analysis

Seven sites in six countries met our criteria for inclusion in the case-control study: Argentina, Canada (Ontario), Spain (Valencia and Catalonia), Switzerland, Taiwan, and the Netherlands (Table 1). All sites collected information in the same electronic case report forms (Chameleon, Erasmus Medical Center, Rotterdam, the Netherlands). Depending on data sharing restrictions, local investigators either transferred aggregated data to a secure remote research environment for further analysis and one stage pooling or ran the same analyses locally and transferred coefficients and counts for inclusion in a two-stage meta-analysis (Fig. 1).

2.3.1. Cases and controls

Local investigators identified narcolepsy cases at sleep centers using diagnosis lists or diagnostic test outcomes. Investigators

---

Table 1 (continued)
abstracted medical records, blinded for pH1N1 vaccination status, and classified cases into certainty levels using the Brighton Collaboration narcolepsy case definition [25]. Cases were included if they were classified as Brighton Collaboration level 1–4 for persons ≥16 years or level 1–2 for persons <16 years, and had an MSLT referral and a diagnosis both made after March 31, 2009 (start of the H1N1 pandemic). Brighton Collaboration classification designates level 1 as the highest level of diagnostic certainty; levels have different cut-off values for MSLT results starting at age 16 years, which were maintained in the study. Primary index date was date of referral for diagnostic MSLT. Sites identified all cases diagnosed from April 1, 2009 until the end of 2015, but this varied by site based on feasibility (Table 1). The Netherlands required consent from cases because of the need to collect data from both GPs as well as the National Public Health Agency.

Up to 20 controls were matched to each case by site on age (year of birth), sex and index date. As per protocol, controls were selected from the population giving rise to the cases, identification could be implemented in different ways based on feasibility and health care structure. Ontario, Valencia, Catalonia, the Netherlands, and Taiwan sampled controls from population-based health record databases. Argentina identified controls from primary care facilities in the same geographic area as the cases. Switzerland recruited controls from the same hospitals as cases, using auxiliary diseases not related to vaccination.

### 2.3.2. Exposure

The main exposure of interest was adjuvanted pH1N1 vaccination (i.e., Pandemrix-AS03, Arepanrix-AS03 or Focetria-MF59). We obtained information on vaccines similarly for cases and controls from medical records, vaccination registries, insurance databases, or vaccination cards. Only written or electronic records of immunization were accepted. Risk windows for pH1N1 vaccine exposure were any time prior to index date and further split in: 1–180 days, 181 days–2 years, and >2 years before index date. The Ontario site provided the only data for Arepanrix-AS03; hence, there was no pooling of the Arepanrix-AS03 data as Ontario was unique. Taiwan, Argentina, the Netherlands, Switzerland, Valencia, and Catalonia contributed data for Focetria-MF59. The Netherlands, Switzerland, and Valencia contributed data for Pandemrix-AS03.

### Table 2

Narcolepsy case characteristics for the case-control and case-coverage analysis by study site.

<table>
<thead>
<tr>
<th></th>
<th>Netherlands</th>
<th>Switzerland</th>
<th>Spain, Catalonia</th>
<th>Spain, Valencia</th>
<th>Argentina</th>
<th>Canada, Ontario</th>
<th>Taiwan</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Children</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
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<tr>
<td><strong>Brighton level [%]</strong></td>
<td></td>
<td></td>
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<td></td>
<td></td>
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<td></td>
<td></td>
</tr>
<tr>
<td>1</td>
<td>31.8</td>
<td>36.4</td>
<td>0</td>
<td>0</td>
<td>9.1</td>
<td>0</td>
<td>7.8</td>
<td>13.3</td>
</tr>
<tr>
<td>2</td>
<td>68.2</td>
<td>54.5</td>
<td>100</td>
<td>63.6</td>
<td>81.8</td>
<td>57.1</td>
<td>66.7</td>
<td>65.3</td>
</tr>
<tr>
<td>3</td>
<td>0</td>
<td>9.1</td>
<td>0</td>
<td>36.4</td>
<td>9.1</td>
<td>42.9</td>
<td>17.7</td>
<td>18.7</td>
</tr>
<tr>
<td>4a</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>7.8</td>
<td>2.7</td>
<td></td>
</tr>
<tr>
<td>Cataplexy present [%]</td>
<td>95.5</td>
<td>86.4</td>
<td>100</td>
<td>63.6</td>
<td>90.9</td>
<td>57.1</td>
<td>72.5</td>
<td>76.7</td>
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<td><strong>Age at diagnosis [%]</strong></td>
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<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>&lt;6 yrs</td>
<td>4.5</td>
<td>0</td>
<td>0</td>
<td>9.1</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>1.3</td>
</tr>
<tr>
<td>6–12 yrs</td>
<td>50.0</td>
<td>40.9</td>
<td>60.0</td>
<td>90.9</td>
<td>63.6</td>
<td>21.4</td>
<td>37.3</td>
<td>43.3</td>
</tr>
<tr>
<td>13–18 yrs</td>
<td>45.5</td>
<td>59.1</td>
<td>40.0</td>
<td>0</td>
<td>36.4</td>
<td>78.6</td>
<td>62.7</td>
<td>55.3</td>
</tr>
<tr>
<td><strong>pH1N1 vaccination coverage cases [%]</strong></td>
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<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Focetria-MF59</td>
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<td>0</td>
<td>0</td>
<td>27.3</td>
<td>0</td>
<td>≤45.1</td>
<td>≤18.4</td>
<td></td>
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<tr>
<td>Pandemrix- and Arepanrix-AS03</td>
<td>31.8</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>≤17.9</td>
<td>0</td>
<td>≤33.1</td>
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<tr>
<td>Unadjuvanted</td>
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<td>0</td>
<td>0</td>
<td>0</td>
<td>≤45.1</td>
<td>≤16.3</td>
<td></td>
</tr>
<tr>
<td><strong>pH1N1 vaccination coverage controls [%]</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
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<tr>
<td>Focetria-MF59</td>
<td>3.4</td>
<td>3.8</td>
<td>0</td>
<td>2.3</td>
<td>10.5</td>
<td>0</td>
<td>0.6</td>
<td>2.1</td>
</tr>
<tr>
<td>Pandemrix- and Arepanrix-AS03</td>
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<td>0</td>
<td>0</td>
<td>0</td>
<td>17.3</td>
<td>0</td>
<td>0.8</td>
<td></td>
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<tr>
<td>Unadjuvanted</td>
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<td>0</td>
<td>0</td>
<td>0</td>
<td>37.3</td>
<td>15.9</td>
<td></td>
</tr>
<tr>
<td><strong>Adults</strong></td>
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<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total cases/controls [N]</td>
<td>32/280</td>
<td>13/260</td>
<td>36/720</td>
<td>4/12</td>
<td>39/75</td>
<td>86/860</td>
<td>210/2207</td>
<td></td>
</tr>
<tr>
<td><strong>Brighton level [%]</strong></td>
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<td></td>
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<td></td>
<td></td>
</tr>
<tr>
<td>1</td>
<td>53.1</td>
<td>7.7</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>1.2</td>
<td>9.1</td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>31.3</td>
<td>84.6</td>
<td>38.9</td>
<td>50.0</td>
<td>≤25.6</td>
<td>39.5</td>
<td>≤38.6</td>
<td></td>
</tr>
<tr>
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<td>31.4</td>
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<td>27.9</td>
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<td>41.7</td>
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<td>41.9</td>
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<tr>
<td>19–59 yrs</td>
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<td>97.2</td>
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<td>2.8</td>
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<td>0</td>
<td>0</td>
<td>0</td>
<td>1.0</td>
</tr>
<tr>
<td><strong>pH1N1 vaccination coverage cases [%]</strong></td>
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<td></td>
<td></td>
<td></td>
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<td></td>
<td></td>
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<tr>
<td>Focetria-MF59</td>
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<td>≤14.0</td>
<td>≤6.2</td>
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<tr>
<td>Pandemrix- and Arepanrix-AS03</td>
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<td>≤12.8</td>
<td>0</td>
<td>1.4</td>
<td></td>
</tr>
<tr>
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<td>0</td>
<td>0</td>
<td>0</td>
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<td>≤6.2</td>
<td></td>
</tr>
<tr>
<td><strong>pH1N1 vaccination coverage controls [%]</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Focetria-MF59</td>
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<td>0</td>
<td>0.1</td>
<td>33.3</td>
<td>0</td>
<td>1.1</td>
<td>1.0</td>
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<tr>
<td>Pandemrix- and Arepanrix-AS03</td>
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<td>1.4</td>
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<td>0</td>
<td>0.8</td>
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</tr>
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<td>0</td>
<td>0</td>
<td>8.8</td>
<td>3.5</td>
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</table>

*Nine child cases were included in a separate case-coverage study for reasons described in the methods. The child case total for the Netherlands includes nine from the case-coverage study and 13 from the case-control study.*

*By definition, Brighton Collaboration (BC) narcolepsy case levels 1 and 2 have unambiguous cataplexy; BC narcolepsy case levels 3 and 4 may not have cataplexy. For inclusion in this study, children ages < 16 years are BC levels 1 and 2, children 17–18 years are BC levels 1–4, and adults ≥ 19 years are BC levels 1–4.

*Cell counts that represent case counts of five or fewer (for Ontario, Canada) or two or fewer (for Taiwan) cannot be displayed due to national patient privacy regulations. Therefore these are represented as range (i.e., ≤ n).*
2.3.3. Case-control analysis

Odds ratios (OR) and 95% confidence intervals (CI) were calculated using conditional logistic regression or exact logistic regression if zero cells occurred. The reference category for estimation of the pH1N1 vaccination effect was no pH1N1 vaccination. Due to low exposure levels, we only present the analysis for the risk window of any time prior to the index date because this provided the maximum power.

To address potential awareness bias in the European Union (EU) sites, we analyzed data from two time periods, a “restricted” period and a “total” period. The restricted period analysis included cases from participating EU sites in the Netherlands, Valencia, Catalonia, and Switzerland only when they were diagnosed prior to onset of awareness about the narcolepsy signal in Europe (August 2010), and also cases from sites outside the EU diagnosed anytime during the entire study period. The total period analysis included cases from all sites for the entire study period, including cases from EU sites diagnosed after media attention.

We pooled data from sites using a hybrid approach (one stage pooling of matched case and control pairs for EU sites and Argentina, which could share data, and two-stage pooling with Taiwan and Ontario, which shared case counts and coefficients which were subsequently meta-analyzed with the one stage pooled data from EU sites and Argentina) (Fig. 1). Children were defined as ≤18 years of age and adults as ≥19 years. Due to incomplete pH1N1 vaccination information from GPs in children born between 2004 and 2009 in the Netherlands (because these children were vaccinated at local health agencies instead of GPs where we obtained exposure information for all study subjects), these cases and controls were excluded from the case-control analysis. However, cases born between 2004 and 2009 in the Netherlands were included in a post hoc case-coverage analysis (see below). In Switzerland, only child cases were included because of potential selection and information biases that was detected in adult cases. (Tables 1 and 2). In addition to using diagnostic MSLT referral as index date, we conducted sensitivity analyses using EDS onset date (requiring EDS starting after March 31, 2009). We used SAS v9.2 and statistical significance was set at p-value <0.05.

2.4. Case coverage analysis

In the Netherlands, cases born from 2004 through 2009 were analyzed using a case-coverage design. During the 2009 H1N1 pandemic these children were vaccinated with Pandemrix-AS03 at Municipal Health Services, and not through their GPs. Vaccinations for these children were registered in a nationwide database, Influsys, managed by the National Public Health Institute. Exposure in cases was therefore obtained from Influsys and exposure prevalence in the population for children born in the same year was obtained by calendar week and year of birth and used in the analysis, similar to the method used in the United Kingdom by Stowe et al. [27]. This post-hoc analytic approach allowed us to include information from the Netherlands, where individual exposure data was not available, to complement other data on Pandemrix-AS03.

2.5. Ethics committee approval

This study was conducted under the principles of the Helsinki declaration [28]. Each site was responsible for obtaining appropriate ethical approvals, the overall study was approved by the Institutional Review Board at Cincinnati Children’s Hospital Medical Center.

2.6. Role of the funding source

Two investigators (TS and FD) from the sponsoring organization, the U.S. Centers for Disease Control and Prevention, participated in development of the study design, analysis and interpretation of data, writing the report, and in the decision to submit the paper for publication.

3. Results

3.1. Narcolepsy incidence rates analysis

540 million person-years from ten sites in seven countries contributed to the narcolepsy IR analysis. In Sweden, a previously identified signaling country, IRs increased significantly after the start of its pH1N1 vaccination campaign for children 5–19 years (IRR = 9.01; 95% CI 6.89–11.80) and adults 20–59 years (IRR = 1.69; 95% CI 1.46–1.95). From 2011 onwards, narcolepsy IRs decreased in Sweden (Fig. 2). In other EU sites, narcolepsy IRs in the post-vaccination period did not change significantly compared to the pre-pH1N1 vaccination period. In Canada, where Arepanrix-AS03 was used, no changes in IRs were observed in any province sites in any age category. In Taiwan, pre-pH1N1 period narcolepsy
IR was lower (0.29 per 100,000 person-years, 95% CI 0.27–0.32) than in EU and Canadian sites (varying between 0.5 and 1.5 per 100,000 person-years) and we observed significant IR increases in children 5–19 years (IRR = 2.50; 95% CI 1.46–4.28) and adults 20–59 years (IRR = 2.23; 95% CI 1.26–3.94) during wild-type pH1N1 virus circulation prior to the vaccination campaign (also previously presented in Dodd et al. [29]).

3.2. Case-control and case-coverage analysis

According to information supplied to us by WHO and the manufacturers of the three adjuvanted 2009 pH1N1 vaccines, these vaccines were distributed in 47 countries. Many of these countries reportedly only used small amounts of vaccine in their private markets. Of these 47 countries, we selected 16 countries for potential participation in the study based upon our estimation of the likelihood that they would meet our eligibility criteria. Ten of the 16 potential participating countries were deemed ineligible after reviewing them against our eligibility criteria. (Of the sites we then approached, only the province of Quebec in Canada declined participation.) The six remaining countries participated in the case-control study.

We included 360 narcolepsy cases with MSLT referral during the study period: 150 were children ≤18 years and 210 were adults ≥19 years, which were matched to a total of 3515 controls (online supplement Table 1). For the restricted period analysis (excluding cases diagnosed after awareness in the EU), 96 child and 121 adult cases were included. For the total period analysis, 141 child and 210 adult cases were included. Nine child cases born between 2004 and 2009 from the Netherlands (all diagnosed after awareness) were only included in the case-coverage analysis.

Brighton Collaboration narcolepsy case definition diagnosis levels varied by site, with EU sites having more level 1 cases (23.40% in EU vs. 2.74% outside EU) and more cataplexy (73.06% in EU vs. 50.68% outside EU) (Table 2). Median delay between EDS onset and narcolepsy diagnosis was longer in adults compared to children and varied between sites, with a very short delay for Valencia and Catalonia, Spain. Pandemrix-AS03: case-coverage study in the Netherlands for children and case-control study in Valencia, Spain, for adults.

4. Discussion

The SOMNIA study, a multi-country effort that included data from sites on four continents, did not find an increase in narcolepsy IRs associated with pH1N1 vaccination campaigns (except in Sweden, a previously identified signaling country) nor did it detect significant associations between narcolepsy following any adjuvanted pH1N1 vaccines studied. To our knowledge, this is the largest and most geographically diverse study with the longest study period examining the association between adjuvanted pH1N1 vaccines and narcolepsy. Oil-in-water adjuvants like AS03 and MF59 increase immunogenicity of influenza vaccines making them attractive (or possibly necessary) for use in future pandemic influenza vaccines, and they may have the potential to improve the performance of seasonal influenza vaccines [30]. Assessing the safety of these adjuvants has substantial public health and clinical importance.

In our study, the IR of narcolepsy increased in Sweden beginning in summer 2010 and declined in 2011, especially in children

![Fig. 3. Odds ratios (OR) for narcolepsy and 95% confidence intervals (CI) by vaccine brands in the total period analysis for children (≤18 years) and adults (≥19 years). Arepanrix-AS03: case-control study in Ontario, Canada. Focetria-MF59: two-stage random effects meta-analysis of data from Taiwan, Argentina, the Netherlands, and Valencia and Catalonia, Spain. Pandemrix-AS03: case-coverage study in the Netherlands for children and case-control study in Valencia, Spain, for adults.](image-url)
5–19 years. No similar increase in IR of narcolepsy was observed at any of the other participating sites. However, in Taiwan, a site with a very short lag time between symptom onset and diagnosis of narcolepsy, a significant increase in IR of narcolepsy was observed during circulation of wild-type pH1N1 virus but prior to pH1N1 vaccination, a phenomenon also reported in China, which had low (unadjuvanted) vaccination coverage [31].

Ontario, where vaccination coverage was 32.2% [32], provided case-control data on Arepanrix-AS03; no association with narcolepsy was found in children or adults, which contrasts with a prior finding from a study in Quebec, where a small increase in risk was found, although with large confidence intervals [23]. Since Arepanrix-AS03 has the same adjuvant and a similar pH1N1 antigen as the Pandemrix-AS03 vaccine used in Finland and Sweden, it appears that the association for Pandemrix-AS03 and narcolepsy observed in some European countries is not likely due to the AS03 adjuvant or the pH1N1 antigen in the vaccine alone. Focetria-MF59 was not associated with narcolepsy in children or adults in this study, although the upper limit of the confidence interval cannot exclude a small increase in risk in children. This is consistent with prior observations of a lack of association (or just a few case reports) in countries using this vaccine [33]. Because of low vaccination coverage in sites for Pandemrix-AS03, we were constrained in our ability to evaluate the possibility of an association in our case-control study; our data from the Netherlands are based on a small number of children who were between six months and five years of age at vaccination.

The SOMNIA study contributes to our understanding of the epidemiology of narcolepsy before, during, and after the 2009 H1N1 influenza pandemic and pH1N1 vaccination campaigns. Importantly, it contributes to the body of evidence regarding the possible association between adjuvanted pH1N1 vaccines and narcolepsy as an adverse event following immunization. Prior data, mostly from Europe, predominantly involved Pandemrix-AS03 exposure and included many cases diagnosed shortly after increased media attention and public awareness. Inclusion of the cases diagnosed in the time period immediately after heightened media attention, may overestimate an association, which is supported by the simulations of Wijnans et al. [34]. Awareness about a possible association with Pandemrix-AS03 may have resulted in vaccinated cases being diagnosed sooner than they normally would have been, resulting in apparent clusters of narcolepsy [35]. We attempted to address this potential bias by including countries outside the EU and countries in the EU that experienced less media and public awareness; we also conducted an analysis restricting cases in Europe to those diagnosed before attention arose. Additionally, we minimized potential bias from accelerated diagnosis of vaccinated cases by recruiting cases up to five years after knowledge of a possible association became widespread. The findings of our SOMNIA study indicate that the impact of media and public awareness, and the resulting detection bias, may have diminished over time. Our risk estimates of narcolepsy following adjuvanted pH1N1 vaccination for the restricted period analysis compared to the total period analysis did not differ substantially. This is in contrast to the prior Vaccine Adverse Event Surveillance & Communication (VAESCO) study of EU countries, which had a much shorter case accrual period [35]. Overall, our study did not find an increased risk of narcolepsy following vaccination with AS03- or MF59-adjuvanted pH1N1 vaccines based on the total period analysis.

Although we did not detect any significant associations between adjuvanted pH1N1 vaccination and narcolepsy beyond Sweden, we acknowledge the overall trend of evidence of an increased risk associated with Pandemrix-AS03 [5,14,15,23]. A biologic mechanism to explain this observation has not been established, but it has been postulated that an interaction involving the immune responses to administration of Pandemrix-AS03 and

infection with wild-type pH1N1 virus could be a contributing factor [20]. This would explain the apparent presence of an association in Finland, Sweden and Norway where wild-type virus circulated coincident with the vaccination program, whereas no association was seen in Ontario where wild-type virus was no longer circulating at the time of the vaccination program. We were not able to address this hypothesis in the SOMNIA study, but it remains a focus area that will likely require a global cooperative research effort.

This retrospective and observational study has several limitations. Despite multiple study sites, statistical power in the restricted period analysis was limited due to fewer cases and low pH1N1 vaccination coverage (online supplement Table 2). For Focetria-MF59, the only country with high coverage in the at-risk age group was Argentina, but the number of cases was low. Although we used standardized case definitions, case misclassification could have occurred as diagnostic procedures and information capture differed across sites. Nonetheless, our application of the Brighton Collaboration case definition criteria for all cases decreased the likelihood of misclassification. Misclassification of exposure could have happened from incomplete recording of pH1N1 vaccinations due to lack of access to school vaccination records in Taiwan. Non-exhaustive inclusion of cases in Ontario (due to distance) and the Netherlands (timeliness of consent) led to incomplete inclusion of cases at the data lock point. For the Netherlands, where consent for study participation was needed, vaccinated cases might be more likely to give consent (given public awareness), which could overestimate the risk; however no significant association was observed. For Ontario, data collection had not been totally completed by the end of the study, but this was not related to vaccination status and therefore impacted power alone. Selection bias was detected in Switzerland for the adult cases (not for children), when we compared our cases to a published series of exposed cases [36], demonstrating lack of inclusion of exposed cases in adults – this led to exclusion of adult cases and controls in Switzerland. Finally, although we used a common protocol across all sites, it was necessary to provide flexibility for implementation at the local study site level for identifying cases and controls. This might have introduced variability; however, the main criterion in selecting controls was that they be representative of individuals receiving pH1N1 vaccination in the general population and that exposure information was obtained similarly for cases and controls.

5. Conclusion

We did not observe increases in population-based narcolepsy IRs associated with pH1N1 vaccination campaigns at participating sites, except for Sweden. In the case–control analysis, we did not detect evidence of a significant increased risk of narcolepsy following any of the adjuvanted pH1N1 vaccines in children or adults in our study population, although upper limits of estimates do not exclude small to moderate risks. The SOMNIA study highlights the usefulness of international collaboration in the evaluation of vaccine safety signals for rare adverse events. Using a common protocol and methods reduces heterogeneity, permits contribution of data from countries across the world, and allows for combining data for increased statistical power necessary to address questions about rare events.

6. Declaration of interests

Maria de Ridder, Caitlin Dodd, Jan Bonhoeffer, Ann Vanrolleghem, Gert Jan Lammers, Sebastiaan Overeem, Jeffrey C. Kwong, Karen Cauch-Dudek, Diana Juhasz, Michael Campitelli, Wan-Ting
Huang, Maria Giner-Soriano, Rosa Morros, Carles Gaig, Ester Tió, Silvia Perez-Vilar, Javier Diez-Domingo, Lawrence W. Svenson, Bruce Carleton, Lisen Arnhem-Dahlström, Lars Pedersen, Frank DeStefano, Tom T. Shimabukuro, Nicoline van der Maas, Brian J. Murray, Alexandre N. Datta, Ulf Kallweit, Yu-Shu Huang, Chung-Yao Hsu, Hsi-Chung Chen, Francisco Javier Puertas, Monika Naus have no conflicts of interest.

Daniel Weibel, receives consultancy honoraria from GSK for a consultancy related to malaria vaccine implementation in Africa, independent from any flu vaccines, or any work related to this publication.

Angela Gentile, Norberto Giglio, Vanessa Castellano received research contracts from the U.S. Centers for Disease Control and Prevention independent from this study. 

Miriam Sturkenboom received honorarium from GSK and post-authorisation safety studies (PASS) research contracts independent from this study.

Salaheddin M. Mahmud received research funding from GSK, Merck, Pfizer, Roche and Sanofi Pasteur and speaking and consulting fees from GSK and Sanofi not related to this study.

Steven Black reports contracts from U.S. Centers for Disease Control, during the conduct of the study; other from GSK Vaccines, outside the submitted work.

We acknowledge funding from the U.S. Centers for Disease Control and Prevention (CDC), Atlanta, USA, under CDC contract number 200-2012-53425_addendum 0001.

7. Authors’ contributions

All authors contributed to reviewing and commenting on the study design, results, and the final report and manuscript.

Miriam Sturkenboom, Steven Black and Jan Bonhoeffer wrote the study protocol and acquired funding, Miriam Sturkenboom and Steve Black wrote the study report.

Miriam Sturkenboom, Jan Bonhoeffer, Ann Vanrolleghem, Nicole van der Maas, Gert Jan Lammers, Sebastiaan Overeem, Angela Gentile, Norberto Giglio, Vanessa Castellano, Jeffrey C. Kwong, Brian J. Murray, Karen Cauch-Dudek, Diana Juhasz, Michael Campbelli, Alexandre N. Datta, Ulf Kallweit, Wan-Ting Huang, Yu-Shu Huang, Chung-Yao Hsu, Hsi-Chung Chen, Maria Giner-Soriano, Rosa Morros, Carles Gaig, Ester Tió, Silvia Perez-Vilar, Javier Diez-Domingo, Francisco Javier Puertas, Lawrence W. Svenson, Salaheddin M. Mahmud, Bruce Carleton, Monika Naus, Lisen Arnhem-Dahlström, Lars Pedersen contributed to local implementation of the protocol in data collection, case review and reporting at the study site level.

Miriam Sturkenboom, Daniel Weibel, María de Ridder and Caitlin Dodd managed data collection across datasets and wrote the analysis plan. María de Ridder, Caitlin Dodd, Miriam Sturkenboom, Michael Campbelli, and Wan-Ting Huang conducted final pooled analyses and guided statistical and data quality assurance.

Two investigators (Tom T. Shimabukuro and Frank DeStefano) from the sponsoring organization, the U.S. Centers for Disease Control and Prevention, participated in development of the study design, analysis and interpretation of data, writing the report, and in the decision to submit the paper for publication.

8. Funding source

This study was funded by the Centers for Disease Control and Prevention (CDC), Atlanta, USA, under CDC contract number 200-2012-53425_addendum 0001. This study was also supported by Public Health Ontario (PHO) and the Institute for Clinical Evaluative Sciences (ICES), which is funded by an annual grant from the Ontario Ministry of Health and Long-Term Care (MOHLTC).

9. Statement

This paper contains original unpublished work and is not being submitted for publication elsewhere.

10. Disclaimers

The findings and conclusions in this report are those of the authors and do not necessarily represent the official position of the Centers for Disease Control and Prevention (CDC). Mention of a product or company name does not constitute endorsement by the CDC.

All inferences, opinions, and conclusions drawn in this publication are those of the author(s), and do not necessarily reflect the opinions or policies of the British Columbia Ministry of Health, PHO, ICES, or MOHLTC. No endorsement by PHO, ICES or MOHLTC is intended or should be inferred.

At the time of study MCJM Sturkenboom was an employee of Erasmus University Medical Center, Rotterdam, Netherlands.

Acknowledgements

We thank the following individuals for their contributions to the SOMNIA study.

Valencia: Mónica Escobar Daroca, Macrina Sastre-Cantón, Lorena Platero-Sanchís, Marian Martín-Navarro for data collection. Local Ethics Committees, Sleep Units and hospital archives services from all public hospitals in the Valencia Region for facilitating study implementation.


Catalonia: Dr Gonzalo Calvo-Rojas, from Pharmacology Service, Hospital Clinic of Barcelona, for facilitating study coordination and contact with sleep disorders specialists. Albert Roso-Llorach, from IDIAP Jordi Gol, for his support in SIDIAP data management. All physicians from the Narcolepsy Catalan Network from sleep units from hospitals in Catalonia who collaborated in data collection for SOMNIA study: Joan Santamaria, Alex Iranzo, Carine Monaste- rio, Juan Luis Becerra, Marta Jiménez, Antonio Bohé, Jaume Vivas, Albert Molins, Ion Álvarez, Núria Caballol, Gemma Sansa, Montserrat Pujol, Òscar Sans, Antonio Escartin, Odile Romero, Mª José Jurado, Roser Cambrodí.

The Netherlands: Petra van Mierlo, Judith Hoppenbrouwers (Sleep Medicine Centre Kempenhaeghe); Petra Oomen (Department of vaccine supply and prevention programmes, National Institute for Public Health and the Environment – RIVM); Peter Rijnbeek, Mees Moseveld (Medical Informatics, Erasmus Medical Center).
Appendix A. Supplementary material

Supplementary data associated with this article can be found, in the online version, at https://doi.org/10.1016/j.vaccine.2018.08.008.

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