**S1 Table. Summary of studies reporting risk factors for pneumococcal carriage, stratified by World Bank income status, WHO region, and country**

|  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| **WHO regiona** | **Country** | **Ref** | **Study timeframe** | **Study design** | **Setting** | **Sample size** | **Age groups included in the study** | **Risk factor analysis method** | **Variable selectionb** |
| **Low-income countriesc (n = 17)** | | | | | | | | | |
| Africa | Ethiopia | [1] | Feb-May 2012 | Cross-sectional | Rural, urban community | 234 | ≤ 10 years | Multivariable logistic regression | Empirical, stepwise selection (P < 0.05) |
| [2] | Jun-Sep 2014 | Cross-sectional | Jimma town, children attending well-chid or sick care visits | 361 | < 5 years | Multivariable logistic regression | Empirical (P < 0.25) |
| [3] | Sep–Dec 2016 | Cross-sectional | Community (within Sodo Zuria Woreda of Wolaita Zone, Ethiopia) | 710 | 3–13 years | Multivariable logistic regression | NR |
|  | [4] | Mar–May 2018 | Cross-sectional | Urban community | 317 | 3–6 years | Multivariable logistic regression | NR |
| Kenya | [5] | 2-24 Mar 2004,  2 Jun-Jul 2004 | Cross-sectional | Community (within the Kilifi Health and Demographic Surveillance System) | 864 | All ages | Random effects logistic regression to adjust for within-subject correlation | a priori (age); empirical via likelihood ratio tests, P < 0.05 |
| [6] | Oct 2006-Dec 2008 | Cross-sectional | Semi-urban communities (within the Kilifi Health and Demographic Surveillance System) | 2840 | 3-59 months | Multivariable logistic regression | Empirical (P > 0.5), backward stepwise exclusion |
| Niger | [7] | Jun 2007-May 2008 | Cross-sectional | Community, health center for routine immunization | 1200 | 0-2 years | Multivariable logistic regression | NR |
| The Gambia | [8] | Nov 2006-Jun 2008 | Nested longitudinal | Rural villages in western Gambia | 636 | > 30 months | Multivariable logistic regression | a priori (age, trial arm) |
| [9] | May-Aug 2009 | Cross-sectional | Rural communities | 847 | All ages | Multivariable logistic regression with robust standard errors to adjust for village-level clustering | a priori (age and sex) |
| [10] | Apr 2013-Apr 2014 | Retrospective nested cohort | Peri-urban health facility | 374 | 0-28 days | Multivariable logistic regression | a priori (birth weight, other children in the household, mother’s age, mother’s education, and season) |
| [11] | NR | Cross-sectional | Rural villages, community | 2972 | All ages | Multivariable logistic regression with robust standard errors to adjust for village-level clustering | a priori (sex, age) |
| Uganda | [12] | Jan-Mar 2014 | Cross-sectional | Four rural sub-counties | 566 | All ages | Age-adjusted log-binomial model with robust variance estimator | Empirical (P < 0.1) |
| [13] | 2008, 2009, 2011 | Cross-sectional | Mainly rural, some peri-urban | 1761 | < 5 years | Multivariable logistic regression | Empirical (P < 0.2) |
| [14] | Jan-Mar 2014 | Cross-sectional | Four rural sub-counties | 1346 | All ages | Multivariable logistic regression | Age-adjusted sex, antibiotic use, symptoms of respiratory tract infection |
| South-East Asia | India | [15] | Oct 1998-Jun 1999 | Nested longitudinal | Rural south Indian | 464 | 2-2.5, 4, and 6 months | Multivariable logistic regression | Empirical (P < 0.1) |
| Nepal | [16] | Oct 2001-Jan 2006 | Nested case-control | Rural district in Southern Nepal | 550 healthy controls | 1-35 months | Multivariable logistic regression | Empirical (P ⩽ 0.10) |
| Western Pacific | Vietnam | [17] | Apr 2008-Mar 2009 | Cross-sectional | Urban, community | 883 | < 5 years | Multivariable logistic regression | NR |
| **Lower-middle-income countriesc (n = 11)** | | | | | | | | | |
| Africa | Angola | [18] | Nov–Dec 2017 | Cross-sectional | Community (city of Luanda, villages surrounding Saurimo) | 940 | 4–12 years | Multivariable logistic regression | NR |
| Nigeria | [19] | NR | Cross-sectional | Community, peri-urban | 1025 | All ages | Logistic regression with random effects to adjust for location-level clustering | a priori (sex and age); adjusted odds ratios for the presence of carriage obtained separately for each risk factor |
| Americas | Bolivia | [20] | May–Jun 2007 | Cross-sectional | Urban, community | 601 | Children (ages not specified) mean 9.5 years (SD 3.5) | Mixed-effects multivariable logistic regression models to account for clustering of samples within schools | Backward deletion based on likelihood ratio test |
| Brazil | [21] | Nov 2002-Jul 2003 | Cross-sectional | Public schools among 11 Sanitary Districts of Brazil | 1013 | 10-19 years | Multivariable logistic regression | Empirical (95% CI not crossing null value) and stepwise adjustment |
| Eastern Mediterranean | West Bank and Gaza | [22] | Mar-Jul 2009 | Cross-sectional | Community based | 379 | < 5.5 years | Multivariable logistic regression | Empirical (P < 0.2) |
| South East Asia | Indonesia | [23] | Feb-Apr 2010 | Cross-sectional | Urban community | 243 | 6-60 months | Multivariable logistic regression | Empirical (backward stepwise with P < 0.2) |
| 253 | 45-70 years |
| [24] | Nov 2014–Jan 2015 | Longitudinal | Urban and semi-rural community | 200 | 2–12 months | Multivariable logistic regression, incorporating generalized estimating equations with robust 95% Cis and an unstructured working correlation matrix to account for repeated sampling of individuals | a priori (age, antibiotic exposure, and presence of upper respiratory tract infection symptoms) |
| Western Pacific | China | [25] | Apr-May, & Oct-Nov 2009 | Cross-sectional | Urban, Shanghai immunization clinics | 614 | 12-18 months | Multivariable logistic regression | a priori (age, season, “urbanicity”); empirical (P < 0.05) |
| Fiji | [26] | Oct 2003-Apr 2004 | Cross-sectional | Rural, urban community | 774 | 3-13 months | Multivariable logistic regression | Empirical (P < 0.25) |
| Mongolia | [27] | May–Jul 2015  May–Jul 2017 | Cross-sectional | Urban, community | 961 | 5–8 weeks | Multivariable logistic regression | Empirical (P < 0.2; then stepwise with P < 0.05) |
| 989 | 12–23 months |
| Lao People’s Democratic Republic | [28] | Nov 2013–Feb 2014  Nov 2015–Feb 2016 | Cross-sectional | Rural, urban community | 999 | 5–8 weeks | Multivariable logistic regression | a priori (symptoms of upper respiratory tract infection, > 2 children < 5 years in the household, poverty) and empirical (P < 0.2) |
| 1010 | 12–23 months |
| **Upper-middle-income countriesc (n = 18)** | | | | | | | | | |
| Africa | South Africa | [29] | Jan 2007-May 2009 | Cohort | Urban, community | 251 | 6-12 weeks to 2 years and mothers of infants aged 6–12 weeks to 2 years | GEE multivariable logistic regression | NR |
| [30] | Mar 2012–Jul 2015 | Nested cohort | Peri-urban community | 986 | Birth–12 months | Multivariable Poisson regression | a priori (weight-for-age-z-score at birth, prematurity, ethnicity, sex, HIV exposure, time on exclusive breastfeeding, the average number of people sleeping per sleeping room, dwelling category, recent respiratory infection, childcare attendance, vaccination, number of other children < 5 years living in the household, and antibiotic use) and exploration of potential confounding by bacterial co-colonization by using indicator variables for each pathogen |
| 982 | Mothers of infants |
| [31] | Jun-Dec 2014  June–Dec 2016 | Cross-sectional | Community, routine immunizations | 202 | ~6–14 weeks | Multivariable logistic regression | Empirical (details not provided) |
| 99 | 9 months |
| 93 | 18 months |
| 60 | 5 years |
| Americas | Brazil | [32] | Jul–May 2001 | Cross-sectional | Favela (slum) community | 262 | All ages | GEE multivariable logistic regression to adjust for household-level clustering | a priori (age, sex) and empirical (P < 0.05) |
| [33] | Jan 2008–Jan 2009 | Cohort | Peri-urban | 203 | 1–48 months | Multivariable logistic regression with bootstrapping | Empirical (P < 0.05 and 95% CI did not include 1) |
| [34] | Sep–Dec 2014 | Cross-sectional | Community, routine check-up / sick visits | 522 | < 6 years | Multivariable logistic regression | NR |
| Cuba | [35] | Oct–Dec 2013 | Cross-sectional | Rural, urban, community | 1050 | 2–18 months | Multivariable logistic regression | Empirical (P < 0.05) |
| Venezuela | [36] | Dec 2006–Jan 2008 | Cross-sectional | Rural, urban community | 1004 | 3–65 months | Multivariable logistic regression | Empirical (P < 0.10) |
| [37] | NR | Cross-sectional | Isolated rural communities | 504 | 0–4 years | GEE multivariable logistic regression to adjust for community-level clustering | NR |
| 227 | 5–10 years |
| 333 | 13–62 years |
| Eastern Mediterranean | Iran | [38] | Feb–Apr 2016 | Cross-sectional | Urban, community | 532 | 7–14 years | Multivariable logistic regression | NR |
| Europe | Poland | [39] | Nov–Dec 2002 (Autumn).  Feb–Mar 2003 (Winter).  May–Jun 2003 (Spring) | Cohort | Community | 311 each season | 3–5 years | Multivariable logistic regression | a priori (age, recent RTI, antibiotic use); Empirical (P < 0.1) |
| Turkey | [40] | Nov 2003–Feb 2004 | Cross-sectional | Rural, urban, community; well-child clinics | 564 | 0–2 years | Multivariable logistic regression | Empirical (P < 0.25) |
| [41] | Feb–Mar 2004 | Cross-sectional | Urban | 301 | 9 days–67 months | Multivariable logistic regression | NR |
| [42] | Apr–Jun 2011 | Cross-sectional | Community, via well-child outpatient clinical/general pediatric outpatient clinic | 1101 | 1 months–18 years | Multivariable logistic regression | Empirical (P < 0.1) |
| [43] | Sep–Dec 2014 | Cross-sectional | Urban, community | 150 | 0–6 years | Multivariable logistic regression | NR |
| Western Pacific | Fiji | [44] | Sep-Dec 2012  Jul–Nov 2013  Jul–Dec 2014  Aug–Nov 2015 | Cross-sectional | Rural, urban community | 2006 | 5–8 weeks | Multivariable logistic regression | a priori (survey year, residential location, low family income, > 2 children < 5 years living in the household) selected via directed acyclic graph |
| [45] | Aug–Nov 2015 | Cross-sectional | Rural, urban community | 496 | 5–8 weeks | Multivariable logistic GEE regression | a priori (ethnicity and residential location) and empirical (P < 0.05) |
| 498 | 12–23 months |
| 510 | 2–6 years |
| 510 | Caregivers of infant and child participants |
| [46] | Sep-Dec 2012  Jul–Nov 2013  Jul–Dec 2014  Aug–Nov 2015 | Cross-sectional | Rural, urban community | 2006 | 5–8 weeks | Multivariable logistic regression | a priori (PCV10 vaccination, survey year, ethnicity, participant group, and symptoms of upper respiratory tract infection) and empirical (P < 0.2) |
| 2004 | 12–23 months |
| 2052 | 2–6 years |
| 2047 | Caregivers of infant and child participants |
| **High-income countriesc (n = 36)** | | | | | | | | | |
| Americas | Canada | [47] | 2003-2006  2010-2012 | Cross-sectional | Community | 6149 | 10 months-5 years | Multivariable logistic regression | a priori, then backward elimination |
| United States of America | [48] | Nov-Dec 1997 | Cross-sectional | Isolated rural communities | 737 | < 8 years | Multivariable logistic regression | Empirical (Likelihood-ratio test P < 0.05) or change in effect estimate of >15% for independent risk factors; and a priori |
| [49] | Apr 1997-Oct 2000 | Cohort, nested within a randomized controlled trial | Community, Navajo, and Apache reservations | 410 | < 6 years | GEE multivariable logistic regression to adjust for within-subject correlation | Empirical (P ≤ 0.10) |
| [50] | Jan 1998-Jan 1999 | Cross-sectional | Urban, healthy attendees at routine well-child checks at a university-based pediatric outpatient clinic | 291 | < 5 years | Multivariable logistic regression | Empirical (P ≤ 0.10) |
| [51] | Mar-May 2001 | Cross-sectional | Rural and urban Massachusetts | 766 | < 7 years | GEE multivariable logistic regression to adjust for community-level clustering | Empirical (P < 0.10), then stepwise removal of non-significant variables |
| [52] | Mar-May 2001 | Cross-sectional | Rural, urban Massachusetts communities | 710 | < 7 years | GEE multivariable logistic regression to adjust for census-tract- level clustering | a priori (recent antibiotic use), empirical (P < 0.05) |
| [53] | Mar-May 2001 | Cross-sectional | Rural, urban Massachusetts communities during well or sick child visits | 678 | 3 months-7 years | Generalized linear mixed models to adjust for community-level clustering | NR |
| Nov-Apr 2004 | 988 |
| Oct 2006-Apr 2007 | 972 |
| [54] | Feb-Mar 2000  Feb-Mar 2001  Feb-Mar 2002 | Cross-sectional | Alaskan community clinic for well-child or acute care | 1275 | 3-59 months | Multivariable logistic regression | a priori (age, clinic, up to date vaccination status), empirical |
| [55] | Feb-Mar 2000  Feb–Mar 2001  Feb-Mar 2002  Feb-Mar 2003  Feb-Mar 2004 | Cross-sectional | Urban Anchorage, Alaska | 2061 | 3-59 months | Multivariable logistic regression | Empirical (P < 0.25) |
| [56] | 2001  2004  2007  2009  2011 | Cross-sectional | Rural, urban Massachusetts communities | 5380 overall | 0-7 years | Multivariable logistic regression | a priori (sex, ethnicity, number of siblings ≤ 6 years, childcare attendance), |
| [57] | 2006-2007 | Cross-sectional (secondary analysis) | Rural, urban Massachusetts communities | 543 from urban Boston | < 7 years | Multivariable logistic regression, accounting for clustering by census tract | NR |
| 794 from outside Boston |
| [58] | Mar-Apr 2008  Mar-Apr 2009  Mar-Apr 2010  Mar-Apr 2011 | Cross-sectional | Rural Alaskan villages | 3417 | < 10 years | Multivariable logistic regression | Empirical (non-automatic backward selection) |
| 2663 | 10-17 years |
| 6455 | ≥ 18 years |
| [59] | 2006-2007  2008-2009 | Cross-sectional | Urban community | 1982 | 3 months-< 7 years | Multivariable logistic regression | NR |
| Eastern Mediterranean | Cyprus | [60] | Nov 2007-May 2008 | Cross-sectional | Urban, community | 402 | 6 months-5 years | Multivariable logistic regression | a priori (all variables) |
| Kingdom of Saudi Arabia | [61] | Hajj season 2011 and 2012 | Cross-sectional | Mass gathering of pilgrims | 3203 | > 18 years | Multivariable logistic regression | Empirical (95% CI did not cross null value) |
| Europe | France | [62] | Nov 2006-June 2009 | Cross-sectional | Rural, urban, distributed throughout France | 3507 | 6-24 months | Multivariable logistic regression | Empirical (P < 0.10) |
| France and the Kingdom of Saudi Arabia | [63] | Hajj season 2018 | Cohort | Gathering of pilgrims from Marseille, France | 121 | 26–83 years | Multivariable logistic mixed models, with random effects to account for repeated measures for pathogen carriage for each participant | Empirical (P < 0.2) |
| Greenland | [64] | Oct-Dec 2011 | Cross-sectional | Rural, urban, community | 352 | 0-6 years | Multivariable logistic regression | Empirical (P < 0.05) |
| Italy | [65] | Oct-Dec 2010 | Cross-sectional | Urban, community | 669 | 0–59 months | Binary regression model, with log link | NR |
| [66] | Nov 2011-Apr 2012 | Cross-sectional | Urban | 571 | < 5 years | Random effects logistic regression, with recruitment center set as a random effect | NR |
| [67] | 2012 | Cross-sectional | Urban in north Italy | 301 | < 6 years | General nonlinear structural equation modeling | Empirical (Log-likelihood ratio test P < 0.05) |
| [68] | Sep-Dec 2011 | Cross-sectional | Urban, community | 1250 | 3-59 months | Multivariable Poisson regression | a priori (all variables) |
| Portugal | [69] | Apr 2010-Dec 2012 | Cross-sectional | Urban, rural, community | 3361 | > 60 years | Multivariable logistic regression | Empirical (P <0.05) |
| Spain | [70] | Jun–Aug 2014  Jan–Mar 2015 | Cross-sectional | Community, southeast Spain, children attending Health Child Program | 906 | 10–14 months | Multivariable logistic regression | NR |
|  | 915 | 3.5–4.5 years |
| The Netherlands | [71] | Jun-Jul 2002  Sep-Nov 2002 | Cross-sectional | National population-based | 3198 | 1-19 years | Multivariable logistic regression | Empirical (P < 0.10), backward stepwise |
| [72] | Jun 2003-Nov 2006 | Nested cohort | Rural, urban, population-based | 1079 | 1.5 months; 6 months; 14 months | GEE multivariable logistic regression to adjust for within-subject correlation | a priori (birth weight, parity, gestation age, sex, siblings, maternal education level, childcare attendance, smoking duration of breastfeeding) |
| [73] | Jul 2005–Feb 2008 | Randomised controlled trial | Population-based | 326 | 6-24 months | GEE multivariable logistic regression to control for repeat measurements | a priori (sex, age, childcare attendance, symptoms of URTI, presence of siblings in household, antibiotic consumption < 2 months before swab, use of pacifier, season of sampling); empirical (P < 0.10) |
| Europe and Eastern Mediterranean | Israel /  West Bank and Gazad | [74] | 2009  2010  2011 | Cross-sectional | Population-based in East Jerusalem under Israeli Health law, and under Palestinian Authority; | 2570 | < 5 years | Multivariable logistic regression | Empirical (P < 0.2) |
| Western Pacific | Australia | [75] | Aug-Nov 2002.  Mar-May 2004 | Cross-sectional | Remote rural, Indigenous Australian communities, | 214 | ⩾ 2 years-< 16 years | Multivariable logistic regression | Empirical (P ≤ 0.20) |
| 324 | > 16 years |
| Hong Kong, British Protectorate | [76] | Sep 1992-Feb 1993 | Longitudinal | Urban Hong Kong; refugee detention camp | 621 Chinese children | < 5 years | Multivariable logistic regression | NR |
| 300 Vietnamese refugees in detention |
| Hong Kong SAR, China | [77] | Jun 2013-June 2014 | Cross-sectional | Four major regions in Hong Kong (Hong Kong Island, Kowloon, New Territories East, and New Territories West) | 1541 | 2, 12, and 18 months | Multivariable logistic regression | Empirical (P < 0.05) with consideration of clinical relevance |
| Japan | [78] | Jan 2008-Dec 2011 | Cohort | Sado Island community | 349 | 0-36 months | Multivariable Cox proportional hazards regression | Empirical (P < 0.05) |
| [79] | Jul 2010-Mar 2012 | Cross-sectional | Rural, urban, community | 229 | 2 months-6 years | Multivariable logistic regression | Empirical |
| Japan | [80] | Jan–Dec 2015 | Cross-sectional | Okinawa main island community, infants and children presenting for vaccination | 769 | 2–24 months | Multivariable logistic regression | NR |
| Taiwan (China) | [81] | Jul 2005-Dec 2010 | Cross-sectional | North, central, and south Taiwan, children presenting for regular vaccination or acute visits | 7747 PCV7 vaccinated (⩾ 1 dose) | 2-5 years | Multivariable logistic regression | Empirical (P < 0.05) |
| 1958 PCV7 unvaccinated (0 doses) |
| [82] | Jul 2005-Jul 2007 | Cohort | Community, via childcare centers, well-child or outpatient clinics | 6060 | 2 months-5 years | Multivariable logistic regression | Empirical (P < 0.05) |

Abbreviations: GEE–generalized estimating equation; NR–not reported; PCV–pneumococcal conjugate vaccine; PCV7–seven-valent pneumococcal conjugate vaccine; PCV10–ten-valent pneumococcal conjugate vaccine; RTI–respiratory tract illness; URTI–upper respiratory tract infection; WHO–World Health Organization. Footnotes: a As per countries listed under WHO regional offices[83]; b Where reported, P-values refer to threshold associated with a hypothesis test for a single variable to be included in a multivariable model, if the P-value is smaller than that threshold, unless otherwise specified; c World Bank Income status at the time the study was undertaken[84]; d This study was conducted in high-income Israel (WHO European region) and lower-middle-income West Bank and Gaza (WHO Eastern Mediterranean regions)[74, 83, 84].

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