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Review

A systematic review of adult tetanus-diphtheria-acellular (Tdap) coverage among healthcare workers

Bruno A. Randi [a,b,*], Odeli Nicole Encinas Sejas [a], Karina T. Miyaji [a,b], Vanessa Infante [a,b], Amanda N. Lara [a], Karim Y. Ibrahim [a], Marta H. Lopes [a,b], Ana Marli C. Sartori [a,b]

[a] Centro de Referencia para Imunobiologicos Especiais, Divisão de Clinica de Molestias Infecciosas e Parasitarias, Hospital das Clinicas, Sao Paulo, Brazil
[b] Departamento de Molestias Infecciosas e Parasitarias da Faculdade de Medicina da Universidade de Sao Paulo, Sao Paulo, Brazil

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ABSTRACT

During the last decades pertussis incidence raised globally. Several vaccination strategies targeting adults to reduce pertussis among young infants have been proposed, including vaccination of healthcare workers (HCWs). The aim of this study was to analyse, by performing a systematic review of literature, published papers that evaluated Tdap coverage among HCWs, variables associated with vaccine uptake and efforts implemented to raise vaccination rates. We searched the MedLine, Embase, SCOPUS, LILACS, Web of Science and Cochrane for full-text studies that evaluated Tdap coverage in HCW. Two independent reviewers screened the articles and extracted the data. Twenty-eight studies published from 2009 to 2018 were reviewed. Most studies were conducted in the USA. Initial Tdap coverage varied from 6.1% to 63.9%. USA and France are the only two countries with studies evaluating Tdap coverage within HCWs using national data. In the USA, Tdap coverage in HCWs raised from 6.1% to 45.1% from 2007 to 2015. In the analysis of French national data, a Tdap coverage of 63.9% was observed. Five studies used interventions to raise Tdap coverage in HCWs. Two intervention studies implemented mandatory vaccination and three used educational strategies. All of them achieved coverages over 86%. Only eleven studies analysed the association of Tdap vaccination with variables of interest. Previous immunization with other vaccines recommended for HCWs (like influenza, hepatitis B and MMR) was positively associated with Tdap uptake in four studies. In conclusion, overall Tdap coverage among HCWs is low, but seems to increase over the years after the vaccine introduction and with implementation of interventions to increase coverage.

Contents

* Corresponding author at: Dr. Ovídio Pires de Campos Street, 225 – Cerqueira César, Zip Code: 05403-010, São Paulo SP, Brazil.
E-mail address: bruno_randi@usp.br (B.A. Randi).

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1. Introduction

Pertussis is an infectious disease caused by *Bordetella pertussis*, a Gram-negative bacillus transmitted by aerosol droplets [1,2]. It affects people of all ages, but children aged less than one year are the most affected and may have severe disease [3]. Adults usually have milder disease and are the source of infection for young children [1]. During the last decades, pertussis incidence rose globally, despite the sustained high childhood vaccination coverage [2]. Waning immunity after vaccination or infection, reduced effectiveness/shorter duration of protection conferred by acellular pediatric vaccines, increased disease awareness, improved diagnoses and surveillance, and *B. pertussis* mutations allowing it to escape from vaccine immunity have been proposed to explain pertussis reemergence in developed countries [1,2].

Several vaccination strategies targeting adults to reduce pertussis among young infants have been proposed, including vaccination of pregnant women, the cocooning strategy (vaccinating all newborn's contacts), and vaccination of healthcare workers (HCWs) [1]. Recommendations on the adult tetanus-diphtheria-acellular pertussis (Tdap) vaccination for HCWs vary by country. Some countries, such as the United States, Canada, Australia, Netherlands, Germany and the United Kingdom adopted Tdap vaccination for all HCWs, while others, such as Austria, Finland, Norway and Brazil introduced Tdap only for those in contact with newborns and infants [4].

There are few data about Tdap coverage among HCWs. Thus, the aim of this study was to analyse, by performing a systematic review of literature, all published papers which evaluated Tdap coverage among HCWs, variables associated with the vaccination and efforts implemented to raise vaccination rates.

2. Methods

This study followed the recommendations for systematic reviews published by the Centre for Reviews and Disseminations (CRD), Institute of Medicine (IOM) and Cochrane Collaboration and Community Guide to Community Preventive Services [5–7].

3. Study identification and selection

The following six databases were searched in Dec 7th, 2016 and updated in Apr 26, 2018: MedLine, Embase, SCOPUS, LILACS, Web of Science and Cochrane. Appendix 1 describes the search strategies in detail. The studies were eligible for inclusion if they were full-text article that evaluated Tdap coverage in any HCWs. The searches were not limited by date or language restriction.

Two reviewers (BAR, ONES) independently screened the papers' titles and abstracts for inclusion. The same inclusion criteria were used to assess full-text articles and any disagreements were resolved by discussion and consensus between the two reviewers or resort to the opinion of a third reviewer (AMCS).

4. Data extraction

Data from included articles were extracted by two reviewers (BAR, ONES), using a form designed for this review. The following data were extracted:

- General information: date of publication, type of study and studýs country of origin.
- Vaccine Coverage evaluation: place of the study, HCWs analysed, number of HCWs evaluated, Tdap coverage in the whole population and by profession (physicians, nurses and others) and methodology used to check HCWs vaccination (self-report or confirmation by vaccination card/electronic medical report).
- Strategies to raise coverage: any strategy used with the objective of increasing Tdap coverage.
- Variables of interest associated to Tdap vaccination.

5. Results

We identified 456 studies that met the selecting criteria, 368 non-duplicate titles were screened for eligibility and 41 were retrieved for full-text evaluation. Thirteen were excluded because they do not evaluate Tdap coverage in HCWs. Thus, 28 studies were included in the analysis (Fig. 1) [8–35].

The first two studies evaluating Tdap coverage among HCWs were published in 2008, in France [21,25]. All studies were conducted in developed countries. Sixteen studies (57.1%) were from North America: United States (14) and Canada (2); ten from Europe (35.7%): France (6), United Kingdom (1), Germany (1), Switzerland (1) and Italy (1); one study (3.57%) was from Asia: Israel; and one (3.57%) from Oceania: Australia (Table 1).

Most (23) studies were cross-sectional; only five studies (17.8%) were intervention studies aiming to raise Tdap coverage [22–24,34,35]. Table 2 presents the main findings of the studies. Initial Tdap coverage varied from 6.1% [8] to 63.9% [16].

United States and France are the only two countries that have studies evaluating Tdap coverage within HCWs using national data. Data from the Centers for Diseases Control and Prevention (CDC-USA) from 2007 to 2015 [8,9,11,12,26,29–31] showed that Tdap coverage in HCWs rose from 6.1% [8] to 45.1% [31] in those eight years. It was observed that White HCWs have higher vaccine coverage (21.5 [29]-49.2% [31]) comparing to Black (14 [29]-28.3% [31]) and Hispanics (13.8 [29]-38.7% [31]). HCWs aged from 19 to 64 years-old have higher Tdap coverage (32.6 [29]-46.3% [31]) when compared to those over 65 years-old (16.9 [29]-38.7% [31]). In the analysis of French national data, a higher Tdap coverage (63.9%) was observed in HCWs [24].

Table 3 shows the studies that used interventions to raise Tdap coverage in HCWs. Two intervention studies implemented mandatory vaccination, achieving coverages ≥90% [22,24]. In a small pediatric hospital (116 beds) in Switzerland, a Tdap vaccination program was developed within one year. The program involved informative messages, lectures and scheduled appointments for counseling and vaccinating each HCW. From 852 HCWs of the hospital, 50.1% (4 2 7) responded to the campaign. The overall pertussis vaccine coverage was 49%. Among the HCWs who participated in the campaign, vaccine coverage rose from 17% to 88% [23].

Jiang et al., also evaluated Tdap coverage in a paediatric hospital, but in the United States. The coverage rose from 58% to 90% after 15 months. This was achieved by sending information by email and through the institution intranet, conducting individual interviews with the unvaccinated HCWs and setting up vaccination sites in places of high flow of HCWs (as the coffee shop) [34]. In the United Kingdom, Paranthaman K et al. achieved a coverage rate of 86% in one hospital and 95% in another after 3 months of implementation of informative posters, oral presentations and vaccination of HCWs in their work sites [35].

Only eleven of the 28 studies (39.2%) evaluated a possible association of Tdap vaccination with variables of interest [10,13,16–20,23,28,31,33]. Two studies did not find any association [15,18]. In the other nine studies, variables positively associated with Tdap coverage were: age under 49 years old [10,16], higher education level [10,33], higher income [33], hospitalization in the last year, having a clinic or health centre as the usual place for healthcare [10,33], being physician [16], influenza vaccination in the last year [10,16,32], previous hepatitis B [16,19] and MMR [19] vaccination, understanding that influenza could be serious in

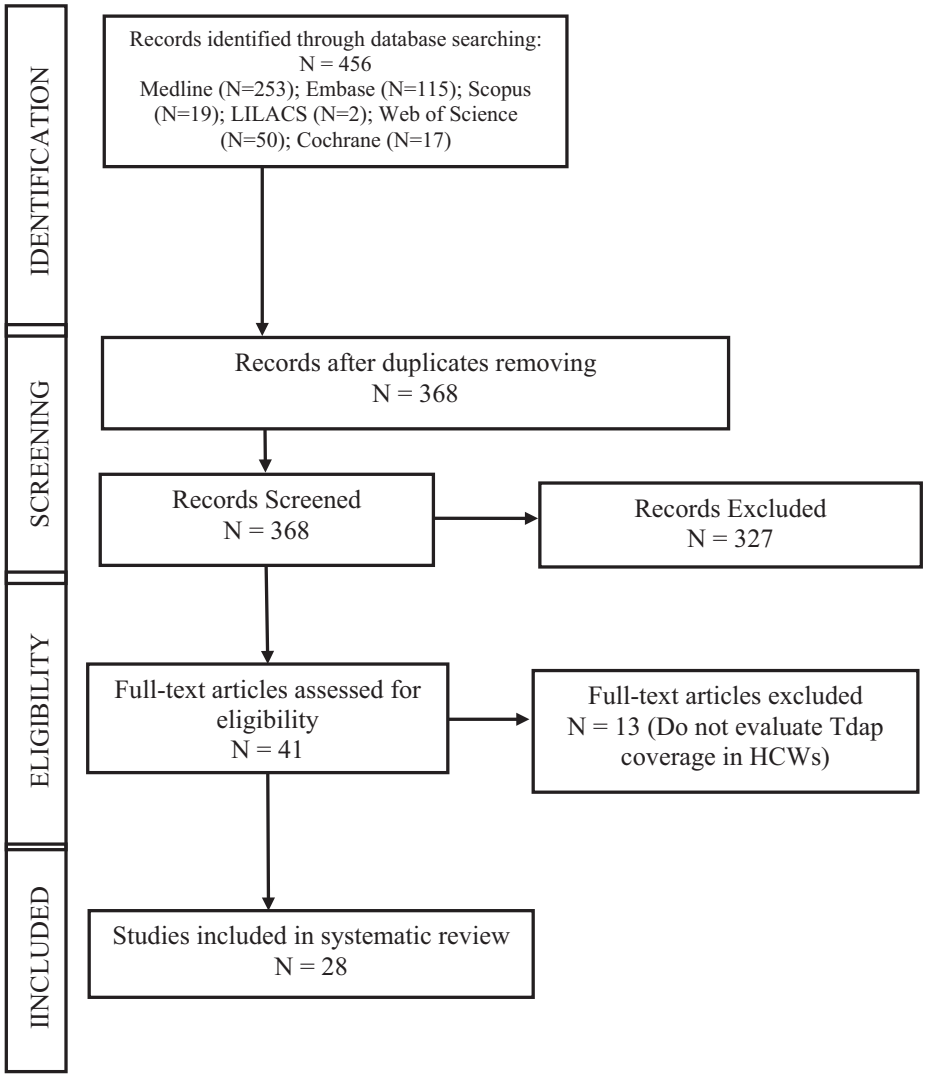

Fig. 1. Flowchart of the selection of the studies included in the systematic review.

infants [19], having contact with infants under 6 months of age [33], higher volume of activity in work during year [16] and a higher score on a questionnaire about HCWs knowledge on Tdap [19]. Srivastav et al. found that living below the poverty line and being Black were negatively associated with Tdap vaccination [32]. Two studies found that different regions of their countries were associated with different Tdap coverages. In USA, western region had higher coverages rates [10]; in France, professionals from the Picardy regions had higher vaccine coverage rates while HCWs from Provence-Alpes-Côte d́ Azur region had lower coverages [16].

6. Discussion

This systematic review found only 28 studies that evaluated Tdap coverage on HCWs. The higher initial coverage rate observed in the reviewed studies included was 63.9%, but most studies showed coverages under 40.0%. It is important to point out that some studies reported national data, whereas others reported single hospitals data. Therefore, it is not possible to draw a solid conclusion on HCWs immunization rates.

Adult vaccination is difficult to implement. Many countries do not have vaccination policies targeting specifically adult populations; for example, only 45% of 115 WHO members have influenza programs targeting elderly as a risk group [36]. Barriers to achieve high vaccination coverage rates in adults include: vaccine hesitancy, lack of awareness due to insufficient information, prioritization of childhood programs by governments, limited promotion of adult vaccination and low healthcare practitioner's awareness of adult immunization [36]. HCWs immunization is also challenging, as they usually show low perception of personal risk involved in their professional activities [15,37].

A cross-sectional study involving HCWs carried out in Italy observed insufficient knowledge of recommended occupational vaccinations (with exception for hepatitis B and tuberculosis) [38]. Partially, low Tdap coverage could be attributed to lower awareness of the vaccine recommendations, fear of injection, misconceptions about efficacy and safety of vaccines and lack of time [39]. Miller et al. found that 39% of HCWs reported having never heard of Tdap vaccine [8]. La Torre et al. observed that only 36.4% of HCWs perceived pertussis as a risk for their health and 49.2% as a risk for patient́s health [38].

HCWs are at increased risk of acquiring pertussis because of contact with infected patients and waning immunity following childhood vaccination or natural infection [10,40]. Nosocomial outbreaks of pertussis have already been reported, with about 8.5–23% of HCWs being infected [41–43]. HCWs can be a source

Table 1
Characteristics of the studies included in this review that evaluated Tdap coverage in healthcare workers (HCWs): country and year, study design, population evaluated and data source for Tdap coverage.

Reference	Year	Country	Recommendation of Tdap vaccine for HCW in the country	Study design	Population	Data source of Tdap coverage
Miller, 2010	2008	USA	HCW of hospitals and clinics in direct contact with patients	Cross-sectional with national data (household survey)	All regions of USA	NHIS* Data
Miller, 2011	2007	USA	HCW of hospitals and clinics in direct contact with patients	Cross-sectional with national data	All regions of USA	NHIS* Data
Williams, 2012	2010	USA	HCW of hospitals and clinics in direct contact with patients	Cross-sectional with national data (household survey)	All regions of USA	NHIS* Data
Esolen, 2013	2010–2011	USA	HCW of hospitals and clinics in direct contact with patients	Intervention	Hospitals of the Geisinger Health System	Continous evaluation during campaign
Williams, 2013	2011	USA	HCW of hospitals and clinics in direct contact with patients	Cross-sectional with national data (household survey)	All regions of USA	NHIS* Data
Lu, 2014	2011	USA	HCW of hospitals and clinics in direct contact with patients	Cross-sectional with national data (household survey)	All regions of USA	Self report
Williams, 2014	2012	USA	HCW of hospitals and clinics in direct contact with patients	Cross-sectional with national data (household survey)	All regions of USA	NHIS* Data
Williams, 2015	2013	USA	HCW of hospitals and clinics in direct contact with patients	Cross-sectional with national data (household survey)	All regions of USA	NHIS* Data
Leibu, 2015	2012–2013	USA	HCW of hospitals and clinics in direct contact with patients	Intervention	Hospitals of the Atlantic Health System	Continous evaluation during campaign
Williams, 2016	2014	USA	HCW of hospitals and clinics in direct contact with patients	Cross-sectional with national data (household survey)	All regions of USA	NHIS* Data
Williams, 2017	2015	USA	HCW of hospitals and clinics in direct contact with patients	Cross-sectional with national data (household survey)	All regions of USA	NHIS* Data
Srivastav, 2017	2012–2014	USA	HCW of hospitals and clinics in direct contact with patients	Cross-sectional with national data	All regions of USA	Internet Panel Survey#
ÓHalloran, 2018	2013	USA	HCW of hospitals and clinics in direct contact with patients	Cross-sectional with national data	All regions of USA	2013 Behavior Risk Factor Surveillance System&
Jiang C, 2018	2014	USA	HCW in direct contact with patient	Intervention	One pediatric hospital	Continous evaluation during campaign
Duclos, 2008	2003–2006	France	HCW in direct contact with patients	Cross-sectional	*Experts* who meet every two years to discuss vaccines	Self report
Hees, 2009	2007	France	HCW in direct contact with patient	Cross-sectional	One hospital	Self report
Loulergue, 2009	2007	France	HCW in direct contact with patient	Cross-sectional	One hospital	Self report
Vic, 2011	2009	France	HCW in direct contact with patients	Cross-sectional	One hospital	Self report
Loulergue, 2013	2009	France	HCW in direct contact with patients	Cross-sectional	All hospitals with maternity, school hospitals and public hospitals of Paris	Vaccination card check
Pulcini, 2013	2010	France	HCW in direct contact with patients	Cross-sectional with national data	Several health services of all regions of France	Self report
MacDougall, 2015	2010	Canada	HCW in direct contact with newborns or infants	Cross-sectional	National survey	Self report
MacDougall, 2015	2010	Canada	HCW in direct contact with newborns or infants	Cross-sectional	National survey	Self report
Böhmer, 2013	2009–2010	Germany	All HCW	Cross-sectional with national data	Pharmacies linked to hospitals and clinics	Health system data
Baron-Epel, 2013	2011	Israel	All HCW	Cross-sectional	Maternity care clinics of one district of Israel	Self report
Taddei, 2014	2011	Italy	All HCW	Cross-sectional	Six public hospitals in Florence-Italy	Self report
Tuckerman, 2015	2013	Australia	HCW in direct contact with newborns or infants	Cross-sectional	One hospital	Self report
Walther, 2015	2012–2013	Switzerland	HCW in direct contact with newborns	Intervention	One pediatric university hospital	Continous evaluation during campaign
Paranthaman, 2016	2012	United Kingdon	HCW in direct contact with patient	Intervention	Two pediatrics hospitals	Continous evaluation during campaign

* NHIS - National Health Interview Survey.
# Internet survey conducted by Abt Associates Inc. for the Centers for Disease Control and Prevention (CDC).
& State based telephone survey that collects information on health conditions and risk behaviours from non-institutionalized U.S. adults.

Table 2
Main findings of the studies that evaluate Tdap coverage in healthcare workers (HCWs).

Reference	HCW evaluated	No. of HCW	Initial Tdap coverage (%)	Coverage in specific groups (%)
Miller, 2010	HCW of hospitals, clinics and nursing homes	984	Overall: 15.9	NA
Miller, 2011	HCW of hospitals, clinics and nursing homes	420	Overall: 6.1	NA
Williams, 2012	HCW of hospitals, clinics and nursing homes	1427	Overall: 20.3	***Ages between 19 and 64*** (Whites: 21.5; Blacks: 14.0; Hispanics: 13.8; Asians: 26.9)
Esolen, 2013	Physicians, nurses and others	15,267	Risk areas[*]: 9.0 Other Areas: 11.0–12.0	NA
Williams, 2013	HCW of hospitals, clinics and nursing homes	1759	Overall: 26.8	***Ages between 19 and 64*** (White: 27.2; Blacks: 21.7; Hispanic: 30.1; Asians: 27.8; Others: 31.2)
Lu, 2014	Physicians, nurses and others	1769	Overall: 26.9; Physicians: 41.5; Nursing: 36.5; other: 27.0	NA
Williams, 2014	HCW of hospitals, clinics and nursing homes	2015	Overall: 31.4	***All Ages*** (White: 33.0; Blacks:22.5; Hispanics: 25.1; Asians: 39.4; Others: 46.1) ***Ages from 19 to 64*** (Total: 32.6; Whites: 34.5; Blacks: 22.9; Hispanics: 25.1; Asians: 41.4; Others: 46.1) ***Older than 65*** (Total: 16.9; Whites: 17.5) [#]
Williams, 2015	HCW of hospitals, clinics and nursing homes	1965	Overall: 37.3	***All Ages*** (White: 39.9; Blacks: 32.3; Hispanics: 29.5; Asians: 32.7; Others: 46.8) ***Ages from 19 to 64*** (Total: 37.9; Whites: 40.7; Blacks: 33.2; Hispanics: 28.6; Asians: 33.8; Others: 48.8) ***Older than 65*** (Total: 30.7; Whites: 32.4) [#]
Leibu, 2015	Physicians, nurses and others	12,000	NA	NA
Williams, 2016	HCW of hospitals, clinics and nursing homes	2062	Overall: 42.1	***All Ages*** (White: 46.4; Blacks: 24.8; Hispanics: 35.8; Asians: 41.2; Others: 39.5) ***Ages from 19 to 64*** (Total: 43.0; Whites: 47.9; Blacks: 25.0; Hispanics: 25.0; Asians: 42.0; Others: 39.6) ***Older than 65*** (Total: 28.7; Whites: 29.6) [#]
Williams, 2017	HCW of hospitals, clinics and nursing homes	1853	Overall: 45,1%	***All ages*** (White: 49,2; Blacks: 28,3; Hispanics: 38,7) ***Ages from 19 to 64***: 46,3 ***Older than 65***: 38,7
Srivastav, 2017	Physicians, nurses and others	2012: 2038 2013: 1613 2014: 1633	**2012** (overall: 34.8; physicians: 50.9; nurses: 48.1) **2013** (overall: 40.2; physicians: 60.1; nurses: 58.8) **2014** (overall: 42.4; physicians: 60.7; nurses: 63.8)	NA
ÓHalloran, 2018	Physicians, nurses and others	10,229	Overall: 47.4; Physicians: 66.8; Nurses: 59.5	NA
Jiang, 2018	Physicians and nurses	984	Overall: 58; Physicians: 57; Nurses: 59	NA
Duclos, 2008	Physicians	75	30.0	NA
Hees, 2009	Physicians and nurses	84	Overall: 33.3; Physicians: 45.8; Nursing: 28.0	NA
Loulergue, 2009	Physicians, nurses and medical students	395	Overall: 12.0; Physicians: 22.0; Nursing 13.0; Nursing technicians: 5.0 Medical students: 11.0 Others: 4.0	NA

Table 2 (*continued*)

Reference	HCW evaluated	No. of HCW	Initial Tdap coverage (%)	Coverage in specific groups (%)
Vic, 2011	Physicians and nurses	138	Overall: 50.7; Physicians: 48.0; Nursing: 57.7; Otherr: 25.0	NA
Loulergue, 2013	Medical and nursing students	376	Overall: 44.0; Physicians: 40.6; Nursing: 51.3; Midwife students: 51.0	NA
Pulcini, 2013	Physicians	1431	63.9	NA
MacDougall, 2015	Physicians, nurses and pharmacists	1167	Overall: 47.5; Family physicians: 44.4 Internal medicine: 53.8; Nursing: 48.0; Pharmacists: 50.0	NA
MacDougall, 2015	Physicians, nurses and pharmacists	1167	Physicians: 54.5; Nursing: 58.9; Pharmacists: 44.3	NA
Böhmer, 2013	Physicians	2009: 712 2010: 916	2009: 13.7 2010: 16.4	NA
Baron-Epel, 2013	Nurses	107	42.0	NA
Taddei, 2014	Physicians, nurses, nursing assistants and midwifes	436	Overall: 6.9	NA
Tuckerman, 2015	Physicians, nurses and others	92	Overall: 50.5	3 wards with higher influenza coverage: 56.4 3 wards with lower influenza coverage: 41.7
Walther, 2015	Physicians, nurses, paramedics and medical students	852 (total); 427 campaign responders	Campaign responders: 17.0 Not responders: not available; Physicians: 24.0; Nursing: 9.0; Paramedics: 14.0 Medical students: 41.0	NA
Paranthaman, 2016	Physicians and nurses	Hospital A: 243 Hospital B: 189	NA	NA

[*] Maternity, pediatrics and emergency.
[#] No data for other ethnicities.

Table 3
Interventions to raise Tdap coverage among healthcare workers (HCWs) and final Tdap coverage.

Reference	Interventions	Final Tdap coverage (%)	Time between initial and final coverage (months)
Esolen, 2013	Mandatory vaccination	General: 90 Risk areas: 98.6 Other areas: 97.6	12
Walther, 2015	Information on intranet; Informative newsletter; Note on hospital newspaper; Oral presentations; Individual propaganda for HCWs[1] emails; Individual interviews with HCW[1]	Campaign responders: 88.0 Physicians: 88.0 Nurses: 85.0 Paramedics: 95.0 Medical students: 98.0 Total coverage*: 49.0	12
Leibu, 2015	Mandatory vaccination	94.9	24
Jiang, 2018	Information on intranet; Information by *email*; Vaccination in sites of HCWs[1] high flux (i.e.: hospital coffee shop); Individual interviews with HCW[1]	90	15
Paranthaman, 2016	Vaccination on HCW site of work; Oral presentation; Posters	Hospital A: 86; Hospital B: 95	3

* Includes campaign responders and non-responders.

of infection for susceptible patients and relatives as well as other HCWs [43–46]. Pertussis outbreaks are expensive for health services [47,48]. In a pertussis outbreak involving 17 confirmed cases among HCWs in a hospital in the United States, 307 contacts were identified, and extensive infection-control measures were implemented. This outbreak costed US$81382. Vaccinating HCWs may be a cost-effective strategy [47]. A mathematical model suggested that vaccinating HCWs against pertussis would prevent 46% of HCW exposures to pertussis per year and the net savings for the hospital was estimated to be 2.38 times the amount invested in vaccinating HCWs [47]. An outbreak in a neonatology ward in a hospital in Amsterdam costed €48682 for the hospital. It was found that 4 Euros could be saved by every Euro invested in vaccinating HCWs to avert outbreaks [49].

Only five studies included in this review implemented interventions to raise Tdap coverage [22–24,34,35]. Three used educational strategies [23,34,35] and two of them implemented mandatory vaccination [22,24]. Both strategies raised Tdap coverage over 85%. However, no study evaluated how the coverage rate would be sustained over time after the implementation of such strategies.

Strategies to increase influenza vaccine coverage among HCW were deeper studied. These strategies include free vaccination, work-site vaccination, mobile vaccination carts, educational materials, communication campaigns and declination form [50]. Other strategies reported were mandatory vaccination and the requirement that all unvaccinated staff should wear a mask when in contact with patients. Mandatory immunization have been more practiced in USA, where its implementation resulted in vaccination rates > 95%, even with initial coverage of less than 30% [50].

Recently, regarding adult immunization, the 4 Pillars [51] program has been strengthened. It is a compilation of practices based on scientific evidence, developed to raise vaccine coverage and decrease opportunity loss in the adult vaccination at the primary health care level. The domains are: Pillar 1 – Convenient vaccination services; Pillar 2 – Communication with patients about the importance of immunization and the availability of vaccines; Pillar 3 – Enhanced office systems to facilitate immunization; Pillar 4 – Motivation through an office immunization champion. Despite the fact that none of the reviewed studies had implemented the 4 Pillar program in a systematic way, three [23,34,35] used components of it and successfully raised vaccine coverage.

In conclusion, overall Tdap coverage among HCWs is low, but seems to increase after years of vaccine introduction (as we could notice with USA national data) and after implementation of interventions to increase coverage.

7. Conflict of interest and authors contributions

Financial support: none reported. *Potential conflicts of interest:* all authors report no conflicts of interests relevant to this article. *Authors contributions:* Bruno A. Randi and Odeli Nicole Encinas Sejas were the reviewers of the systematic review. Karina T. Miyaji, Amanda N. Lara, Karim Y. Ibrahim, Vanessa Infante, Marta H. Lopes and Ana Marli C. Sartori actively participated on the manuscript preparation.

Appendix A. Supplementary material

Supplementary data to this article can be found online at https://doi.org/10.1016/j.vaccine.2018.12.046.

References

[1] Gabutti G, Azzari C, Bonanni P, Prato R, Tozzi AE, Zanetti A, et al. Pertussis. Hum Vaccin Immunother 2015;11:108–17.
[2] Domenech de Cellès M, Magpantay FM, King AA, Rohani P. The pertussis enigma: reconciling epidemiology, immunology and evolution. Proc Biol Sci 2016;283.
[3] Forsyth K, Plotkin S, Tan T, Wirsing von König CH. Strategies to decrease pertussis transmission to infants. Pediatrics 2015;135:e1475–82.
[4] Maltezou HC, Poland GA. Vaccination policies for healthcare workers in Europe. Vaccine 2014;32:4876–80.
[5] IOM (Institute of Medicine). Finding what works in health care: standards for systematic reviews. In: Eden J, Levit L, Berg A, S M, editors. Washington, DC: The National Academies Press; 2011. p. 317.
[6] Higgins J, Cochrane Green S. Handbook for systematic reviews of interventions version 5.1.0 [updated March 2011]. Cochrane Collaboration 2011.
[7] Carande-Kulis VG, Maciosek MV, Briss PA, Teutsch SM, Zaza S, Truman BI, et al. Methods for systematic reviews of economic evaluations for the guide to community preventive services. task force on community preventive services. Am J Prev Med 2000;18:75–91.
[8] Miller BL, Kretsinger K, Euler GL, Lu PJ, Ahmed F. Barriers to early uptake of tetanus, diphtheria and acellular pertussis vaccine (Tdap) among adults-United States, 2005–2007. Vaccine 2011;29:3850–6.
[9] Williams WW, Lu PJ, O'Halloran A, Bridges CB, Pilishvili T, Hales CM, et al. Noninfluenza vaccination coverage among adults - United States, 2012. MMWR Morb Mortal Wkly Rep. 2014;63:95–102.
[10] Lu PJ, Graitcer SB, O'Halloran A, Liang JL. Tetanus, diphtheria and acellular pertussis (Tdap) vaccination among healthcare personnel-United States, 2011. Vaccine 2014;32:572–8.
[11] Williams WW, Lu PJ, O'Halloran A, Bridges CB, Kim DK, Pilishvili T, et al. Vaccination coverage among adults, excluding influenza vaccination - United States, 2013. MMWR Morb Mortal Wkly Rep 2015;64:95–102.
[12] Williams WW, Lu PJ, O'Halloran A, Kim DK, Grohskopf LA, Pilishvili T, et al. Surveillance of vaccination coverage among adult populations - United States, 2014. MMWR Morb Mortal Wkly Rep. 2016;65:1–36.
[13] Loulergue P, Moulin F, Vidal-Trecan G, Absi Z, Demontpion C, Menager C, et al. Knowledge, attitudes and vaccination coverage of healthcare workers regarding occupational vaccinations. Vaccine 2009;27:4240–3.

[14] Vic P, Puech J. Health care workers' knowledge and vaccination coverage against pertussis in a French pediatric and maternity ward. Arch Pediatr 2011;18:1339–40.
[15] Loulergue P, Fonteneau L, Armengaud JB, Momcilovic S, Levy-Brühl D, Launay O, et al. Vaccine coverage of healthcare students in hospitals of the Paris region in 2009: the Studyvax survey. Vaccine 2013;31:2835–8.
[16] Pulcini C, Massin S, Launay O, Verger P. Factors associated with vaccination for hepatitis B, pertussis, seasonal and pandemic influenza among French general practitioners: a 2010 survey. Vaccine 2013;31:3943–9.
[17] Baron-Epel O, Madjar B, Grefat R, Rishpon S. Trust and the demand for autonomy may explain the low rates of immunizations among nurses. Hum Vaccin Immunother 2013;9:100–7.
[18] Taddei C, Ceccherini V, Niccolai G, Porchia BR, Boccalini S, Levi M, et al. Attitude toward immunization and risk perception of measles, rubella, mumps, varicella, and pertussis in health care workers working in 6 hospitals of Florence, Italy 2011. Hum Vaccin Immunother 2014;10:2612–22.
[19] Tuckerman JL, Collins JE, Marshall HS. Factors affecting uptake of recommended immunizations among health care workers in South Australia. Hum Vaccin Immunother 2015;11:704–12.
[20] Böhmer MM, Hellenbrand W, Matysiak-Klose D, Heininger U, Müters S, Wichmann O. Pertussis vaccination coverage among adults in Germany. Dtsch Med Wochenschr 2013;138:1451–7.
[21] Duclos A, Bouhour D, Baptiste C, Launay O, Guiso N. Group AVE Assessment of individual vaccine status in a vaccinology experts' group. J Eval Clin Pract 2008;14:610–4.
[22] Esolen LM, Kilheeney KL. A mandatory campaign to vaccinate health care workers against pertussis. Am J Infect Control 2013;41:740–2.
[23] Walther K, Burckhardt MA, Erb T, Heininger U. Implementation of pertussis immunization in health-care personnel. Vaccine 2015;33:2009–14.
[24] Leibu R, Maslow J. Effectiveness and acceptance of a health care-based mandatory vaccination program. J Occup Environ Med 2015;57:58–61.
[25] Hees L, Afroukh N, Floret D. Vaccination coverage among health care workers in the pediatric emergency and intensive care department of Edouard Herriot hospital in 2007, against influenza, pertussis, varicella, and measles. Arch Pediatr 2009;16:14–22.
[26] Miller BL, Ahmed F, Lu PJ, Euler GL. Tetanus and pertussis vaccination coverage among adults aged ≥ 18 years –- United States, 1999 and 2008. MMWR Surveill Summ 2010;59(40):1302–6.
[27] MacDougall DM, Halperin BA, MacKinnon-Cameron D, Li L, McNeil SA, Langley JM, et al. The challenge of vaccinating adults: attitudes and beliefs of the Canadian public and healthcare providers. BMJ Open. 2015;5:e009062.
[28] MacDougall D, Halperin BA, MacKinnon-Cameron D, Li L, McNeil SA, Langley JM, et al. Universal tetanus, diphtheria, acellular pertussis (Tdap) vaccination of adults: what Canadian health care providers know and need to know. Hum Vaccin Immunother. 2015;11:2167–79.
[29] Williams WW, Lu PJ, Singleton JA, Bridges CB, Wortley PM. Adult vaccination coverage–United States, 2010. MMWR Surveill Summ. 2012;61(4):66–72.
[30] Williams WW, Lu PJ, Greby S, Bridges CB, Ahmed F. Noninfluenza vaccination coverage among adults - United States, 2011. MMWR Surveill Summ. 2013;62 (4):66–72.
[31] Williams WW, Lu PJ, O'Halloran A, Kim DK, Grohskopf LA, Pilishvili T, et al. Surveillance of vaccination coverage among adult populations - United States, 2015. MMWR Surveill Summ. 2017;66:1–28.
[32] Srivastav A, Black CL, Lu PJ, Zhang J, Liang JL, Greby SM. Tdap vaccination among healthcare personnel, internet panel survey, 2012–2014. Am J Prev Med 2017;53:537–46.
[33] O'Halloran AC, Lu PJ, Meyer SA, Williams WW, Schumacher PK, Sussell AL, et al. Tdap vaccination among healthcare personnel-21 States, 2013. Am J Prev Med 2018;54:119–23.
[34] Jiang C, Whitmore-Sisco L, Gaur AH, Adderson EE. Group TW A quality improvement initiative to increase Tdap (tetanus, diphtheria, acellular pertussis) vaccination coverage among direct health care providers at a children's hospital. Vaccine 2018;36:214–9.
[35] Paranthaman K, McCarthy N, Rew V, van Zoelen S, Cockerill L. Pertussis vaccination for healthcare workers: staff attitudes and perceptions associated with high coverage vaccination programmes in England. Public Health 2016;137:196–9.
[36] Teresa Aguado M, Barratt J, Beard JR, Blomberg BB, Chen WH, Hickling J, et al. Report on WHO meeting on immunization in older adults: Geneva, Switzerland, 22–23 March 2017. Vaccine 2018.
[37] Seale H, Leask J, Macintyre CR. Do they accept compulsory vaccination? Awareness, attitudes and behaviour of hospital health care workers following a new vaccination directive. Vaccine 2009;27:3022–5.
[38] La Torre G, Scalingi S, Garruto V, Siclari M, Chiarini M, Knowledge Mannocci A. Attitude and behaviours towards recommended vaccinations among healthcare workers. Healthcare (Basel) 2017;5.
[39] Kassianos G. Willingness of European healthcare workers to undergo vaccination against seasonal influenza: current situation and suggestions for improvement. Drugs Context 2015;4:212268.
[40] Calderón TA, Coffin SE, Sammons JS. Preventing the spread of pertussis in pediatric healthcare settings. J Pediatric Infect Dis Soc 2015;4:252–9.
[41] Bryant K, Brothers K, Humbaygh K, Kistler V, Stites S, Madega S. Outbreaks of pertussis associated with hospitals–Kentucky, Pennsylvania, and Oregon, 2003. MMWR Surveill Summ 2005;54(3):67–71.
[42] Pascual FB, McCall CL, McMurtray A, Payton T, Smith F, Bisgard KM. Outbreak of pertussis among healthcare workers in a hospital surgical unit. Infect Control Hosp Epidemiol 2006;27:546–52.
[43] Boulay BR, Murray CJ, Ptak J, Kirkland KB, Montero J, Talbot EA. An outbreak of pertussis in a hematology-oncology care unit: implications for adult vaccination policy. Infect Control Hosp Epidemiol 2006;27:92–5.
[44] Wright SW, Decker MD, Edwards KM. Incidence of pertussis infection in healthcare workers. Infect Control Hosp Epidemiol 1999;20:120–3.
[45] Deville JG, Cherry JD, Christenson PD, Pineda E, Leach CT, Kuhls TL, et al. Frequency of unrecognized Bordetella pertussis infections in adults. Clin Infect Dis 1995;21:639–42.
[46] Sandora TJ, Gidengil CA, Lee GM. Pertussis vaccination for health care workers. Clin Microbiol Rev 2008;21:426–34.
[47] Calugar A, Ortega-Sánchez IR, Tiwari T, Oakes L, Jahre JA, Murphy TV. Nosocomial pertussis: costs of an outbreak and benefits of vaccinating health care workers. Clin Infect Dis 2006;42:981–8.
[48] Baggett HC, Duchin JS, Shelton W, Zerr DM, Heath J, Ortega-Sanchez IR, et al. Two nosocomial pertussis outbreaks and their associated costs - King County, Washington, 2004. Infect Control Hosp Epidemiol 2007;28:537–43.
[49] Tariq L, Mangen MJ, Hövels A, Frijstein G, de Boer H. Modelling the return on investment of preventively vaccinating healthcare workers against pertussis. BMC Infect Dis 2015;15:75.
[50] Haviari S, Bénet T, Saadatian-Elahi M, André P, Loulergue P, Vanhems P. Vaccination of healthcare workers: A review. Hum Vaccin Immunother 2015;11:2522–37.
[51] Nowalk MP, Lin CJ, Pavlik VN, Brown AE, Zhang S, Moehling KK, et al. Using the 4 Pillars™ practice transformation program to increase adult Tdap immunization in a randomized controlled cluster trial. Vaccine 2016;34:5026–33.