VIEWPOINT

Childhood pneumonia in New Zealand

Eseta Loto-Aso,1 Stephen RC Howie2,3 and Cameron C Grant 3,4

1Kidz First Neonatal Care, Counties Manukau District Health Board, 2Department of Paediatrics: Child & Youth Health, University of Auckland, 3Child, Women and Family Services, Waitemata District Health Board and 4General Paediatrics, Starship Children’s Hospital, Auckland District Health Board, Auckland, New Zealand

While deaths from pneumonia during childhood in New Zealand (NZ) are now infrequent, childhood pneumonia remains a significant cause of morbidity. In this viewpoint, we describe pneumonia epidemiology in NZ and identify modifiable risk factors. During recent decades, pneumonia hospitalisation rates decreased, attributable in part to inclusion of pneumococcal conjugate vaccine in NZ’s immunisation schedule. Irrespective of these decreases, pneumonia hospitalisation rates are four times higher for Pacific and 60% higher for Māori compared with children of other ethnic groups. Consistent with other developed countries, hospitalisation rates for pneumonia with pleural empyema increased in NZ during the 2000s. Numerous factors contribute to childhood pneumonia acquisition, hospitalisation and morbidity in NZ include poor quality living environments, malnutrition during pregnancy and early childhood, incomplete and delayed vaccination during pregnancy and childhood and variable primary and secondary care management. To reduce childhood pneumonia disease burden, interventions should focus on addressing modifiable risk factors for pneumonia. These include using non-polluting forms of household heating; decreasing cigarette smoke exposure; reducing household acute respiratory infection transmission; improving dietary nutritional content and nutrition during pregnancy and early childhood; breastfeeding promotion; vaccination during pregnancy and childhood and improving the quality of and decreasing the variance in primary and secondary care management of pneumonia.

Globally, pneumonia remains a major cause of childhood death and disease, being the leading infectious disease cause of death in children <5 years old.1 In New Zealand (NZ), pneumonia is an infrequent cause of childhood death,2 but remains a frequent cause of hospital admission.

In this viewpoint, childhood pneumonia mortality and morbidity in NZ is reviewed, modifiable factors associated with pneumonia acquisition and hospitalisation in NZ described and challenges to best practise care for childhood pneumonia summarised. A literature search was conducted in Medline using the search strategies shown in Table 1. An agenda of research about early childhood acute respiratory infections (ARIs) is proposed to address current deficits in our knowledge and care (Table 2).

Childhood Pneumonia Mortality

In 2018, there were approximately ≈800 000 pneumonia deaths among children <5 years old.1 Most occurred in developing countries.1 Globally since 2000, pneumonia deaths in children <5 years old declined by >50%.3,4

In NZ, there were only ≈10 deaths/year from pneumonia in the 0- to 24-year age group from 2000 to 2012.2 However, the NZ childhood pneumonia mortality rate is not decreasing.2

Within NZ, pneumonia mortality rates and proportion of deaths from pneumonia are higher for Pacific children.5 In the 1- to 14-year age group from 2008 to 2012, the pneumonia mortality rate (1.29/100 000) and percentage of all deaths (4.9%) was higher for Pacific children compared with all NZ children (0.43/100 000, 2.5%).5

Childhood Pneumonia Morbidity

The <5-year-old childhood pneumonia hospitalisation rate in developing countries in 2015 was 20.9/1000,6 four times higher than the NZ average annual rate (2012–2016, 4.82/1000).7 The <2-year-old annual childhood pneumonia hospitalisation rate in NZ (2006–2010) is twice that for the United States (2007–2009).8,9

Pneumonia hospitalisation rates in NZ in the 0- to 24-year age group decreased by ≈15% from 2000 to 2014 (2.81/1000 to 2.42/1000).2 The decreases were specific to the 0- to 14-year age group and were larger for Pacific and Māori compared with European.2 Despite this, pneumonia hospitalisation rates among children 0–14 years old from 2010 to 2014 for Pacific children (9.04/1000) were four times higher and for Māori children (3.82/1000) ≈60% higher than for other ethnic groups (2.36/1000).5,10

Globally, ≈29% of pneumonia deaths are vaccine preventable (pneumococcal conjugate vaccine (PCV) 19%, Haemophilus influenza type b (Hib) vaccine 10%). From 1990 to 2017, increased PCV and Hib vaccine coverage, alongside reductions in household air pollution, accounted for most of the decreases in preventable pneumonia deaths among children <5 years old.11

Decreased pneumonia hospitalisations, following introduction of PCV into NZ’s Immunisation Schedule in 2008,12 were...
reported from Counties-Manukau District Health Board (CMDHB) from 2001 to 2011 for children <2 years old. In addition to the gradual decrease over this interval (age <2 years ≥25/1000 to 20/1000 (2001/2002–2007/2008), an additional decline in pneumonia hospitalisation rates occurred from 2009 to 2011 (to ≥12/1000 in 2010–2011). That this occurred for pneumonia but not bronchiolitis is consistent with prevention of pneumococcal infections. Decreases were largest for Pacific children. Despite this, pneumonia hospitalisation rates remained several times higher for Pacific vs. European children.

Over the same interval that childhood pneumonia hospitalisation rates have decreased, rates for pneumonia complicated by pleural empyema have increased (age 0–14 years: 1/100 000 to 10/100 000 (1998–2012)). Increased incidence of pleural empyema was also reported from Canada (2008), the United States (2010), Denmark (2014) and Germany (2019).

Risk Factors for Childhood Pneumonia and Pneumonia Hospitalisation in NZ

Observational studies have identified multiple factors associated with pneumonia and pneumonia hospitalisation. Studies have used case definitions from those specific to pneumonia, to others including a broader range of ARTs. A case–control study in Auckland which enrolled children <5 years old from 2002 to 2004 identified factors associated with community-acquired pneumonia (CAP) and pneumonia requiring hospital admission. Factors independently associated with CAP were lower weight-for-height, spending less time outside, previous chest infections and mould in the child’s bedroom. Factors independently associated with the risk of CAP hospitalisation were maternal history of pneumonia, crowded households, household cigarette smokers and mould in the child’s bedroom.

A case series of children <2 years old hospitalised from August to December 2007 at Kidz First Children’s Hospital in CMDHB with a lower respiratory infection (LRI) documented the prevalent adverse living circumstances. Admissions with an International Classification of Diseases (ICD-10) LRI primary discharge code were included. The 465 children enrolled had 580 LRI admissions during the 5-month study interval, 132 (26%) for pneumonia. Household characteristics were described for 394 children. Caregivers described highly prevalent crowding (25% of children in households with ≥7 other people and 33% with ≥4 children); household cigarette smoking (65% of children exposed) and inadequate heating. Twenty-seven percent of households had no heating and 17% used bottled gas.
Within NZ’s contemporary child cohort study, *Growing Up in New Zealand* (GUiNZ) (www.growingup.co.nz), three studies have investigated the epidemiology of ARIs resulting in early childhood hospital presentations. The GUiNZ cohort was established by the recruitment of 6843 pregnant women living in the Auckland, Counties-Manukau and Waikato DHB regions. The child cohort included the 6853 children born in 2009–2010 to these women. At birth, the cohort aligned closely with all NZ births from 2007 to 2010.

The first of these studies investigated the relationship of internal living environments with ARI hospital admissions from 0 to 4 years of age. Household crowding (22%) and dampness (20%) and, in the child’s bedroom, heavy condensation (20%) or mould/mildew (13%) were prevalent, as were maternal smoking (14%) and household smoking (30%). When all internal living environment and socio-demographic factors were considered, the risk of ARI hospitalisation was increased for children living in households where a gas heater was used in the child’s bedroom and where it was the sole form of household heating. The risk of ARI hospitalisation was decreased for children living in households that used electric heaters or wood burners for household heating.

A subsequent study showed adverse effects of wood burners on the health of children in neighbouring households. Density of wood or coal-smoke producing households/ha increased, the odds of <3-year-old children having a non-accident-related emergency department (ED) visit increased, and of being prescribed respiratory medications increased.

**Priority Areas for Management of Childhood Pneumonia in NZ**

Frameworks developed to prevent childhood pneumonia deaths in developing countries are applicable to preventing childhood pneumonia in NZ (Table 3). Some interventions will decrease ARI morbidity, some are pneumonia specific. Ongoing evaluation of tractable risk factors and novel interventions is required.

**Improve the quality of indoor living environments**

Developing strategies to prevent within household transmission of ARIs to young children remain an important area of research focus.

At the 2018 NZ census, >280 000 children lived in damp housing and >230 000 in moudly houses. Installing non-polluting, more effective heating into NZ homes where asthmatic children live, reduces LRI symptoms, school absence and health-care utilisation.

Forms of household heating having the most adverse environmental effects (coal, wood, gas) are also associated with increased odds of early childhood ARI. Replacing these with electrical heating potentially reduces global warming and childhood ARI morbidity, but only if the electricity is generated using environmentally safer means, such as hydro-, solar and wind generation.

Smoke-free legislation reduces children’s exposure to tobacco smoke, and prevents ARI-related health-care visits. Smoking remains prevalent among NZ women of child bearing age. GUiNZ data show that 20% of such women were cigarette smokers, with almost half ceasing smoking once becoming pregnant. For smoking cessation to occur during pregnancy and be sustained during infancy requires focus on the households rather than just the mothers smoking habits.

Crowding is a recognised NZ housing issue and contributor to ARI morbidity. In GUiNZ, at age 2 years, 20% of children lived in households with ≥2 people/bedroom. Strategies can be used in overcrowded households to reduce ARI transmission risk to young children. Bed sharing with a coughing adult is a risk factor for severe pneumonia among children in Africa. Implementation of non-bed sharing or room sharing practises when household members have ARIs should be evaluated in NZ.

**Improve the nutritional content of pregnancy and early childhood diets**

Malnutrition underlies 50% of <5-year-old childhood pneumonia deaths globally. Malnutrition includes macro- and micronutrient deficiency and excess. These are interrelated, for example, micronutrient deficiency is more prevalent in children with either macronutrient deficiency or excess.

In the developing world, risk of fatal or severe childhood pneumonia increases as weight-for-height decreases. In NZ, risk of pneumonia hospitalisation increases as weight-for-height decreases. In NZ, to be in the lowest risk group for pneumonia hospitalisation, weight-for-height ≥ score is ≥ +1 standard deviation, implying a nutrient poor diet relative to its energy content.

NZ needs to acknowledge malnutrition is prevalent, that dietary nutritional content is poor and that these reflect and contribute to current child health inequities, and specifically to risk of childhood pneumonia hospitalisation. Policy is required that addresses pregnancy and early childhood nutrition. Examples, successfully implemented in other countries, include free nutritious food and micronutrient supplements during pregnancy and childhood and micronutrient food fortification.

Breastfeeding halves early childhood ARI hospitalisation risk. In NZ, 16% of infants are exclusively breastfed for 6 months. The odds of exclusively breastfeeding for >4 months are lower for Māori, Pacific or Asian vs. European infants. Strategies specific to each ethnic group enabling longer breastfeeding duration are required. For example, determinants...
of exclusive breastfeeding duration among Māori women include breastfeeding knowledge, return-to-work issues, motherhood experiences, Māori worldview connection, antenatal depression and vaccine hesitancy. 

Greater emphasis needs to be placed on understanding the contributions that malnutrition makes to childhood pneumonia in NZ and the evaluation of interventions that seek to improve nutritional status during pregnancy and early childhood.

Pregnancy vaccination and timely childhood vaccination for those most at risk of vaccine preventable pneumonia

It is estimated that of global deaths from LRs in children <5 years old, 19% are attributable to low PCV and 9.6% to low Hib vaccine coverage. Approximately 14% of severe pneumonia cases in developing countries requiring hospital admission are attributable to pathogens targeted by available vaccines (Hib, PCV and pertussis, tuberculosis and influenza vaccines). Both viral and bacterial pneumonia hospitalisation rates decreased following PCV introduction, for example, in Australia, consistent with more than one respiratory pathogen frequently being identified in children hospitalised with pneumonia.

Childhood vaccination programmes now start during pregnancy. Pregnancy influenza vaccination halves the risk of influenza hospitalisation in <6-month-old infants. Pregnancy pertussis vaccination prevents early infancy pertussis hospitalisation and intensive care unit admission. Despite being fully funded, NZ coverage for pregnancy influenza and pertussis vaccine in NZ from 2013 to 2018 was ≤22% for influenza and 26% for pertussis vaccine. Pregnant women of Māori or Pacific ethnicity are at decreased odds of being vaccinated.

NZ has never achieved on-time childhood vaccination delivery to children most at risk of vaccine preventable pneumonia. Inequities in vaccination timeliness persist, for children in households in poorer neighbourhoods, and Māori children. Children with delayed vaccinations are frequent health-care service users, but have repeated missed vaccination opportunities. COVID-19-related disruptions to vaccination have been larger for Māori and Pacific children.

NZ’s approach to childhood vaccine delivery requires a refocus. Priority should be on-time delivery of pregnancy and childhood vaccinations for children most at risk of vaccine preventable diseases. Alternative vaccination systems are needed. Potential examples include pharmacy vaccination, and vaccination programmes aligned with cultural structures such as those developed by Southseas Healthcare (https://www.southseas.org.nz) for COVID-19 vaccine delivery. Every pregnancy and childhood health-care interaction should be considered a potential vaccination event.

Improve community-acquired childhood pneumonia diagnosis and management

Consistent use of key clinical symptoms and signs to diagnose pneumonia and decide upon hospital referral has dramatically reduced early childhood pneumonia mortality rates globally. In developing countries, this approach has reduced <5-year-old pneumonia mortality by one-third.

In NZ, primary care factors associated with pneumonia ED presentation and hospitalisation were described in an Auckland study in the 2000s. Among <5-year-old children, pneumonia ED presentation was more likely for children without a regular GP, if their GP worked ≥20 h/week or the practise lacked immunisation-recall. Lower parental rating for continuity, communication and satisfaction increased the likelihood of pneumonia ED presentations. Parents of Pacific children reported greater dissatisfaction with primary care aspects including continuity, communication, interpersonal care and knowledge. For Pacific children hospitalised with pneumonia, mistrust of primary care was the primary parental reason for hospital presentation. The importance of communication and primary care childhood pneumonia management in NZ was shown by a study investigating why children hospitalised with pneumonia had not received antibiotics in primary care. While some illnesses progressed too rapidly, pneumonia was sometimes not diagnosed despite indicative symptoms and antibiotics sometimes were not prescribed despite diagnosed pneumonia.

Development of a simplified approach in NZ to improve precision and accuracy of childhood pneumonia diagnosis and management is required. This approach could utilise device-based clinical decision support tools. For example, use of these to aid febrile infant management is associated with improved guideline adherence.

Establishing endpoints for hospital childhood pneumonia management

Currently, the Starship Clinical Guidelines recommend follow-up for childhood pneumonia hospitalisations if cough for >6 weeks, and follow-up chest radiograph for complicated pneumonia or chronic/recurrent symptoms.

Are these endpoints robust? When <2-year-old children, hospitalised with pneumonia or severe bronchiolitis, are followed, persisting respiratory abnormalities are evident. Follow-up of 237 <2-year-old children admitted to Kids First Children’s Hospital with pneumonia showed that 1-year post-admission chronic moist cough was present in 30%, moist cough and/or crackles in 32% and chest radiograph abnormalities in 62%. Although current international guidelines do not recommend follow-up radiography for most childhood pneumonia, a symptom- and sign-based algorithm may need development. The Koira4Rukahukahu: Lungs4Life programme which seeks to reduce inequity in respiratory health outcomes for children across the Northern region of NZ is a new initiative which has the potential to address this issue.

Conclusion

Pneumonia is an infrequent cause of childhood death in NZ, but accounts for ≥2 times more deaths among Pacific children. Irrespective of the decreases in pneumonia hospitalisation rates that have occurred in NZ in recent decades, pneumonia hospitalisation rates are ≥4 times higher for Pacific and 60% higher for Māori children compared with other ethnic groups. NZ internal living environments are poor and contribute to the high ARI burden. Contemporary data highlight the contribution of poor air quality, secondary to the use of coal, wood or gas for household heating. Specific policy could address the contributions of overcrowding to pneumonia risk.
Malnutrition is an important risk factor for pneumonia in NZ. Policy which improves dietary quality and nutritional status during pregnancy and childhood is needed.

NZ has never achieved equitable access to vaccines which can prevent childhood pneumonia. Our national vaccine strategy needs focus on timely protection of children most at risk of vaccine-preventable pneumonia.

Pneumonia is a disease that examines health-care systems and tests how well a country cares for its more vulnerable populations. From this perspective, NZ does not currently fare well. Deficits are evident in primary and secondary care of childhood pneumonia and result in children receiving suboptimal care for pneumonia.

Acknowledgements

Open access publishing facilitated by The University of Auckland, as part of the Wiley - The University of Auckland agreement via the Council of Australian University Librarians. [Correction added on May 19, 2022, after first online publication: CAUL funding statement has been added.]

References

1 Izadnegahdar R, Cohen AL, Klugman KP, Qazi SA. Childhood pneumonia in developing countries. Lancet Respir. Med. 2013; 1: 574–84.
2 Simpson J, Duncanson M, Oben G et al. The Health Status of Children and Young People in New Zealand 2015. Dunedin: New Zealand Child and Youth Epidemiology Service, University of Otago; 2016.
3 UNICEF. Pneumonia 2019 Available from: https://data.unicef.org/topic/child-health/pneumonia/ [accessed 3 March 2020].
4 Global Burden of Disease Lower Respiratory Infection Collaborators. Estimates of the global, regional, and national morbidity, mortality, and aetiologies of lower respiratory tract infections in 195 countries: A systematic analysis for the global burden of disease study 2015. Lancet Infect. Dis. 2017; 17: 1133–61.
5 Simpson J, Duncanson M, Oben G et al. The health status of Pacific children and young people in New Zealand 2015 (Pacific child and youth health). In: New Zealand Child and Youth Epidemiology Service. Dunedin: University of Otago; 2017.
6 McAllister DA, Liu L, Shi T et al. Global, regional, and national estimates of pneumonia morbidity and mortality in children younger than 5 years between 2000 and 2015: A systematic analysis. Lancet Glob. Health 2019; 7: e47–57.
7 Duncanson M, Oben G, Adams J et al. Health and Wellbeing of under-Five Years Olds in New Zealand 2017. Dunedin: New Zealand Child and Youth Epidemiology Service, University of Otago; 2019.
8 Craig E, Adams J, Oben G, et al. The Health Status of Children and Young People in New Zealand. Department of Women’s and Children’s Health at the University of Otago’s Dunedin School of Medicine: University of Otago, 2013.
9 Griffin MR, Zhu Y, Moore MR, Whitney CG, Grijalva CG. U.S. hospitalizations for pneumonia after a decade of pneumococcal vaccination. N. Engl. J. Med. 2013; 369: 155–63.
10 Simpson J, Duncanson M, Oben G, et al. Te Ohonga Ake The Health Status of Māori Children and Young People in New Zealand Series Two (Health Status of Children and Young People). New Zealand Child and Youth Epidemiology Service: University of Otago, 2017.
11 Global Burden of Disease Lower Respiratory Infections Collaborators. Quantifying risks and interventions that have affected the burden of lower respiratory infections among children younger than 5 years: An analysis for the global burden of disease study 2017. Lancet Infect. Dis. 2020; 20: 60–79.
12 Ministry of Health. Immunisation Handbook. Wellington: Ministry of Health; 2020.
13 Vogel AM, Trenholme AA, Stewart JM et al. Impact of pneumococcal vaccine on hospital admission with lower respiratory infection in children resident in South Auckland, New Zealand. N. Zealand Med. J. 2013; 126: 26–35.
14 Mahon C, Walker W, Drage A, Best E. Incidence, aetiology and outcome of pleural effusions and pleural-pneumonic effusion from 1998 to 2012 in a population of New Zealand children. J. Paediatr Child Health 2016; 52: 662–8.
15 Finley C, Clifton J, Fitzgerald JM et al. Empyema: An increasing concern in Canada. Can. Respir. J. 2008; 1: 85–9.
16 Grijalva CG, Nuorti JP, Zhu Y, Griffin MR. Increasing incidence of empyema complicating childhood community-acquired pneumonia in the United States. Clin. Infect. Dis. 2010; 50: 805–13.
17 Yu D, Buchvald F, Brandt B, Nielsen KG. Seventeen-year study shows rise in parapneumonic effusion and empyema with higher treatment failure after chest tube drainage. Acta Paediatr. 2014; 103: 93–9.
18 Liese JG, Schoen C, van der Linden M et al. Changes in the incidence and bacterial aetiology of paediatric parapneumonic pleural effusions/empyema in Germany, 2010-2017: A nationwide surveillance study. Clin. Microbiol. Infect. 2019; 25: 857–64.
19 Grant CC, Emery D, Milne T et al. Risk factors for community-acquired pneumonia in pre-school-aged children. J. Paediatr. Child Health 2012; 48: 402–12.
20 Trenholme A, Vogel A, Lennon D et al. Household characteristics of children under 2 years admitted with lower respiratory tract infection in Counties Manukau, South Auckland. N. Z. Med. J. 2012; 125: 15–23.
21 Tin T, Woodward A, Saraf R et al. Intrauterine living environment and respiratory disease in children: Findings from the growing up in New Zealand longitudinal child cohort study. Environ. Health Global Access Sci. Source 2016; 15: 120.
22 Lai HK, Berry SD, Verbiest MEA, Tricker PJ, Atatoa Carr PE, Morton SMB, Grant CC. Emergency department visits of young children under 2 years admitted with lower respiratory tract infection in New Zealand from 1997 to 2017: Findings from the growing up in New Zealand child cohort study. Environ. Pollut. 2017; 231: Pt 1:533–40.
23 Lai HK, Camargo CA Jr, Woodward A et al. Long-term exposure to household heating - the growing up in New Zealand child cohort study. Allergy 2018; 22: 39–55.
24 Scragg R, Jackson R, Holdaway IM et al. Myocardial infarction is inversely associated with plasma 25-hydroxyvitamin D3 levels: A community-based study. Int. J. Epidemiol. 1990; 19: 559–63.
25 Saraf R, Jensen BP, Camargo CA Jr et al. Vitamin D status at birth and acute respiratory infection hospitalisation during infancy. Paediatr. Perinat. Epidemiol. 2021; 01: 1.
26 Morton SM, Atatoa Carr PE, Grant CC et al. Cohort profile: Growing up in New Zealand. Int. J. Epidemiol. 2013; 42: 65–75.
27 Morton SM, Ramke J, Kinloch J et al. Growing up in New Zealand cohort alignment with all New Zealand births. Aust. N. Z. J. Public Health 2015; 39: 82–7.
28 Howden-Chapman P, Pierse N, Nicholls S et al. Effects of improved home heating on asthma in community dwelling children: Randomised controlled trial. BMJ 2008; 337: a1411.
29 Tong D, Zhang Q, Zheng Y et al. Committed emissions from existing energy infrastructure jeopardize 1.5 degreeC climate target. Nature 2019; 572: 373–7.
30 Jarvis MJ, Feyerabend C. Recent trends in children’s exposure to second-hand smoke in England: Cotinine evidence from the health survey for England. Addiction 2015; 110: 1484–92.
31 Faber T, Been JV, Reiss K, Mackenbach JP, Sheikh A. Smoke-free legislation and child health. NPJ Prim Care Respir Med 2016; 26: 16067.
32 Schilling C, Hedges MR, Carr PA, Morton S. Transitions in smoking across a pregnancy: New information from the growing up in...
New Zealand longitudinal study. Matern. Child Health J. 2018; 22: 660–9.

Baker MG, McDonald A, Zhang J, et al. Infectious diseases attributable to household crowding in New Zealand: A systematic review and burden of disease estimate. Wellington: He Kainga Oranga/ Health and Housing Research Programme, University of Otago, 2013, 2013.

Morton SMB, Ataotau Carr P, Grant CC, et al. Growing up in New Zealand: A longitudinal study of New Zealand children and their families. Now we are two: Describing our first 1000 days. Auckland: Growing Up in New Zealand. 2014.

Howie SRC, Schellenberg J, Chimah O et al. Pneumonia, crowding, and the role of the coughing bedmate: A case-control study from The Gambia. Int. J. Tuberc. Lung Dis. 2016; 20: 1405–15.

Bryce J, Boschi-Pinto C, Shibuya K, Black RE. WHO estimates of the causes of death in children. Lancet 2005; 365: 1147–52.

Black RE, Allen LH, Bhusra ZA et al. Maternal and child undernutrition: Global and regional exposures and health consequences. Lancet 2008; 371: 243–60.

Grant CC, Wall CR, Gibbons MJ, Morton SM, Santosham M, Black RE. Child nutrition and lower respiratory tract disease burden in New Zealand: A global context for a national perspective. J. Paediatr. Child Health 2011; 47: 497–504.

Grant CC, Wall CR, Crengie S, Scragg R. Vitamin D deficiency in early childhood: Prevalent in the sunny South Pacific. Public Health Nutr. 2009; 12: 1893–901.

Cole N, Fox MK, Genser JL. Diet quality of American Young children by WIC participation status: Data from the National Health and Nutrition Examination Survey, 1999-2004 Alexandria, VA: U.S. Department of Agriculture, Food and Nutrition Service, Office of Research, Nutrition and Analysis. 2008.

Catov JM, Bodnar LM, Olsen J, Olsen S, Nohr EA. Periconceptional multivitamin use and risk of preterm or small-for-gestational-age births in the Danish National Birth Cohort. Am. J. Clin. Nutr. 2011; 94: 906–12.

Moy RJ, McGee E, Debelle GD, Mather I, Shaw NJ. Successful public health action to reduce the incidence of symptomatic vitamin D deficiency. Arch. Dis. Child. 2012; 97: 952–4.

Calvo MS, Whiting SJ, Barton CN. Vitamin D intake: A global perspective of current status. J. Nutr. 2005; 135: 310–6.

Victoria CG, Bahl R, Barros AJ et al. Breastfeeding in the 21st century: Epidemiology, mechanisms, and Weling. Lancet 2016; 387: 475–90.

Horta BL, Victora CG. World Health Organization. Short-Term Effects of Breastfeeding: A Systematic Review on the Benefits of Breastfeeding on Dianthoesia and Pneumonia Mortality. Geneva: World Health Organization; 2013.

Castro T, Grant C, Wall C et al. Breastfeeding indicators among a nationally representative multi-ethnic sample of New Zealand children. N. Z. Med. J. 2017; 130: 34–44.

Bennett D, Gilchrist CA, Lee R et al. Determinants of exclusive breastfeeding for Māori women. N. Z. Med. J. (forthcoming).

Levine OS, O'Brien KL, Deloria-Knoll M, Murdoch DR, Feikin DR, DeLuca AN, Driessl AJ, Baggett HC, Brooks WA, Howie SRC, Kotloff KL, Madhi SA, Maloney SA, Sow S, Thea DM, Scott IA. The pneumonia etiology research for child health project: A 21st century childhood pneumonia etiology study. Clin. Infect. Dis. 2012; 54 Suppl. 2:S93-101.

Pneumonia Etiology Research for Child Health (PERCH) Study Group. Causes of severe pneumonia requiring hospital admission in children without HIV infection from Africa and Asia: The PERCH multi-country case-control study. Lancet 2019; 27: 27.

Fathima P, Blyth CC, Lehmann D et al. The impact of pneumococcal vaccination on bacterial and viral pneumonia in Western Australian children: Record linkage cohort study of 469589 births, 1996-2012. Clin. Infect. Dis. 2018; 66: 1075–85.

Trenholme AA, Best EJ, Vogel AM, Stewart JM, Miller CJ, Lennon DR. Respiratory virus detection during hospitalisation for lower respiratory tract infection in children under 2 years in South Auckland, New Zealand. J. Paediatr. Child Health 2017; 53: 551–5.

Nunes MC, Madhi SA. Influenza vaccination during pregnancy for prevention of influenza confirmed illness in the infants: A systematic review and meta-analysis. Hum. Vaccin. Immunother. 2018; 14: 758–66.

Winter K, Cherry JD, Harriman K. Effectiveness of prenatal tetanus, diphtheria, and acellular pertussis vaccination on pertussis severity in infants. Clin. Infect. Dis. 2017; 64: 9–14.

Howard AS, Pointon L, Gould N, Paynter J, Welling E, Turner N. Pertussis and influenza immunisation coverage of pregnant women in New Zealand. Vaccine 2020; 38: 6766–76.

Nowlan M, Welling E, Turner N. Influences and policies that affect immunisation coverage—a summary review of literature. N. Z. Med. J. 2019; 132: 79–88.

Turner N, Grant C, Goodyear-Smith F, Petousis-Harris H. Seize the moments: Missed opportunities to immunize at the family practice level. Fam. Pract. 2009; 26: 275–8.

Ministry of Health. Immunisation Coverage at Milestone Age (6 Months of Age): 12 Month Period Ending 31-December-2020. Wellington: Ministry of Health; 2021.

Sinclair O, Grant C. New Zealand’s immunisation policy fails again and entrenches ethnic disparities. N. Z. Med. J. 2021; 134: 92–5.

Gould N, Martin S, Sinclair O, Petousis-Harris H, Dumble F, Grant CC. A qualitative study of views and experiences of women and health care professionals about Free maternal vaccinations administered at community pharmacies. Vaccine 2020; 8: 29.

World Health Organization. Technical Basis for the WHO Recommendations on the Management of Pneumonia in Children at First-Level Health Facilities. Geneva: World Health Organization; 1991.

Sazawal S, Black RE. Pneumonia case management trials group. Effect of pneumonia case management on mortality in neonates, infants, and preschool children: A meta-analysis of community-based trials. Lancet Infect. Dis. 2003; 3: 547–56.

Emery DP, Milne T, Gilchrist CA et al. The impact of primary care on emergency department presentation and hospital admission with pneumonia: A case-control study of preschool-aged children. NPI Prim. Care Respir. Med. 2015; 25: 14113.

Grant CC, Forrest CB, Starfield B. Primary care and health reform in New Zealand. N. Z. Med. J. 1997; 110: 35–9.

Emery DP. Primary Care and its Impact upon Pneumonia and Pneumonia Hospitalisation in Auckland Children. University of Auckland. 2008.

Young N. The pre-hospital experiences of Samoan families in New Zealand who have had a child admitted to hospital with pneumonia: A qualitative exploratory study. Pac. Health Dialog 2001; 8: 20–8.

Grant CC, Harnden A, Mant D, Emery D, Coster G. Why do children hospitalised with pneumonia not receive antibiotics in primary care? Arch. Dis. Child. 2012; 97: 21–7.

Kems EK, Staggs VS, Fouquet SD, McCulloch RJ. Estimating the impact of deploying an electronic clinical decision support tool as part of a national practice improvement project. J. Am. Med. Inform. Assoc. 2019; 26: 630–6.

Starship Children’s Hospital Starship Clinical Guidelines. Pneumonia. Auckland: Starship Children’s Hospital; 2019. Available from: https://www.starship.org.nz/guidelines/pneumonia (accessed 2 March 2022).

Trenholme AA, Byrnes CA, McBride C et al. Respiratory health outcomes 1 year after admission with severe lower respiratory tract infection. Pediatr. Pulmonol. 2013; 48: 772–9.

Harris M, Clark J, Coote N, et al. British Thoracic Society guidelines for the management of community acquired pneumonia in children: Update 2011. Thorax 2011; 66 Suppl. 2:i1–23.

Starship Child Health Koirak4Rukahukahu: Lungs4Life Auckland: Starship Child Health; 2021 Available from: https://www.starship.org.nz/guidelines/coirak4rukahukahu-lungs4life/ (accessed 25 August 2021).