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Review

Setting priorities for safe motherhood interventions in resource-scarce settings

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ABSTRACT

Objective: Guide policy-makers in prioritizing safe motherhood interventions.
Methods: Three models (LOW, MED, HIGH) were constructed based on 34 sub-Saharan African countries to assess the relative cost-effectiveness of available safe motherhood interventions. Cost and effectiveness data were compiled and inserted into the WHO *Mother Baby Package Costing Spreadsheet.* For each model we assessed the percentage in maternal mortality reduction after implementing all interventions, and optimal combinations of interventions given restricted budgets of US$ 0.50, US$ 1.00, US$ 1.50 per capital maternal health expenditures respectively for LOW, MED, and HIGH models.
Results: The most cost-effective interventions were family planning and safe abortion (fpsa), antenatal care including misoprostol distribution for postpartum hemorrhage prevention at home deliveries (anc-miso), followed by sepsis treatment (sepsis) and facility-based postpartum hemorrhage management (pph).
Conclusions: The combination of interventions that avert the greatest number of maternal deaths should be prioritized and expanded to cover the greatest number of women at risk. Those which save the most number of lives in each model are 'fpsa, anc-miso' and 'fpsa, sepsis, safe delivery' for LOW; 'fpsa, anc-miso' and 'fpsa, sepsis, safe delivery' for MED; and 'fpsa, anc-miso, sepsis, eclampsia treatment, safe delivery' for HIGH settings. Safe motherhood interventions save a significant number of newborn lives.
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1. Introduction

The Safe Motherhood Initiative, jointly launched by the World Health Organization (WHO), the United Nations Children's Fund, the United Nations Population Fund, the World Bank, and other organizations, brought maternal and child health to the forefront of public health concerns. Among other goals, this initiative aims to reduce maternal mortality by 75% between 1990 and 2015. However, it has been widely documented that desired improvements in maternal health have not been achieved despite this increased attention and commitment to safe motherhood. Countries in sub-Saharan Africa, in particular, experienced on average no change in the percentage of deliveries assisted by a skilled attendant between 1989 and 1999 [1] and show no signs of achieving the scheduled reductions in maternal mortality [2].

There are several reasons for this lack of success in improving maternal health, but three stand out. First, there is a lack of evidence on the relative effectiveness of safe motherhood interventions in terms of their impact on maternal and neonatal mortality, particularly for those interventions that prevent and treat common causes of these deaths in developing countries. For example, important questions regarding the primary prevention, detection, and treatment of anemia and hypertensive disorders of pregnancy remain unanswered [3,4]. Second, we have failed to implement known effective practices and subsequently improve coverage and quality of maternal health services [5]. For example, although complications of incomplete and unsafe abortions are a major cause of maternal death, a recent survey reported that less than 50% of health centers in 49 developing countries had the capacity to perform manual vacuum aspiration (MVA) [6]. Finally, although the burden of mortality in developing countries accounts for the great majority of maternal and neonatal deaths worldwide, developing countries have scarce resources to attend to these problems and lack the information required to mobilize commitment to improving maternal health and effect policy making for this goal.

The Mother Baby Package (MBP) prescribes a set of interventions that are technically and economically feasible in developing countries [7]. Devised by the WHO, the MBP consists of 18 basic interventions considered essential for decreasing maternal and neonatal mortality in resource-poor settings. The package describes simple, effective interventions needed before and during pregnancy, during delivery, and after delivery for the mother and the newborn (Annex 1). It outlines what can be done to prevent and manage the major obstetric complications at different health care facility levels, and describes the most efficient use of available resources for these interventions. The MBP Costing Spreadsheet estimates the cost of implementing these interventions given local setting parameters and coverage goals. However, these tools do not adequately equip developing countries to maximize their investments in maternal health. A recent study estimated that it would cost US$ 1.80 per capita to implement the MBP standards in Uganda, compared to the US$ 0.50 per capita being spent at the time on maternal and newborn care [8]. Unless Uganda can apportion an additional US$ 1.30 per capita for maternal health, it will need to prioritize the most cost-effective and high impact interventions.

Very little is known about the relative cost-effectiveness of maternal health interventions in developing countries. Recent reports either estimate the cost to implement a specific package of interventions—such as the WHO Report of the Commission for Macroeconomics and Health Report [9]—leaving little to no room for variation, or the most cost-effective group of interventions—but fail to include interventions that would tip the scale in their conclusions. Jowett reviewed the evidence on cost-effectiveness of safe motherhood interventions, but due to incompatibility of outcome measures, was unable to compare the cost-effectiveness of various antenatal, obstetric, and abortion services [10]. More recently, Adam et al. attempted to determine the cost-effectiveness of different maternal health packages and concluded that facility level care (incl. non-comprehensive antenatal care, skilled birth attendance, active management of third stage of labour, management of postpartum hemorrhage (pph) with additional oxytocin, uterine massage, manual removal of placenta, repair of lacerations, and management of shock, as well as neonatal resuscitation) for mothers was considered to be the most cost-effective [11]. However, authors did not include the costs of extremely beneficial interventions such as safe abortion and family planning or misoprostol for home-based deliveries, which would have undoubtedly altered the results. Graham et al. and Levine et al. both conducted cost-effectiveness analyses of interventions that would avert maternal and newborn deaths [12,13]. However, authors of these studies do not include family planning or misoprostol with other safe motherhood interventions, nor do they consider safe abortion services (only post-abortion care, which is considered a part of basic and comprehensive obstetric care, rather than as a separate intervention). Furthermore, in the analysis by Graham et al., the var-

ious intervention packages analyzed were determined beforehand, not allowing for optimization of the most cost-effective interventions within a restricted budget [12].

This study attempts to guide policy-decision makers in prioritising the different components of safe motherhood programs in resource-scarce settings. Here we bring together existing data on effectiveness of safe motherhood interventions and cost these interventions using the MBP Costing Spreadsheet. First, we compare the cost-effectiveness (in terms of cost per death averted) of the basic interventions included in the MBP as well as safe abortion and misoprostol in three model settings (LOW, MEDIUM, and HIGH-infrastructure settings) based on countries in sub-Saharan Africa. Secondly, we assess the percent in maternal mortality reduction of implementing all interventions included in our analysis. Third, we conduct multivariate sensitivity analyses to assess the contribution to variance in cost per death averted for each intervention. Finally, to assess the optimal combinations of safe motherhood interventions within an expected financial constraint, we perform budgetary simulations for each of the three model settings, assuming per capita maternal health expenditures of US$ 0.50, US$ 1.00, and US$ 1.50, respectively (PPP$). These ranges are realistic as according to available National Health Accounts for Africa, countries are spending an average of only 0.50 cents per capita [14], even though the Report of the Commission Macroeconomics and Health recommends US$ 1.80 per capita [8].

2. Data

Socio-demographic data and maternal health indicators were used from the latest available Demographic and Health Surveys (indicated where appropriate). Maternal mortality and economic data used for each country was based on the 2007/2008 Human Development Report [15]. Maternal health program impact ranges were set according to two sources: from existing published estimates [16–24] and from the WHO's estimates included in the MBP Costing Spreadsheet [25]. Sources are described below where appropriate. Cost data for interventions was estimated using the MBP Costing Spreadsheet, except for (i) the cost of providing safe abortion services and (ii) the cost of using misoprostol for the prevention and/or treatment of pph, which were taken from available published cost studies in developing countries [26–28] and the website for Venture Strategies for Health and Development (a non-governmental organization which works directly with misoprostol manufacturers and distributors [29]), respectively.

3. Methods of analysis

3.1. Construction of three model settings

Information from 34 countries in sub-Saharan Africa was gathered to form three models representing LOW-, MEDIUM-, and HIGH-resource settings (Annex 2). Countries were ordered according to per capita health expenditures and divided into thirds to form LOW, MED, HIGH model settings. The models were intended as proxies for the level of infrastructure available in those countries. Means and ranges for each model were estimated for each indicator included in the analyses (Annex 3).

3.2. Cost estimation

All costs used in this analysis are direct costs to the health services. We used the MBP Costing Spreadsheet to estimate the costs of implementing the interventions contained in the package [25]. The costing spreadsheet is flexible, allowing users to change data in the model according to the context in which the interventions are to be implemented. This includes the cost estimates for the individual interventions, for different types of input (drugs, salaries, etc.), different types of costs (recurrent and capital costs), per facility, per capita, per birth, etc. Furthermore, the MBP costing tool also allows the user to estimate costs for three levels of healthcare—health post, health centre, and hospital levels—including the ability to adjust the number of patients able to access care at the different levels, the number of referrals to higher levels of care, and even patient compliance.

All cost estimations used in this study are based on MBP "standard" treatment as well as MBP estimates for the number needing a referral and the number considered as "treated". Exceptions were made, however, in the cases of family planning and safe abortion provision and the prevention/treatment of pph using misoprostol. Data on socio-demographic and health data, as well as coverage rates of interventions, prevalence and incidence of complications and family planning method mix used in cost estimations are based on the profiles established for the LOW, MED, and HIGH model settings (Annex 4).

Two different models for antenatal care (anc) were considered for our analyses. We grouped under 'anc-standard' interventions proposed by the MBP.[1] Under anc-miso, the same interventions were considered, as well as, misoprostol distribution for the prevention of pph in home-based deliveries. Cost estimates for treatment of neonatal complications and postpartum care were included under "Other" MBP interventions. Family planning, treatment of abortion complications, and safe abortion provision were considered as one intervention. The cost of providing safe abortion is added to the estimated family planning costs. Three methods for safe abortion were considered: misoprostol and mifepristone, MVA, as well as dilation and curettage

[1] Treatment of anaemia and sexually transmitted infections were grouped with the standard antenatal care services proposed by the WHO Mother-Baby Package. Antenatal care according to standard WHO Mother-Baby Package consists of: at least four visits of at least 20 min each starting before the last trimester of pregnancy. Diagnostic tests include: haemoglobin, blood group, urine analysis and RPR syphilis test. Treatment entails: iron and folate supplements (60 mg 3 time a day for 90 days; 2 tetanus vaccinations; treatment of malaria and hookworm. Normal delivery under the standard practice includes: haemoglobin, blood group and urine test before delivery; active management of third stage of labor; tetracycline eye ointment for the newborn; iron supplements 3×/day for 14 days after delivery; and a routine postpartum check-up.

(D&C), ranging from US$ 10.95 to US$ 101.36 per client (2007 US$). For the management of postpartum hemorrhage, the standard treatment proposed by the WHO as well as the use of misoprostol were considered: 600 μg of misoprostol for prevention at US$ 0.42 per dose and 1000 μg of misoprostol for treatment at US$ 0.68 per dose (2007 US$).

Standard estimates of the number of women needing a referral or considered treated from the MBP were used for all interventions. However, for anc-miso, family planning and abortion care, and pph management, the estimated number of women treated (taking into account referral and compliance rates) is based on the literature review.

Cost ranges per intervention reflect the range in services provided at lower and higher level facilities (health post vs. health center vs. hospital), what percentage of the population is expected to seek care at each type of facility (including referrals) and costs for procedure or service for all interventions considered. The range in costs for abortion and family planning services, anc, as well as pph management, is also reflective of the type of procedure that is carried out or type of service provided to the patient (misoprostol and mifepristone, MVA, or D&C for safe abortion, distribution of misoprostol or none during anc or pph intervention). For the three model settings, the cost of drugs and other medical materials/equipment are presumed to be the same (given by the MBP). Salaries for health professionals were also assumed to be the same except for in the LOW model where salaries were decreased by 25%.

3.3. Effectiveness and cost-effectiveness estimation

For each intervention we estimated the cost per death averted and the number of potential deaths averted given a fixed budget available for each setting profile (Annex 4). For these analyses, we ran Monte Carlo simulations with 10,000 trials for each intervention, using the established demographic and health profiles and underlying assumptions presented in Annex 3 and 4. We use Crystal Ball 11.1, a stochastic modeling supplement for Excel, to run the simulations [30].

Interventions considered for this analysis were grouped into six categories, family planning and safe abortion, facility-based pph management (which included the use of misoprostol in a small percentage of women seeking care), anc, puerperal sepsis, eclampsia, and safe delivery. Because each intervention (with the exception of family planning and safe abortion) has an estimated potential impact on newborn deaths, the estimates for the cost per death averted also include the newborn deaths averted. The estimates of potential impact of each intervention on newborn deaths are those used by the WHO, embedded in the MBP Costing Spreadsheet (Annex 5). We use information from AbouZahr [31][2] and the MBP [7][3] to link causes of newborn deaths and maternal deaths. In this way, newborn deaths averted due to birth injuries are attributed to obstructed labor; sepsis and meningitis to maternal sepsis; neonatal tetanus, pneumonia, and diarrhea[4] to antenatal care; and birth asphyxia was proportionally distributed to pph and eclampsia.

The cost of averting a death due to unsafe abortion assumes (for all settings) an abortion rate of 34 per 1000 women aged 15–44 [16]. Abortion is largely restricted throughout sub-Saharan Africa, contraception remains difficult to access, and current data on abortions is incomplete as they are often hidden, missed, or misclassified. Assuming a single abortion rate for all three settings is sensible in light of these issues. Although imperfect, the anc intervention is linked to other direct and indirect causes of maternal death which represent 21%, 27%, and 27% of the total maternal deaths for LOW and MED and HIGH settings, respectively (Annex 4). However, the estimates used for potential impact on deaths averted due to anc-standard are from studies of specific interventions generally covered by anc such as malaria chemoprophylaxis [32], and iron supplementation [33]. The estimates used for potential impact on deaths averted due to anc-miso are considered additive. The cost of averting a death due to facility-based pph is based on pph incidence rates of 30% in LOW, 20% in MED, and 13% in HIGH-infrastructure settings [6,20,23]. These conservative assumptions were chosen based on existing reports of pph incidence in extremely poor to less poor settings around sub-Saharan Africa and Asia.

For each intervention assessed, we performed a multivariate sensitivity to test the robustness of the estimates to changes in underlying assumptions.

3.4. Optimization analysis

To assess what combination of interventions would avert the greatest number of maternal deaths in LOW, MEDIUM, and HIGH-resource settings, we conducted an optimization analysis. This was done by establishing the total program costs and associated estimated number of maternal deaths averted for every possible combination of the six safe motherhood interventions. The analysis was run once using anc- standard and once using anc-miso. Sixty-three unique combinations were found using Java programming software. The total budget for each setting was estimated based on per capita expenditures on maternal health of US$ 0.50, US$ 1.00, and US$ 1.50 in the LOW, MEDIUM, and HIGH models, respectively. Based on the estimations for each model setting, combinations whose total program cost exceeded the budget constraint for that setting were also excluded. For each remaining combination, the total potential number of deaths averted was calculated. The results were then sorted to reflect combinations of safe motherhood interventions that maximized the number of maternal lives saved with the available budget.

4. Results

All results are based on women serviced by the safe motherhood program. Tables 1–3 present results from the

[2] See Table 10, titled "How complications affect mother and baby." [31].
[3] See Table 2, title "How complications affect mother and baby." [7].
[4] Via information provided to mothers during ANC visits regarding the importance of exclusive breastfeeding and cholostrum.

Table 1
LOW-infrastructure profile: simulation results.[a,b].

Intervention	Total program direct cost	Direct cost per client	Cost range	Attributed causes of maternal deaths	% Maternal deaths	Estimated # maternal deaths averted	Potential impact in deaths averted	Estimated # newborn deaths averted
FP and SA	US$ 67,222.66			Unsafe abortion	25.0%	32	75–95%	–
Family planning	US$ 43,413.96	US$ 12.05	US$ 4.93–33.42					
Safe abortion	US$ 23,808.70	US$ 45.61	US$ 10.95–101.56					
Antenatal care				Other direct + indirect				
anc-standard	US$ 152,623.39	US$ 7.14	US$ 3.02–12.99		21.0%	7	12–23%	145
anc-miso	US$ 157,523.81	US$ 7.26	US$ 3.02–13.41			30		
Hemorrhage (incl. in anc-miso)				Hemorrhage	25.0%		55–86%	181
Essential obstetric care	US$ 152,419.90			Obstructed labour	8.0%	11	80–90%	36
Normal delivery care	US$ 113,895.55	US$ 20.44	US$ 19.97–20.93					
Obstructed labor	US$ 38,524.35	US$ 75.54	US$ 75.54					
Other obstetric care								
Eclampsia	US$ 76,125.00	US$ 167.93	US$ 167.93	Eclampsia	6.0%	7	48–65%	36
Hemorrhage (incl. misoprostol)	US$ 294,251.18	US$ 34.01	US$ 0.42–64.47	Hemorrhage	25.0%	23	55–86%	36
Sepsis	US$ 18,070.00	US$ 37.31	US$ 30.94–43.68	Sepsis	15.0%	19	75–86%	19
Other MBP interventions	US$ 79,558.75		US$ 1.00–57.65	–	–	–	–	–
Total (anc-standard pkg)	US$ 1,059,913.44				100.0%	99		272
Total (anc-miso pkg)	US$ 1,064,813.86				100.0%	122		308

[a] Costs are presented in 2007 USD.
[b] Results are taken from adjusted MBP Costing Spreadsheet.

Table 2
MED-infrastructure profile: simulation results.[a,b].

Intervention	Total program direct cost	Direct cost per client	Cost range	Attributed causes of maternal deaths	% Maternal deaths	Estimated # of maternal deaths averted	Potential impact in deaths averted	Estimated # newborn deaths averted
FP and safe abortion	US$ 77,740.38			Unsafe abortion	13.0%	16	75–95%	–
Family Planning	US$ 49,273.63	US$ 13.33	US$ 6.10–34.59					
Safe abortion	US$ 28,466.76	US$ 46.88	US$ 10.95–101.56					
Antenatal care				Other direct + indirect				
anc-standard	US$ 208,670.75	US$ 8.51	US$ 4.18–16.04		27.0%	7	12–23%	176
anc-miso	US$ 214,239.39	US$ 8.63	US$ 4.18–16.45			30		
Hemorrhage (incl. in anc-miso)				Hemorrhage	25.0%		55–86%	219
Essential obstetric care	US$ 301,793.22			Obstructed labour	8.0%	11	80–90%	43
Normal delivery care	US$ 232,999.39	US$ 25.97	US$ 25.50–26.45					
Obstructed labor	US$ 68,793.83	US$ 84.13	US$ 84.13					
Other obstetric care								
Eclampsia	US$ 149,528.00	US$ 205.63	US$ 205.63	Eclampsia	12.0%	13	48–65%	43
Hemorrhage (incl. misoprostol)	US$ 334,505.00	US$ 38.00	US$ 0.42–71.42	Hemorrhage	25.0%	23	55–86%	45
Sepsis	US$ 30,873.00	US$ 39.87	US$ 33.28–46.45	Sepsis	15.0%	19	75–86%	24
Other MBP interventions	US$ 125,544.97	US$ 15.60	US$ 1.30–57.65	–	–	–	–	–
Total (anc-standard pkg)	US$ 1,608,188.93				100.0%	89		331
Total (anc-miso pkg)	US$ 1,613,757.57				100.0%	112		374

[a] Costs are presented in 2007 USD.
[b] Results are taken from adjusted MBP Costing Spreadsheet.

Table 3
HIGH-infrastructure profile: simulation results.[a,b].

Intervention	Total program direct cost	Direct cost per client	Cost range	Attributed causes of maternal deaths	% Maternal deaths	Estimated # maternal deaths averted	Potential impact in deaths averted	Estimated # newborn deaths averted
FP and safe abortion	US$ 94,139.31			Unsafe abortion	13.0%	11	75–95%	–
Family planning	US$ 65,293.55	US$ 13.33	US$ 6.10–34.59					
Abortion services	US$ 28,845.76	US$ 46.88	US$ 10.95–101.56					
Antenatal care				Other direct + indirect				
anc-standard	US$ 211,616.63	US$ 8.51	US$ 4.18–16.04		27.0%	4	12–23%	113
anc-miso	US$ 217,263.97	US$ 8.63	US$ 4.18–16.45			19		
Hemorrhage (incl. in anc-miso)				Hemorrhage	25.0%		55–86%	141
Essential obstetric care	US$ 258,875.64			Obstructed labour	8.0%	7	80–90%	28
Normal delivery care	US$ 199,881.12	US$ 25.97	US$ 25.50–26.45					
Obstructed labor	US$ 58,994.52	US$ 106.90	US$ 84.13					
Other obstetric care								
Eclampsia	US$ 128,167.00	US$ 205.63	US$ 205.63	Eclampsia	12.0%	9	48–65%	28
Hemorrhage (incl. misoprostol)	US$ 286,976.00	US$ 38.00	US$ 0.42–71.42	Hemorrhage	25.0%	15	55–86%	28
Sepsis	US$ 26,524.00	US$ 39.87	US$ 33.28–46.45	Sepsis	15.0%	12	75–86%	15
Other MBP interventions	US$ 110,959.00	US$ 15.60	US$ 1.30–57.65	–	–	–	–	–
Total (anc-standard pkg)	US$ 1,470,272.53				100.0%	58		212
Total (anc-miso pkg)	US$ 1,475,919.87				100.0%	73		240

[a] Costs are presented in 2007 USD.
[b] Results are taken from adjusted MBP Costing Spreadsheet.

adjusted MBP Costing Spreadsheet for six major maternal health interventions.

4.1. Total package implementation

Overall, the maternal health interventions presented in Tables 1–3 (except the provision of family planning and abortion services), can avert more newborn deaths than maternal deaths. As expected, the total cost of implementing maternal health programs varies according to the model setting. The cost of providing services in LOW settings is relatively lower, because of the smaller number of available facilities and the lower salaries of health professionals. MED and HIGH model settings have the same cost per client of providing services; differences in total program costs reflect higher coverage rates found in HIGH setting. A breakdown of the contribution of each intervention to the overall cost of implementing the adjusted MBP packages (anc-miso and anc-standard) can be found in Table 4. Facility-based pph management, safe delivery and anc services (-standard and -miso) contribute to the greatest percentage of total program cost, followed by eclampsia, family planning and safe abortion, and puerperal sepsis services.

4.2. Maternal mortality reduction

As the model settings also have different maternal mortality ratios (Annex 3), the expected number of annual maternal deaths differs. Overall implementation of the standard MBP will reduce maternal mortality by an average of 50%. However, implementing the standard MBP plus safe abortion services and facility-based pph management with misoprostol has the potential to reduce maternal mortality slightly more: 59% in LOW-, 53% in MED-, and 52% in HIGH-infrastructure settings. Furthermore, implementation of an MBP that includes safe abortion services, facility-based pph management with misoprostol, and misoprostol distribution during anc for pph prevention during home-based deliveries has the potential to reduce maternal mortality by much more: 73% in LOW-, 67% in MED-, and 66% in HIGH-infrastructure settings.

4.3. Average cost and deaths averted by intervention

Figures 1–3 present results from the cost-effectiveness analyses, based on the estimated number of maternal deaths averted and the cost per death averted by each intervention in LOW, MED, and HIGH settings. The figures demonstrate that the number of maternal lives saved is relatively greater in LOW settings than in MED, or HIGH settings. Furthermore, the cost per death averted is relatively lower in LOW settings.

In LOW, MED, and HIGH settings, *the most cost-effective interventions* are family planning and safe abortion as well as anc-miso. These interventions can potentially save the most number of lives. In LOW settings, the implementation of family planning and abortion services saves the most number of maternal lives, followed by anc-miso, and facility-based pph management which also includes the use of misoprostol. In MED and HIGH settings, implementation of anc-miso averts the most number of maternal deaths, followed by pph management and sepsis.

Safe delivery and eclampsia are *the least cost-effective interventions* in LOW and MED settings, followed by anc-standard. Within HIGH settings, anc-standard is the least effective intervention, followed by safe delivery and eclampsia. Furthermore, anc-standard, eclampsia, and safe delivery care potentially avert the fewest number of maternal deaths compared to all other interventions included in the analysis. In all three settings, anc-miso and family planning and safe abortion services, are the most cost-effective interventions, followed by sepsis and pph management.

Results from the sensitivity analysis on cost per death averted for each intervention show that the cost per client and the percentage of women who have or do not have skilled care during delivery are the major contributors to variance. A negative sensitivity coefficient indicates that with a decrease in the contributing variable, cost per death averted will increase. For deaths due to unsafe abortion, the major contributor to variance is the average cost of family planning per client (LOW: 87%, MED: 79%, HIGH: 86%), followed by contraceptive prevalence (LOW: −8%, MED: −17%, HIGH: −11%). For sepsis and pph, the major contributor to variance is the percent of women being delivered by a skilled birth attendant (sepsis—LOW: 97%, MED: 81%, HIGH: 90%; pph—MED: 89%, HIGH: 81%), followed by the average cost per client (Sepsis—LOW: 3%, MED: 18%, HIGH: 9%; pph—MED: 10%, HIGH: 19%). For pph in LOW-settings, the major contributor to variance is average cost per client (53%) followed by the proportion of women being delivered by a skilled birth attendant (46%). For both eclampsia and safe delivery, the variance is nearly entirely due to the percent of deliveries being delivered by a skilled provider (eclampsia—LOW: 100%, MED: 99%, HIGH: 99%; safe delivery—LOW: 100%, MED: 100%, HIGH: 100%). For anc-standard, within LOW settings, the major contributors are average cost per client (62%) followed by the percentage of women using anc services (38%) in the model setting. Within MED and HIGH settings, the main contributor is average cost per client (MED: 89%, HIGH: 99%). For anc-miso, within LOW and HIGH settings, the major contributors to variance in cost per death averted are percentage of women who deliver without a skilled birth attendant (LOW: −51%, HIGH: −52%), followed by the cost of providing anc-miso services (LOW: 49%, HIGH: 48%). For MED settings, the major contributors are first the average cost (66%), followed by the percent of deliveries without a skilled attendant (−34%).

4.4. Maximizing expected deaths averted

Combining the interventions can potentially avert more deaths in LOW-resource settings. A combination of interventions that includes anc with misoprostol distribution and/or family planning and safe abortion services will avert more deaths than a combination of interventions that includes anc-standard. As expected, implementing all of the maternal health interventions exceeds the avail-

Table 4
Implementation of all interventions: % total program cost.

Intervention	% Total program cost					
	LOW-infrastructure setting		MEDIUM-infrastructure setting		HIGH-infrastructure setting	
	anc-std pkg	anc-miso pkg	anc-std pkg	anc-miso pkg	anc-std pkg	anc-miso pkg
Hemorrhage (incl. miso)	39%	38%	30%	30%	29%	28%
Safe delivery	20%	20%	27%	27%	26%	26%
anc-standard	20%	n/a	19%	n/a	21%	n/a
anc-miso	n/a	21%	n/a	19%	n/a	21%
Eclampsia	10%	10%	14%	13%	13%	13%
Family planning and safe abortion	9%	9%	7%	7%	9%	9%
Sepsis	2%	2%	3%	3%	3%	3%

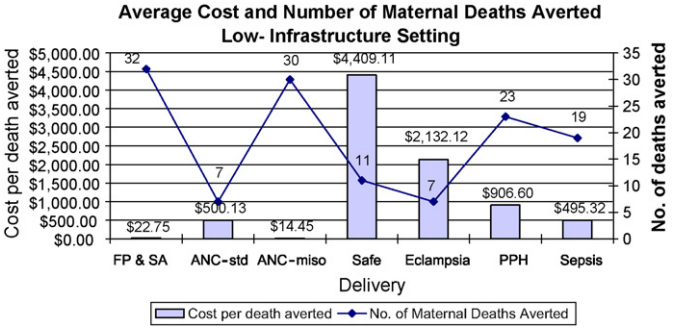

Fig. 1. Average cost and number of maternal deaths averted LOW-infrastructure setting.

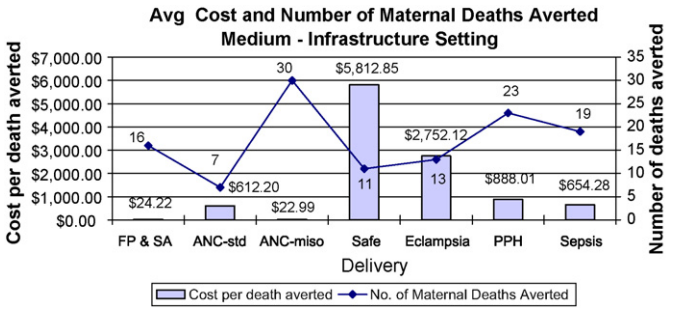

Fig. 2. Average cost and number of maternal deaths averted medium-infrastructure setting.

able budget we established for the three model settings. Tables 5–7 present results from the optimization analysis which utilized our set budget constraints. More than one combination of interventions can result in a similar number of maternal deaths averted. Safe motherhood programs included in order avert the highest number of maternal deaths are the same: family planning and safe abortion as well as anc-miso. Only in HIGH settings, however, additional interventions are required to reach their maximum number of maternal lives saved within a budget constraint. Additional interventions included are sepsis, eclampsia, and safe delivery services.

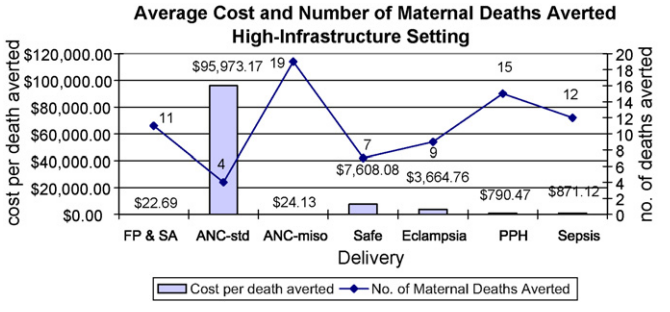

Fig. 3. Average cost and number of maternal deaths averted high-infrastructure setting.

Table 5
Optimal combinations of safe motherhood interventions LOW-infrastructure: budget constraint of US$ 250,000.

Intervention	Total program cost	Estimated # deaths averted
fpsa anc-miso	US$ 224,746.47	62
fpsa sepsis delivery	US$ 237,712.56	62
fpsa delivery	US$ 219,642.56	43
fpsa anc	US$ 219,846.05	39
Sepsis delivery	US$ 170,489.90	30
Sepsis eclampsia delivery	US$ 245,614.90	37
Eclampsia delivery	US$ 228,544.90	18

Table 6
Optimal combinations of safe motherhood interventions MEDIUM-infrastructure: budget constraint of US$ 500,000.

Intervention	Total program cost	Estimated # Deaths Averted
fpsa anc-miso	US$ 291,979.77	46
fpsa sepsis delivery	US$ 410,406.60	46
Sepsis eclampsia delivery	US$ 482,194.22	43
fpsa pph	US$ 412,245.38	39
Sepsis delivery	US$ 332,666.22	30
fpsa delivery	US$ 379,533.60	27
Eclampsia delivery	US$ 451,321.22	24
fpsa anc	US$ 286,411.13	23

5. Discussion and policy implications

The present study has some limitations that need to be acknowledged. For costing interventions we relied mostly on the MBP Costing Spreadsheet. Although the MBP has many advantages, in that it is flexible and allows the user to modify or adapt settings, it has some limitations in that its standard costing estimates are rough and do not vary as they would in real-life. For example, salaries and percent time are the same for similar cadre of health worker for each intervention, even though these will have some variation depending on the local-infrastructure. Costs of drugs and medical equipment are also assumed to have the same values regardless of local-infrastructure and therefore may not reflect current local prices.

In constructing the three model settings, there were also some limitations. The models are based on data from the latest available Demographic and Health Surveys as well as the 2007/2008 Human Development Index. The models assume that the indicators we used are reliable because they are the most currently available. However, we understand that there are limitations in the collection of the data that can impact that accuracy of the indicators. Furthermore, the prevalence and incidence of complications are based on reporting of women that survived.

Table 7
Optimal combinations of safe motherhood interventions HIGH-infrastructure: budget constraint of US$ 750,000.

Intervention	Total program cost	Estimated # deaths averted
fpsa anc-miso sepsis eclampsia delivery	US$ 724,969.92	58
fpsa anc-miso sepsis delivery	US$ 596,802.92	49
anc-miso sepsis eclampsia delivery	US$ 630,830.61	47
fpsa anc-miso eclampsia delivery	US$ 698,445.92	46
fpsa sepsis delivery pph	US$ 666,514.95	45
fpsa anc-miso pph	US$ 598,379.28	45
Sepsis eclampsia delivery pph	US$ 700,542.64	43
fpsa anc sepsis eclampsia delivery	US$ 719,322.58	43
fpsa sepsis eclampsia delivery	US$ 507,705.95	39
anc-miso sepsis delivery	US$ 502,663.61	38
fpsa anc-miso delivery	US$ 570,278.92	37
anc-miso eclampsia delivery	US$ 604,306.61	35
Sepsis delivery pph	US$ 572,375.64	34
fpsa anc sepsis delivery	US$ 591,155.58	34
anc-miso pph	US$ 504,239.97	34
fpsa delivery pph	US$ 639,990.95	33
anc sepsis eclampsia delivery	US$ 625,183.27	32
fpsa anc eclampsia delivery	US$ 692,798.58	31
Eclampsia delivery pph	US$ 674,018.64	31
fpsa sepsis delivery	US$ 379,538.95	30
fpsa anc-miso	US$ 311,403.28	30
fpsa anc pph	US$ 592,731.94	30
Sepsis eclampsia delivery	US$ 413,566.64	28
fpsa eclampsia delivery	US$ 481,181.95	27
fpsa pph	US$ 381,115.31	26
anc-miso delivery	US$ 476,139.61	26
anc sepsis delivery	US$ 497,016.27	23
fpsa anc delivery	US$ 564,631.58	22
Delivery pph	US$ 545,851.64	22
anc eclampsia delivery	US$ 598,659.27	20
Sepsis delivery	US$ 285,399.64	19
anc pph	US$ 498,592.63	19
fpsa delivery	US$ 353,014.95	18
Eclampsia delivery	US$ 387,042.64	16
fpsa anc	US$ 305,755.94	15
anc delivery	US$ 470,492.27	11

Interventions' efficacy are assumed to be the same for all settings, although this may vary depending on local capacity.

As with all modeling exercises, the final results depend on the accuracy of the assumptions used. For this study, some assumptions relate to coverage rates and others to the potential impact of the interventions on maternal mortality. While coverage rates we used are within reach of countries that compose the three settings, it is unclear if every country can achieve the same efficacy of interventions. The efficacy and the costing of interventions used assume standards, a certain level of quality of care, and efficiency in service delivery embedded in the MBP. Moreover, efficacy rates are usually taken from relatively small and well-run studies, and for most of them we have very little evidence of impact on a population level. However, in order to inform all of our decisions, we used the best available data.

Two of the three most cost-effective interventions are preventative, and only require low-cost technologies. The most cost-effective intervention, in terms of cost per death averted, for all three settings is anc-miso which is mostly due to the added value of including misoprostol distribution during standard anc visits to prevent pph in home-based deliveries. Since the MBP was devised, data has accumulated that misoprostol is an effective uterotonic [34].[5] It can be easily administered orally, rectally, vaginally or sublingually, and does not require syringes or intravenous (IV) equipment. In anc-miso, women would be given 600 μg of misoprostol and asked to take the tablets after the birth of their babies and before the delivery of the placenta should they be unable to come to the facility for a delivery. Furthermore, misoprostol is also inexpensive, easy to store, and stable in field conditions [35]. Overall, compared to other interventions, anc-miso saves the most number of lives in MED- and HIGH-settings. anc-miso saves the second most number of lives in LOW-settings.

In LOW-settings, the provision of family planning and safe abortion services saves the most number of lives and has the second lowest cost per death averted compared to the other interventions. The third most cost-effective intervention in LOW-settings is sepsis care. However, pph management is the third highest contributor to the number of deaths averted. In MED-settings the second and third most cost-effective interventions are the same as in LOW-settings. In terms of number of deaths averted, pph management is the second highest contributor, followed by Sepsis care. In HIGH-settings, the second most cost-effective intervention is the same as in LOW- and MED-settings, followed by pph management. The second and third highest contributors to number of deaths averted are the same as in MED-settings.

These findings suggest that maternal deaths due to unsafe abortion and program costs related to treatment of abortion complications could be reduced with the expansion of family planning programs and the inclusion of medication abortion and post-abortion care. Increasing access to high quality contraceptive services would decrease unwanted pregnancies and would also prevent a large number of induced abortions [36].

An interesting finding is that although pph is the largest cause of maternal death worldwide, it is only the third highest contributor to the number of deaths averted in LOW-settings and the second highest contributor in MED- and HIGH-settings. However, this is not surprising especially in LOW-settings, where a large number of deliveries are still taking place at home and pph management is mainly facility-based. Overall, any effective intervention that could reach a high coverage would avert the most deaths and prove to be cost-effective.

Although anc-standard, saves drastically fewer maternal lives, we recognize its importance in averting newborn deaths, by treating and preventing underlying diseases such as malaria and hookworms, educating women about warning signs, possible complications and where to seek help. It would be imprudent, however, to spend a large portion of resources solely on antenatal care. Most of the complications that happen during delivery and shortly thereafter, cannot be predicted during antenatal care screening [37]. Moreover, more than half of deliveries in developing countries occur in the home, without a skilled birth attendant [38]. As such, the addition of misoprostol distribution to anc visits for women who are unable to have a facility-based delivery greatly improves the cost-effectiveness of anc by preventing the most common cause of maternal death worldwide—postpartum hemorrhage.

As shown in Tables 5–7, more than one combination of interventions can result in the same average number of maternal deaths averted. The combination of interventions resulting from the optimization model can be used as an indication of the programs that should be prioritized and expanded. Furthermore, program planers can also select from a combination of interventions that best suits the local context, infrastructure and human resources capacity, as well as considers local achievements in maternal mortality reduction with already established interventions. In scenarios where achievements have not been made with currently established interventions, we suggest that more cost-effective strategies be prioritized to increase gains in maternal lives saved. For example, in a high fertility setting where abortion is restricted by law, most deliveries take place at home, and standard anc coverage is relatively high, we recommend that a combination of interventions that will make significant progress in averting deaths, such as anc with misoprostol distribution plus family planning services, be prioritized and scaled-up to reach highest possible coverage.

To increase local capacity to fully implement all available interventions, we suggest exploration of strategies to overcome budgetary shortfalls, such as those to increase resources through cost-savings, recovery, and reduction. Cost-saving strategies, such as the implementation of fees, are encouraged for all interventions, and should be set according to ability to pay. For example, some family planning clients in sub-Saharan Africa already contribute by paying for commodities and should continue to do so. Monies saved can be used to subsidize commodities for individuals who are unable to pay their cost [39]. Subsidizing contraceptive methods to the poor is highly

[5] See Tables 4 and 6 in Ref. [34].

recommended because of its high-cost benefit [37]. Furthermore, this can be managed through public-private partnerships, such as using social marketing outlets to distribute non clinic-based family planning methods such as pills, condoms (male and female), and injectables.

An example of a cost-reducing strategy is the examination of specific methods to carry out an intervention and choosing that which is most cost-effective. For example, drastic changes in the program cost of abortion services can be observed depending on the type of procedure or method of carrying out the abortion. MVA is shown to be the more cost-effective of the surgical methods [40–42]. However, new evidence shows that medication abortion (e.g. misoprostol and mifepristone) not only has similar program effectiveness as surgical methods but is more cost-effective because it costs significantly less [34,43]. Therefore, when implementing comprehensive abortion services, efforts should be made to expand access to the lower costing technology—medication abortion—and to make it the first line procedure for induced abortions and treatment of incomplete abortions.

The ability and willingness to pay can assist in recovering program costs. For example, recent findings from a study ($n = 755$) in rural Tanzania using misoprostol for the management of pph indicate that overwhelmingly, women are wiling to purchase the tablets (86%), with as many as 39% willing to pay as much as 1500TSH (US$ 1.20). In Tanzania, this is equivalent to the cost of dinner for a family of six [29]. Therefore, although anc can be very expensive, we see it can be a cost-effective intervention by simply adding the distribution of misoprostol at anc for home-based deliveries. Misoprostol distribution through anc would not only increase access to pph preventative services, it would reduce costs of anc because the drug is low in cost, does not require a skilled birth attendant to be administered, and addresses the leading cause of maternal mortality.

Utilization of higher level facilities such as hospitals should be reserved for referrals. Higher level facilities should not spend resources on primary health care service provision. The only exception could be delivery, in cases where the hospital is the nearest facility. Some procedures requiring low technology could be directed toward lower level health providers. For example nurse-midwives should be designated to insert IUDs instead of doctors, and also trained in MVA, medication abortion, and post-abortion care. At the same time, these procedures could be performed at the lower level facilities instead of hospitals, with the exception of necessary referrals. Antenatal care should be provided by nurse-midwives at health centers and the health post, and in general doctors should see only referrals. The WHO review of standard routine anc concluded, moreover, that reducing the number of visits would not decrease the potential impact on mother or newborn health [3]. Combining these changes could result in cost reductions.

Setting priorities based on cost-effectiveness analyses does not take into consideration the influence of cultural, political and organizational factors in each setting. These factors can positively or negatively influence priority setting processes even in places where more resources could potentially be allocated to safe motherhood. For example, although family planning and safe abortion services may be the most cost-effective strategy in reducing maternal deaths in resource-scarce settings, there are significant cultural barriers that can result in challenges in implementation.

Various strategies have been used with a noticeable degree of success for increasing attention to reducing maternal mortality. They vary from generation of political will to using human rights principles [44]. Shiffman has identified four key factors that program planners need to address in order to help create political will: (i) give evidence of the problem, (ii) identify political figures related to the cause, (iii) organize events that disseminate information about the problem, and (iv) provide politicians with evidence that the problem is surmountable [45].

6. Conclusion

Maternal Health program planners need reliable estimates of costs to renew their efforts to address maternal mortality and morbidity. The MBP Costing Spreadsheet has been designed to assist local program managers in quickly making these cost estimates. This paper contributes to existing evidence on the importance of setting priorities for safe motherhood in resource-scarce settings. Our results show that family planning and safe abortion services and antenatal care which includes the distribution of misoprostol for pph prevention at home births are the two most cost effective interventions. Many maternal health interventions save a significant number of newborn lives. A dollar spent in LOW-settings saves more lives than in HIGH-settings. To save the most number of maternal lives, programmatic decisions need to be made based on how much is allocated for safe motherhood programs and, of the priority interventions, which ones can be implemented on a large scale given the current budget.

To achieve the expected 75% reduction in maternal mortality by 2015 will require program planners to make informed and evidence-based choices when allocating scarce resources. The combination of interventions that result in the largest number of maternal and newborn deaths averted should be prioritized and expanded to cover the greatest number of women at risk. Concurrent efforts to generate political will can help draw more attention to safe motherhood problems.

Appendix A. Supplementary data

Supplementary data associated with this article can be found, in the online version, at doi:10.1016/j.healthpol.2009.08.012.

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