**Modelling of the postnatal period of pregnancy within the Thanzi La Onse Model**

**Background: The Thanzi La Onse Model**

As part of the Thanzi La Onse program a model is being developed which aims to capture the health experiences of the population of Malawi and the consequent interactions with the health care system. The intent is that this model will help to inform future delivery of health care in Malawi. The model is an individual based model – which means we explicitly simulate the individual life and health experiences of a representative proportion of population of Malawi. The simulation initiates on 1 Jan 2010 and we attempt to simulate the attributes of the population at that point. We can run the model forward to any specified future time point. Each potential intervention and its associated diseases are being modelled. This is being divided into separate disease/intervention modules. This document describes the module on the postnatal period of pregnancy.

**Background: General approach to decisions on modelling causal influences and effects of interventions**

This module was designed in the context of an overall approach to modelling causal effects in general and causal effects of interventions in particular. The overall intent is to adopt as simple a structure as can be conceived, whilst still capturing the essential elements of a disease and the interventions used to prevent or treatment. We include a causal link between a “variable” (by which we mean a characteristic or property of an individual, whether that be demographic, social or biologic), and risk of disease or another variable if there is strong evidence from an overall body of studies that such a causal link exists and is at least moderately strong. In informing such decisions we place particular value on RCTs or studies with a quasi-experimental design such as analyses based on an instrumental variable. There is no expectation that such studies will be from Malawi or even from Africa. If there are such local studies and in the unlikely event that they provide strong evidence to suggest that the causal link is substantively different in Malawi then the intent is that this is taken into account and the Malawi-specific link included.

In the special case of a potential causal variable which relates to whether an individual has experienced or is experiencing an intervention the intent is to only include interventions if there is substantial RCT evidence of their beneficial effect, based on trials with objectively ascertained clinical endpoints with low risk of serious bias. Whilst DCP-3 (and to some extent the Malawi EHP) provides an initial list of such interventions and the evidence to support them, where possible our intent has been to form our own opinion on intervention efficacy based on the source trials.

Unless there is evidence to the contrary, the intent is to summarize and incorporate intervention effects into the model as relative risks or rates rather than absolute differences due to the fact that such measures are less likely to differ substantively by context. Interactions between characteristics (on the multiplicative scale) are only to be incorporated if there is strong evidence. Again, we have not intended to rely on data from Malawi or Africa for such evidence but if local evidence exists which strongly suggests a different effect than elsewhere then the intent is that this modified effect is incorporated in the model.

**Background: Demographic and social characteristics modelled**

Based on data on the distribution of the population in Malawi according to geographic location we assign individuals a geographic location, which maps onto whether they are classified as living in a rural or urban area. Informed largely by data from the Malawi DHS, variables are also created indicating the person’s wealth level (based on 5 quintiles), whether the person has access to improved sanitation, clean drinking water, hand washing facilities, and whether they experience indoor air pollution (wood burning stove). We assign individuals a current education status (none, primary, secondary) which is updated 3 monthly from age 5 to 20. We assign individuals a current education status (none, primary, secondary) which is updated 3 monthly from age 5 to 20. From age 15 on BMI (in 5 groups) is assigned, as well as using tobacco, drinking excess alcohol, having low exercise, high salt intake, high sugar intake. The status with regard to such variables for individuals can change over time. The influences between these variables are described in detail in a separate document.

**Approach to modelling a natural history of the postnatal period of pregnancy: rationale for model structure and choice of parameter values**

This model describes the maternal and neonatal outcomes of the postnatal and neonatal periods (see table 1) including interventions reasonably delivered as part of routine postnatal care (PNC) inpatient care for mothers and newborns with complications during this time. Determining individual outcomes for mother and newborns within the first 24-48 hours after birth is managed by the labour and newborn outcome models respectively – please see the associated methods documents for a full description of this. As with all maternal and perinatal health models a natural history approach was used to develop this model. We have modelled the onset and progression of each condition (where appropriate), including the causal impact of predictor variables, in the absence of healthcare interventions. Likelihood of death, calculated as described below, is applied to all women or neonates who develop complications associated with the postnatal period.

**Table 1. Definitions used within this module**

|  |  |
| --- | --- |
| **Term** | **Definition and Source** |
| *Postnatal Period* | *The period beginning immediately after the birth of the baby and extending up to six weeks (42 days) after birth (WHO 2010)* |
| *Neonatal period*  | *The first 28 days of a child’s life (WHO 2006)* |
| *Early neonatal period* | *Days 0-6 of a child’s life (Oza et al., 2015)* |
| *Late neonatal period*  | *Days 7-28 of a child’s life (Oza et al., 2015)* |
| *Maternal Sepsis* | *A life-threatening condition defined as organ dysfunction resulting from infection during pregnancy, childbirth, post-abortion, or postpartum period (The World Health Organisation 2017).*  |
| *Endometritis* | *Infection of the upper genital tract including endometrium, myometrium, and surrounding tissue (Dalton and Castillo, 2014)* |
| *Secondary postpartum haemorrhage* | *Abnormal bleeding at 24 hrs to 6-12 weeks postnatal (The Association of Obstetricians & Gynaecologists of Malawi, 2014)* |
| *Vesicovaginal fistula* | *An abnormal opening between the bladder and the vagina that results in continuous and unremitting urinary incontine*nce. (Stamatakos et al., 2014) |
| *Rectovaginal fistula*  | *An abnormal epithelial-lined connections between the rectum and vagina (Debeche-Adams and Bohl, 2010)* |
| *Early-onset neonatal sepsis* | *Sepsis evident within the first 7 days of life (Chan et al., 2015)* |
| *Late-onset neonatal sepsis*  | *Sepsis evident after the first 7 days of life (Chan et al., 2015)* |

**Variables modelled**

Variables stored within this model are concerned with information about a woman’s current postnatal period, complications experienced by either a mother or her child during this period and any treatment delivered to mother or baby.

Variables about the current postnatal period include the identification number of a woman’s most recent child (integer) and the number of weeks into the postnatal period a woman is (integer (1-6)). Complication variables for the mother include if she is experiencing postnatal hypertension (none, resolved, gestational hypertension, severe gestational hypertension, mild pre-eclampsia, severe pre-eclampsia, eclampsia), postnatal infection (endometritis, urinary tract, skin/soft tissue or other) or sepsis (True/False), secondary postpartum haemorrhage (True/False), anaemia causing deficiencies (iron/folate/b12) or anaemia (mild, moderate, severe) and obstetric fistula (vesicovaginal, rectovaginal). Currently, in this period, the only complications for neonates that we have modelled are early-onset neonatal sepsis (True/False) and late-onset neonatal sepsis (True/False).

Treatment variables for the mother include the number of PNC visits attended during this postnatal period (integer), if she is receiving oral antihypertensives (True/False) or received intravenous antihypertensives during an emergency (True/False), if she has received case management for secondary postpartum haemorrhage (True/False) if she has received case management for postnatal sepsis (True/False) or if she has received magnesium sulphate as management for severe pre-eclampsia/eclampsia (True/False)

Treatment variables for the neonate include the number of PNC visits attended during this postnatal period (integer), if they received injectable antibiotics as management of neonatal sepsis (True/False) or if they received full supportive care as management of neonatal sepsis (True/False).

**Updating variables**

This model updates the variables described above at a number of different points as the simulation moves forward in time. When the simulation generates a birth we update variables in the model relating to obstetric fistula and persistence or resolution of maternal antenatal hypertension and or anaemia. Following this, incidence of maternal and neonatal complications is applied weekly, starting in week 1 (day 2-7 post birth) until week 6 (day 36-42 post birth), to a population of women who have just delivered and their newborns. Figure one shows the sequential application of incidence of maternal complications within the model. This format is replicated, unchanged, for weeks 1-6. Not show in this figure, but described below, is the management of progression and resolution of hypertension per week or the risk of maternal death associated with complications.

**Figure 1. Application of incidence of maternal complications** **in the postnatal period**

We do not replicate the structure in figure one for neonates as we simply apply risk of developing sepsis each week. Currently we use week 7 as the point at which all variables are reset (to prevent issues with future pregnancies) except those which represent properties that remain with the mother/neonate for life. This is a broadly similar structure to the application of risk within the antenatal period, except that individual level risk is applied weekly as opposed to monthly. Variables relating to treatment are updated within the individual health care seeking interactions in order to modify individual risk of death in the instance of successful treatment.

**Incidence of Maternal Complications and Death in this model**

There are a number of complications, seen in figure 1, which a mother is at risk of developing at multiple time points across the continuum of pregnancy (i.e. hypertension or anaemia). In order to prevent repetition in documentation the following sections will provide detail descriptions of complications that are novel to the postnatal period and only provide information related to how other complications, that have been descried elsewhere, vary contextually within this time period of pregnancy. Additionally we will signpost to relevant documentation where a more detail natural history model is provided. Calculation of individual risk of death is described towards the end of this section.

***Secondary Postpartum Haemorrhage (PPH)***

Within the labour model, and the labour model methods document, we describe in detail the natural history and associated treatment of primary PPH. Within this model we apply an individual risk of secondary PPH, which constitutes any amount of significant bleeding from the genital tract from 24 hours after birth until 6 weeks postpartum (Babarinsa, Hayman and Draycott, 2011), every week until the end of the postnatal period. The two most common suggested causes of secondary PPH are ‘infection’ and retained products of conception however but there are a multitude of other possible factors increasing risk of bleeding including uterine or placental abnormalities, caesarean section wound dehiscence, bleeding disorders and trauma (Babarinsa, Hayman and Draycott, 2011; Aiken *et al.*, 2012).

**Figure 2. Natural history model of secondary PPH**



Due to the considerable variation in possible causes, many of which are not explicitly modelled within TLO, we assume all women experience a baseline risk of secondary PPH which will be modified by identified risk factors that are captured within the framework. The search process for these factors has not yet been completed.

***Postnatal infection and sepsis***

As with PPH, risk of infection and sepsis following birth is first applied in the labour model. A full description of the natural history model of postnatal infection and sepsis is described within the labour model methods document. We use the same model during the remainder of the postnatal period, assuming women are at risk of developing endometritis, urinary tract infection, skin/soft tissue or ‘other’ infections (Dalton and Castillo, 2014; Bonet *et al.*, 2020) during this time which may develop into sepsis requiring treatment. The search process for risk factors has not yet been completed.

***Hypertensive disorders***

Incidence of the hypertensive disorders is first applied in the antenatal model where women are able to develop pre-eclampsia or gestational hypertension and experience progression of these diseases to more severe forms (severe gestational hypertension, severe pre-eclampsia or eclampsia) during the course of their pregnancy and into the intrapartum period.

Whilst the majority of cases of hypertensive disorders onset during pregnancy there is a significant burden of de novo hypertension which onsets for the first time during the postnatal period (Matthys *et al.*, 2004; Sibai, 2012; Goel *et al.*, 2015) Additionally, whilst a significant proportion of women with hypertension will become normotensive following delivery some will also continue to experience hypertension, and even a worsening of disease, within the postnatal period (Goel *et al.*, 2015). To reflect the epidemiology of these conditions we manage the incidence and resolution of hypertension in the postnatal period in the following ways, varying according to whether the individual is hypertensive at the time of birth. For those women:

* On birth we apply a probability that women with a pre-existing hypertensive disorder of pregnancy will experience resolution of their condition – otherwise they remain in the same disease ‘state’ as during labour
* From week one we apply a probability of resolution to all hypertensive women weekly throughout the postnatal period
* For women whose hypertension doesn’t resolve we apply risk of progression to a more severe state

For women who are not hypertensive at birth:

* We apply a weekly risk of developing either mild pre-eclampsia or mild gestational hypertension (see figure 1) from week 1
* From the following week we apply a apply risk of progression to a more severe state

Risk factors increasing risk of disease onset and the structure of the natural history models remains unchanged from the antenatal model. Please see the associate methods documents for these flow diagrams.

***Anaemia and deficiencies***

The prevalence of maternal anaemia within the postnatal period remains high in settings contextually similar to Malawi (Kofie *et al.*, 2019; Abebaw, Gudayu and Kelkay, 2020) and remains an important predictor of maternal death (Daru *et al.*, 2018). As with the hypertensive disorders, we assume that individuals with anaemia and/or associated deficiencies will carry these properties into the postnatal period and women therefore retain the ‘severity’ of their anaemia following birth. As with the pregnancy model we do not apply a probability that anaemic women will progress to more severe anaemia either after birth or later within the postnatal period. Women without anaemia are at risk of developing the condition postnatally and this risk is applied weekly. Any risk factors identified for antenatal anaemia are currently used within this model to modify individual risk of anaemia postnatally.

**Obstetric fistula**

Within low-income countries obstetric fistula (vesicovaginal or rectovaginal – defined in table 1) remains a significant cause of morbidity in women following birth (Tunçalp *et al.*, 2015) with an estimate incidence in Malawi of 1.6 per 1000 women (Kalilani-Phiri *et al.*, 2010) . The impact of fistula on women is profound and complex and can lead to clinical outcomes such as incontinence and repeated infection as well as nuanced social outcome such as degradation of martial relationships and community stigmatisation (Yeakey *et al.*, 2009; Drew *et al.*, 2016; Changole *et al.*, 2019). Within Malawi and similar settings the burden of obstetric fistula is driven, almost exclusively, by delays in women receiving adequate care around the time of delivery- especially in the context of prolonged and/or obstructed labour (Changole, Combs Thorsen and Kafulafula, 2018). Therefore whilst we apply a one-off risk of fistula to all women, to account for other iatrogenic causes, and that risk will be significantly increased in women who have experience obstructed labour.

We do not assume obstetric fistula contributes to maternal mortality as a primary cause of death. Morbidity is captured through the associated DALY weights for both vesicovaginal and rectovaginal fistula.

**Incidence of Neonatal Complications and Death in this model**

At present neonatal sepsis is the only neonatal complication included in this model. Whilst sepsis is one of the primary causes of neonatal death (Oza *et al.*, 2015) there are a considerable number of other drivers of mortality which are either managed by models already under development (such as pneumonia or diarrhoea) or models that have yet to be developed. As the underlying determinants of early-onset sepsis are largely associated with birth and delivery (see below) late-onset sepsis is largely due to community transmission – which is outside of the focus of the maternal and perinatal health models, but will be a focus of child health modelling.

***Neonatal Sepsis***

As seen in table 1, the definitions of sepsis within the neonatal period are based around the timing of onset. Therefore the application of risk of early-onset sepsis is split between the newborn outcomes model (responsible for day 0-2) and this model (responsible for the remainder of week 1). As with maternal sepsis we apply the same natural history structure and risk factors first introduced in the newborn outcomes module, within this module also. This is consistent with the literature which suggests that determinants of early-onset infection and sepsis are largely due to vertical transmission from the mother and/or nosocomial factors around the time of delivery (Simonsen *et al.*, 2014; Chan *et al.*, 2015). This means neonates have incidence of early-onset sepsis applied twice, once on birth and again in week one. Currently onset of sepsis within week one is randomised to replicated greater burden towards the first few days of the week.

From week 2 of the neonatal period we apply individual risk of late onset sepsis which follows a very simple natural history model seen in figure 3.

**Figure 3. Natural history model of late-onset neonatal sepsis**

As mentioned above, we are applying an incidence rate of all-cause late-onset neonatal sepsis for the remaining weeks of the neonatal period. This is currently a placeholder for more detailed work but allows us, for the time being, to replicate incidence, disability and rates of death associated with sepsis in the wider TLO model.

**Disability weights for this model**

Disability weights for maternal and neonatal complications associated with postnatal period are show in table 2 and are taken from Salomon (2012). We apply the same weights as used within the antenatal, labour and neonatal outcome modules as appropriate. We have highlighted in the table which weights are associated with acute events and which are life-long or until treatment has been received.

**Table 2. DALY weights used within this module**

|  |  |  |
| --- | --- | --- |
| **Condition** | ***Weight*** | **Notes** |
| Moderate maternal haemorrhage | 0.114 (0.078,0.159) | **-** |
| Severe maternal haemorrhage | 0.324 (0.22,0.442) |  |
| Maternal sepsis | 0.133 (0.088,0.19) |  |
| Vesicovaginal fistula | 0.342 (0.227,0.478) |  |
| Rectovaginal fistula | 0.501 (0.339,0.657) |  |
| Mild maternal anaemia | 0.004 (0.001,0.008) |  |
| Moderate maternal anaemia | 0.052 (0.034,0.076) |  |
| Severe maternal anaemia | 0.149 (0.101,0.209) |  |
| Mild maternal hypertension | 0.049 (0.031,0.072) |  |
| Mild motor impairment due to neonatal sepsis and other neonatal infections  | 0.01,0.005,0.019 |  |
| Moderate motor impairment due to neonatal sepsis and other neonatal infections  | 0.061,0.04,0.089 |  |
| Severe motor impairment due to neonatal sepsis and other neonatal  | 0.402,0.268,0.545 |  |
| Severe infection due to neonatal sepsis and other neonatal infections  | 0.133,0.088,0.19 |  |
| Mild motor plus cognitive impairments due to neonatal sepsis and other neonatal infections | 0.031,0.018,0.05 |  |

**Maternal death**

For any women who experience an acute complication during the postnatal period (sepsis, secondary PPH and eclampsia) we apply a case fatality rate to determine if they will survive or die due to this complication. As with the labour model, women are able to develop multiple complications within the same week and therefore have risk of death for each complication applied- considerably increasing the overall risk of death. For women who seek care for treatment, risk of death is applied after care has been delivered to allow for treatment effects to modify risk. Additionally to the risk of death secondary to acute complications, we apply a weekly risk of death from severe hypertension, which is largely asymptomatic, but can contribute to death.

**Neonatal death**

Similarly to maternal deaths, neonates who experience early or late onset sepsis have an individual risk of death applied (modified by treatment). Surviving neonates are then at risk of developing disability.

**Table 3. Description of variables created relating to the postnatal period**

|  |  |  |
| --- | --- | --- |
| **Variable** | **Description** | **Notes and Major Assumptions** |
| pn\_id\_most\_recent\_child' | person\_id of a mothers most recent child |  |
| pn\_postnatal\_period\_in\_weeks | The number of weeks a woman is in the postnatal period (1-6) |  |
| pn\_pnc\_visits\_maternal | The number of postnatal care visits a woman has undergone following her most recent delivery |  |
| pn\_pnc\_visits\_neonatal | The number of postnatal care visits a neonate has undergone following delivery |  |
| pn\_htn\_disorders | Hypertensive disorders of the postnatal period ('none', 'resolved', 'gest\_htn', 'severe\_gest\_htn', 'mild\_pre\_eclamp', 'severe\_pre\_eclamp', 'eclampsia' |  |
| pn\_mag\_sulph\_treatment | Whether this woman has received magnesium sulphate as treatment for eclampsia/ severe pre-eclampsia' |  |
| pn\_gest\_htn\_on\_treatment | Whether this woman is receiving regular oral medication for hypertension in the postnatal period |  |
| pn\_iv\_anti\_htn\_treatment | Whether this woman has received IV anti-hypertensive therapy during a hypertensive emergency |  |
| pn\_postpartum\_haem\_secondary | Whether this woman is experiencing a secondary postpartum haemorrhage |  |
| pn\_postpartum\_haem\_secondary\_treatment' | Whether this woman has received treatment for secondary PPH |  |
| pn\_sepsis\_late\_postpartum | Whether this woman is experiencing postnatal (day7+) sepsis |  |
| pn\_sepsis\_late\_postpartum\_treatment | Whether this woman has received treatment for postpartum sepsis |  |
| pn\_maternal\_pp\_infection | bitset column for infection |  |
| pn\_obstetric\_fistula | Type of fistula developed after birth ( 'none', 'vesicovaginal', 'rectovaginal') |  |
| pn\_sepsis\_early\_neonatal | Whether this neonate has developed early onset neonatal sepsis during week one of life |  |
| pn\_sepsis\_late\_neonatal | Whether this neonate has developed late neonatal sepsis following discharge |  |
| pn\_neonatal\_sepsis\_disab | Level of disability experience from a neonate post sepsis', ('none', 'mild\_motor\_and\_cog', 'mild\_motor', 'moderate\_motor', 'severe\_motor') |  |
| pn\_sepsis\_neonatal\_inj\_abx | Whether this neonate has received injectable antibiotics as treatment for late onset sepsis |  |
| pn\_sepsis\_neonatal\_full\_supp\_care | Whether this neonate has received full supportive care as treatment for late onset sepsis |  |
| pn\_deficiencies\_following\_pregnancy | bitset column, stores types of anaemia causing deficiencies following pregnancy |  |
| pn\_anaemia\_following\_pregnancy | severity of anaemia following pregnancy ( 'none', 'mild', 'moderate', 'severe') |  |
| pn\_emergency\_event\_mother | Whether a mother is experiencing an emergency complication postnatally |  |

**Table 4. Description of natural history parameters and proposed values.**

Value provided in this table are not finalised and are pending a more detailed review of the relevant literature. This is a working document updated regularly.

|  |  |  |  |
| --- | --- | --- | --- |
| **Parameter** | **Proposed value** | **Description** | **Reference/ Notes** |
| prob\_htn\_resolves | **0.8** | weekly probability hypertension resolves during postpartum |  |
| prob\_secondary\_pph | **0.05** | baseline probability of secondary PP |  |
| prob\_secondary\_pph\_severity | **[0.33, 0.33, 0.34]** | probability of mild, moderate or severe secondary PPH |  |
| prob\_obstetric\_fistula | **0.1** | probability of a woman developing an obstetric fistula after birth |  |
| prevalence\_type\_of\_fistula | **[0.5, 0.5]** | Prevalence of 1.) vesicovaginal 2.)rectovaginal fistula |  |
| prob\_iron\_def\_per\_week\_pn | **0.01** | weekly probability of a women developing iron deficiency following pregnancy |  |
| prob\_folate\_def\_per\_week\_pn | **0.0025** | weekly probability of a women developing folate deficiency following pregnancy |  |
| prob\_b12\_def\_per\_week\_pn | **0.0025** | weekly probability of a women developing b12 deficiency following pregnancy |  |
| baseline\_prob\_anaemia\_per\_week | **0.001** | Weekly probability of anaemia in pregnancy |  |
| prob\_type\_of\_anaemia\_pn | **[0.33, 0.33, 0.34]** | probability of a woman with anaemia having mild, moderate or severe anaemia |  |
| rr\_anaemia\_if\_iron\_deficient\_pn | **1.5** | risk of developing anaemia when iron deficient |  |
| rr\_anaemia\_if\_folate\_deficient\_pn | **1.25** | risk of developing anaemia when folate deficient |  |
| rr\_anaemia\_if\_b12\_deficient\_pn | **1.25** | risk of developing anaemia when b12 deficient |  |
| prob\_endometritis\_pn | **0.1** | probability of endometritis in week one |  |
| prob\_urinary\_tract\_inf\_pn | **0.1** | probability of urinary tract infection in week one |  |
| prob\_skin\_soft\_tissue\_inf\_pn | **0.1** | probability of skin and soft tissue infection in week one |  |
| prob\_other\_inf\_pn | **0.1** | probability of other maternal infections in week one |  |
| prob\_late\_sepsis\_urinary\_tract\_inf | **0.1** | probability of developing sepsis following postpartum UTI |  |
| prob\_late\_sepsis\_skin\_soft\_tissue\_inf | **0.1** | probability of developing sepsis following postpartum skin/soft tissue infection |  |
| prob\_late\_sepsis\_other\_maternal\_infection\_pp | **0.1** | probability of developing sepsis following postpartum other infection |  |
| prob\_late\_onset\_neonatal\_sepsis | **0.1** | probability of late onset neonatal sepsis (all cause) |  |
| prob\_sepsis\_disabilities | **[0.4, 0.1, 0.3, 0.1, 0.1]** | Probabilities of varying disability levels after neonatal sepsis |  |
| prob\_htn\_persists | **0.2** | Probability that women who are hypertensive during pregnancy remain hypertensive in the postnatal period |  |
| weekly\_prob\_gest\_htn\_pn | **0.001** | weekly probability of a woman developing gestational hypertension during the postnatal period |  |
| cfr\_eclampsia\_pn | **0.0014** | 'case fatality rate of eclampsia in the postnatal period |  |
| cfr\_severe\_htn\_pn | **0.0014** | case fatality rate of severe hypertension in the postnatal period |  |
| cfr\_early\_onset\_neonatal\_sepsis | **0.25** | case fatality for early onset neonatal sepsis |  |
| cfr\_secondary\_pph | **0.0014** | case fatality rate for secondary PPH |  |
| cfr\_postnatal\_sepsis | **0.0014** | case fatality rate for postnatal sepsis |  |

**Approach to modelling interventions related to Postnatal Care: rationale for model structure and choice of parameter values**

**Postnatal care in Malawi**

The Malawi Essential Health Package (EHP) separates reproductive, maternal and neonatal health interventions into three broad packages; antenatal care, modern family planning and delivery care (Government of the Republic of Malawi, 2017). Whilst postnatal care (PNC) does not fall within any of these packages, and is not explicitly listed within the EHP as a service delivered via the public sector, it does feature prominently within the National Reproductive Health Service Delivery Guidelines (NRHSDG) (Government of the Republic of Malawi, 2014) as part of essential care for mothers and newborns . Additionally postnatal care and essential newborn care form part of the minimum package of high impact Interventions which target maternal and neonatal mortality reduction in the Ministry of Health’s ‘Road Map for Accelerating the reduction of Maternal and Neonatal Morbidity and Mortality’ (Malawi Ministry of Health, 2012). We have used the NRHSDG to structure the health system interactions within this model after confirmation with ministry officials that this is the most relevant national policy in regards to PNC.

The NRHSDG does not have an explicit PNC schedule or intervention matrix (as it does with ANC) but does provide suggested visit times for women depending on place of delivery (facility vs home). Women, and their newborns, who delivered at home should receive a first PNC visit within three days of birth whilst those women who have delivered in a facility should receive initial postnatal management and care prior to discharge. Following this women should then be encouraged to return at 7 and 42 days postnatal for additional assessment. This schedule is mimicked within our model as discussed in the following section.

**Care seeking**

Within the model we assume, as discussed above, that immediate postnatal care for the mother and the newborn is delivered to any individuals who deliver/have been delivered in a facility. The details of these interventions are covered in the next section. For all women and/or newborns who have survived until the first week postnatal, we apply a probability that mother and baby will seek routine postnatal care around day 7 after we have applied risk of complications in that week.

Historically, and according to recent estimates, uptake of routine postnatal care for both mothers and neonates is poor within Malawi (Machira and Palamulen, 2017; Khaki and Sithole, 2019; Kim *et al.*, 2019). Analysis from the 2015-2016 DHS in Malawi found that only 48.4% of women in the sample received routine postnatal care within 42 days of birth (Khaki and Sithole, 2019). Factors associated with maternal PNC attendance reported in Khaki and Sithole’s study (2019) included:

* Being aged 30-35 - aOR 1.75 (95% CI 1.22 - 2.51)
* Being aged 36 and older - aOR 1.86 (95% CI 1.19-2.92)
* Being employed - aOR 1.44 (95% CI 1.22-1.70)
* Living rurally - aOR 0.55 (95% CI 0.40-0.76)
* Living in the central region – aOR 0.55 (95% CI 0.41-0.7)
* Living in the southern region – aOR 0.47 (95% CI 0.35-0.61)
* Richest wealth quintile – aOR 0.72 (95% CI 0.53-0.98)
* 4+ ANC visits – aOR 1.20 (95% CI 1.02-1.40)
* Caesarean delivery – aOR 1.93 (95% CI 1.38-2.69)
* Facility birth – aOR 1.91 (95% CI 1.03-3.55)
* Number of living children greater than 5 – aOR 0.33 (95% CI 0.46-0.95)

Currently care- seeking is determined with a fixed probability, not influenced by the above risk factors, which is increased for women who experience complications in week one, as we assume they are more likely to return to a facility for additional treatment. Following a finalised comparison of studies evaluating the effect of maternal characteristics on PNC attendance we intend to include relevant effects within a care seeking equation.

**Postnatal care interventions**

We have adapted the recommended postnatal interventions from the NRHSDG document (Government of the Republic of Malawi, 2014) and the Malawi Standard Treatment Guidelines (Ref). Figure 4 provides an overview of the health system interactions relevant to the postnatal period.

**Figure 4. Flow of health system interactions in the postnatal period**

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***Initial PNC following delivery***

As described above and seen in figure 4, initial prophylactic and curative interventions provided by skilled birth attendants to women and newborns immediately following birth are managed within the Labour and newborn models. For reference these interventions are:

* Active management of the third stage of labour
* Case management of primary postpartum haemorrhage
* Case management of hypertension and severe pre-eclampsia/eclampsia
* Case management of maternal sepsis (prior to discharge)
* Case management of neonatal sepsis (prior to discharge)
* Neonatal resuscitation
* Essential newborn care (chlorhexidine cord care, vitamin K prophylaxis, tetracycline eye care, early initiation of breastfeeding)
* Kangaroo mother care

The modelled effects, underlying descriptions of these interventions and the approach to modelling quality of care are provided in the labour and newborn model methods documentation. Prior to discharge, for those who have survived the immediate postnatal period guidelines recommend a number of interventions for mother and/or baby – described in the following sections.

***HIV screening and prophylaxis***

The NRHSDG offer guidance for the management of HIV and HIV related risk in the postnatal period. The natural history of HIV in the population, all related interventions and screening are managed by the HIV model. This model links with the HIV model in regards to scheduling some screening interventions during antenatal care and postnatal care.

For women with unknown serostatus, HIV testing is recommended. Currently all women in the model who deliver in a facility are scheduled to receive a routine HIV testing following delivery. This testing intervention is managed by the HIV model which will initiate treatment and monitoring for any women found to be HIV positive (and not currently on treatment) after delivery. Additionally to testing the HIV model is responsible for interventions around prevention of mother to child transmission of HIV (PMTC). Broadly, neonates born to mothers who are HIV positive are tested for HIV following delivery. If the neonate is found to be HIV+ they are started on treatment and monitoring, if they are negative they are started on prophylaxis. Additional follow-up screening for HIV in exposed neonates occurs in future PNC visits described below.

***Immunisation***

As part of PNC pre-discharge we assume all neonates are offered routine post-birth vaccinations including tuberculosis and polio. The effect of these interventions on disease burden are managed via the EPI model but consumables are managed within this model.

***Family planning***

Routine post birth family planning is managed by the contraception model and described in detail in the associated methods documentation.

***Iron and Folic acid***

Daly iron and folic acid supplementation is recommended for three months following all deliveries and is imitated prior to discharge. We use an identical approach to that of the pregnancy supervisor and antenatal care models in that we apply a treatment effect (RR 0.44 (Peña-Rosas *et al.*, 2015)) to an individual woman’s risk of developing an iron or folate deficiency which may lead to anaemia in the postnatal period.

***Outpatient PNC visits***

Additional PNC visits, following discharge, should then occur on days 7 and 42 for both mother and baby. As mentioned above, national reproductive health guidelines in Malawi do not provide an explicit matrix of interventions to be delivered during each of these routine PNC visits. In order to model intervention delivered as part of routine PNC within Malawi we reviewed possible data sources that would provide details of care delivered as part of PNC as described below.

***Quality of care in outpatient PNC***

In order to capture variations in quality of care between PNC contacts we have adopted the same approach used within antenatal care to determine if an intervention (predominantly screening/assessment) will be conducted during the PNC visit. These probabilities will be informed by the SPA data (2014) for each intervention to replicate the quality of care of PNC contact in Malawi. These probabilities appear to vary by facility type (hospital vs health centre) and this will need to be modelled accordingly. Including this logic, delivery of interventions is therefore conditional on:

1. Probability that the HCW will initiate this intervention/screening process
2. (if applicable) sensitivity and specificity of the screening test
3. Probability that the consumables required for this intervention are available at the facility level

***Content of PNC for newborns***

 The Malawi DHS (2015) collected data related to care delivered to newborns as part of PNC and included responses for the following interventions; examination of the cord, temperature check, weight measurement, counselling on possible neonatal danger signs and counselling and observation of breastfeeding. This aligns with WHO recommendations on the content of PNC for newborns which includes assessment of the baby, initiation and monitoring of breastfeeding and cord care (WHO 2013). For neonates who were delivered in a facility we assume that recommend interventions (breastfeeding, cord care, immunisations) have been delivered and the content of PNC revolves around assessment for neonatal sepsis and referral for inpatient care. If the HCW performs an assessment and detects that the neonate is suffering from sepsis they will be admitted for inpatient care (described below).

***Content of PNC for mothers***

Similarly to neonates, PNC for mothers revolves around assessment for potential complications and referral for additional treatment. Within each PNC visit women should receive:

* Blood pressure measurement to assess for hypertension
* Urine dipstick to detect proteinuria
* Point of care test for anaemia
* Assessment for maternal sepsis
* Assessment for secondary PPH

If one or more complications are detected then the mother is scheduled to receive additional treatment as an inpatient via the postnatal ward.

**Inpatient PNC**

***Postnatal ward***

Women in the model are admitted for inpatient care if assessment during PNC has led to the detection of a hypertensive disorder, anaemia (any severity), sepsis or secondary postpartum haemorrhage. As with care delivered on the antenatal ward clinical management of these conditions is modelled to match treatment protocols outlined in the Malawian Obstetrics and Gynaecology Guidelines (The Association of Obstetricians & Gynaecologists of Malawi, 2014) and Standard Treatment Guidelines ().

**Treatment for maternal sepsis**

As with the management of maternal sepsis during labour, antibiotic therapy is the primary treatment intervention for maternal sepsis included in the model. We apply the same treatment effect and therefore assume women who receive treatment for sepsis have a reduced risk of sepsis-death (RR 0.2 (Pollard, Mathai and Walker, 2013a)). Please see labour documentation for further details.

**Treatment for hypertensive disorders**

Inpatient treatment of hypertension varies according to severity and underlying hypertensive disorder.Women with more mild hypertension (mild gestational hypertension/mild pre-eclampsia) are simply initiated on regular oral antihypertensives and discharged- we assume that oral antihypertensives administered postnatally work similar to the antenatal period in that they reduce a woman’s risk of developing severe gestational hypertension (RR 0.49 (Abalos *et al.*, 2018a)) but no other significant effects on maternal or perinatal outcomes.

Severe hypertension (severe gestational hypertension, severe pre-eclampsia and eclampsia) is treated with intravenous antihypertensives which reduces risk of death in severe pre-eclamsia and eclampsia (RR 0.5 (Pollard, Mathai and Walker, 2013b)) or reverts severe gestational hypertension to the milder state, reducing monthly risk of death.

Severe pre-eclampsia and eclampsia are also treated with magnesium sulphate which reduces risk of death from eclampsia (RR 0.5 (Pollard, Mathai and Walker, 2013b) and reduces the likelihood that a woman with severe pre-eclampsia will develop eclampsia (RR 0.41 (Duley *et al.*, 2010)).

**Treatment for secondary PPH**

**TBD.**

**Treatment for anaemia**

**TBD**. Not modelled.

***Neonatal ward***

Neonates admitted to the neonatal ward due to sepsis will receive full supportive case management of sepsis (see newborn module methods document for description). Risk of death associated with sepsis is reduced by 80% (treatment effect 0.2 (Zaidi et al., 2011))

**Table 5. Description of treatment parameters and proposed values.**

|  |  |  |  |
| --- | --- | --- | --- |
| **Parameter** | **Proposed value** | **Description** | **Reference Notes** |
| rr\_iron\_def\_ifa\_pn | **0.43** | effect of iron and folic acid treatment on risk of iron deficiency | (Peña-Rosas *et al.,* 2015) |
| rr\_folate\_def\_ifa\_pn | **0.43** | effect of iron and folic acid treatment on risk of folate deficiency | (Peña-Rosas *et al.,* 2015) |
| treatment\_effect\_early\_init\_bf | **0.85** | 'effect of early initiation of breastfeeding on neonatal sepsis rates  | Breastfeeding effect sizes on mortality in LiST (technical note found in spectrum help section) |
| treatment\_effect\_abx\_prom | **0.61** | effect of early antibiotics given to a mother with PROM on neonatal sepsis rates  | (Cousens *et al.*, 2010) |
| treatment\_effect\_inj\_abx\_sep | **0.35** | effect of injectable antibiotics on neonatal sepsis mortality | (Zaidi *et al.*, 2011) |
| treatment\_effect\_supp\_care\_sep | **0.2** | effect of full supportive care on neonatal sepsis mortality | (Zaidi *et al.*, 2011) |
| treatment\_effect\_cord\_care | **0.77** | Treatment effect of chlorhexidine cord care on early onset neonatal sepsis risk | (Blencowe *et al.*, 2011) |
| treatment\_effect\_clean\_birth | **0.73** | Treatment effect of clean birth practices on early onset neonatal sepsis risk | (Blencowe *et al.*, 2011) |
| prob\_attend\_pnc2 | **0.25** | Probability that a woman receiving PNC1 care will return for PNC2 care | *DUMMY* |
| prob\_attend\_pnc3 | **0.25** | Probability that a woman receiving PNC2 care will return for PNC3 care | *DUMMY* |
| treatment\_effect\_anti\_htns\_progression\_pn | **0.49** | Treatment effect of oral anti hypertensives on progression from mild/mod to severe gestational hypertension | (Abalos *et al.*, 2018b) |
| treatment\_effect\_parenteral\_antibiotics | **0.2** | Treatment effect of parenteral antibiotics on maternal sepsis mortality | (Pollard, Mathai and Walker, 2013a) |
| treatment\_effect\_bemonc\_care\_pph | **0.25** | Treatment effect of BEmONC care on postpartum haemorrhage mortality | (Pollard, Mathai and Walker, 2013a) |
| treatment\_effect\_anti\_htns | **0.5** | Treatment effect of hypertensive therapy on death from eclampsia | (Pollard, Mathai and Walker, 2013a) |
| treatment\_effect\_mag\_sulph | **0.4** | Treatment effect of magnesium sulphate therapy on death from eclampsia | (Pollard, Mathai and Walker, 2013a) |
| neonatal\_sepsis\_treatment\_effect | **0.2** | Treatment effect for neonatal sepsis | (Zaidi *et al.*, 2011) |
| prob\_care\_seeking\_postnatal\_emergency | **0.5** | baseline probability of emergency care seeking for women in the postnatal period' | *DUMMY* |
| prob\_care\_seeking\_postnatal\_emergency\_neonate | **0.5** | baseline probability care will be sought for a neonate with a complication | *DUMMY* |
| prob\_pnc1\_at\_day\_7 | **0.4** | baseline probability a woman will seek PNC for her and her newborn at day + 7  | *DUMMY* |
| multiplier\_for\_care\_seeking\_with\_comps | **2** | number by which prob\_pnc1\_at\_day\_7 is multiplied by to increase care seeking for PNC1 in women with complications | *DUMMY* |
| sensitivity\_bp\_monitoring\_pn | **0.9** | sensitivity of BP monitoring during PNC | *DUMMY* |
| specificity\_bp\_monitoring\_pn | **0.9** | specificity of BP monitoring during PNC | *DUMMY* |
| sensitivity\_urine\_protein\_1\_plus\_pn | **0.9** | sensitivity of urine dipstick during PNC | *DUMMY* |
| specificity\_urine\_protein\_1\_plus\_pn | **0.9** | specificity of urine dipstick monitoring during PNC | *DUMMY* |
| sensitivity\_poc\_hb\_test\_pn | **0.9** | sensitivity of point of care testing during PNC | *DUMMY* |
| specificity\_poc\_hb\_test\_pn | **0.9** | specificity of urine dipstick monitoring during PNC | *DUMMY* |
| sensitivity\_maternal\_sepsis\_assessment | **0.9** | sensitivity of assessment for maternal sepsis' | *DUMMY* |
| sensitivity\_pph\_assessment | **0.9** | sensitivity of assessment for secondary pph | *DUMMY* |
| sensitivity\_lons\_assessment | **0.9** | sensitivity of assessment for late onset neonatal sepsis' | *DUMMY* |
| sensitivity\_eons\_assessment | **0.9** | sensitivity of assessment for earl onset neonatal sepsis | *DUMMY* |
| prob\_intervention\_delivered\_sep\_assessment\_pnc | **0.9** | 'probability a woman will be assessed for sepsis during PNC | *DUMMY* |
| prob\_intervention\_delivered\_pph\_assessment\_pnc | **0.9** | 'probability a woman will be assessed for PPH during PNC | *DUMMY* |
| prob\_intervention\_delivered\_urine\_ds\_pnc | **0.9** | 'probability a woman will receive a urine dipstick during PNC | *DUMMY* |
| prob\_intervention\_delivered\_bp\_pnc | **0.9** | probability a woman will receive blood pressure testing during PNC' | *DUMMY* |
| prob\_intervention\_poct\_pnc | **0.9** | probability a woman will receive point of care Hb testing during PNC | *DUMMY* |
| prob\_intervention\_neonatal\_sepsis\_pnc | **0.9** | probability a newborn will be assessed for sepsis during PNC | *DUMMY* |

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