The Maternal Mortality Incidence Rate (MMIR)

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Abstract

This paper proposes the estimation of maternal mortality with the use of an occurrence/exposure rate (hazard), the maternal mortality incidence rate (MMIR), which places maternal exposure in the denominator. Estimation of maternal exposure requires information on the numbers and average durations of live births, early and late fetal deaths, induced abortions, ectopic pregnancies and on twinning rates. An example estimate of age-specific MMIR is provided for the case of the United States, 2002. The commonly used maternal mortality ratio (MMR) is concluded to overestimate maternal mortality in the extreme ages of childbearing, but to underestimate it in the peak ages of childbearing. Calculated as a crude ratio, MMR has been subject to underestimation due to denominator distortion, a trend that increased in magnitude over the years 1997-2004. I however recommend the continued use of MMR based on its relative ease of calculation and continued uncertainty regarding maternal exposure in MMIR.

Introduction

Maternal mortality is most commonly measured as a ratio of obstetric (maternal) deaths divided by total births in a given period (MMR). This paper proposes to modify this measure to reflect an occurrence/exposure rate, which would correspond conceptually with the way events (maternal deaths) are recorded per the ICD 10 definition. Deaths are properly coded as maternal deaths whenever there is any possible aggravation or relation with pregnancy or childbearing (see Def 1, in following). This includes, for instance, sudden death from ectopic pregnancy, or suicides related to post-partum depression, neither of which are captured by figures of live births. Furthermore counts of live births have no aspect of duration. The objective of this paper is to compare MMR with such an occurrence/exposure measure of maternal mortality.

I briefly evaluate the most commonly used measures of maternal mortality, and consider how one may go about estimating the idea of maternal exposure using data frequently available from national statistical offices. Each component of maternal exposure is made explicit, as well as a proposed method of estimation. These components- live births, early and late fetal deaths, induced abortions, ectopic pregnancies- are treated separately due to the manner in which data are collected. An example estimate of the maternal mortality incidence rate (MMIR) is made with an estimate of maternal exposure in the denominator using US data from the year 2002. This measure is then compared with the most commonly used measure of maternal mortality, the maternal mortality ratio (MMR). MMR turns to out to approximate MMIR very closely at most ages, but to overestimate maternal mortality at the extreme ages of childbearing, especially at ages above 40. It is concluded that further effort is needed to improve estimates of maternal exposure, especially with respect to the proper accounting of exposure from pregnancies resulting in early fetal loss, which are likely underestimated in this exercise. The degree of underestimation is likely muted, though, due to the short duration contributed to exposure by most early fetal loss. Were this exposure to be adequately included, this would likely increase the apparent gap between MMR and MMIR in the upper ages of childbearing.

Measures and Definitions

Maternal Mortality Defined

According to the ICD 10th Revision, a *maternal death* is defined as:

> **Def 1**
> Maternal Death: The death of a woman while pregnant or within 42 days of termination of pregnancy, irrespective of the duration and site of the pregnancy, from any cause related to or aggravated by the pregnancy or its management but not from accidental or incidental causes (WHO, 2007).

This definition is much more inclusive than those used for other causes of death. For instance, suicides associated with postpartum depression occurring within 6 weeks of pregnancy are properly classified as maternal mortality, as are HIV-related deaths within the relevant time-scope [1]. By definition, maternal mortality is therefore not independent from other causes of death. The WHO offers two other variants of the definition, including *late maternal death*, and the more inclusive *pregnancy-associated death*:

> **Def 2**
> Late Maternal Death: The death of a woman from direct or indirect obstetric causes, more than 42 days but less than one year after termination of pregnancy (WHO, 2007).

> **Def 3**
> Pregnancy-Associated Death: The death of a woman while pregnant or within 42 days of termination of pregnancy, irrespective of the cause of death (WHO, 2007).

In populations with relatively low maternal mortality, late maternal deaths often comprise a high proportion of overall maternal mortality (see Högberg et al., 1994; Li et al., 1996, for Sweden and the USA, respectively). Pregnancy-associated death is a purely temporal definition, and therefore more inclusive than the above. This is the definition typically referred to when maternal mortality is indirectly estimated using survey data [2], and it will not be addressed further in this paper.

Existing Indicators

The three most common measures used to quantify any of the above definitions, defined in the following Box 1, are the *Maternal Mortality Ratio* (MMR), the *Maternal Mortality Rate* (MM Rate), and the proportion maternal among deaths of females of reproductive age (PMDF):

PMDF tells us the weight of maternal mortality over all mortality for women of reproductive ages, and it informs as to the potential *relative* gains that could be made by reducing maternal mortality. The MM Rate informs about the maximum *absolute* mortality improvements that could be realized by reductions in maternal mortality. Holding all else equal, decreases in fertility will reduce PMDF and the MM Rate simply by placing fewer women at risk, and so they are not useful for making comparisons over periods of fertility change or between populations with different fertility patterns. The Maternal Mortality Ratio, MMR, removes most of the distortion due to differences in fertility levels. It tries to approximate the mortality hazard due to or associated with childbearing.

[1] Both of these causes have been shown to be important contributors to maternal mortality in particular contexts (see e.g. Frautschi et al., 1994; Black et al., 2009)

[2] Such as with the *Sisterhood Method* Graham et al. (1989)

Box 1

$$\text{MMR} = \frac{\text{Maternal Deaths}}{\text{Live Births}}$$

$$\text{MM Rate} = \frac{\text{Maternal Deaths}}{\text{Females 15-49}}$$

$$\text{PMDF} = \frac{\text{Maternal Deaths}}{\text{All Deaths, Females 15-49}}$$

The numerator in any of the above indicators can be any of the given definitions of maternal mortality, whereas the denominators are firmly defined. Despite this clarity, the three different denominators are all approximations of what would provide the most precise information. PMDF and the MM Rate miss their intended targets by fixing conventional upper and lower bounds to the ages of fertility, whereas events in the numerator are unbounded by age. In both cases, pushing the age limits further out would be an unsatisfying solution; due to very low fertility at these ages, including these girls and women in exposure would subject the measures to excessive age structure distortion. Assuming a perfect numerator, the MM Rate and PMDF tend to overestimate maternal mortality when calculated in age-aggregated form. As with any such measure, the most conservative (and informative) procedure is to disaggregate by age where sample size permits, most often in 5- or 10-year age-groups, since maternal mortality is generally a rare event in industrialized countries. This key step, all too often impractical in many data sources, greatly improves comparability over time and between populations.

The MMR is called a ratio rather than a risk or rate because the units of its denominator, live births, do not capture the true exposure to maternal mortality: maternities. It can neither be interpreted as a probability nor as a hazard, although it does rather closely approximate its target information: the mortality risk entailed by pregnancy and the immediate postpartum period. The difference between births and maternities owes to two additive factors, one positive, the other negative, thereby making the overall direction of bias ambiguous. First, live births underestimate maternities because not all pregnancies result in live births. The WHO definition of maternal death indicates *pregnancy* as the salient identifier, irrespective of live birth outcome. The magnitude of bias due to omitting pregnancies that result in fetal death (early, late, spontaneous or induced) and ectopic pregnancies therefore varies with levels of fetal death and may affect some ages more than others. On the other hand, live births tend to overestimate pregnancies due to the occurrence of multiple births (twins and higher pluralities) by double-counting. This also pertains to higher pluralities of fetal deaths, and it is known to display considerable variation by age. Both of these sources of bias may operate to some degree independently of fertility (as typically calculated), and the underlying levels and age-patterns may change over time. Due to these two factors, even age-specific MMR can provide a biased picture of maternal mortality. Furthermore, even a good estimate of the count of maternities would still technically be considered a probability (case fatality rate) rather than an occurrence/exposure demographic rate.

Measurement Challenges

Where maternal mortality levels are low, small changes in counts of maternal deaths may cause large fluctuations in indicators, whereas small adjustments to denominators may be barely noticeable. Recent studies have therefore rightly focused on the proper identification and classification of maternal deaths in the numerator. The most widely available and used source of information on maternal mortality in countries with advanced statistical systems is multiple cause of death data. Such data have been shown to generally underestimate maternal deaths due to problems arising from observability and proper classification on death certificates (Atrash et al., 1995). Assessments of numerator underestimation have been based on intensive matching and cross-checking of sources such as hospital records, autopsy reports, birth registry microdata and comprehensive confidential enquiries. Recent comparative investigations and several state-level maternal mortality surveillance centers have shown the degree of underestimation to vary greatly between states in the USA and between countries in Europe (Schuitemaker et al., 1997; Salanave et al., 1999; Horon, 2005; Deneux-Tharaux et al., 2005). Studies also conclude that better identification and classification in recent years[3] has led to apparent increases in maternal mortality that likely owe to better information. (Hoyert, 2007).

Even these laudable efforts[4] are most often unable to identify maternal deaths as such when they occur very early in normal pregnancy. This owes primarily to shortcomings in the detection of pregnancy during early weeks of gestation. In cases of maternal death early in a normal pregnancy, it is much less likely that medical examiners will become aware of the pregnancy and record this information on death certificates unless the death is directly related to the pregnancy. In a large study of hospital records, Clark et al. (2008) note about 10% of observed maternal deaths occurring in the first 12 weeks of gestation, which coincides with the hump in both induced and spontaneous fetal loss. This is the only recent evidence available on the shape of aggregated maternal mortality by duration of gestation [5]. A fuller capture of early maternal deaths in normal pregnancy is not technically impossible. While postmortem advanced diagnostic imagery, such as computed tomography (CT) or magnetic resonance imaging (MRI) for all deaths of women in fertile ages would likely identify a sizeable share of otherwise unobserved pregnancies, these technologies are expensive and time-consuming, and thus not in use for such purposes (Stawicki et al., 2008; Uchigasaki, 2006). Sonography is significantly less expensive and cumbersome Uchigasaki (2006), but this has not been explicitly proposed in the literature on maternal mortality as a means of postmortem ascertainment of pregnancy status.

Adjusted Indicators

The Maternal Mortality Probability and Incidence Rate

Despite the progress ahead to be made in properly identifying and recording maternal deaths, significant improvements have already been made in information gathering, and there is already a sizable effort underway working on these issues. The current paper provides no additional treatment of the numerator, the count of maternal deaths, but rather focuses on the estimation of maternal exposure in the denominator, as mentioned above. The objective is to provide a conceptually sound measure of maternal mortality in agreement with conventional measures used in epidemiology and demography. The Maternal Death Probability (MDP) places a simple count of maternities in the denominator, and it can be interpreted as the probability of pregnancy-related or pregnancy-aggravated death from conception until 6 weeks after termination of pregnancy (irrespective of outcome). This is a period measure of the level of maternal mortality and provides no information about variation in mortality over the course of maternity.

Taking the additional step of converting the denominator into exposure converts this to a rate, the Maternal Mortality Incidence Rate (MMIR) (see Box 2, below). This differs from the MM Rate in that the denominator is not person years for all women of reproductive ages, but rather person years lived in the state of maternity as defined in the WHO definition (Def 1). This step is conceptually simple but procedurally

[3]for example, since the 1999 introduction of pregnancy checkboxes on the US standard death certificate

[4]as well as those of state maternal morbidity and mortality surveillance

[5]Studies have examined the shape of maternal death by gestation duration for the specific cases of maternal deaths following spontaneous abortions and ectopic pregnancies (Saraiya et al., 1999b; Berman et al., 1985; Dorfman et al., 1984; Atrash et al., 1995), all showing important contributions to maternal death in early gestation, where a low hazard coincides with large numbers of events (spontaneous abortions or termination of ectopic pregnancies). Both of these cases are however very likely to be correctly identified and recorded.

complicated, given the way data are typically gathered. In principle, one need only multiply the number of pregnancies by the average duration of pregnancy plus 42 days.

In these two measures, maternities are free from double counting of multiple births and include maternities of pregnancies resulting in induced or spontaneous fetal death. The definition provided below (Def 4) corresponds with the primary definition of maternal mortality (Def 1), but may also shift its temporal bounds to correspond with the definition of late maternal mortality (Def 2).

Def 4
Maternity: A pregnancy counted from the moment of conception and until 42 days after the termination of gestation, irrespective of live birth outcome.

Box 2

$$\text{MDP} = \frac{\text{Maternal Deaths}}{\text{Maternities}}$$

$$\text{MMIR} = \frac{\text{Maternal Deaths}}{\text{Maternities} * \text{avg maternity duration}}$$

MMIR is thus an occurrence/exposure rate (a hazard or *force*), while MDP is a probability (a case fatality rate, in epidemiology) for the special case of maternity, and is not subject to distortions from changes in twinning rates, fetal mortality rates or induced abortions. It still may not be interpreted as *excess* mortality due to pregnancy: Assuming full and accurate classification of maternal deaths, this would greatly exaggerate maternal mortality because the WHO definition is explicitly non-independent. Such assessments would require additional cause disaggregation in the numerator beyond the scope of this paper.

Estimation of Maternal Exposure

The remainder of this paper proposes a method to estimate MMIR using vital register microdata as collected by national statistical offices and occasionally available in public use format, with an example offered for the case of the United States for the year 2002. Other studies have estimated series of annual pregnancies (e.g. Saraiya et al., 1999a, for the USA), such as can be used to calculate the MDP, but these do not take the extra step of estimating exposure, nor are the estimates disaggregated by age. There is also remaining uncertainty regarding how to account for unrecorded events. The denominator presented here, person years of maternity, may also be of use for the measurement of other pregnancy-related conditions, such as maternal morbidity.

Our point of departure is the notion that maternal exposure is equal to the number of pregnancies, P, multiplied by the average duration of maternity, $\overline{t_m}$, which is the average duration of pregnancy plus six weeks, $t_p + 6$ (See Box 3).

Pregnancies in the United States are not registered as such, but rather are inferred on the basis of event registration or the estimation of particular pregnancy outcomes. As such, the practical estimation of maternal exposure proceeds by summing the maternal exposure owing to each of these components. These components are pregnancies ending in live birth, P_l, spontaneous fetal death (both early and late), P_f, induced abortion, P_a and ectopic pregnancies, P_e. Each of these elements is then weighted by its respective average duration plus 6 weeks, and then summed.

Box 3

$$\begin{aligned}\text{Maternal Exposure} &= P * \overline{t_m} \\ &= P * (\overline{t_p} + 6wks)\end{aligned}$$

Box 4

$$\text{Maternal Exposure} = P_l * (\overline{t_l} + 6wks) + P_f * (\overline{t_f} + 6) + P_a * (\overline{t_a} + 6) + P_e * (\overline{t_e} + 6)$$

Most registered events allow for the direct estimation of the key elements of maternal exposure. These conventient components are deaths, live births, and late fetal deaths. In the United States, all registered events are recorded by individual state vital statistics offices on the basis of certificates, and reported annually to the National Center for Health Statistics (NHCS) branch of the Center for Disease Control and Prevention (CDC). State statistics are compiled into national files, which are released as national public use microdata files with a two to four year lag CDC Vital Stats. Since 1985, these files have included 100% of registered events, and in each year since 1968 they have included all variables necessary to directly estimate maternal exposure. Induced abortions, early fetal deaths and ectopic pregnancies must be accoutned for using various methods of semi-direct and indirect estimation, detailed in the following sections.

Box 5

$$\text{Maternal Exposure} = \sum_{i=1}^{L} \frac{t_i + 6wks}{pl_i} + \sum_{i=1}^{F} \frac{t_i + 6wks}{pl_i} + \sum_{i=1}^{A} \frac{t_i + 6wks}{pl_i} + \sum_{i=1}^{E} \frac{t_i + 6wks}{pl_i}$$

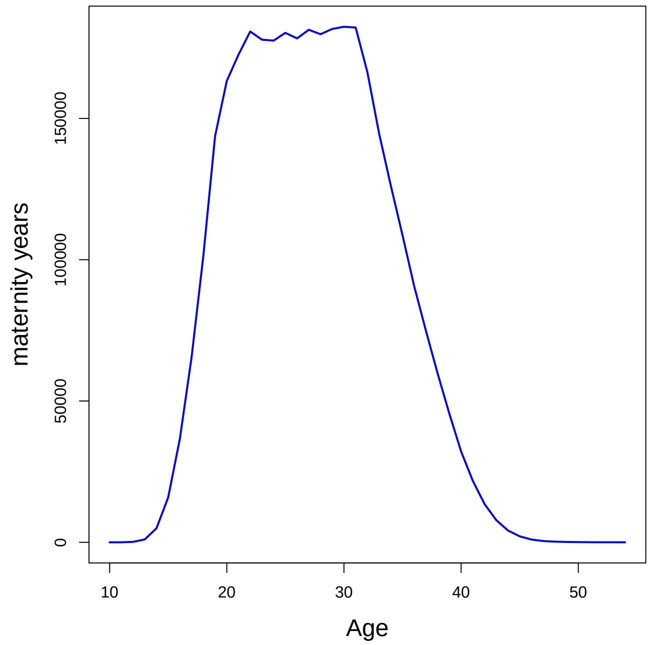
The formula presented in Box 4 is still not adequate to be applied to data. Events are recorded per *product* of conception, and not per mother, thus we must discount for plurality, pl, of conceptus. This is done by weighting as a function of plurality. For instance, births or fetal deaths to twins are weighted half of their respective gestations. Thus the sum of the gestations from both twins (plus 6 weeks) will amount to the maternity duration for one mother. Here, instead of counting from pregnancies P, counting occurs from records of live births L, fetal deaths F, induced abortions, A, and ectopic pregnancies, E. This step can be included in the formula as depicted above in Box 5. Estimation steps used for each of the components are described separately in following.

Live Births

As expressed in the formula above, public use microdata from the CDC on live births allows for direct calculation of this component of exposure. This procedure can be done separately for each age in single ages from 10-54. Figure 1, below, displays age-specific maternal exposure calculated for 2002, the only year where CDC birth data were recorded over the entire age range, 10-54[6].

[6]CDC age imputations are used with no further adjusting. Missing values for gestation weeks were randomly imputed using the age-specific gestation distributions from declared values.

Figure 1: Maternal Exposure from Live Births, USA 2002



Induced Abortions

Induced abortions are only available in tabular form from CDC Abortion Surveillance, and do not represent full coverage for the US, since reporting from states is voluntary and not all states report these events to the CDC. The Guttmacher Institute provides annual estimates of abortion based on regular surveys of all known abortion providers in the US, compiled into a time-series by Henshaw and Kost (2008), and available in expanded tabular form from the Institute's website[7]. This report is widely regarded as the best source of information on the total count and distribution of abortions in the USA. It contains, however, no cross-tabulation of abortions by age of mother and duration of gestation. In order to allow the gestation pattern of abortions to vary by single ages, I disaggregate the CDC-published age-gestation rate pattern into single weeks of gestation using a loess smoother [8]. Proportions of each gestation week in each age-group are then applied to single-age counts of abortions from the Henshaw and Kost (2008) estimates, thereby preserving annual totals and allowing age variation in gestation patterns. In order to arrive at single age estimate of abortion counts, age-group rates are smoothed using the same loess procedure as above, and then applied to known single age birth counts. Data are taken from this tabular format and exposures are calculated for each age, per the formula in Box 5, and are depicted below in Figure 2 for the year 2002. This procedure may introduce error if the age-gestation pattern of induced abortions occurring in those states that report to the CDC is different from the national average[9].

Fetal Deaths and Ectopic Pregnancies

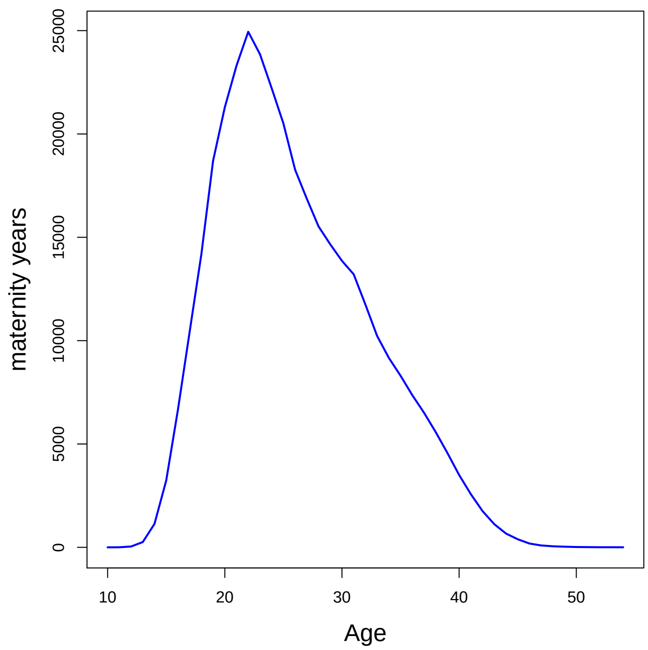
Ideally, estimates of maternal exposure from pregnancies resulting in fetal loss will be included over the entire range of gestation durations, from conception until termination. This introduces the main source of

[7] `http://www.guttmacher.org`

[8] the *loess* function in the base R installation, with *span* set to .7

[9] It would be possible to calculate more than one standard age-gestation pattern per year and to weight these according to the population compositions (for example by race) or fertility patterns for those states missing this information, but this would only change the final estimate if the *mean* gestation were significantly different between states, which is doubtful.

Figure 2: Maternal Exposure from Induced Abortions, USA, 2002



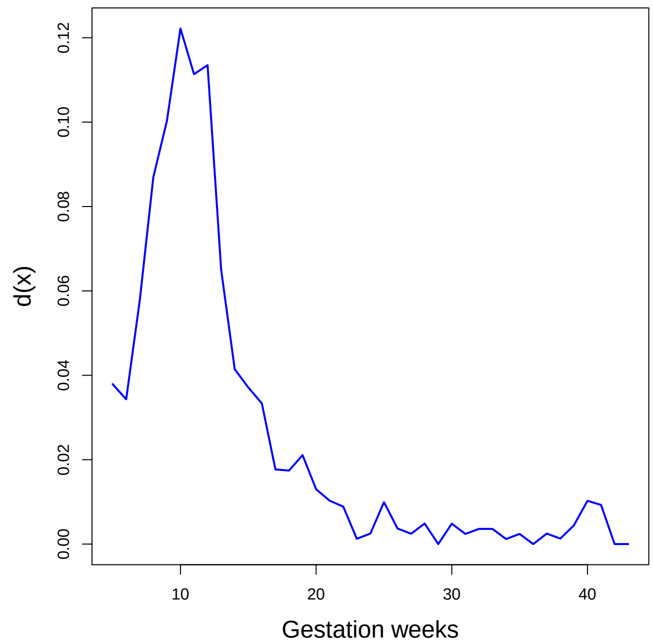
uncertainty in the estimation of maternal exposure. Fetal death data from the CDC are only considered to be complete for late fetal deaths (28+ weeks), and reasonably complete for fetal deaths after gestation week 20. This is due to variable reporting requirements from states, which often require certificates after certain weight and or gestation thresholds. Numbers are reasonably large to allow the calculation of age-specific maternal exposure from fetal deaths occurring at 20+ weeks of gestation [10]. This value is first computed for late fetal deaths.

In order to approach maternal exposure over the entire gestation range (i.e. account for early fetal loss), I use a standard gestation pattern of fetal loss derived from the Goldhaber and Fireman (1991) fetal life table. This fetal life table is a reasonable choice of standard because it was formulated from a large and diverse population with a considerable presence of induced abortion. This choice also has two drawbacks: the lifetable is now about two decades old and the study design did not allow for adequate capture of very early fetal loss (under 6 weeks)[11]. In order to adjust upward the exposure from fetal deaths at 20+ weeks of gestation, this amount is multiplied by the standard ratio of exposures in the Goldhaber lifetable, as depicted in Box 6, where $d(x)$ is the standard lifetable probability distribution function. This ratio comes to a fixed 5.191664. In the calculations presented here, no adjustment was made to allow this ratio to vary by year or by age. In practice, the Goldhaber lifetable allows for separate calculation of ectopic pregnancies. These were included in the numerator below, in order account for them in a rudimentary way. All ectopic pregnancies in the Goldhaber lifetable occur before week 20, thus their inclusion in the numerator below appears to be reasonable. Scaling of this adjustment proceeds only via year to year variation in fetal deaths at 20+ weeks of gestation. The standard probability distribution function by gestation extracted from the Goldhaber lifetable, $d(x)$, is depicted below in Figure 3 (removed of live births and aborted fetuses). Figure 4, below, depicts the age-pattern of maternal exposure from fetal deaths and ectopic pregnancies for the year 2002.

[10] Missing values for gestation weeks were randomly imputed using the age-specific gestation distributions from declared values.

[11] neither of these deficiencies are adjusted for, although this is a particular location for improvement in this adjustment

Figure 3: Goldhaber (1991) d(x) for Fetal Deaths + Ectopic Pregnancies



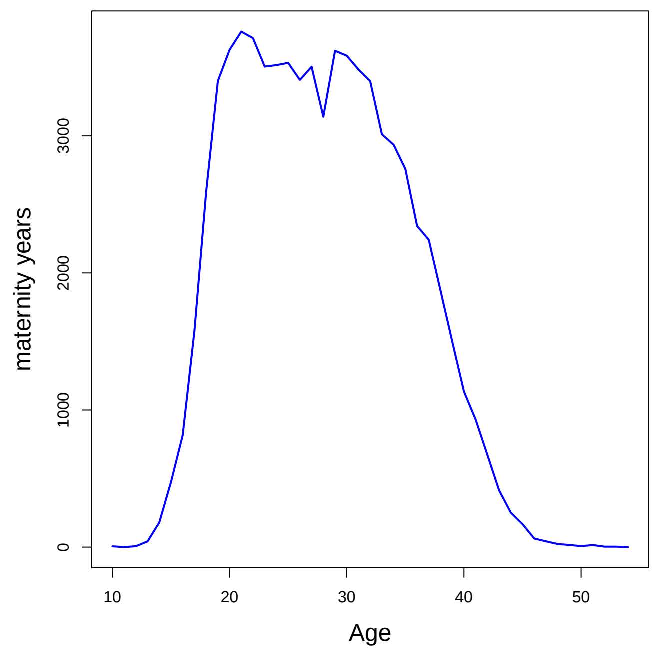
Box 6

$$\text{Goldhaber Ratio} = \frac{\int_{5}^{44} (x + 6wks)d(x)\ dx}{\int_{20}^{44} (x + 6wks)d(x)\ dx} = 5.191664$$

Total Exposure

The sum of the above components, maternal exposure counted backward from events, live births, induced abortions, spontaneous abortions and ectopic pregnancies, is equal to the total maternal exposure preceding events and including the 6 weeks after events counted in a given period, t. It ought not be understood as exposure occurring in year t, although it would be possible to add and subtract exposure from neighboring years where month of event information is available for live birth and fetal death data. For example, most maternal exposure from birth occurring early in a year will have happened in the prior year, whereas some exposure from births counted in December will occur in the following year. This is however slightly less problematic because maternal deaths are often grouped across years in order to reduce noise and arrive at good point estimates. Furthermore, our limited knowledge of the risk of maternal death by weeks of gestation indicates that the highest risk *within* a maternity happens around the time of birth or termination, making event-based allotment of exposure to a particular year somewhat less problematic. The importance of each of the above components to total exposure is evident from the following Figure 5. Despite large numbers of

Figure 4: Adjusted Maternal Exposure from Fetal Deaths + Ectopic Pregnancies, USA, 2002



induced abortions in the United States, these are given considerably less weight, due to their much shorter duration. This also holds for fetal deaths, although their numbers are certainly underestimated here; any early fetal deaths added to this picture would be given even less weight, since most would occur at under 6 weeks of gestation.

Maternal Mortality

In order to proceed to calculate the MMIR, maternal deaths in the numerator were tabulated from public use Multiple Cause of Death data (CDC Vital Stats). This step is taken primarily to illustrate the full result of the method and how it may differ from estimates of age-specific MMR. That these numbers are underestimates of the true numerator is currently well-established in the literature (see e.g. Deneux-Tharaux et al., 2005). More complete estimates for the present study would require access to confidential data from many sources. Figure 6 displays an estimate of the MMIR for the year 2002 [12], where maternal deaths were tabulated only using the variable for main underlying cause of death. The dashed line represents the value of MMR calculated in the same way, but with total live births in the denominator, unsmoothed as tabulated directly from the CDC microdata. The Y-scale is in natural log form.

Worthy of particular mention is that the two estimates are very nearly identical. The only difference of note is that MMR appears to overestimate mortality in the upper ages of childbearing. This difference (much larger than it appears when rates are shown on a natural log scale) may in fact be understated, since exposure from very early fetal loss is not undertaken in this version of MMIR, and it is known that fetal loss increases with age. Furthermore, since the adjustment of fetal death was not allowed to vary by age, adjusting with an age-dependent multiplier may also have the effect of increasing exposure at later ages, thereby decreasing MMIR even more. The overall closeness of these two measures is in fact a very surprising result, especially given the magnitude and directional ambiguity of adjustments made in order to calculate

[12] this estimate was a weighted average of the numerators of 5 years, with 2002 as the central year. The weights were: 2000=.05; 2001=.2; 2002=.5; 2003=.2; 2004=.05. Since ages 10 and 12 were still zero, ages 10-12 were averaged. All other point estimates are in single ages. Smoothing was done with the *loess* command in R, with a *span* of .5.

Figure 5: Total Maternal Exposure, USA, 2002

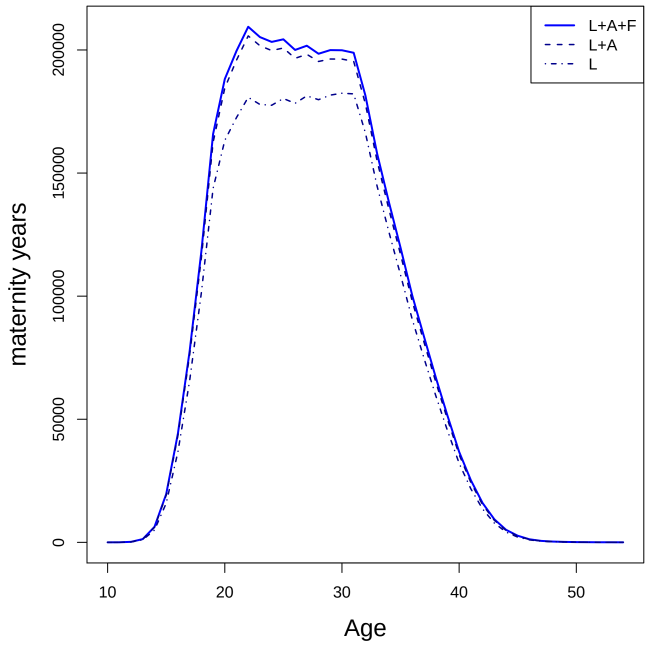
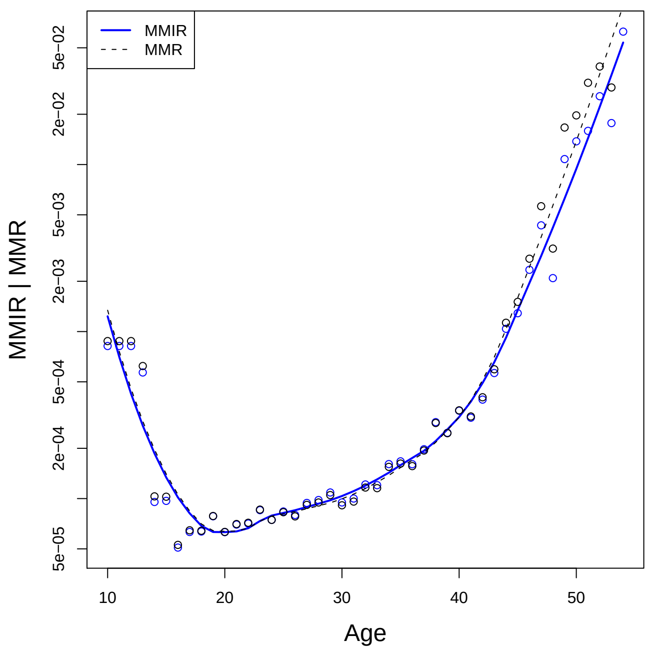


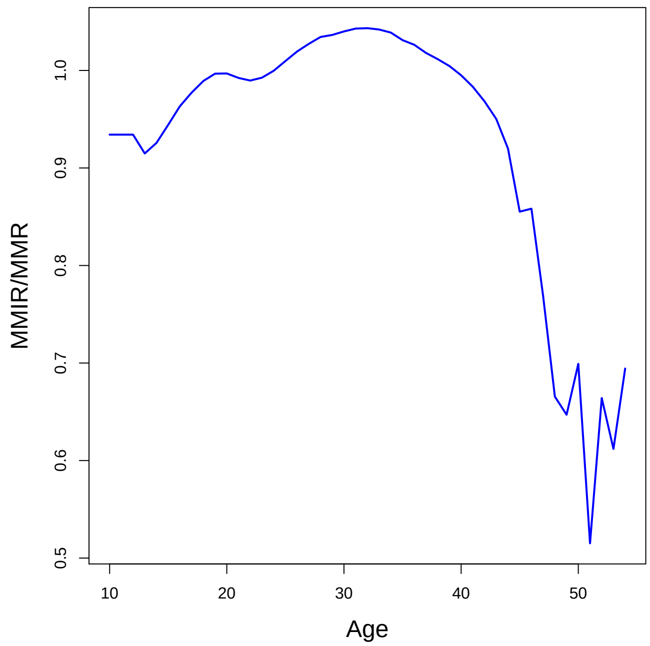
Figure 6: MMIR and MMR, USA, 2002



maternal exposure. This leads me to provisionally conclude that the reductive effect of accounting for twinning and duration very nearly equals the the inflating effect of including induced abortions, fetal loss and the 6 postpartum weeks, at least until age 40.

The ratio of MMIR and MMR is plotted in Figure 7, in order to make more obvious the degree of apparent overestimation that occurs at higher ages of childbearing. Again, the true difference may be much greater. This result ought not lead policy-makers to reduce efforts to combat maternal mortality or morbidity in upper ages. Advice from care providers ought to remain the same, and caution ought to be exercised with childbearing above age 40. It must be born in mind that the curve in Figure 6 remains nearly exponential despite being plotted on a log axis, thereby accelerating much faster than all-cause mortality, which would otherwise appear linear after about age 30.

Figure 7: Age-Specific MMIR/MMR, USA, 2002

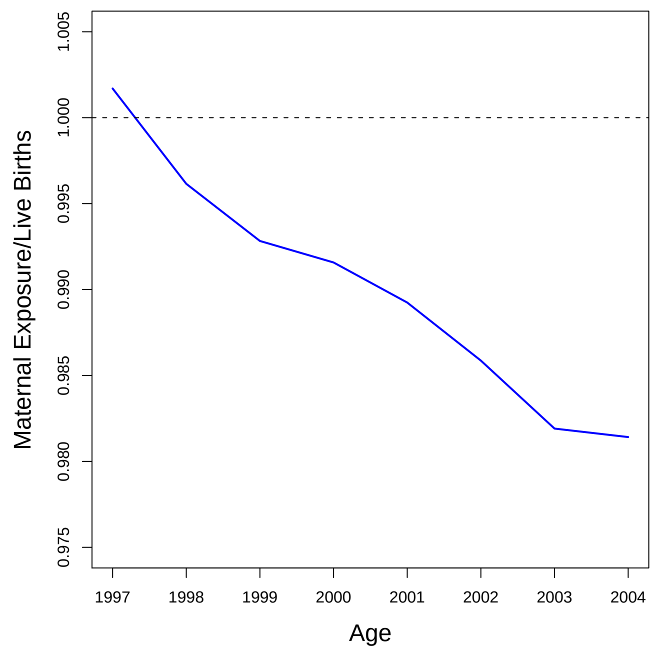


As mentioned earlier, numerator data have been increasing in quality in recent years, thereby including more events in each year and creating the illusion of overall worsening maternal mortality. I therefore compare the ratio of denominators only in order to display trends in distrortion that crude MMR may have been subject to. In this case, over the years 1997-2004, the ratio of maternal exposure to live births has been decreasing every year, meaning that the degree of denominator overestimation has been increasing every year (only in 1994 was MMR inflated due to denominator underestimation). In other words, crude MMR has been subject to underestimation in recent years due to denominator distortion, and this trend has been increasing in magnitude over the entire period (see Figure 8).

Discussion

Further work is needed in order to improve the quality of denominator calculated here. The estimation of maternal exposure has likely been avoided thus far by demographers and epidemiologists due to its challenging pitfalls, especially accounting for unobserved fetal loss and the lack of national statistics on ectopic pregnancies. Saraiya et al. (1999a) uses semi-direct estimation in order to estimate counts of spontaneous abortions, applying rates from an earlier study (Wilcox et al., 1981). Goldhaber et al. (2000) argue that the choice of this standard may not have been optimal, but both authors agree that the issue of estimating counts of early (<20 weeks of gestation) spontaneous abortions remains unresolved, especially given the

Figure 8: Maternal Exposure / Live Births, USA, 1997:2004



competing risk of induced abortions. While there will likely be further developments in estimating numbers of unrecorded pregnancies, current shortcomings present a much smaller obstacle for the semi-direct estimation of maternal *exposure*. Fetal deaths under 20 weeks of gestation receive about 1/4 to 1/5 of the weight assigned to the average pregnancy ending in live birth, simply because the average total gestation of these events is less than or equal to 10 weeks [13], with most fetal wastage occurring by week 10. I argue that estimating maternal exposure is therefore subject to a much lower degree of potential error than estimating the total number of pregnancies.

Nonetheless, the currently proposed estimate certainly underestimates early fetal loss. In the case of the maternal mortality incidence rate, there is uncertainty as to how problematic the absence of this early exposure is. The frequency of very early fetal and embryonic loss is very high, but appears to submit women to considerably less physiological stress than any event occurring in later stages of pregnancy. However, since the ICD definition of maternal mortality also includes deaths from homicide and self inflicted trauma, there is reason to suspect that some deaths may occur *over* this currently unaccounted for exposure (Dannenberg et al., 1995; Frautschi et al., 1994). Psychological or relationship stress may be higher in the moment one learns of a pregnancy. This factor has been studied as it related to birth outcomes, but much less so for maternal outcomes (see Austin and Leader, 2000, for a broad overview). Proper accounting of such events remains a challenge for future assessments of all aspects of maternal death and morbidity, and this study is in need of further sensitivity testing.

Furthermore, a good estimate of exposure in the denominator is also not a perfect solution, since this inherently assumes homogeneity in risk across the course of pregnancy, irrespective of outcome: Week 7 of an early ectopic pregnancy is lumped together with week 20 of a pregnancy ending in live birth and week 5 after an induced abortion. Risks are known to vary by stage of pregnancy and by pregnancy outcome, and

[13] in Goldhaber and Fireman (1991), the mean duration of spontaneous abortions and ectopic pregnancies under 20 weeks was 10, while other studies with different observation schemes, e.g. Wilcox et al. (1989) find much higher proportions of total loss in earlier weeks. The early distribution is not unimodal, but has modes around day 10 and again around week 6.

so lose detail that would be useful in assessing specific causes and risk groups of maternal death.

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