Global respiratory syncytial virus-associated mortality in young children (RSV GOLD): a retrospective case series

Nienke M Scheltema, Angela Gentile, Florencia Lucion, D James Nokes, Patrick K Munywoki, Shabir A Madhi, Michelle J Groome, Cheryl Cohen, Jocelyn Moyes, Kentigem Thorburn, Somsak Thamthitiwat, Hitoshi Oshitani, Socorro P Lupisan, Aubree Gordon, José F Sánchez, Katherine L O’Brien, on behalf of the PERCH Study Group, Bradford D Gessner, Agustín Sutanto, Asunción Mejías, Octavio Ramilo, Nijwa Khuri-Bulos, Natasha Halasa, Fernanda de-Paris, Márcia Rosane Pires, Michael C Spaeder, Bosco A Paes, Eric A F Simões, Ting F Leung, Maria Teresa da Costa Oliveira, Carla Cecilia de Freitas Lázaro Emediato, Quique Bassat, Warwick Butt, Hsin Chi, Uzma Bashir Aamir, Asad Ali, Marilla G Lucero, Rodrigo A Fasce, Olga Lopez, Barbara A Rath, Fernanda P Polack, Jesse Papenburg, Srdjan Roglic, Hisato Ito, Edward A Goka, Diederick E Grobbee, Harish Nair*, Louis J Bont*

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Summary
Background Respiratory syncytial virus (RSV) infection is an important cause of pneumonia mortality in young children. However, clinical data for fatal RSV infection are scarce. We aimed to identify clinical and socioeconomic characteristics of children aged younger than 5 years with RSV-related mortality using individual patient data.

Methods In this retrospective case series, we developed an online questionnaire to obtain individual patient data for clinical and socioeconomic characteristics of children aged younger than 5 years who died with community-acquired RSV infection between Jan 1, 1995, and Oct 31, 2015, through leading research groups for child pneumonia identified through a comprehensive literature search and existing research networks. For the literature search, we searched PubMed for articles published up to Feb 3, 2015, using the key terms “RSV”, “respiratory syncytial virus”, or “respiratory syncytial viral” combined with “mortality”, “fatality”, “death”, “died”, “deaths”, or “CFR” for articles published in English. We invited researchers and clinicians identified to participate between Nov 1, 2014, and Oct 31, 2015. We calculated descriptive statistics for all variables.

Findings We studied 358 children with RSV-related in-hospital death from 23 countries across the world, with data contributed from 31 research groups. 117 (33%) children were from low-income or lower middle-income countries, 77 (22%) were from upper middle-income countries, and 164 (46%) were from high-income countries. 190 (53%) were male. Data for comorbidities were missing for some children in low-income and middle-income countries. Available data showed that comorbidities were present in at least 33 (28%) children from low-income or lower middle-income countries, 36 (47%) from upper middle-income countries, and 114 (70%) from high-income countries. Median age for RSV-related deaths was 5·0 months (IQR 2·3–11·0) in low-income or lower middle-income countries, 4·0 years (2·0–10·0) in upper middle-income countries, and 7·0 years (3·6–16·8) in high-income countries.

Interpretation This study is the first large case series of children who died with community-acquired RSV infection. A substantial proportion of children with RSV-related death had comorbidities. Our results show that perinatal immunisation strategies for children aged younger than 6 months could have a substantial impact on RSV-related child mortality in low-income and middle-income countries.

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Introduction
Respiratory syncytial virus (RSV) infection is the primary pathogen identified in children with acute lower respiratory tract infection during the first year of life.2–4 RSV-related acute lower respiratory tract infection is an important cause of death in young children (aged younger than 5 years); approximately 48 000–75 000 children in this age group died in hospital with the condition in 2015.5 About 99% of RSV-related childhood mortality occurs in developing countries.6 Although RSV-related mortality in children poses an important global health problem, clinical data for global RSV-related mortality are scarce. Data suggest that most RSV-related childhood mortality occurs during the first year of life.6,8 Although the case fatality rate is highest in children with underlying conditions, such as congenital heart disease, chronic lung disease, Down’s syndrome, or premature birth,7,31 most cases of life-threatening RSV infection occur among previously healthy children.22–23 This finding suggests that in settings without intensive care facilities, otherwise healthy children could also be at risk of dying from RSV infection. A study from Argentina25 reported that poor access to intensive care was associated with RSV-related death.

RSV-related mortality in young children has primarily been described sporadically in studies22,23,25,26,32,33 from intensive care units in high-income or middle-income countries.
To date, the largest case series of 35 RSV-related deaths was reported from an intensive care unit in the UK, with numbers smaller than 35 having been reported in other studies. In 2015, the WHO’s Product Development for Vaccines Advisory Committee identified RSV as “a pathogen for which there is major vaccine pipeline activity”, with a vaccine likely to be available in the next 5–10 years.

Two broad approaches to RSV immunisation are being considered in young children: maternal immunisation for children aged younger than 6 months and paediatric vaccines for children aged older than 6 months. A good understanding of the age distribution of RSV-related deaths is likely to assist in development of an evidence base to inform vaccine policy, particularly in low-income and middle-income settings.

Previous reports of RSV-related mortality in young children described studies done in one centre, region, or country. None of them were large enough to draw robust conclusions on the clinical and socioeconomic profile of children who die with community-acquired RSV infection globally. To gain insight into the clinical characteristics of RSV-related mortality in young children, we initiated the RSV Global Online Mortality Database (RSV GOLD) study with the aim to gather available retrospective data for fatal community-acquired RSV infections across the world.

Methods

**Study design and patients**

RSV GOLD is a global study that retrospectively analysed individual data for children aged 0–59 months who died with community-acquired RSV infection between Jan 1, 1995, and Oct 31, 2015. We identified research groups through a comprehensive literature search on PubMed (for articles published up to Feb 3, 2015) using the key terms “RSV”, “respiratory syncytial virus”, or “respiratory syncytial viral” combined with “mortality”, “fatality”, “death”, “died”, “deaths”, or “CFR” for articles published up to Feb 3, 2015, in English, to identify research groups with relevant cases and obtained additional cases through existing research networks. We report on 358 in-hospital deaths with laboratory-confirmed RSV infection from 23 countries across the world. A substantial proportion of in-hospital RSV-related deaths occurred in children with pre-existing comorbidities. Most children in low-income and middle-income countries were aged younger than 6 months at the time of death.

**Implications of all the available evidence**

This study is the first case series of children who died with RSV infection in hospital, giving insight into the clinical and socioeconomic background of children with RSV-related death. Young age at death supports the concept that maternal vaccination against RSV infection could be an effective strategy to prevent RSV-related childhood mortality.

**Procedures**

We collected data using an online questionnaire designed by a group of investigators (NMS, LJB, HN, FPP, BDG, and DEG). The questionnaire aimed to collect information about clinical and socioeconomic characteristics of children with RSV-related mortality. Characteristics of interest were based on risk factors for RSV-related and pneumonia-related mortality as described in the literature and on expert opinion (appendix).

We carefully validated patient information by direct communication with participating researchers for data entry errors, missing variables, and conflicting data. We deemed age at death within 0–59 months, laboratory-confirmed RSV diagnosis, and community-acquired RSV infection minimum essential data for inclusion. After assessment of data quality, we excluded children if...
The literature search resulted in 1154 publications (figure 1). From these publications, we identified 85 research groups, which we complemented with research groups identified through existing research networks, particularly through the RSV Global Network. 85 research groups identified via research networks.

Figure 1: Study selection

RSV=respiratory syncytial virus.

Role of the funding source
The funder had no role in study design, data collection, data analysis, data interpretation, or writing of the report.

NMS and LJB had full access to all the data in the study and the corresponding author had final responsibility for the decision to submit for publication.

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Epidemiology Network. We obtained data for 451 children with RSV-related mortality from the 31 research groups that shared data. We obtained both published and unpublished cases. Using original publications to contact research groups, we estimated that we could have missed a maximum of 140 cases from the published literature as most researchers who did not respond to our invitation to participate had reported solitary cases of RSV-related mortality: in 28 publications, the number of potential RSV-related deaths was mentioned and in 15 (54%) of those, one or two RSV-related deaths were described. Many non-responders were research groups from high-income countries (41 [60%] of 68) and had published their results between 2010 and 2015 (21 [47%] of 45). Publications used to identify research groups that contributed data are shown in the appendix. After initial assessment of the 451 children, we excluded 93 (21%). Most exclusions were associated with nosocomial RSV infection. We excluded six (1%) duplicate entries. We included 358 (79%) children with RSV-associated mortality originating from 23 different countries across the world (figure 2, appendix). RSV diagnosis was established most often by immunofluorescence or PCR (appendix). PCR was mostly used in children who died after 2005. Clear seasonality with an annual peak was reported in 18 (78%) of the 23 countries.

117 (33%) children were from low-income or lower middle-income countries, 77 (22%) were from high-income countries and 164 (46%) were from middle-income countries (table). 190 (53%) children were male; we observed no sex differences between countries of different incomes. Children from high-income countries had a higher median age at death than did those in low-income or lower middle-income countries and children from high-income countries had stayed in hospital for a longer period and were more often admitted to a paediatric intensive care unit than those from upper middle-income countries or low-income or lower middle-income countries. Median time between onset of symptoms and death was longer in children from high-income countries (21·0 days [IQR 12·0–37·0]) than in those from low-income or lower middle-income countries (9·5 days [7·0–16·8]) or upper middle-income countries (10·0 days [8·0–14·0]; appendix). We analysed the prevalence of comorbidities in our study (table) and distinguished clinical characteristics of children with and without comorbidities (appendix). Data for comorbidities were missing for some children. Available data showed that comorbidities were present in at least 183 (51%) children. Congenital heart disease was the most frequent comorbid condition identified. The proportion of children with comorbidities was similar during sensitivity analyses when children with missing data (for comorbidities and gestational age) were excluded, except that the proportion with comorbidities in low-income or lower middle-income countries was more than doubled (appendix). Specific information about the presence of comorbidities and prematurity was available in 243 (68%) children. The proportion of missing information about comorbidities and prematurity was similar for children aged younger than 6 months at the time of death (54 [30%] of 178) and older children (61 [34%] of 180).
We analysed how the presence of comorbidities affected age at death (figure 3). Most healthy term and healthy preterm children were aged younger than 6 months at the time of RSV-related death (appendix). The proportion of children aged younger than 6 months at the time of death was even larger when only children with complete data for comorbidity and gestational age status were included than when all children were included (appendix). Age at death of children with comorbidities from high-income countries was higher than that of those from low-income or middle-income countries.

We analysed the proportion of children with low weight for age. More than half of all children had a weight for age of less than –2 SDs (table). In high-income countries, this finding was mainly explained by a large proportion of preterm children and children with comorbidities. Only eight (28%) of 29 healthy term children in high-income countries had low weight for age compared with eight (89%) of nine healthy preterm children and 33 (54%) of 61 children with comorbidities (appendix). By contrast, in the other two income regions, we found a high proportion (≥48%) of low weight for age in all three children groups, including healthy term infants.

Data for co-infection were scarce. Microbiological data other than RSV diagnosis were sparsely available. We identified co-pathogens in 70 children, with 22 (31%) who tested positive for two or more pathogens besides RSV (data not shown). Positive blood cultures were reported in four (6%) children (two [3%] with *Pseudomonas aeruginosa*, one [1%] with *Klebsiella* spp, and one [1%] with *Staphylococcus aureus*).

Data from Argentina (78 [22%]) and Kenya (43 [12%]) contributed to about one third of all RSV-related deaths (121 [34%]). We did a sensitivity analysis excluding these data. The results from these analyses showed a higher age at death for children from high-income countries (10·0 months [4·0–24·0]) than from upper middle-income (4·0 months [2·0–10·0]) or low-income or lower middle-income (4·0 months [2·2–7·0]) countries, which was the same trend as for the main analysis. Other clinical characteristics, including sex and the proportion of prematurity or comorbidities, were also unchanged from the main analysis (data not shown).

### Discussion

Severe RSV infection is one of the major causes of global mortality in young children, with 99% of deaths occurring in developing countries in 2015.7 RSV GOLD

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**Table: Clinical characteristics and risk factors in RSV-related child deaths**

| Male sex | Low-income or lower middle-income countries (n=117) | p value* | Upper middle-income countries (n=77) | p value† | High-income countries (n=164) | p value‡ |
|----------|---------------------------------------------------|----------|------------------------------------|----------|-------------------------------|----------|
| Male sex | 58 (50%)                                           | 0·976    | 38 (49%)                           | 0·247    | 94 (57%)                      | 0·199    |
| Age at death (months) | 5·0 (2·3–11·0)                                   | 0·973    | 4·0 (2·1–10·0)                     | 0·023    | 7·0 (3·6–16·8)                | 0·006    |
| Younger than 6 months at death | 68 (58%)                                         | 0·803    | 44 (57%)                           | 0·014    | 66 (40%)                      | 0·003    |
| Prematurity§ | 9 (8%)                                           | 0·083    | 12 (16%)                           | 0·043    | 45 (27%)                      | 0·000    |
| Gestational age (weeks) | 38·0 (38·0–39·0); n=22                           | 0·144    | 38·0 (34·5–38·0); n=38             | 0·250    | 38·1 (32·1–40·0); n=80        | 0·688    |
| Comorbidity§ | 33 (28%)                                         | 0·008    | 36 (47%)                           | 0·001    | 114 (70%)                     | 0·000    |
| Oxygen saturation on room air at hospital admission (%) | 92·0% (85·8–97·3); n=94 | 0·022    | 87·0% (85·0–94·0); n=47            | 0·448    | 89·0% (76·5–91·0); n=37       | 0·001    |
| Weight for age Z score of less than –2 | 64/111 (58%)                                    | 0·924    | 33/58 (57%)                        | 0·370    | 49/99 (50%)                   | 0·236    |
| Contact with health-care provider before admission to hospital | 28/65 (43%)                                    | 0·870    | 17/38 (45%)                        | 0·123    | 41/68 (60%)                   | 0·047    |
| Time between onset of symptoms and admission (days) | 5·0 (3·0–7·0); n=71 | 0·002    | 3·0 (2·0–4·0); n=45                | 0·387    | 3·0 (1·0–5·0); n=135          | 0·000    |
| Length of stay in hospital (days) | 3·0 (2·0–6·0)                                   | 0·000    | 7·0 (3·0–11·5)                     | 0·000    | 15·0 (7·0–32·0); n=149        | 0·000    |
| Availability of intensive care unit | 28 (24%)                                         | 0·000    | 75 (97%)                           | 0·038    | 164 (100%)                    | 0·000    |
| Intensive care unit admission | 23/116 (20%)                                    | 0·000    | 27/56 (48%)                        | 0·000    | 152 (93%)                     | 0·000    |
| Mechanical ventilation | 23/114 (20%)                                    | 0·000    | 33/60 (55%)                        | 0·000    | 138/155 (89%)                 | 0·000    |
| Urban living area | 22/66 (33%)                                      | 0·000    | 39/40 (98%)                        | 0·087    | 129/133 (97%)                 | 0·000    |
| At least one sibling present in household | 30/39 (77%)                                     | 0·122    | 16/17 (94%)                        | 0·003    | 62/109 (57%)                  | 0·027    |
| Time of death relative to RSV seasonality | 61/79 (77%)                                     | 0·004    | 35/64 (55%)                        | 0·000    | 122/134 (91%)                 | 0·005    |
| Death during RSV season | 7/79 (9%)                                       | 0·050    | 13/64 (20%)                        | 0·000    | 7/134 (5%)                    | 0·303    |

Data are n (%), median (IQR), or n/N (%). Statistical comparisons with Mann-Whitney U test or χ² test with p values of less than 0·0167 taken to be significant according to Bonferroni correction for multiple testing. RSV=respiratory syncytial virus. *Low-income or lower middle-income country versus upper middle-income country. †Upper middle-income country versus high-income country. ‡Low-income or lower middle-income country versus high-income country. §Considered absent when missing.
is the first descriptive study of global RSV-related mortality using individual case records. We studied clinical characteristics of children who died with RSV in hospitals across the world. We supplemented data from previously published cases of RSV-related in-hospital death with unpublished data by contacting individual investigators, research groups, and networks. Complete clinical information was generally available for children from high-income countries, but clinical data from low-income and middle-income countries were often incomplete. For the first time, we showed that a substantial proportion of in-hospital RSV-related deaths in young children occurred in those with severe comorbidities. In low-income and middle-income countries, most children who died with RSV infection were aged younger than 6 months.

This study describes, to our knowledge, the largest number of children with RSV-related mortality to date. We obtained good global representation, with coverage of all six continents. Clinical profiles of children who die with RSV are essentially different in lower-income countries, where most childhood RSV-associated mortality occurs.1,5 In low-income or lower middle-income countries, we found that at least 28% of deaths occurred in children with severe comorbidities, such as congenital heart disease. Our data suggest that most RSV-related in-hospital deaths in both low-income and middle-income countries occur in children aged younger than 6 months. Most children with comorbidities (eg, severe prematurity or congenital heart disease) in these countries might already have died during neonatal age. Additionally, a longer time interval between the onset of symptoms and admission to hospital in low-income countries than in middle-income and high-income countries and a lower proportion of children being admitted to intensive care units and receiving mechanical ventilation in low-income countries than in middle-income and high-income countries suggest that high RSV mortality in these countries might reflect limitations in health-care quality or access to care rather than specific susceptibility of the children. Young age at death of children with comorbidities in low-income and middle-income countries might have been related to low access to care as well. Paediatric intensive care was available to only 24% of children from low-income or lower middle-income countries and to most children from upper middle-income countries, although only 48% of these children were actually admitted to the intensive care unit.

The role of comorbidities in RSV-related childhood mortality has mostly been described in high-income countries.10,11,24 The differences in characteristics of children with or without comorbidities were in line with previously published data from high-income settings. Previous studies1,4,11,12,25,26 have also described a higher age of children with comorbidities at admission or death than of previously healthy children, whereas young age is a risk factor for severe RSV disease in otherwise healthy preterm children.19 For high-income countries, we substantiate that the age distribution of children who die with RSV infection is substantially different between children with and without severe comorbidities.
Several strategies to prevent RSV infection and RSV-related mortality are being developed. Age at death could influence the effectiveness of perinatal immunisation strategies, including passive immunisation by maternal vaccination during pregnancy and administration of RSV-specific long-half-life monoclonal antibody at birth. Our age distribution data suggest that maternal vaccination will be more effective for healthy term children than for children with comorbidities because antibody concentrations decrease after birth over time. Our data suggest that children with comorbidities will need additional preventive interventions, such as extended passive immunisation or infant vaccination to optimise prevention of RSV-related mortality.

A key strength of this study is that we obtained most previously published cases of RSV-related mortality in children and supplemented this data with data sourced through existing networks, leading to a sample size large enough to draw robust conclusions and do some sensitivity analyses. Second, we verified the quality of each case record through direct interaction with the local researchers. Finally, RSV GOLD is a case series with global representation. Limitations also deserve discussion. First, although RSV GOLD forms, to our knowledge, the largest case series of RSV-related childhood mortality in hospital, this case series still reflects only a small proportion of all RSV-related deaths worldwide, as most global acute lower respiratory tract infection deaths occur outside of hospital. Data are scarce for RSV-related deaths in the community. Second, in RSV GOLD, only 117 (33%) of the children studied were from low-income or lower middle-income countries, which contrasts with the estimate that 99% of RSV-related mortality occurs in developing countries. Third, RSV GOLD is a case series, which does not allow for calculation of effect sizes of risk factors for RSV-associated mortality. A population-based study from Buenos Aires reported sepsis and pneumothorax as clinical risk factors for RSV-associated mortality, although sepsis was not pathogen specific. To calculate risk ratios for global RSV-related death with use of original case records, a large prospective population-based study would be needed, which would be challenging given the estimated RSV-attributable mortality rate of 0.86–0.94 per 1000 livebirths. Fourth, our data are limited by several biases. Data are primarily from research sites with availability of diagnostic tests for RSV and RSV diagnostics changing over time, with more sensitive molecular diagnostics used after 2005 than before 2005 (selection bias). Differences in the proportion of available data between income regions could have caused additional selection bias. For example, white blood count and haemoglobin concentration were more often available in low-income regions, which probably reflects measurements in a clinical research setting. Some authors who published data for RSV-related deaths did not respond (response bias), and data for prematurity and comorbidities were often missing, particularly from low-income and middle-income countries (misclassification bias). Misclassification bias could have led to inaccurate interpretation of results. The estimated prevalence of comorbidities in children from low-income or lower middle-income countries is probably an underestimation caused by missing data for comorbidities, but could also be an overestimation caused by selection bias due to a research setting, for example. However, results from our sensitivity analysis supported the main results of our study. Finally, since a substantial proportion of sociodemographic data were missing, these data should be interpreted with caution. For example, the high proportion of RSV-related deaths outside of the RSV season in some countries could reflect inaccurate seasonality data, but could also result from year-round RSV activity, as most of these countries had subtropical climates.

RSV-related infection is an important cause of death in children aged younger than 5 years. Data for RSV-related deaths are scarce and, when available, these data are limited to in-hospital deaths in research settings. Additionally, data for some of the key variables, such as comorbidities and gestational age, are missing. RSV GOLD is being further expanded to collect data for RSV-related deaths from any health facility or community-based study worldwide. Investments to understand the cause of death in young children need to be sustained to inform vaccine policy, particularly in low-income and middle-income settings.

Contributors
NMS, HN, and LJB designed the study and collected, analysed, and interpreted data. FPP, BDG, and DFG designed the study. NMS, AG, FL, DJN, PKM, SAM, MIG, CC, JM, KT, ST, HO, SPL, AGo, JFS, KLO, BDG, AS, AM, OR, NK-B, NH, ED-P, MRW, MCM, MCS, BAP, EAFS, TFL, MBACO, CCdFLE, QB, WB, HC, UBA, AA, MGL, RAR, OL, BAR, FPP, JP, SR, HI, EAG, and LJB shared data for analysis. All authors contributed to manuscript writing. HN and LJB were principal investigators of the study.

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Author/s:
Scheltema, NM; Gentile, A; Lucion, F; Nokes, DJ; Munywoki, PK; Madhi, SA; Groome, MJ; Cohen, C; Moyes, J; Thorburn, K; Thamthitiwat, S; Oshitani, H; Lupisan, SP; Gordon, A; Sanchez, JF; O’Brien, KL; Gessner, BD; Sutanto, A; Mejias, A; Ramilo, O; Khuri-Bulos, N; Halasa, N; de-Paris, F; Pires, MR; Spaeder, MC; Paes, BA; Simoes, EAF; Leung, TF; Oliveira, MTDC; Emediato, CCDFL; Bassat, Q; Butt, W; Chi, H; Aamir, UB; Ali, A; Lucero, MG; Fasce, RA; Lopez, O; Rath, BA; Polack, FP; Papenburg, J; Roglic, S; Ito, H; Goka, EA; Grobbee, DE; Nair, H; Bont, LJ

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