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Epidemiology and aetiology of maternal bacterial and viral infections in low- and middle-income countries

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Background Maternal morbidity and mortality in low and middle income countries has remained exceedingly high. However, information on bacterial and viral maternal infections, which are important contributors to poor pregnancy outcomes, is sparse and poorly characterised. This review aims to describe the epidemiology and aetiology of bacterial and viral maternal infections in low and middle income countries.

Methods A systematic search of published literature was conducted and data on aetiology and epidemiology of maternal infections was extracted from relevant studies for analysis. Searches were conducted in parallel by two reviewers (using OVID) in the following databases: Medline (1950 to 2010), EMBASE (1980 to 2010) and Global Health (1973 to 2010).

Results Data from 158 relevant studies was used to characterise the epidemiology of the 10 most extensively reported maternal infections with the following median prevalence rates: Treponema pallidum (2.6%), Neisseria gonorrhoeae (1.5%), Chlamydia trachomatis (5.8%), Group B Streptococcus (8.6%), bacterial vaginosis (20.9%), hepatitis B virus (20.9%), hepatitis C virus (1.4%), Cytomegalovirus (95.7% past infection), Rubella (8.9% susceptible) and Herpes simplex (20.7%). Large variations in the prevalence of these infections between countries and regions were noted.

Conclusion This review confirms the suspected high prevalence of maternal bacterial and viral infections and identifies particular diseases and regions requiring urgent attention in public health policy planning, setting research priorities and donor funding towards reducing maternal morbidity and mortality in low and middle income countries.

Maternal morbidity and mortality in low and middle income countries are still unacceptably high. It was estimated that 529,000 maternal deaths occurred throughout the world annually in 2000 (1). This estimate was recently updated with a figure of 273,500 deaths in 2011, the majority of which occurred in poor countries (2). The problem of maternal health has gained the attention of the global community, as exemplified by United
Nations Millennium Development Goal (MDG) 5, which is aimed at reducing the maternal mortality ratio by three quarters and ensuring universal access to reproductive healthcare by 2015 (3). With only 5 years left to achieve MDGs, progress towards the maternal health MDG has been one of the most disappointing, leading to its being highlighted as an urgent global priority at the September 2010 UN Summit on MDGs (4).

The disparity in maternal health between the developed and developing world can be attributed largely to poor access and quality of reproductive healthcare in developing countries (5). As a result, maternal mortality in developing countries remains high due to largely preventable causes such as haemorrhage, hypertensive disorders, abortion related complications and sepsis/infection (6).

An estimated 9.7% of maternal deaths in Africa are due to puerperal sepsis (6). Bacterial and viral infections during pregnancy contribute towards maternal morbidity and mortality and are associated with adverse pregnancy outcomes including spontaneous abortion, stillbirth, prematurity and low birth weight. Furthermore, some infections can be transmitted vertically to neonates, leading to subsequent neonatal morbidity and mortality (7). Most maternal infections can be diagnosed and treated during pregnancy, preventing morbidity and mortality of both mother and child. The reduction of maternal infections in the developing world is highly dependent on the effective use of limited health resources to diagnose and treat these infections.

The planning of effective public health measures is currently limited by the lack of information available on the precise epidemiology and aetiology of bacterial and viral maternal infections. Lack of information can also negatively impact donor interest and international commitment. This review aims to summarize published literature on the aetiology and epidemiology of bacterial and viral maternal infections in low and middle income countries. Additionally, the review aims to identify gaps in available information on the subject. This epidemiological information can subsequently be used to identify similarities and differences in the causes of maternal infection within and between geographic regions, and to guide local and international public health initiatives to reduce the prevalence and burden of these infections.

**METHODS**

**Literature search terms**

Initial searches were conducted to identify suitable keywords and MeSH headings to use in the final search (Table 1). The search strategy was prepared with input from a librarian. Searches were conducted in parallel by two reviewers (using OVID) in the following databases on 1 August 2010: Medline (1950 to August Week 4 2010), EMBASE (1980 to 2010 Week 30) and Global Health (1973 to August 2010).

**Study inclusion and exclusion criteria**

Studies were screened by title and then by abstract for relevance. Studies were deemed relevant if they provided information on the aetiology or epidemiology of bacterial and viral infections in pregnant women in developing countries. These studies were then grouped according to pathogen studied, with some studies providing information on multiple pathogens. Studies providing information on the epidemiology of parasitic infections in pregnant women were identified but not analyzed, as they were addressed in a separate review. Studies reporting the prevalence of maternal HIV infection were identified but not included for analysis, as this information is available through other sources. Relevant English language papers were analyzed
in this work, along with the Chinese electronic databases, with the intention of translating and analyzing non-English papers, too. The inclusion criteria were:

**Subjects**: Pregnant women at any stage of pregnancy or labour, including the puerperium (up to 42 days after labour);

**Study location**: Low and middle income countries (as defined by The World Bank in 2010);

**Study design and sampling methods**: No restrictions applied;

**Data collection**: Only studies that provided evidence of bacterial or viral infection using microbiological or serological test results were included;

**Results**: Papers were selected if they provided information on the burden of a particular pathogen (the prevalence of a particular infection in pregnant women in the community over time/incidence) and/or the aetiology of bacterial and viral maternal infections (prevalence of a specific pathogen/infection).

**Quality criteria**

Only studies with more than 500 subjects were included, because we wanted to protect strongly against implausible proportional contributions of certain pathogens which could have occurred due to chance in smaller data series. Papers were required to describe their samples and methods in detail, and provide microbiological or serological evidence of the aetiology of infection.

**Data extraction**

Information on pathogen studied, sample population (pregnant women studied during pregnancy or at labour) and size, study setting, duration and type, microbiological/serological test used and results were extracted from abstracts and full papers for analysis.

**Data analysis**

Epidemiology and aetiology of bacterial and viral maternal infections were summarized according to the pathogen studied. Only pathogens with 5 or more studies reporting on its epidemiology and/or aetiology were analyzed. Median prevalence of each infection was calculated and trends in the prevalence of maternal infections were noted.

**Selection of studies**

The final search yielded 8580 relevant titles. Figure 1 outlines the results of the search process and application of inclusion and exclusion criteria, resulting in the final panel of studies from which data was extracted.

Studies retained for data extraction (n=158) characterized the prevalence of 5 bacterial pathogens (*Treponema pallidum, Neisseria gonorrhoeae, Chlamydia trachomatis, Group B Streptococcus, bacterial vaginosis*) and 5 viral pathogens (hepatitis B virus, hepatitis C virus, Cytomegalovirus, Rubella, Herpes simplex) among pregnant women in developing countries, with three further reports providing secondary cross-sectional insights or reviews of the literature in this field which were considered useful (8–168). Studies reporting prevalence maternal HIV infection (n=167) were not included in the analysis.

**RESULTS**

**Prevalence of bacterial infections**

**Syphilis (Treponema pallidum)**. Seventy-two studies characterizing the prevalence of maternal syphilis in 36 developing countries were identified (Supplementary Table 1). The features and results of these studies are summarized in Figures 2–5.

In terms of study design, 58.3% of the identified studies were cross sectional, whilst 18.1% were screening studies. The majority of the studies (90.3%) were conducted in healthcare facilities (58.3% in antenatal or prenatal clinics), suggesting either awareness towards the need for antenatal screening for maternal syphilis infection, or merely that it is much easier to recruit study subjects in health care facilities. The remaining studies (5.6%) were community-based and the study setting was not specified in 4.2%.

Rapid Plasma Reagent (RPR) testing was used to detect antitreponemal antibodies in many studies (49%), often in combination with another test, most commonly the Treponema
Haemagglutination Assay (TPHA) (Figure 4). This is because RPR is cheap and simple to perform, but false positive results are common, necessitating confirmatory testing (7). Particularly high prevalence of maternal syphilis was reported in studies from Cameroon, South Africa and Zimbabwe (around 15.0%). Both studies from Cameroon were conducted in the Yaounde province, and show an increase in the prevalence of maternal syphilis from 15.9% in 1992 to 17.4% in 1998 (17,66,107,130).

Gonorrhoea (Neisseria gonorrhoeae). Twenty-one studies providing information of the prevalence of maternal Neisseria gonorrhoeae infection were identified (Supplementary table 2). The characteristics of these studies and the prevalence reported are summarized in the Figures 6–9.

With regards to study design, 20 studies (95.2%) were cross sectional and 1 was a randomized controlled trial (data from the control group was extracted). The majority of the studies (80.9%) were carried out in healthcare facilities and a minority was community-based (19.1%). Median prevalence of maternal gonococcal infection was relatively low, at 1.5% (Figure 9). However, higher prevalence of maternal gonococcal infection was reported in studies from Mongolia (6.1%), Vanuatu (5.9%) and Zimbabwe (5.8%) suggesting the need for targeted action in these countries (12,79,145).

Chlamydia trachomatis. Nineteen studies reporting the prevalence of maternal Chlamydia trachomatis (CT) infection were identified (Table 2). The characteristics of these studies and the prevalence reported are summarized in the Figures 6–9.

These studies diagnosed maternal infection by detecting antibodies towards C. trachomatis or by pathogen detection in urine samples or endocervical swabs using PCR. The median prevalence of maternal C. trachoma-
**Table 2** Characteristics and results of studies (n=19) reporting prevalence of maternal *Chlamydia trachomatis* infection

<table>
<thead>
<tr>
<th>Article</th>
<th>Location, setting of study</th>
<th>Type, duration of study</th>
<th>Population</th>
<th>Results / Prevalence</th>
<th>Technique used</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mooya et al, 2009 (100)</td>
<td>Tanzania, 2 primary health clinics</td>
<td>Cross sectional study, 8 months</td>
<td>690 pregnant women</td>
<td>17.7% positive for GBS colonisation</td>
<td>ELISA detecting anti-Chlamydial IgG</td>
</tr>
<tr>
<td>Jalil et al, 2008 (63)</td>
<td>Brazil, prenatal services in 6 cities</td>
<td>Cross sectional study, 21 months</td>
<td>2654 pregnant women</td>
<td>17.5%</td>
<td>ELISA detecting anti-Chlamydial IgG</td>
</tr>
<tr>
<td>Kinoshita-Moleka et al, 2008 (70)</td>
<td>Democratic Republic of Congo, 2 maternity clinics</td>
<td>Cross sectional study, 1 year</td>
<td>3003 pregnant women</td>
<td>CT prevalence of 9.4%</td>
<td>Hybrid capture technique</td>
</tr>
<tr>
<td>Lujan et al, 2008 (89)</td>
<td>Mozambique, antenatal clinic</td>
<td>Cross sectional study, 5 months</td>
<td>835 first void urine samples from pregnant women</td>
<td>4.1%</td>
<td>PCR</td>
</tr>
<tr>
<td>Romoren et al, 2007 (127)</td>
<td>Botswana, antenatal clinic</td>
<td>Cross sectional study, singular time point</td>
<td>703 pregnant antenatal care attendees</td>
<td>8% prevalence</td>
<td>LCR</td>
</tr>
<tr>
<td>Chen et al, 2006 (27)</td>
<td>China, antenatal clinic</td>
<td>Cross sectional study, 3 months</td>
<td>504 pregnant women</td>
<td>10.1%</td>
<td>PCR</td>
</tr>
<tr>
<td>Thammalangsy et al, 2006 (136)</td>
<td>Laos, 2 hospitals</td>
<td>Cross sectional study, 7 months</td>
<td>500 antenatal attendees</td>
<td>10.2% by nucleic acid hybridisation and 9.6% by PCR</td>
<td>Nucleic acid hybridisation, PCR</td>
</tr>
<tr>
<td>Amindava et al, 2005 (12)</td>
<td>Mongolia, prenatal clinics</td>
<td>Cross sectional survey, 11 months</td>
<td>2000 pregnant women</td>
<td>19.3%</td>
<td>PCR</td>
</tr>
<tr>
<td>Apea-Kubi et al, 2004 (14)</td>
<td>Ghana, gynaecology clinics at teaching hospital</td>
<td>Cross sectional study, singular time point</td>
<td>517 pregnant women</td>
<td>3% prevalence</td>
<td>RNA detection kit</td>
</tr>
<tr>
<td>Sullivan et al, 2003 (145)</td>
<td>Vanuatu, antenatal clinic</td>
<td>Cross sectional study, 12 months</td>
<td>547 pregnant women</td>
<td>21.5%</td>
<td>PCR</td>
</tr>
<tr>
<td>Gray et al, 2001 (53)</td>
<td>Uganda, community based</td>
<td>Randomised control trial, duration not specified</td>
<td>1576 pregnant women in the control arm of the study</td>
<td>2.7%</td>
<td>LCR</td>
</tr>
<tr>
<td>Mayank et al, 2001 (97)</td>
<td>India, community based</td>
<td>Cross sectional study, duration not specified</td>
<td>600 pregnant women</td>
<td>4.3%</td>
<td>ELISA</td>
</tr>
<tr>
<td>Latif et al, 1999 (79)</td>
<td>Zimbabwe, Antenatal and primary care clinics</td>
<td>Cross sectional study</td>
<td>1189 asymptomatic pregnant women</td>
<td>5.8% (and/or gonococcal infection) Not specified</td>
<td></td>
</tr>
<tr>
<td>Mulanga-Kabeya et al, 1999 (101)</td>
<td>Mali, community based</td>
<td>Cross sectional study, 1 month</td>
<td>549 pregnant women</td>
<td>5.0%</td>
<td>EIA</td>
</tr>
<tr>
<td>Bourgeois et al, 1998 (21)</td>
<td>Gabon, 3 antenatal clinics</td>
<td>Cross sectional study, 5 months</td>
<td>646 pregnant women</td>
<td>9.9%</td>
<td>EIA</td>
</tr>
<tr>
<td>Bilmare et al, 1998 (69)</td>
<td>Thailand, antenatal clinics</td>
<td>Cross sectional study, singular time point</td>
<td>500 pregnant mothers in Chiang Rai, 3.70% prevalence</td>
<td>521 pregnant mothers in Bangkok</td>
<td>PCR</td>
</tr>
<tr>
<td>Diallo et al, 1997 (38)</td>
<td>Ivory Coast, antenatal clinic</td>
<td>Cross sectional study, 4 months</td>
<td>546 pregnant women</td>
<td>5.5%</td>
<td>Culture, EIA</td>
</tr>
<tr>
<td>Mele et al, 1997 (98)</td>
<td>Burkina Faso, 2 antenatal clinics</td>
<td>Cross sectional study, duration not specified</td>
<td>645 pregnant women</td>
<td>3.1%</td>
<td>EIA</td>
</tr>
<tr>
<td>Joosief et al, 1996 (65)</td>
<td>Indonesia, prenatal clinic</td>
<td>Cross sectional study, 15 months</td>
<td>599 pregnant women</td>
<td>8.2%</td>
<td>Direct immuno-fluorescence</td>
</tr>
</tbody>
</table>

EIA – enzyme immunoassay, ELISA – enzyme-linked immunosorbent assay, LCR – ligase chain reaction, PCR – polymerase chain reaction.

**Table 3** Characteristics and results of studies (n=12) reporting prevalence of maternal Group B *Streptococcus* (GBS) colonisation

<table>
<thead>
<tr>
<th>Article</th>
<th>Location, setting of study</th>
<th>Type, duration of study</th>
<th>Population</th>
<th>Results / Prevalence</th>
<th>Technique used</th>
</tr>
</thead>
<tbody>
<tr>
<td>Seoud et al, 2010 (134)</td>
<td>Lebanon, 3 hospitals</td>
<td>Cross sectional study, 8 months</td>
<td>775 pregnant mothers</td>
<td>17.7% positive for GBS colonisation</td>
<td>Not specified</td>
</tr>
<tr>
<td>Mavnyenwga et al, 2010 (96)</td>
<td>Zimbabwe, 3 communities</td>
<td>Cohort study, duration not specified</td>
<td>780 women (one or more samples collected)</td>
<td>60.3% positive for GBS colonisation</td>
<td>Culture</td>
</tr>
<tr>
<td>Mansouri et al, 2008 (94)</td>
<td>Iran, 3 major non-private hospitals</td>
<td>Cross sectional study, duration not specified</td>
<td>602 pregnant women</td>
<td>9.1% were colonised by GBS</td>
<td>Culture</td>
</tr>
<tr>
<td>Namavar et al, 2008 (105)</td>
<td>Iran, hospital</td>
<td>Cross sectional study, duration not specified</td>
<td>1191 pregnant women at childbirth</td>
<td>9.1% had rectovaginal communication with GBS</td>
<td>Culture</td>
</tr>
<tr>
<td>Zusman et al, 2006 (168)</td>
<td>Brazil, 2 hospitals</td>
<td>Prospective study, duration not specified</td>
<td>988 pregnant women</td>
<td>17.9% maternal colonisation rate</td>
<td>Culture</td>
</tr>
<tr>
<td>Goto et al, 2005 (52)</td>
<td>Vietnam, community based</td>
<td>Survey, duration not specified</td>
<td>505 pregnant women</td>
<td>4%</td>
<td>Culture</td>
</tr>
<tr>
<td>Larcher et al, 2005 (78)</td>
<td>Argentina, hospital</td>
<td>Prospective study, 18 months</td>
<td>1228 pregnant women</td>
<td>1.4% maternal colonisation rate</td>
<td>Culture</td>
</tr>
<tr>
<td>Siddley &amp; Thomas et al, 2002 (139)</td>
<td>UAE, hospital</td>
<td>Cross sectional study, 2 months</td>
<td>891 pregnant women at delivery</td>
<td>21.5% maternal colonisation rate</td>
<td>Culture</td>
</tr>
<tr>
<td>Torresani et al, 2001 (158)</td>
<td>Argentina, hospital</td>
<td>Cross sectional study, duration not specified</td>
<td>531 pregnant women</td>
<td>3.2% were positive for GBS</td>
<td>Culture</td>
</tr>
<tr>
<td>Werawatkul et al, 2001 (164)</td>
<td>Thailand, hospital</td>
<td>Cross sectional study, duration not specified</td>
<td>902 pregnant women presenting at labour</td>
<td>6.2% maternal colonisation rate</td>
<td>Culture</td>
</tr>
<tr>
<td>Ocampo-Torres et al, 2000 (111)</td>
<td>Mexico, 3 public hospitals</td>
<td>Cross sectional study, duration not specified</td>
<td>910 pregnant women at delivery</td>
<td>8.6% GBS colonisation rate</td>
<td>Culture, Latex agglutination</td>
</tr>
<tr>
<td>Olaniye &amp; Adetosoye, 1986 (113)</td>
<td>Nigeria, 4 government hospitals</td>
<td>Cross sectional study, duration not specified</td>
<td>500 pregnant women (2nd and 3rd trimester)</td>
<td>1.6% positive for GBS</td>
<td>Culture</td>
</tr>
</tbody>
</table>

UAE – United Arab Emirates
matis infection was identified in Vanuatu (21.5%), Mongolia (19.3%) and Tanzania (17.5%) (12,100,145).

**Group B Streptococcus.** Twelve studies reporting the prevalence of maternal Group B Streptococcus (GBS) (*S. agalactiae*) colonisation were identified (Table 3).

The majority of studies diagnosed GBS colonization by direct culture of vaginal swabs. Median prevalence of maternal GBS colonization was 8.85%. The highest prevalence of maternal GBS colonization reported was 60.3% in 3 communities across Zimbabwe, which was significantly higher than the prevalence reported by other studies. However this prevalence was reported as not significantly associated with adverse perinatal outcomes (96). Higher prevalence was also noted in Lebanon and the United Arab Emirates (136,139).

**Bacterial vaginosis.** Eleven studies reported the prevalence of bacterial vaginosis (Table 4).

The median prevalence of maternal bacterial vaginosis was 20.9%. Especially high prevalence was reported in Uganda, Botswana and Zimbabwe, highlighting high prevalence of bacterial vaginosis in sub-Saharan Africa. The majority of studies used microscopy of vaginal wet mounts in combination with established criteria for diagnosing bacterial vaginosis (53,75,126).

**Prevalence of Viral Pathogens**

**Hepatitis B virus.** Thirty-nine studies characterizing the prevalence of maternal Hepatitis B infection were identified (Supplementary Table 3), and their features and results are summarized in Figures 10–13.

The majority of identified studies were conducted in a healthcare facility (87.2%) whilst 5.1% were community based and 7.7% of studies did not specify the setting. Most of the studies were also cross sectional (69.2%) in nature, with remaining studies being retrospective observational.
### Table 4: Characteristics and results of studies (n=11) reporting prevalence of bacterial vaginosis in pregnant women

<table>
<thead>
<tr>
<th>Article</th>
<th>Location, setting of study</th>
<th>Type, duration of study</th>
<th>Population</th>
<th>Results / Prevalence</th>
<th>Technique used</th>
</tr>
</thead>
<tbody>
<tr>
<td>Kurewa et al, 2010 (75)</td>
<td>Zimbabwe, peri-urban clinics</td>
<td>Cross sectional study, 19 months</td>
<td>691 pregnant women</td>
<td>32.6%</td>
<td>Amsel's criteria</td>
</tr>
<tr>
<td>Msuya et al, 2009 (100)</td>
<td>Tanzania, 2 primary health clinics</td>
<td>Cross sectional study, 21 months</td>
<td>2654 pregnant women</td>
<td>20.9%</td>
<td>Amsel's criteria</td>
</tr>
<tr>
<td>Kirakoya-Samadoulougou et al, 2008 (71)</td>
<td>Burkina Faso, 4 primary health centres</td>
<td>Cross sectional study, 3 months</td>
<td>2133 pregnant women with analysable data</td>
<td>6.4%</td>
<td>Nugent scoring method</td>
</tr>
<tr>
<td>Romoren et al, 2007 (127)</td>
<td>Botswana, multiple antenatal clinics</td>
<td>Cross sectional study, 5 months</td>
<td>703 pregnant women</td>
<td>38.0%</td>
<td>Microscopy</td>
</tr>
<tr>
<td>Azargoon &amp; Darvishzadeh, 2006 (16)</td>
<td>Iran, hospital</td>
<td>Cohort study, duration not specified</td>
<td>1223 pregnant women</td>
<td>16.0%</td>
<td>Vaginal pH, saline wet mount, Amsel tests</td>
</tr>
<tr>
<td>Thammalangsy et al, 2006 (156)</td>
<td>Laos, 2 hospitals</td>
<td>Cross sectional study, 7 months</td>
<td>500 pregnant antenatal attendees</td>
<td>14.4% by Amsel's criteria and 22.0% by Nugent's score</td>
<td>Amsel's criteria, Nugent's score</td>
</tr>
<tr>
<td>Goto et al, 2005 (52)</td>
<td>Vietnam, community based</td>
<td>Survey, duration not specified</td>
<td>505 pregnant women in 10 communes</td>
<td>7%</td>
<td>Nugent criteria</td>
</tr>
<tr>
<td>Gray et al, 2001 (53)</td>
<td>Uganda, community based</td>
<td>Randomised control trial, duration not specified</td>
<td>1576 pregnant women in the control arm of the study</td>
<td>48.5%</td>
<td>Microscopy</td>
</tr>
<tr>
<td>Mayank et al, 2001 (97)</td>
<td>India, community based</td>
<td>Cross sectional study, duration not specified</td>
<td>600 pregnant women</td>
<td>18%</td>
<td>Microscopy</td>
</tr>
<tr>
<td>Taha et al, 1999 (150)</td>
<td>Malawi, hospital</td>
<td>Cross sectional study, 25 months</td>
<td>9126 pregnant women</td>
<td>30%</td>
<td>Vaginal wet mounts</td>
</tr>
<tr>
<td>Meda et al, 1997 (98)</td>
<td>Burkina Faso, 2 anteatal clinics</td>
<td>Cross sectional study, duration not specified</td>
<td>645 pregnant women</td>
<td>13%</td>
<td>Microscopy</td>
</tr>
</tbody>
</table>

**Figure 10** Geographical distribution of studies (n=39) providing information on prevalence of maternal hepatitis B virus (HBV) infection; “no data” in the legend refers to low and middle-income countries only, as data from high-income countries were not the subject of this study.

**Figure 11** Techniques used to identify hepatitis B virus (HBV) infection in 39 studies.

**Figure 12** Sizes of study populations in 39 studies reporting maternal hepatitis B virus (HBV) infection prevalence.

**Figure 13** Box plot showing prevalence of hepatitis B virus (HBV) infection detected in relevant studies (n=37). Only 30 of 37 relevant studies measured prevalence by detecting hepatitis B surface antigen (HBsAg) in pregnant women. The following number summaries are depicted in the boxplot: the smallest observation (sample minimum), lower quartile (25%), median (50%), upper quartile (75%), and largest observation (sample maximum). Asterisk indicates an outlier.
(17.9%), surveys (5.1%) and either prospective, cohort or case control studies (2.5% each).

The majority of studies screened for the presence of maternal HBV infection by detecting Hepatitis B surface antigen (HBsAg) in maternal serum. Particularly high maternal HBV prevalence (25%) was identified in Zimbabwe (90), Brazil (20) and Taiwan (83).

**Hepatitis C virus.** Twenty-one studies reporting the prevalence of maternal Hepatitis C virus (HCV) infection were identified (Supplementary Table 4). The features and findings of these studies are summarized in Figures 14 to 17.

Almost all studies reporting maternal HCV prevalence were conducted in healthcare facilities (95.2%) and one did not specify the study setting. The majority of studies were also cross sectional (80.9%), with the remaining studies being case control studies (14.3%), prospective studies (9.5%) and one serological survey (4.8%).

Median maternal exposure to HCV (anti-HCV) prevalence reported was 1.4%. Active infection prevalence (HCV RNA) was reported in 6 studies and median active HCV infection prevalence from these studies was 1.2%. Two studies from Egypt reported especially high prevalence of maternal HCV exposure (15.8% and 15.7%) and active infection rates (10.8% and 10.9%), highlighting a local problem with maternal HCV infection in Egypt (136,143).

**Rubella virus.** Fifteen studies characterizing the epidemiology of maternal rubella were identified (Table 5).

These studies detected the presence of maternal anti-rubella IgG as a marker of past infection or immunization and mothers who did not possess these antibodies were susceptible to rubella infection. Maternal IgM was detected in some studies as a marker of recent or current infection, which is associated with an increased risk of vertical transmission. Median maternal susceptibility to rubella was

### Table 5 Characteristics and results of studies (n=15) reporting prevalence of maternal rubella infection

<table>
<thead>
<tr>
<th>Article</th>
<th>Location, setting of study</th>
<th>Type, duration of study</th>
<th>Population</th>
<th>Results / Prevalence</th>
<th>Technique used</th>
</tr>
</thead>
<tbody>
<tr>
<td>Lin et al, 2010</td>
<td>Taiwan, hospital</td>
<td>Cross sectional study, 7 years</td>
<td>10,089 pregnant women</td>
<td>Seronegativity was 14.0%</td>
<td>Microparticle EIA</td>
</tr>
<tr>
<td>Tamer et al, 2009</td>
<td>Turkey, antenatal clinic</td>
<td>Cross sectional study, duration not specified</td>
<td>1972 serum samples from pregnant women</td>
<td>Seropositivity for anti-rubella IgG, IgM and IgG+IgM together was 96.1%, 0.2% and 1.8%, respectively</td>
<td>Commercial ELISA (detecting IgG and IgM)</td>
</tr>
<tr>
<td>Ai &amp; Ee, 2008</td>
<td>Malaysia, antenatal clinics and hospital</td>
<td>Cross sectional study, duration not specified</td>
<td>500 pregnant mothers</td>
<td>11.4% were susceptible to Rubella</td>
<td>Rubella IgG studies</td>
</tr>
<tr>
<td>Majlessi et al, 2008</td>
<td>Iran, health centres</td>
<td>Cross sectional study, 2 years</td>
<td>965 pregnant women</td>
<td>Estimated rubella immunity rate was 91.1%, Nonimmunity rate was 8.9%</td>
<td>ELISA</td>
</tr>
<tr>
<td>Das et al, 2007</td>
<td>India, hospital</td>
<td>Screening, duration not specified</td>
<td>1115 pregnant women with bad obstetric history, 500 normal pregnant women</td>
<td>3.6% seronegativity (≠BOH), 0% seropositivity (normal)</td>
<td>ELISA (Detecting IgM)</td>
</tr>
<tr>
<td>Ocak et al, 2007</td>
<td>Turkey, antenatal clinic</td>
<td>Retrospective observational, 23 months</td>
<td>1632 pregnant women</td>
<td>Anti-rubella IgG and IgM antibodies were reactive in 95.0%, and in 0.54%</td>
<td>ELISA (detecting IgG and IgM)</td>
</tr>
<tr>
<td>Pehlivan et al, 2007</td>
<td>Turkey, community based</td>
<td>Cross sectional study, 7 months</td>
<td>824 women from 60 clusters, 803 eligible for serological study</td>
<td>93.8% positive for anti-rubella IgG, 0.6% were IgM and IgG positive, 3.6% were susceptible</td>
<td>Micro ELISA (detecting IgG and IgM)</td>
</tr>
<tr>
<td>Tseng et al, 2006</td>
<td>Taiwan, hospital</td>
<td>Retrospective observational, 4 years</td>
<td>5007 pregnant women</td>
<td>13.4% susceptible among Taiwanese women, 29.1% susceptible among non-Taiwanese women</td>
<td>Microparticle EIA</td>
</tr>
<tr>
<td>Barreto et al, 2006</td>
<td>Mozambique, antenatal clinics</td>
<td>Cross sectional serosurvey, 3 months</td>
<td>974 pregnant women at antenatal clinic attendance</td>
<td>95.3% positive for Rubella IgG</td>
<td>ELISA</td>
</tr>
<tr>
<td>Corcoran &amp; Hardie, 2006</td>
<td>South Africa, antenatal clinics</td>
<td>Cross sectional study, duration not specified</td>
<td>1200 serum samples from a 2003 HIV/syphilis survey</td>
<td>96.5% immune</td>
<td>ELISA</td>
</tr>
<tr>
<td>Desiner et al, 2004</td>
<td>Haiti, hospital</td>
<td>Cross sectional study, 4 months</td>
<td>503 pregnant women; 8 excluded leaving 495</td>
<td>95.2% were seropositive</td>
<td>ELISA</td>
</tr>
<tr>
<td>Weerasekera et al, 2003</td>
<td>Sri Lanka, antenatal clinic</td>
<td>Cross sectional study, 2 years</td>
<td>500 maternal blood samples, before 16th week of gestation</td>
<td>82% were positive for rubella specific IgG, 73% gave a history of vaccination against rubella before their present pregnancy</td>
<td>ELISA (detecting IgG and IgM)</td>
</tr>
<tr>
<td>Palihawadana et al, 2003</td>
<td>Sri Lanka, multiple antenatal clinics</td>
<td>Cross sectional study, duration not specified</td>
<td>620 pregnant women</td>
<td>76% of pregnant females were seropositive</td>
<td>ELISA (detecting IgG)</td>
</tr>
<tr>
<td>Ashrafunnessa Khatun et al, 2000</td>
<td>Bangladesh, hospital</td>
<td>Cross sectional study, 11 months</td>
<td>609 pregnant women</td>
<td>85.9% were seropositive and 14.1% were seronegative</td>
<td>ELISA</td>
</tr>
<tr>
<td>Dos Santos et al, 2003</td>
<td>Brazil, prenatal testing</td>
<td>Cross sectional study, 8 months</td>
<td>1024 pregnant women</td>
<td>77.4%</td>
<td>Haemagglutinin Inhibition Assay</td>
</tr>
</tbody>
</table>

EIA – enzyme immunoassay, ELISA – enzyme-linked immunosorbent assay
Epidemiology and aetiology of maternal bacterial and viral infections in developing countries

8.9%. Higher susceptibility rates were reported in Sri Lanka, Brazil and Taiwan (2 studies) (39,84,160,163).

Cytomegalovirus. Five studies on maternal cytomegalovirus (CMV) infection prevalence were identified (Table 6). The median prevalence of maternal IgG to CMV (calculated from 4 studies that reported this) was 95.7%, indicating a high proportion of mothers with previous exposure to CMV. One hospital-based study in India identified a statistically significant higher prevalence of CMV IgM (indicating active or recent infection) in mothers with Bad Obstetric History (BOH), highlighting a role for maternal CMV infection in adverse pregnancy outcome in this setting (34).

Herpes simplex virus. Five studies outlining the prevalence of maternal Herpes simplex virus 2 (HSV-2) were identified (Table 7). These studies detected the presence of antibodies to HSV as a marker of maternal infection. Median prevalence of HSV-2 was 20.7%. Higher seroprevalences were noted in Zimbabwe, Vanuatu and Tanzania (56,75,166).

DISCUSSION

Prevalence of bacterial and viral maternal infections

Our search of published literature relevant to the aetiology and epidemiology of bacterial and viral maternal infections in the developing world retrieved 499 titles. Analysis of these titles yielded 158 studies which provided detailed epidemiological information on 10 maternal infections. The 5 bacterial and 5 viral maternal infections identified in this panel represent maternal infections that were most extensively studied, suggesting that these infections have a high burden on pregnancy outcomes in the developing world. These infections also have potential adverse effects on neonates.

Our review confirms the suspected high prevalence of bacterial and viral maternal infections in the developing world, as demonstrated by the median prevalence rates calculated for each pathogen studied. Of particular concern are the
In the process of reviewing the subject, we identified several gaps in existing knowledge. High prevalence rates of maternal syphilis (2.6%), C. trachomatis (5.8%), bacterial vaginosis (20.9%), hepatitis B virus (4.3%) and Herpes simplex virus (20.7%).

The prevalence of these infections also showed significant variance between countries and regions. The prevalence of maternal infections in sub-Saharan Africa is especially high, specifically in Zimbabwe (75, 79, 96, 130), Tanzania (101, 166) and Cameroon (66, 107). Previous studies have shown that all-cause obstetric risk and maternal mortality ratio are highest in Sub-Saharan Africa (1). The high prevalence of maternal infections in this region may have an important contributory role towards the high maternal morbidity and mortality seen in Sub-Saharan Africa. Regional differences in the prevalence of maternal infections are likely to be closely related to the quality of reproductive healthcare available in different regions, or unique local scenarios.

### Gaps in existing knowledge

In the process of reviewing the subject, we identified several facility-based retrospective studies reporting causes of maternal mortality. Many of these studies attributed a proportion of deaths to infection or sepsis, but were unable to provide microbiological or serological evidence of the specific aetiology of infection. Thus, these studies had to be excluded from the final panel of studies that we reviewed. This highlights a gap in existing knowledge on the epidemiology and impact of maternal infection, especially on the aetiology of infectious agents that lead to puerperal sepsis and subsequent mortality. Increased surveillance and diagnostic capabilities in healthcare facilities and in the community is needed to identify the aetiological agents responsible for puerperal sepsis and maternal mortality.

The prevalence of maternal infection reported by the studies identified in this review may be an underestimate of actual rates of infection as not all pregnant women in developing countries may have access to or choose to access formalized antenatal care. This could be due to financial constraints, difficulties in accessing these facilities and personal or cultural beliefs. In addition, antenatal care services may not have the capacity to routinely screen for maternal infections, especially those that are asymptomatic (such as N. gonorrhoeae and C. trachomatis) and those that require serological tests such as PCR and ELISA to diagnose (Hep-

### Table 6 Characteristics and results of studies (n=5) reporting prevalence of maternal cytomegalovirus (CMV) infection

<table>
<thead>
<tr>
<th>Article</th>
<th>Location, setting of study</th>
<th>Type, duration of study</th>
<th>Population</th>
<th>Results / Prevalence</th>
<th>Technique used</th>
</tr>
</thead>
<tbody>
<tr>
<td>Tabatabaei et al., 2009 (149)</td>
<td>Iran, hospital</td>
<td>Cross sectional study, 7 months</td>
<td>1472 pregnant women presenting at labour</td>
<td>97.69% seropositivity, 2.31% seronegativity; prevalence of active infection 4.35%</td>
<td>ELISA detecting anti-CMV IgM</td>
</tr>
<tr>
<td>Das et al., 2007 (34)</td>
<td>India, hospital</td>
<td>Cross sectional study</td>
<td>1113 pregnant women with bad obstetric history; 500 normal pregnant women</td>
<td>11% prevalence in women with bad obstetric history; 4% prevalence in normal pregnant women</td>
<td>Commercial ELISA kit detecting anti-CMV IgM</td>
</tr>
<tr>
<td>Ocak et al., 2007 (110)</td>
<td>Turkey, hospital</td>
<td>Retrospective observational study, 2 years</td>
<td>1652 pregnant women</td>
<td>94.9% seropositivity for anti-CMV IgG, 0.4% positive for anti-CMV IgM</td>
<td>ELISA detecting anti-CMV IgG and IgM</td>
</tr>
<tr>
<td>Suarez et al., 1994 (144)</td>
<td>Chile, public outpatient department and a special clinic for university students</td>
<td>Cross sectional study, 3 years</td>
<td>939 pregnant women of a low socioeconomic level, and 123 pregnant university students</td>
<td>95% in low socioeconomic class; 69.9% in pregnant students; 2 primary infections occurred (1 in each group)</td>
<td>ELISA; initially seronegative women were tested again during 2nd and 3rd trimester to identify primary infections</td>
</tr>
<tr>
<td>Tamer et al., 2009 (152)</td>
<td>Turkey, antenatal clinics</td>
<td>Cross sectional study, singular time point</td>
<td>1972 samples of sera from pregnant women</td>
<td>Seroprevalence of anti-CMV IgG, IgM and IgG+IgM together were found in 96.4%, 0.7% and 1.9% of the pregnant women, respectively</td>
<td>Commercial ELISA kit</td>
</tr>
</tbody>
</table>

ELISA – enzyme-linked immunosorbsent assay

### Table 7 Characteristics and results of studies (n=5) reporting prevalence of maternal Herpes simplex virus (HSV) infection

<table>
<thead>
<tr>
<th>Article</th>
<th>Location, setting of study</th>
<th>Type, duration of study</th>
<th>Population</th>
<th>Results / Prevalence</th>
<th>Technique used</th>
</tr>
</thead>
<tbody>
<tr>
<td>Kurewa et al., 2010 (75)</td>
<td>Zimbabwe, peri-urban clinics</td>
<td>Cross sectional study, 19 months</td>
<td>691 pregnant women</td>
<td>51.10% seropositive</td>
<td>ELISA detecting IgG</td>
</tr>
<tr>
<td>Yahya-Malima et al., 2008 (166)</td>
<td>Tanzania, antenatal clinics (6)</td>
<td>Cross sectional study, duration not specified</td>
<td>1296 sera collected from pregnant women</td>
<td>20.7% prevalence of genital herpes</td>
<td>ELISA</td>
</tr>
<tr>
<td>Chen et al., 2007 (28)</td>
<td>China, antenatal clinic</td>
<td>Cross sectional study, 3 months</td>
<td>502 pregnant women</td>
<td>10.8% seroprevalence of HSV-2</td>
<td>Commercial ELISA to detect IgG</td>
</tr>
<tr>
<td>Haddow et al., 2007 (56)</td>
<td>Vanuatu, antenatal clinic</td>
<td>Cross sectional study, 1 to 2 years</td>
<td>535 pregnant women</td>
<td>32% seroprevalence of HSV-2</td>
<td>ELISA</td>
</tr>
<tr>
<td>Joesoef et al., 1996 (65)</td>
<td>Indonesia, prenatal clinic</td>
<td>Cross sectional study, 15 months</td>
<td>599 pregnant women</td>
<td>9.9% seroprevalence of HSV-2</td>
<td>Immuno-blot</td>
</tr>
</tbody>
</table>

ELISA – enzyme-linked immunosorbsent assay
Epidemiology and aetiology of maternal bacterial and viral infections in developing countries

Reducing the prevalence of maternal infections, and consequently maternal and neonatal morbidity and mortality, requires a concerted, multifaceted approach. Improvements in the provision, accessibility and uptake of antenatal care services are absolutely essential to reduce the prevalence of not only maternal infection but also other causes of maternal morbidity and mortality. This entails an improvement in antenatal booking, the number of antenatal visits and childbearing with professional assistance (40). Wherever possible, routine screening and treatment for maternal infections should be conducted. Alternatives to antenatal screening include syndromic management or risk assessment based approaches to treat maternal infection. Routine immunisation against vaccine-preventable diseases should also be implemented to reduce the eventual burden that these infections may have on pregnancy outcomes and neonates (7,132).

We hope that the gaps in information highlighted in this study will guide the design and implementation of studies to accurately assess the epidemiology of maternal infections in the developing world, especially in countries where the prevalence of maternal infection is unreported. Ideally, studies should be large, community-based and longitudinal, and investigate the association between pregnancy outcome and microbiological and serological evidence of maternal infection to accurately define the burden of maternal infections and their impact on pregnancy outcome (132). There is also a great need for the design of rapid point-of-care diagnostic tests for use in the field for the diagnosis of maternal infections. Affordable and novel therapeutics and interventions will also be beneficial in reducing the impact of maternal infections. These measures are dependent upon the co-operation of the research community and the altruism of industry to succeed.

More than US$ 40 billion (€ 30 billion) has been pledged towards the newly formed Global Strategy for Women’s and Children’s Health (169). These funds should be spent prudently on effective and sustainable measures to improve maternal health. The majority of this allocation should go towards the strengthening of basic antenatal care systems in developing countries. Because serious maternal infections are a major contributor to maternal morbidity and mortality, the early detection and treatment of infections is an important component of prenatal care. The continued support of the global community is also needed to ensure the improvement of maternal health in the developing world.

CONCLUSION

This review highlights the high bacterial and viral maternal infection rates in the developing world. Urgent, concerted action is required to reduce the burden of these infections. In addition to raising awareness about the severity of the problem of maternal infections in the developing world, data from this review will be beneficial in guiding public health policy, research interests and donor funding towards achieving MDG 5.
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