Cost-effectiveness of adult vaccinations: A systematic review

Appendices

Appendix A. Publications in analytical dataset from systematic review

This section contains the complete records from the analytical dataset for each vaccine. Regarding the tables in this appendix, the population descriptions listed in the following tables describe the population relevant to our review. So the original publication may have included assessment of child-aged vaccinations, but we only focus on adult-only results and the populations are described in terms of adults. This is also the reason the column headers in this section refer to "Relevant study population". All populations are US-based, unless otherwise indicated. All costs reported in 2016 US dollars.

Table A1. Influenza vaccination results summary

Outcome #	First author's last name	Year published	Relevant study population(s)	Outcomes	Outcome unit with any more specific population information	Citation
1	Office of Technology Assessment	1981	Adults, 25 years and older	$235 to $7,458	$ / year of healthy life saved among 25 to 44 year olds	[20]
2				$85 to $7,667	$ / year of healthy life saved among 45 to 64	
3				Cost-saving to $6,556	$ / year of healthy life saved among 65 years and older	
4	Mullooly	1994	Adults, 65 years and older	$2	Savings per person vaccinated among 65 year olds and older	[66]
5				$14	Savings per person vaccinated among 65 year olds and older who are high-risk	
6				$11	Savings per person vaccinated among 65 year olds and older who are not high-risk	
7	Nichol	1994	Adults, 65 years and older	$38 to $106	Savings in pneumonia and influenza hospitalization costs, not including vaccine costs, among 65 year olds and older	[67]
8				$26 to $318	Savings in acute and chronic respiratory conditions related hospitalization costs, not including vaccine costs, among 65 year olds and older	

9				$43 to $409	Savings in acute and chronic respiratory- and congestive heart failure-related hospitalization costs, not including vaccine costs, among 65 year olds and older	
10	Campbell	1997	Adult, working-age	$4	Savings per dollar invested in vaccine program among 18 to 64 year olds	[68]
11	Nichol	1999	Adults, 65 to 74 years old	$60	Savings per person vaccinated among 65 to 74 year olds	[69]
12	Bridges	2000	Adults, 18 to 64 years old	$16 to $95	Cost per person vaccinated among 18 to 64 year olds from Michigan	[70]
13	Davis	2001	Adults, 65 years and older	$133	Savings per person vaccinated among 65 year olds and older	[71]
14				$117	Savings per person vaccinated among 65-79 year olds and older	
15				$123	Savings per person vaccinated among persons without major disease	
16	Nichol	2001	Adults, 18 to 65 years old	$20	Savings per person vaccinated among 18-64 year olds	[72]
17	Lee	2002	Adults, 18 to 50 years old	$40	Net benefit per person vaccinated among 18-50 year olds	[73]
18	Nichol	2002	Adults, 65 to 74 years old	$54 to $71	Savings per person vaccinated among 65-74 year olds, depending on vaccine price	[74]
19	Nichol	2003	Adults, aged 18 to 64 years old	$73	Savings per person vaccinated assuming no cost for vaccine materials and administration	[64]
20	Rothberg	2005	Adults, 18 to 50 years old	$29,046	$ / QALY among adults 18-50 years old	[75]
21	Maciosek	2006	Adults, 50 years and older	$8,165	$ / QALY among 50 year olds and older	[76]
22				$39,087	$ / QALY among 50 to 64 year olds	
23				$1,366	$ / QALY among 65 year olds and older	
24	Roberts	2006	Pregnant women, 18 to 44	Cost-saving	$ / QALY among pregnant women aged 18-44 years old	[77]

			years			
25	Avritscher	2007	Cancer patients, 20 to 64 years old	$275	$ / QALY among 20 to 64 year old cancer patients	[78]
26	Prosser	2008	Adults, aged 18 years and older, with and without high risk	$114 to $1,105	$ / influenza episode averted among 18-49 year olds, depending on vaccination setting	[79]
27				Cost-saving to $521	$ / influenza episode averted among 50-64 year olds, depending on vaccination setting	
28				Cost-saving	$ / influenza episode averted among 65+ year olds, depending on vaccination setting	
29	Beigi	2009	Adults, pregnant females in the US	$8,635	$ / QALY among pregnant females, receiving single-dose	[80]
30				$21,846	$ / QALY among pregnant females, receiving two-doses	
31	Smith	2010	Adults, 50 years old	Cost-saving	$ / QALY of influenza and pneumococcal vaccine among 50 year olds	[81]
32				Cost-saving	$ / QALY of influenza vaccine among 50 year olds	
33	Lee	2011	Adults, 30 and 40 years old	$326 to $8,635	$ / influenza case averted among insured persons with varying influenza vaccine type, costs, and administration time	[82]
34				$141 to $7,572	$ / influenza episode averted among uninsured persons with varying influenza vaccine type, costs, and administration time	
35	Myers	2011	Pregnant females	$121,176	$ / QALY among pregnant women, with benefits to new mothers only	[83]
36				$77,145	$ / QALY among pregnant women, with benefits to new mothers and newborn children	
37	Prosser	2011	Adults 18 to 65 and older in the US	$27,032 to $170,237	$ / QALY among low-risk adults 18 years and older	[65]
38				Cost-saving	$ / QALY among high-risk adults 18 -64 years	
39	Skedgel	2011	Pregnant females in Canada	$35,610	$ / QALY among pregnant females in Canada	[84]
40	Ding	2012	Pregnant	$14	Net benefit per vaccinated mother	[85]

			females			
41	Patterson	2012	Adults 50 years and older in US	$38,581	$ / life saved among 50 year olds and older, during ED visit	[86]
42				$14,585	$ / life saved among 65 year olds and older, during ED visit	
43	Chit	2015	Adults 65 and older in the US	$9,036	$ / QALY for HD trivalent flu vaccine among 65 years and older	[87]
44				$11,907	$ / QALY for trivalent flu vaccine among 65 years and older	
45				$15,773	$ / QALY for quadrivalent flu vaccine among 65 years and older	
46	Xu	2016	Pregnant females	Cost-saving	$ / QALY among pregnant females in a moderate season	[88]
47				$258,274	$ / QALY among pregnant females in a mild season	
48				Cost-saving	$ / QALY among pregnant females in a moderately severe season	

Note(s): QALY=quality-adjusted life-year. Smith (2010) [81] is included in the table for influenza and pneumococcal vaccines. All costs reported in 2016 US dollars.

Table A2. Pneumococcal vaccination results summary.

#	First author's last name	Year published	Relevant study population(s)	Outcomes	Outcome unit with any more specific population information	Citation
1	Willems	1980	Adults, aged 25 and older	$84,254	$ / QALY among 25-44 year olds	[21]
2				$20,972	$ / QALY among 45-64 year olds	
3				$3,679	$ / QALY among 65+ year olds	
4	Sisk	1986	Adults, aged 65 years and older	$22,642	$ / QALY among 65+ year olds	[89]
5				$10,520 to $20,109	$ / QALY among 65+ year olds, Medicare perspective	
6	Holzer	1993	Adults aged 50 years and older, adults 18-49 with high-risk conditions	$160	Savings per vaccination among 19-49 year olds who are high-risk, and 50+ year olds	[90]
7	Sisk	1997	Adults, aged 65 years and older in 3 geographic areas	Cost-saving	$ / QALY among 65+ year olds	[91]
8				Cost-saving to $68,465	$ / QALY among 65+ year olds	
9				Cost-saving to $43,389	$ / QALY among 65-74 year olds	
10	Herman	1998	Adults, aged 55 years and older	$26 to $29	Savings per person vaccinated among 55-64 year olds, depending on strain resistance	[92]
11				$15 to $17	Savings per person vaccinated among 65-74 year olds, depending on strain resistance	
12				$10 to $11	Savings per person vaccinated among 75-84 year olds, depending on strain resistance	
13	Stack	1999	Adults, 18 years and older in Ohio	$106	Savings per person vaccinated among emergency department visitors, 65+ years old or with comorbidity indicators	[93]
14	Marra	2000	HIV-positive clinic patients in Vancouver, Canada	$260	Savings per person vaccinated among individuals with HIV	[94]
15	Pepper	2000	Active-duty members of the military in the United States	Cost-saving	$ / QALY among active-duty U.S. military, 17-64 years old	[95]
16	Mukamel	2001	Community clinic patients, aged 65 years and older in Monroe County, New York	$12,732	$ / QALY among community clinic patients, 65+ year olds receiving PPSV23	[96]
17				$18,577	$ / QALY among community clinic patients, 65+ year olds receiving PPSV23 and influenza vaccine	
18	Pepper	2002	Young adults	$74,231	$ / QALY among 22 year olds	[97]

19				$32,160	$ / QALY among 35 year olds	
20	Sisk	2003	Adults, 50 to 64 years old	$5,409 to $17,980	$ / QALY among 50+ year olds, with and without future medical costs of survivors	[98]
21				Cost-saving to $28,595	$ / QALY among high-risk 50+ year olds, with and without future medical costs of survivors	
22	Smith	2008	Adults, aged 50 years and older	$4,324	$ / QALY among 65 year olds and younger persons with comorbidities	[99]
23				$21,266	$ / QALY among 65 year olds	
24				$19,410	$ / QALY for four decennial vaccinations, given at the age of 50, 60, 70, and 80	
25	Smith	2009	Adults, aged 65 years and older	$34,052	$ / QALY among 65 year olds	[100]
26				$93,024	$ / QALY among 75 year olds	
27				$98,895	$ / QALY among 80 year olds	
28	Smith	2010	Adults, 50 years old	Cost-saving	$ / QALY of pneumococcal vaccine among 50 year olds	[81]
29				Cost-saving	$ / QALY of influenza and pneumococcal vaccine among 50 year olds	
30	Smith	2010	Healthcare workers	$3,494	$ / QALY among health care workers 20-59 years old, in scenario with no pandemic flu	[101]
31				$474	$ / QALY among health care workers 20-59 years old, in scenario with pandemic flu	
32	Smith	2012	Adults, age 50 years and older	$34,407	$ / QALY among 65 year olds and younger persons with comorbidities, with PCV13	[102]
33				$40,819	$ / QALY among 65 year olds and younger persons with comorbidities, with PPSV23	
34				$43,087	$ / QALY for two vaccinations, given at 50 and 65 year olds, with PCV13	
35	Cho	2013	Adults, immunocompromised	Cost-saving	$ / QALY among immunocompromised 19+ year olds	[103]
36				Cost-saving	$ / QALY among ages 19+ with dialysis	
37				$4,350	$ / QALY among ages 19+ with HIV	
38	Smith	2013	Adults, immunocompromised, aged 18 to 64 years	$84,455	$ / QALY among immunocompromised individuals, aged 19-65 years old, with PCV13 single dose	[104]
39				$87,003	$ / QALY among immunocompromised individuals, aged 19-65 years old, with PPSV23 single dose	
40				$52,761	$ / QALY among HIV-infected individuals, aged 19-65 years old, with PCV13 single dose	
41	Smith	2013	Adults, aged 65 years	$13,453	$ / QALY among 65 year olds, with PCV13	[105]

42	and older	$74,767	$ / QALY among 75 year olds, with PCV13	

Note(s): QALY=quality-adjusted life-year. Smith (2010) [81] is included in the table for influenza and pneumococcal vaccines. All costs reported in 2016 US dollars.

Table A3. HPV vaccination results summary.

#	First author's last name	Year published	Relevant study population(s)	Outcomes	Outcome unit with any more specific population information	Citation
1	Taira	2004	Young adults, 18 years old	$78,339	$ / QALY among 18 year old males	[106]
2	Brisson	2007	Young adults in Canada, females only	$65,938	$ / QALY among 25 year olds with bivalent vaccine	[107]
3				$44,635	$ / QALY among 25 year olds with quadrivalent vaccine	
4	Elbasha	2007	Young adults, 18 to 24 years old	$8,892	$ / QALY among males and females at age 18 years with 18-24 year old catch up	[108]
5				$2,286	$ / QALY among females age 18 years females with 18-24 year old catch up	
6				$25,354	$ / QALY among males age 18 years with 18-24 year old catch up (compared to female only vaccination)	
7	Kim	2008	Young adults, aged 19 to 26, females only	$120,604 to $143,344	$ / QALY among females aged 19 to 21, with cervical cancer outcomes only and with cervical cancer and genital warts	[109]
8				$159,059 to $181,799	$ / QALY among females aged 22 to 26, with cervical cancer outcomes only and with cervical cancer and genital warts	
9	Elbasha	2009	Young adults, 18 to 24 years, females only	$4,316 to $,5235	$ / QALY among 18-19 year olds with 5 year and permanent expansion of an age-based catch-up recommendation	[110]
10				$13,986 to $14,259	$ / QALY among 20-24 year olds with 5 year and permanent expansion of an age-based catch-up recommendation	
11	Kim	2009	Adults, 35 and 45 years old, females only	$139,236 to $324,249	$ / QALY among females 35-45 years old with cytology or triaged HPV DNA testing	[46]
12				$230,600 to $454,306	$ / QALY among females 35-45 years old with combined cytology and HPV DNA testing	
13	Kim	2010	Young adults, 20 to 26 years old, males only, MSM	$21,252 to $42,551	$ / QALY among MSM 20 year olds with varied levels of past exposure to HPV type	[111]
14				$14,477 to $45,039	$ / QALY among MSM 26 year olds with varied levels of past exposure to HPV type	
15	Tully	2012	Young adults in Canada, females only	$6,797	$ / QALY among 18 year olds	[112]
16				$8,432	$ / life years saved among 18 year olds	
17	Deshmukh	2014	Adults, 27 to 55 years old, males only, MSM	$96,022	$ / QALY among MSM, HIV-negative 27 year olds	[113]
18				$134,231	$ / QALY among MSM, HIV-negative 40 year olds	
19				$186,052	$ / QALY among MSM, HIV-negative 55 year olds	

Note(s): QALY=quality-adjusted life-year; MSM=men who have sex with men. All costs reported in 2016 US dollars.

Table A4. Hepatitis B vaccination results summary.

#	First author's last name	Year published	Relevant study population(s)	Outcomes	Outcome unit with any more specific population information	Citation
1	Mulley	1982	Adults, MSM, health care workers	Not cost-saving	$ / case prevented among MSM population	[114]
2				Cost-saving	$ / case prevented among surgical residents	
3	Bloom	1993	Adults, high-risk	Cost-saving	$ / life year saved among adults at high-risk for HBV	[115]
4	Oddone	1993	Adults, with chronic kidney disease	$65,715	$ / case prevented among predialysis patients with renal system impairment	[116]
5				$53,468	$ / case prevented among patients with renal system impairment on dialysis	
6				$1,043,256 to $1,232,159	$ / life year saved among patients with renal system impairment, with and without dialysis	
7	Pisu	2002	Adults, incarcerated	Cost-saving to $615	$ / case prevented among prisoners, from the societal perspective and the prison system perspective	[117]
8				$65	$ / case prevented among prisoners who are never released, from the societal perspective or the prison system perspective	
9				Cost-saving to $3,285	$ / case prevented among prisoners who are released after 2 years and do not return to prison, from the societal perspective or the prison system perspective	
10	Kim	2006	Adults, 20 to 49 years old, attending STD counseling and testing clinics	$6,133	$ / QALY among 20-49 year olds visiting freestanding HIV counseling and testing sites	[118]
11				$4,878	$ / QALY among 20-49 year olds visiting STD clinics	
12	Hu	2008	Adults, with history of injection drug use in the past 30 days	Cost-saving	$ / QALY among 18+ year old injection drug users	[119]
13	Miriti	2008	Adults, attending STD clinics	$323	Net economic benefit per vaccinated person among 18+ year olds visiting STD clinics	[120]
14				$6,112	Cost savings per case avoided among 18+ year olds visiting STD clinics	
15	Hoerger	2013	Adults, 20 years and older, diabetics	$82,654	$ / QALY among diabetic 20-59 year olds	[45]
16				$3,038,678	$ / QALY among diabetic 60+ year olds	
17				$216,344	$ / QALY among diabetic 20+ year olds	

18	Rossi	2013	Adults, immigrants and refugees in Canada	Dominated	$ / QALY among 30 year old immigrants to Canada, with universal vaccination	[121]
19				Dominated	$ / QALY among 30 year old immigrants to Canada, with screening for prior immunity and vaccination	

Note(s): QALY=quality-adjusted life-year; MSM=men who have sex with men; Dominated=more expensive and fewer health outcomes. All costs reported in 2016 US dollars.

Table A5. Tetanus-diphtheria-pertussis vaccination results summary.

#	First author's last name	Year published	Relevant study population(s)	Outcomes	Outcome unit with any more specific population information	Citation
1	Balestra	1993	Adults, 19 to 85 years old	$9,913	$ / life year saved among 65 year olds receiving a tetanus booster	[122]
2	Lee	2005	Adults, 20 years and older	Dominated	$ / QALY among adults receiving one-time booster at age 20	[44]
3				Dominated	$ / QALY among adults receiving booster every 10 years	
4				$329,872	$ / QALY among postpartum mothers and an adult caregiver	
5	Lee	2007	Adults, 20 to 64 years old	$44,243	$ / QALY among 20-64 year olds with pertussis incidence of 150/100k	[43]
6				$79,883	$ / QALY among 20-64 year olds with pertussis incidence of 100/100k	
7				$208,925	$ / QALY among 20-64 year olds with pertussis incidence of 50/100k	
8	Coudeville	2009	Adults, 20 years and older	Cost-saving	$ / life year saved among adults receiving a Tdap dose at age 40	[123]
9				Cost-saving	$ / life year saved among adults receiving decennial Tdap doses at age 20 and older	
10				Cost-saving	$ / life year saved among adults following a cocooning strategy around expected infants	
11	Greer	2011	Healthcare workers, neonatal ICU	Cost-saving to $29,659	$ / QALY among health care workers in neonatal units with 25% to 95% vaccination coverage	[124]
12	McGarry	2013	Adults, 65 years and older	$369,944	$ / QALY with pertussis incidence of 25/100k	[42]
13				$69,030	$ / QALY with pertussis incidence of 100/100k	
14				$18,876	$ / QALY with pertussis incidence of 200/100k	
15	McGarry	2014	Adults aged 65 years and older	Cost-saving	$ / QALY among 65 year olds receiving a Tdap booster	[125]
16	Atkins	2016	Adults, 20 to 40 years old, pregnant women and	$117,852	$ / QALY among pregnant women 20-40 years old with antepartum vaccination	[126]

17			parents	$838,964	$ / QALY among two parents 20-40 years old with antepartum vaccination	
18	Kamiya	2016	Young adults, 21 years old	$28,808,448	$ / QALY among 21 year olds receiving Tdap booster	[127]

Note(s): QALY=quality-adjusted life-year; Dominated=more expensive and fewer health outcomes. All costs reported in 2016 US dollars.

Table A6. Herpes zoster vaccine vaccination results summary.

#	First author's last name	Year published	Relevant study population(s)	Outcomes	Outcome unit with any more specific population information	Citation
1	Hornberger	2006	Adults, 60 years and older	$189,746	$ / QALY among 69 year olds	[128]
2				$34,229 to $240,344	$ / QALY among 69 year olds, depending on vaccine cost and vaccine efficacy duration	
3				$30,215	$ / QALY among immunocompetent 60+ year olds	
4	Pellissier	2007	Adults, 60 years and older	$32,870	$ / QALY among immunocompetent 60+ year olds, from payer perspective	[129]
5				$2,363	$ / HZ case prevented among immunocompetent 60+ year olds	
6	Rothberg	2007	Adults, 60 years and older	$110,074 to $176,628	$ / QALY among 60 year olds, depending on sex	[130]
7				$53,644 to $81,179	$ / QALY among 70 year olds, depending on sex	
8				$151,758 to $235,180	$ / QALY among 80 year olds, depending on sex	
9	Brisson	2008	Adults, 50 to 80 years old in Canada	$54,625	$ / QALY among 60 year olds with vaccine price of $150	[131]
10				$80,250	$ / QALY among 60 year olds with vaccine price of $200	
11	Najafzadeh	2009	Adults, 60 years and older in Canada	$49,599	$ / QALY among 60+ year olds	[132]
12				$42,046	$ / QALY among 60-75 year olds	
13				$77,291	$ / QALY among 75+ year olds	
14	Le	2015	Adults, 50 to 59 years old	$327,925	$ / QALY among 50 year olds	[47]
15	Le	2016	Adults, 60 to 80 years old	$59,446	$ / QALY among 60 year olds	[133]

Note(s): QALY=quality-adjusted life-year. All costs reported in 2016 US dollars.

Appendix B. Additional results and discussion

Outcomes evaluating cost per QALY saved, at different willingness-to-pay thresholds

For additional results on cost-effectiveness outcomes, percentages that estimated a cost per QALY saved under one of three different willingness-to-pay thresholds are presented in Table B1. These outcomes were stratified by vaccine group, by assessment of either age-based or indication-based vaccinations, and by three cost per QALY thresholds. Several values in Table B1 are also stated in the main text that accompanies Figure 2 of the main text, which is a graphical presentation of the information in Table B1.

Previous research on age-based vaccinations

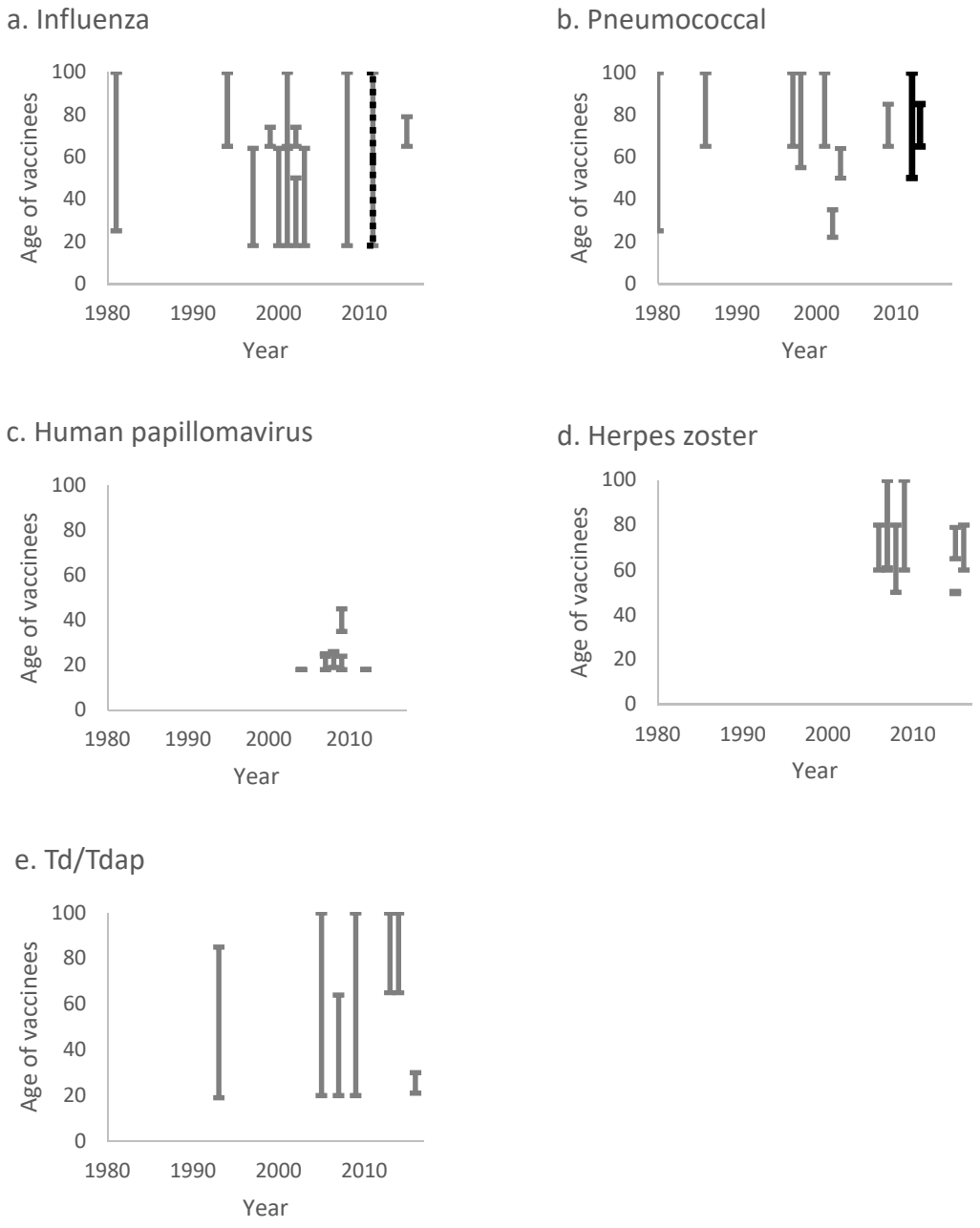
The age range and publication date for each publication assessing age-based recommendations are summarized in Figure B1. Influenza vaccination economic evaluation has been an active area of research since the early 1980s and has examined economic values across a large range of adult ages. Similarly, pneumococcal vaccinations have a history of economic evaluation research going back to the early 1980s, with substantial variation in age ranges investigated but not as comprehensive as the range of ages explored in influenza publications. The earliest Td/Tdap research occurred in the early 1990s. The Td/Tdap economic research has investigated a broad range of adult ages as well. The two more recently developed vaccines, HZ and HPV vaccines have a shorter history of literature, only going back to mid-2000s. This research has also focused on a more specific set of age groups than the other vaccine groups. While the age groups investigated for HZ and HPV vaccines aligned closely with the age groups that ACIP recommends to receive those vaccines, a few exceptions include a publication that investigated HPV vaccinations among 35 and 45 year old females [46], while the ACIP recommends HPV vaccination of women only through age 26 year, and two publications that investigated HZ vaccinations among 50 year olds [47, 131], which were not the recommended age group for HZ vaccination at the time of those publications.

Table B1. Summary of cost-effectiveness results presented as costs per QALY saved from a systematic review of adult vaccination cost-effectiveness and economic evaluation publications, stratified by vaccine group

Type of vaccination	Cost-savings results	Vaccine group: Influenza FNA	Pneumo-coccal FNA	Human papilloma-virus	Herpes zoster	Tetanus-diphtheria-pertussis	Hepatitis B
Age-based vaccinations	Number of outcomes using $/QALY	10	23	13	14	10	0
	Percent of outcomes with CER <= $50,000/QALY	100	78	54	36	30	
	Percent of outcomes with CER <= $100,000/QALY	100	100	69	71	50	
	Percent of outcomes with CER <= $300,000/QALY	100	100	100	93	60	
Indication-based vaccinations	Number of outcomes using $/QALY	11	13	5	0	4	8
	Percent of outcomes with CER <= $50,000/QALY	73	77	40		25	38
	Percent of outcomes with CER <= $100,000/QALY	82	100	60		25	50
	Percent of outcomes with CER <= $300,000/QALY	100	100	100		50	63

Note(s): QALY=quality-adjusted life-year; LY=life-year. For the purposes of calculating the percentages in this table, we used the lower values from outcomes where ranges of cost-effectiveness was abstracted.

Figure B1. Age ranges used in cost-effectiveness analyses of age-based vaccinations by year of publication for five different adult vaccines or vaccine preventable diseases



Note(s): Td/Tdap=tetanus-diphtheria-pertussis vaccines. Many publications reported no upper age limit (e.g., target population was 65 years and older), so for these we just used 100 years for convenience of presenting results. For the purposes of this graph, the elderly are considered general population and publications looking at the elderly are included. The dark, dashed bar in the influenza panel (panel a) indicate pandemic influenza model with all other bars in this panel referring to seasonal influenza models. The dark, solid bars in panel b indicate the conjugate vaccine was assessed with all other bars in this panel referring to the polysaccharide vaccine.

Appendix C. Search results from electronic databases.

Table C1. Summary of search results by electronic database and for the title and abstract review.

Electronic database	Number of publications
PubMed	476
EconLit	11
Embase	663
Cochrane	538
All databases	1688
Revisions for title/abstract review	Number of publications
Duplicates identified	735
All databases total with duplicates removed	953
Ad hoc additions	15
Total publications for title/abstract review	968

Table C2. Search criteria and results counts from electronic databases by vaccine group.

Vaccine group	Search terms[a]	Data-base	Date range	Number of publications	Access date
Influenza	(cost-effectiveness OR cost-utility) AND (vaccine OR vaccination OR immunization) AND (influenza OR flu)	PubMed	1980 to present	105	12/13/2016
Pneumococcal	(cost-effectiveness OR cost-utility) AND (vaccine OR vaccination OR immunization) AND (pneumococcal)			143	12/13/2016
Tetanus-diphtheria-pertussis	(cost-effectiveness OR cost-utility) AND (vaccine OR vaccination OR immunization) AND (tetanus OR diphtheria OR pertussis OR Td OR Tdap)			23	12/13/2016
Human papillomavirus	(cost-effectiveness OR cost-utility) AND (vaccine OR vaccination OR immunization) AND (human papillomavirus OR HPV)			114	12/13/2016
Zoster	(cost-effectiveness OR cost-utility) AND (vaccine OR vaccination OR immunization) AND (herpes zoster OR zoster OR shingles)			31	12/13/2016
Hepatitis B	(cost-effectiveness OR cost-utility) AND (vaccine OR vaccination OR immunization) AND (hepatitis B)			60	12/13/2016
All vaccines	(cost-effectiveness OR cost-utility) AND (vaccine OR vaccination OR immunization) AND (influenza OR flu OR pneumococcal OR tetanus OR diphtheria OR pertussis OR Td OR Tdap OR human papillomavirus OR HPV OR herpes zoster OR zoster OR shingles OR hepatitis B)	EconLit	1980 to present	11	12/13/2016
Influenza	(cost-effectiveness OR cost-utility) AND (vaccine OR vaccination OR immunization) AND (influenza OR flu)	Embase	1988 to present[b]	134	12/13/2016
Pneumococcal	(cost-effectiveness OR cost-utility) AND (vaccine OR vaccination OR immunization) AND (pneumococcal)			217	12/13/2016
Tetanus-diphtheria-pertussis	(cost-effectiveness OR cost-utility) AND (vaccine OR vaccination OR immunization) AND (tetanus OR diphtheria OR pertussis OR Td OR Tdap)			27	12/13/2016
Human papillomavirus	(cost-effectiveness OR cost-utility) AND (vaccine OR vaccination OR immunization) AND (human papillomavirus OR HPV)			171	12/13/2016
Zoster	(cost-effectiveness OR cost-utility) AND (vaccine OR vaccination OR			40	12/14/2016

	immunization) AND (herpes zoster OR zoster OR shingles)				
Hepatitis B	(cost-effectiveness OR cost-utility) AND (vaccine OR vaccination OR immunization) AND (hepatitis B)			74	12/13/2016
Influenza	(cost-effectiveness OR cost-utility) AND (vaccine OR vaccination OR immunization) AND (influenza OR flu)			135	12/14/2016
Pneumococcal	(cost-effectiveness OR cost-utility) AND (vaccine OR vaccination OR immunization) AND (pneumococcal)	Cochrane Library, Economic Evaluations	No restriction	124	12/14/2016
Tetanus-diphtheria-pertussis	(cost-effectiveness OR cost-utility) AND (vaccine OR vaccination OR immunization) AND (tetanus OR diphtheria OR pertussis OR Td OR Tdap)			49	12/14/2016
Human papillomavirus	(cost-effectiveness OR cost-utility) AND (vaccine OR vaccination OR immunization) AND (human papillomavirus OR HPV)	Cochrane Library, Economic Evaluations	No restriction	106	12/14/2016
Zoster	(cost-effectiveness OR cost-utility) AND (vaccine OR vaccination OR immunization) AND (herpes zoster OR zoster OR shingles)			36	12/14/2016
Hepatitis B	(cost-effectiveness OR cost-utility) AND (vaccine OR vaccination OR immunization) AND (hepatitis B)			88	12/14/2016

[a.] The search field was “Title” for all searches.

[b.] Embase only provides publications for 1988 and later.

Appendix D. Age ranges and indications

Table D1. Age ranges and indications that were identified in the systematic review for each vaccine group.

Vaccine or vaccine-preventable disease	Age ranges[a]	Indications
Influenza	≥ 18 years old	Cancer patients[b], individuals with chronic pulmonary and significant cardiac conditions, and others conditions included in recommendations; pregnant women
Pneumococcal	≥ 18 years old	Individuals with chronic renal failure, on dialysis, systemic lupus erythematosus, asplenia, and primary and metastatic cancer; individuals with chronic obstructive pulmonary disease, chronic hepatic disease, chronic renal insufficiency without dialysis, stroke, rheumatoid arthritis, alcoholism, dementia, congestive heart failure, coronary heart disease, and diabetes mellitus; HIV patients; active-duty military; healthcare workers; immunocompromised
Human papilloma virus	18 to 45 years old	MSM including individuals with and without HIV
Herpes zoster	≥ 50 years old	[c]
Tetanus-diphtheria-pertussis	≥ 18 years old	Healthcare workers; pregnant women and new parents
Hepatitis B	[d]	Individuals with chronic kidney disease, diabetics, healthcare workers, IDUs, immigrants and refugees, incarcerated individuals, MSM, STD clinic attendees

Note(s): HIV=human immunodeficiency virus; IDU=injection drug users; MSM=men who have sex with men; STD=sexually transmitted disease.

[a.] The age ranges column reflects study populations that were identified using age-based criteria only. These groups were assumed to represent a general and immunocompetent population with no other indicators suggesting increased risk except for age.

[b.] The base case cancer patients eligible for vaccination in this study [78] were 51 years old, were within 5 years of diagnosis, and had a life expectancy of at least 3 months.

[c.] No studies evaluating herpes zoster vaccinations investigated a study population that was characterized by any indication except for age.

[d.] No studies evaluating hepatitis B vaccinations investigated a study population that was characterized only by age.

Appendix E. Citation counts for included studies

Table E1. Citation counts from Scopus for each study in the full text sample of the systematic review, in order from highest number of citations.

First author	Publication year	Title	Journal	Citations
Nichol	1994	The efficacy and cost effectiveness of vaccination against influenza among elderly persons living in the community	NEJM	846
Bridges	2000	Effectiveness and Cost-Benefit of Influenza Vaccination of Healthy Working Adults	JAMA	526
Elbasha	2007	Model for assessing human papillomavirus vaccination strategies	Emerg Inf Dis	327
Taira	2004	Evaluating human papillomavirus vaccination programs	Emerg Inf Dis	300
Mullooly	1994	Influenza vaccination program for elderly persons: Cost-effectiveness in a health maintenance organization	Ann Intern Med	300
Kim	2008	Health and economic implications of HPV vaccination in the United States	NEJM	263
Nichol	2001	Cost-benefit analysis of a strategy to vaccinate healthy working adults against influenza	Arch Intern Med	187
Campbell	1997	Cost-effectiveness of the influenza vaccine in a healthy, working-age population	J Occ Env Med	148
Bloom	1993	A reappraisal of hepatitis B Virus Vaccination strategies using cost-effectiveness analysis	Ann Intern Med	146
Brisson	2007	The potential cost-effectiveness of prophylactic human papillomavirus vaccines in Canada	Vaccine	141
Mulley	1982	Indications for use of hepatitis B vaccine, based on cost-effectiveness analysis	NEJM	134
Kim	2010	Targeted human papillomavirus vaccination of men who have sex with men in the USA: a cost-effectiveness modeling analysis	Lancet	127
Hornberger	2006	Cost-effectiveness of a vaccine to prevent herpes zoster and postherpetic neuralgia in older adults	Ann Intern Med	109
Rothberg	2007	Cost-effectiveness of a vaccine to prevent herpes zoster and postherpetic neuralgia in older adults	Clin Inf Dis	108
Willems	1980	Cost effectiveness of vaccination against pneumococcal pneumonia	NEJM	104
Pellissier	2007	Evaluation of the cost-effectiveness in the United States of a vaccine to prevent herpes zoster and postherpetic neuralgia in older adults	Vaccine	103
Nichol	2003	Cost benefit of influenza vaccination in healthy, working adults: an economic analysis based on the results of a clinical trial of trivalent live attenuated influenza virus vaccine	Vaccine	100
Lee	2005	Pertussis in adolescents and adults: should we vaccinate?	Pediatrics	99

Lee	2002	Economic analysis of influenza vaccination and antiviral treatment for healthy working adults	Ann Intern Med	98
Sisk	2003	Cost-effectiveness of vaccination against IPD among people 50 through 64 years of age: Role of comorbid conditions and race	Ann Intern Med	93
Maciosek	2006	Influenza Vaccination: Health impact and cost effectiveness among adults aged 50 to 64 and 65 and older	Am J Prev Med	93
Sisk	1986	Cost effectiveness of vaccination against pneumococcal pneumonia: An update	Ann Intern Med	90
Smith	2012	Cost-effectiveness of adult vaccination strategies using pneumococcal conjugate vaccine compared with PPV	JAMA	90
Rothberg	2005	Vaccination versus treatment of influenza in working adults: a cost-effectiveness analysis	Am J Med	75
Beigi	2009	Economic value of seasonal and pandemic influenza vaccination during pregnancy	Clin Inf Dis	72
Prosser	2008	Non-traditional settings for influenza vaccination of adults	Pharmacoeconomics	70
Nichol	1999	The health and economic benefits of influenza vaccination for healthy and at-risk persons aged 65 to 74 years	Pharmacoeconomics	65
Balestra	1993	Should adult tetanus immunization be given as a single vaccination at age 65?	J Gen Intern Med	61
Kim	2009	Cost-effectiveness of human papillomavirus vaccination and cervical cancer screening in women older than 30 years in the United States	Ann Intern Med	60
Brisson	2008	The potential cost-effectiveness of vaccination against herpes zoster and post-herpetic neuralgia	Hum Vac	59
Coudeville	2009	Adult vaccination strategies for the control of pertussis in the United States: An economic evaluation including the dynamic population effects	Plos One	53
Lee	2007	Cost effectiveness of pertussis vaccination in adults	Am J Prev Med	51
Pisu	2002	Cost-effectiveness of hepatitis B vaccination of prison inmates	Vaccine	46
Nichol	2002	Cost effectiveness of influenza vaccination for healthy persons between ages 65 and 74	Vaccine	44
Davis	2001	Influenza vaccination, hospitalizations, and costs among members of medicare managed care plan	Med Care	43
Smith	2008	Alternative strategies for adult pneumococcal polysaccharide vaccination: a cost-effectiveness analysis	Vaccine	41
Najafzadeh	2009	Cost effectiveness of herpes zoster vaccine in Canada	Pharmacoeconomics	38
Roberts	2006	Cost-effectiveness of universal influenza vaccination in a pregnant population	Obst Gyn	37
Sisk	1997	Cost-effectiveness of vaccination against pneumococcal bacteremia among elderly people	JAMA	36
Oddone	1993	A cost-effectiveness analysis of hepatitis B Vaccine in predialysis patients	Health Services Research	29

Pepper	2000	Cost-effectiveness of the pneumococcal vaccine in the United States Navy and Marine Corps	Clin Inf Dis	29
Elbasha	2009	Age-based programs for vaccination against HPV	Value Health	23
Chit	2015	Expected cost effectiveness of high-dose trivalent influenza vaccine in US seniors	Vaccine	23
Hoerger	2013	Cost-effectiveness of hepatitis B vaccination in adults with diagnosed diabetes	Diabetes Care	23
Rossi	2013	Hepatitis B Screening and Vaccination Strategies for Newly Arrived Adult Canadian Immigrants and Refugees: A Cost-effectiveness analysis	Plos ONE	23
Stack	1999	An emergency department-based pneumococcal vaccination program could save money and lives	Ann Emerg Med	23
Avritscher	2007	Cost-effectiveness of influenza vaccination in working-age cancer patients	Cancer	23
Myers	2011	Influence of timing of seasonal influenza vaccination on effectiveness and cost-effectiveness in pregnancy	Am J Obs Gyn	23
Smith	2013	Modeling of cost effectiveness of pneumococcal conjugate vaccination strategies in US older adults	Am J Prev Med	21
Prosser	2011	Cost-effectiveness of 2009 pandemic influenza A (H1N1) vaccination in the United States	Plos ONE	21
Le	2015	Cost-effectiveness of herpes zoster vaccine for persons aged 50 years	Ann Intern Med	21
Kim	2006	Cost effectiveness of hepatitis B vaccination at HIV counseling and Testing sites	Am J Prev Med	21
Hu	2008	Economic evaluation of delivering hepatitis B Vaccine to Injection Drug Users	Am J Prev Med	21
Deshmukh	2014	Clinical effectiveness and cost-effectiveness of quadrivalent human papillomavirus vaccination in HIV-negative men who have sex with men to prevent recurrent high-grade anal intraepithelial neoplasia	Vaccine	20
Pepper	2002	Cost-effectiveness of the pneumococcal vaccine in healthy younger adults	Med Desc Mak	19
Lee	2011	From the patient perspective: The economic value of seasonal H1N1 influenza vaccination	Vaccine	19
Smith	2010	Cost-effectiveness of dual influenza and pneumococcal vaccination in 50-year-olds	Vaccine	18
Tully	2012	Time for change? An economic evaluation of integrated cervical screening and HPV immunization programs in Canada	Vaccine	17
Greer	2011	Use of models to identify cost-effective interventions: pertussis vaccination for pediatric health care workers	Pediatrics	17
Smith	2013	Cost-effectiveness of pneumococcal conjugate vaccination in immunocompromised adults	Vaccine	17
McGarry	2014	Cost-effectiveness of Tdap vaccination of adults aged 65+ in the prevention of pertussis in the US: A Dynamic model of disease transmission	Plos ONE	13

Cho	2013	Cost-effectiveness of administering 13-valent pneumococcal conjugate vaccine in addition to 23-valent pneumococcal polysaccharide vaccine to adults with immunocompromising conditions	Vaccine	13
Mukamel	2001	Cost utility of public clinics to increase pneumococcal vaccines in the elderly	Am J Prev Med	11
Atkins	2016	Cost-effectiveness of pertussis vaccination during pregnancy in the US	Am J of Epi	11
Smith	2009	Age, revaccination, and tolerance effects on pneumococcal vaccination strategies in the elderly: A cost-effectiveness analysis	Vaccine	9
Miriti	2008	Economic benefits of hepatitis B vaccination at STD clinics in the US	Public Health Report	9
Skedgel	2011	An incremental economic evaluation of targeted and universal influenza vaccination in pregnant women	Can J Pub Health	9
McGarry	2013	Cost-effectiveness analysis of Tdap in the prevention of pertussis in the elderly	Plos ONE	7
Marra	2000	A cost-effective analysis of pneumococcal vaccination in street-involved, HIV-infected patients	Can J Pub Health	7
Ding	2012	Cost-Benefit Analysis of In-Hospital Influenza Vaccination of Postpartum Women	Obs Gyn	7
Patterson	2012	Cost-effectiveness of influenza vaccination of older adults in the ED setting	Am J Emerg Med	7
Le	2016	Determining the optimal vaccination schedule for herpes zoster: a cost-effectiveness analysis	J Gen Intern Med	6
Smith	2010	Cost-effectiveness of healthcare worker pneumococcal polysaccharide vaccination during pandemic influenza	Am J Man Care	6
Kamiya	2016	Impact and cost-effectiveness of a second tetanus toxoid, reduced diphtheria toxoid, and acellular pertussis(Tdap) vaccine dose to prevent pertussis in the US	Vaccine	5
Herman	1998	Pneumococcal penicillin resistance and the cost-effectiveness of pneumococcal vaccine	Inf in Med	3
Office of Technology Assessment	1981	Cost Effectiveness of Influenza Vaccination	Govt Publication	3
Xu	2016	Cost-effectiveness of seasonal inactivated influenza vaccination	Vaccine	1
Holzer	1993	Cost effectiveness of pneumococcal vaccine: Implications for managed care	J Resrch Pharm Econ	NA[a]

Note(s): ED=emergency department; HIV=human immunodeficiency virus; HPV= human papillomavirus; STD=sexually transmitted disease.

[a.] This paper was not covered by Scopus because Scopus records only covered 1996-1998 and 2000-2001 for the *Journal of Research in Pharmaceutical Economics*. According to Google Scholar, this publication had 5 citations.