An analysis of neonatal mortality following gastro-intestinal and/or abdominal surgery in a tertiary hospital in South Africa

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Abstract
Purpose Thirty-day, 6-month and 12-month post-operative mortality and assessment of factors associated with 30 day post-operative mortality were ascertained.

Method A retrospective medical record audit for neonates who underwent gastrointestinal or abdominal wall surgery within the neonatal period at a tertiary free standing paediatric hospital during the 12-year period from 1 January 2007 to 31 December 2018.

Results The 30-day post-operative mortality rate was 83/762 (11%). Mortality resulted from: sepsis (74%), palliation due to ultra-short bowel length (12%), ventilation-associated pneumonia (10%), associated congenital cardiac lesions (3%) and intestinal failure-associated liver disease (1%). Surgery for necrotizing enterocolitis had the greatest 30-day post-operative mortality (28%). Most neonates (69%) who died were prematurely born. Mean age at surgery was ten days and mean age at death was six days. Abdominal compartment syndrome was noted post operatively in 15% patients. Risk factors for sepsis included central line-associated bloodstream infections (65%), respiratory tract infections (41%) and surgical complications [anastomotic breakdown (7%) and wound infection (24%)]. Mortality in patients from referral hospitals more than an hour’s drive away was high (15/39, 38%).

Conclusion Mortality is double that of high-income countries, although significantly lower than most African settings. Strategic quality-improvement interventions are required to optimize outcomes.

Keywords Neonatal · Post-operative mortality · Congenital anomalies · South Africa

Introduction
Congenital malformations are the fifth leading cause of death in children under five years of age globally [1]. This equates to approximately half a million deaths from congenital anomalies each year, 97% of which occur in low- and middle-income countries (LMIC) [1]. Neonatal mortality was reported between 16 and 40% in these countries [2]. Mortality in neonatal surgery in high income countries stands at less than 5% in recent years [2, 3]. The World Health Organisation estimates approximately 10% of neonatal deaths in sub-Saharan Africa and South Asia are due to congenital malformations [4]. Many of these require appropriate surgical management to ensure survival. Congenital and acquired gastrointestinal and abdominal wall conditions make up a large portion of surgical burden in Africa [5, 6]. A significant proportion of Infant mortality occurs in the neonatal period. Mortality due to congenital abnormalities is estimated at 10% of the overall neonatal mortality rate according to the UNICEF data from South Africa in 2016 [7]. In 2019, overall neonatal mortality rate for South Africa was 11.5 deaths per 1,000 live births [8]. Significant differences still exist between high income countries (HIC) and LMICs in terms of neonatal surgical outcomes [9, 10]. Literature outcomes in most African countries indicate neonatal surgery has challenges with regards to neonatal intensive care facilities, surgical training, and support personnel just to mention a few, resulting in a high rate of morbidity and mortality following neonatal surgery [11]. Many possible factors are potentially responsible for...
mortality in neonates. Reported mortality rates vary widely between hospitals as well as different countries. Factors that impact neonatal surgical outcomes can be grouped as pre-operative, intra-operative and post-operative. The factors related to mortality can also be identified as modifiable or non-modifiable. Defining these assists addressing the concerns at different points of care for these surgical neonates in an attempt to improve outcome. A high mortality of more than 40% has been reported particularly for diseases such as oesophageal atresia, diaphragmatic hernia, omphalocele, gastrochisis, and intestinal atresia in LMICs [3, 6, 12, 13]. The mortality rates were substantially higher compared to the 10% mortality reported from HICs during the same period [2, 3, 12, 13]. Paediatric abdominal surgical emergencies in LMIC settings have high morbidity and mortality. 

Prematurity and low birth weight are associated with poor prognosis in neonates [2, 3, 14–16]. Delayed presentation is an independent risk factor that predicts the mortality for neonates who have undergone surgical intervention [17]. Neonates born outside the tertiary centre’s where definitive management is undertaken have a worse reported outcome in some low-income African countries [2, 3, 6, 14–16, 18, 19]. This is exacerbated by very distant referral sites as well as underdeveloped transport systems e.g., poor road infrastructure. Delays in transfer may also be affected by limited intensive care unit facilities at the receiving hospital [1]. Literature reviewing sepsis in African neonates reported 50% of outbreaks were caused by extended-spectrum β-lactamase-producing Klebsiella pneumoniae. Poor prognosis and outcomes may potentially be a result of sepsis and shock among other factors. Surgical technique, central line care and early detection of sepsis with appropriate antibiotic treatment [3, 4, 20–24]. Programmes in African neonatal units are urgently required to improve sepsis prevention, early septic shock recognition and treatment to reduce hospital mortality [21, 22, 25, 26]. South Africa has implemented strategies to reduce under-five mortality and stabilize infant mortality, but more research is needed to identify areas for further improvement [27, 28]. 

Bringing down infant mortality rate is a major goal for low- and middle-income countries including South Africa. This study aims to assess factors that influence neonatal mortality in a South African tertiary hospital setting to identify problems underlying poor outcomes that can be rectified to improve care. Only post-operative mortality was analyzed in this study, to evaluate how the Red Cross War Memorial Children’s Hospital (RCWMCH) mortality rate compared to other LMIC and HIC. Factors affecting pre-operative mortality are largely due to factors surrounding care at referral hospitals and transport infrastructure as well as comorbid conditions. By focusing on cases operated on, factors directly affecting surgical care at RCWMCH can be identified for improvement.

Objective

The primary objective was to assess post-operative mortality for neonates operated under general anaesthesia for gastrointestinal and abdominal wall defects at a single free-standing tertiary paediatric hospital (Red Cross War Memorial Children’s Hospital; RCWMCH) over a 12-year period. One-month, 6-month and 12-month post-operative mortality were evaluated. The secondary objective was to identify causes and modifiable risk factors for 30-day post-operative mortality.

Method

The study was a retrospective audit of patient records over a 12-year period from 1 January 2007- 31 December 2018 at RCWMCH in the division of paediatric surgery.

Source of data included

Patient medical record review, Paediatric Surgery Department operative database (names, dates of birth, folder numbers, operation dates, type of operation), Patient medical records (demographics, clinical risk factors for death e.g., gestational age, sepsis, comorbidities, late presentation, cause of death), Red Cross War Memorial Children’s Hospital Intensive Care Unit discharge summaries, Referring Neonatal Intensive Care Units records, National Health Laboratory Service (NHLS) records (histological records of resected surgical specimens, evidence for sepsis), Picture Archive and Communication System (“PACS”) Radiological database (radiological evidence of bowel obstruction or perforation),Department of Western Cape Clinicom administrative database (date of demise if not at RCWMCH).

All patients operated at RCWMCH for gastrointestinal or abdominal wall conditions were included if they were under 28 days old for term infants or under 44 weeks corrected gestational age for premature neonates. The following index 14 neonatal congenital gastrointestinal conditions were evaluated: anorectal malformation (ARM), biliary atresia (BA), choledochal malformation (CM), congenital diaphragmatic defects (CDH), spontaneous intestinal perforation (SIP), gastrochisis (GS), Hirschsprung disease (HD), inguinal hernia (IH), malrotation with volvulus (MV), necrotizing enterocolitis (NE), oesophageal atresia +/trachea-oesophageal fistula (OA ± TOF), omphalocele (OMPH), hypertrophic pyloric stenosis (HPS) and intestinal atresia (IA).

Patient were excluded from the study if operated for one of the study conditions outside the neonatal period or if they received their index surgery at another institution i.e., at a
hospital other than RCWMCH. Those who did not have complete information with regards to weight or gestational age were excluded from the analysis. Neonates not operated by the division of paediatric surgery at RCWMCH were not included in the study i.e., thoracic surgery other than for oesophageal atresia, central line insertions, and surgery for ear, nose and throat, neurosurgical or urologic conditions.

Retrospective data was collected and stored electronically in a password-protected database. Data was anonymized, with each patient assigned a study number, and no identifying data e.g., name and surname or hospital number. All data used was routinely collected information used in the management of these patients. Data collected included: cause of death, risk factors for death (modifiable and non-modifiable), presenting surgical condition, demographics, ante-natal history, referring Hospital, distance of transferring hospital from RCWMCH, type surgical procedure performed, comorbidity, complications related to the surgery, causes of Sepsis within the 30-days post-operative period. Descriptive statistics was generated using Microsoft Excel® including mean, median and interquartile range.

Sample size

An estimated 100 neonates are operated at RCWMCH annually for general surgical conditions, giving an estimated population size of 1000 over 10 years. Assuming a mortality of 10%, a study population of 100 patients was estimated. It was then estimated that due to the retrospective nature of the study and lack of availability of medical records, approximately 50% of the medical records may not be available, reducing the potential study population to 50 patients with adequate information to confirm death and determine the cause of mortality.

This research protocol was submitted and approved by the Committee for Human Research at the University of Cape Town and was carried out according to internationally accepted ethical standards and guidelines. Human Research Ethics Committee (HREC) approval was granted for the project (University of Cape Town HREC approval number 036/2019). As this was routinely collected data needed for patient management, no parent/patient interaction was necessary for data collection. All information extracted was stored in an excel database and access restricted to the investigators and password protected. Once relevant data was extracted it was anonymized for analysis. Because of the routine nature of the data under investigation, and anonymous handling of extracted data, informed consent was thus not considered necessary for this retrospective review. Consent for collecting the data was obtained from the medical manager and RCWMCH research and ethics committee after ethical approval to carry out the study.

Results

Neonates accounted for ten percent of the patients operated by the Division of Paediatric Surgery at RCWMCH over the 10-year period between 2007 and 2018, totalling 1130 neonates. Seven hundred and sixty-two of these had gastrointestinal (GIT) or abdominal wall conditions (67%).

The overall 30-day post-operative neonatal mortality rate was (83/762, 11%). Mortality was found in 9 of the 14 index neonatal conditions analysed. Most patients died within the first week after birth with a mean of 6 days and range of (1–30).

An additional 57/762 patients (7%) died between 30 days from surgery and 6 months of age. A further 34/762 patients (4%) died between 6 and 12 months of age. Overall mortality at one year of age for the 10-year period was thus (174/762, 23%) for neonates undergoing GIT surgery. There were incomplete records for 12 cases who died who were thus excluded from detailed analysis of cause of death. Ten of these excluded patients died within 30 days of surgery for necrotizing enterocolitis, and two had biliary atresia, of which one died within 6 months and one within 12 months post-operatively. Neonatal mortality according to surgical condition at thirty days post-operatively, at six months and at one year are demonstrated in Table 1.

Causes of early (30-day) post-operative mortality resulted from the following: Sepsis in (54/73, 74%), ventilation associated pneumonia in (7/73, 10%), palliation for intestinal failure due to pan-intestinal necrosis and atresia with ultra-short bowel syndrome in (9/73, 12%), associated congenital cardiac lesions in (2/73, 3%), liver failure in (1/74, 1%) as a result of liver cirrhosis (intestinal failure associated liver disease). The majority of surgical procedures in patients who died were for abdominal surgery 70/73 (96%).

The majority of patients were born at a gestation less than 37 weeks (49/71; 69%), with a mean gestational age of 33 weeks. The gestational ages for patients ranged between 25 to 40 weeks. A total of 59/70 neonates (81%) had a birthweight below 2500 g with the highest percentage being low birth weight at 43%. Thirty-seven (51%) of the 73 patients who died had associated comorbidities at presentation with (10/73, 14%) which contributed to death. This included respiratory, cardiac and liver failure.

Ninety-seven percent of patients who died were admitted post-operatively into the intensive care unit (ICU) with an average ICU stay of 5 days (median 7 days; interquartile range 1–10; absolute range 1–30 days).

Four referral hospitals are more than 100 km from RCWMCH, requiring more than an hour for transfer. These centres are George Regional, Worcester, Oudtshoorn and
Mossel Bay Hospitals. All referral hospitals and their associated distance from RCWMCH are shown in Fig. 1, together with their respective contribution to referral volume and the absolute numbers and percentages of patients who died. For patients whose transfer took over an hour of travel time, 15 out of 39 (38%) died. Where transfer took less than one hour, 58/335 patients (17%) died. The odds ratio for death for patients with travel time over one hour from the referral hospital was 3.6 [95% confidence interval 1.8 to 7.3; \(z\) statistic 3.6; \(p = 0.0003\)].

Ninety two percent (67/73) of patients clinically septic leading up to death with (54/73, 74%) had an identified source of sepsis. This included central line associated sepsis (35/54, 65%), wound sepsis (13/54, 24%), infective endocarditis (2/54, 4%) and anastomotic leaks (4/54, 7%). No source of infection was identified in (13/73, 18%). Positive blood culture (45/73, 62%) of the patients who died, with Enterococcus species (10/45, 14%), Klebsiella pneumonia (19%), Actinobacteria baumannii (12%) and Candida species (7%) being the most common organisms cultured.

Sepsis related to underlying surgical pathology was (36/73, 49%): included intestinal perforation and intraabdominal soiling (13/36, 36%), ischaemic bowel (11/36, 31%) and necrotic diseased bowel (12/36, 33%).

Sepsis was associated with acute kidney injury in (30/73, 47%) and ventilator associated pneumonia with 10% of

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**Table 1** Neonatal mortality according to surgical condition at thirty days postoperatively, at six months and at one year

| Condition                          | Patients operated | 30-day mortality n (%) | Additional mortality at 6 months n (%) | Additional mortality at 12 months n (%) | Total (cumulative) mortality at 12 months n (%) |
|------------------------------------|-------------------|------------------------|---------------------------------------|----------------------------------------|-----------------------------------------------|
| Necrotising enterocolitis          | 137               | 38 (28%)               | 26 (19%)                              | 16 (12%)                               | 80 (58%)                                      |
| Spontaneous intestinal perforation | 17                | 5 (29%)                | 2 (12%)                               | –                                      | 7 (41%)                                       |
| Gastrochisis                       | 50                | 9 (18%)                | 2 (4%)                                | 3 (6%)                                 | 14 (28%)                                      |
| Oesophageal atresia                | 35                | 3 (9%)                 | 5 (14%)                               | 2 (6%)                                 | 10 (29%)                                      |
| Malrotation                        | 67                | 6 (9%)                 | 4 (6%)                                | 1 (1%)                                 | 11 (16%)                                      |
| Congenital diaphragmatic hernia    | 32                | 3 (9%)                 | 2 (6%)                                | –                                      | 5 (16%)                                       |
| Intestinal atresia                | 137               | 11 (8%)                | 4 (3%)                                | 7 (5%)                                 | 22 (16%)                                      |
| Anorectal malformation             | 94                | 5 (5%)                 | 6 (6%)                                | 3 (3%)                                 | 14 (15%)                                      |
| Ingual hernia                      | 116               | 3 (3%)                 | 1 (1%)                                | –                                      | 4 (3%)                                        |
| Omphalocele                        | 31                | –                      | 4 (13%)                               | 1 (3%)                                 | 5 (16%)                                       |
| Biliary atresia                   | 5                 | –                      | 1 (20%)                               | 1 (20%)                                | 2 (40%)                                       |
| Hypertrophic pyloric stenosis      | 25                | –                      | –                                     | –                                      | –                                             |
| Hirschsprung disease               | 15                | –                      | –                                     | –                                      | –                                             |
| Choledochal malformation           | 1                 | –                      | –                                     | –                                      | –                                             |
| Total                              | 762               | 83 (11%)               | 57 (7%)                               | 34 (4%)                                | 174 (23%)                                      |

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**Fig. 1** Distance from referral hospital in kilometres and number of neonates and corresponding referral volume with one-month post-operative mortality from each referral hospital (distance to Red Cross War Memorial Children’s Hospital (RCWMCH) shown in brackets; centres over 100 km away are highlighted in bold); Hospital, TBH Tygerberg Hospital, MPH Mitchells Plain Hospital

**Table 1** Neonatal mortality according to surgical condition at thirty days postoperatively, at six months and at one year

mmH-Mowbray Maternity Hospital, GSH- Groote Schuur Hospital, NSH- New Somerset Hospital, TBH- Tygerberg Hospital, MPH Mitchells Plain Hospital

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patients who died succumbing to this. Sepsis related morbidity was in 65% central line-associated bloodstream infections, 41% respiratory tract infections, 4% wound infection, 7% anastomotic breakdown.

A total of (21, 29%) patients had short bowel syndrome. Causes of short bowel included intestinal atresia (7/21) and necrotizing enterocolitis (7/21), gastrochisis (5/21) and malrotation with volvulus (2/21). Of these patients (9/21) 43% had ultrashort bowel resulting in these patients being palliated. Half of the patients with short bowel syndrome died from sepsis and multi organ failure.

Seventy four percent (54/73) of patients who died post-operative had associated complications (see Fig. 2). Common post-operative organ dysfunction included acute kidney injury in (34/73, 47%); respiratory failure (requiring respiratory support of various forms) in (30/73, 41%), and disseminated intravascular coagulopathy in (12/73, 16%).

Anastomosis leaks occurred in (5/73, 7%) of patients who had primary anastomosis of the following conditions: jejunal atresia, duodenal atresia, SIP, oesophageal atresia. Anastomotic leak resulted in gram negative sepsis following intraabdominal soiling and multi organ failure in 4/5 patients.

Abdominal compartment syndrome was noted post operatively in (11/73, 15%) patients who died. This was further complicated by sepsis and multi-organ failure. There were two patients who died due to short bowel syndrome as a result of extensive ischaemic bowel.

Re-operative procedures in 37% of patients with 42% for NEC. Reasons for repeat laparotomy procedures were abdominal compartment syndrome (11/26, 42%), initial damage control surgery (7/26, 27%), anastomotic leak (5/26, 19%), colonic perforation with evolving NEC (2/26, 8%) and adhesive bowel obstruction (1/26, 4%).

Discussion

The overall 30-day post-operative mortality rate for neonatal surgical conditions examined in this study was 11% which is double the rate in HIC over the same period for all neonates with surgical conditions. The one-year postnatal mortality in neonates receiving gastro-intestinal/abdominal surgery in this study cohort is 23%, highlighting the need for further evaluation beyond the 30-day post-operative period of cause of mortality. The 30-day post-operative mortality of 11% as a MIC hospital compared better to countries on the African continent who were LIC, where mortality rates are between 30 and 40% [1, 4]. High income countries have mortality rates lower than 10% for most conditions [1]. This study’s neonatal post-surgery 30-day mortality for commonly encountered gastrointestinal and abdominal wall conditions requiring surgery is shown in comparison to other reported HIC and LMIC mortality rates in Table 2. For the high-income countries this comparison is made for all patients, operated and not operated, indicative of an even lower post-operative mortality rate. It also underscores the significant differences that still exist between neonatal post-operative mortality rates in HIC and LMIC [9]. There are few publications on neonatal mortality in Africa but the post-operative mortality in this study compares favourably to other African countries as well as the limited reports from other South African centres [16, 18]. A large paediatric surgical centre in South Africa reported their overall 30-day neonatal patient mortality to be 22% with sepsis which contributed to death in over 80% of their cohort [18]. Another study at a different tertiary hospital in South Africa showed a 66% overall mortality for surgical patients admitted to their ICU and a 35% post-surgical mortality (16). Patients with NEC made up 39% of admissions with an overall mortality of 56% and post-surgical mortality of 53% [16]. It is evident from this that RCWMCH has post-operative mortality rates that are lower in comparison to LIC but worse than HIC.

Prematurity, low birth weight, respiratory failure, sepsis and shock at presentation are amongst many factors potentially responsible for poor prognosis in neonates [2, 14–16, 29]. Most of our neonates were born prematurely and the cohort of patients who died had a mean gestational age in the cohort of 33 weeks. Prematurity is known to have significant influence on outcome. Most premature neonates were noted in the necrotizing enterocolitis and spontaneous intestinal perforation group. These are among the same two groups with the highest mortality.

Fig. 2 Post-operative complications associated with mortality. RESP respiratory, AKI acute kidney injury, DIC disseminated intravascular coagulation, CNS central nervous system, ACS abdominal compartment syndrome

Systemic complications
Neonates with major surgical conditions accounted for a significant burden on intensive care unit admissions at RCWMCH with 97% of patients admitted post operatively and an average stay of 5 days. Two patients were not admitted into the ICU, for the NEC group, as no further intervention was planned for these patients due to a decision for palliative care. The limitation in bed availability related to demand has always been a challenging problem, especially in the ICU. This resulting in delays in transfer and definite management of neonates who are already critically ill. This further affected by associated life-threatening anomalies (cardiac and central nervous system anomalies) which may be a significant predictor of death unrelated to the pathology for which the neonate undergoes a surgical procedure [9]. Health system infrastructure and planning to increase bed availability needs to be prioritized as a healthcare intervention to reduce neonatal mortality in LMIC. Therefore efficient transfer systems and availability of intensive care facilities at receiving definitive care hospitals are important factors to improving neonatal surgical outcome.

Delayed presentation is an independent risk factor that predicts the mortality for neonates who have undergone surgical intervention [6, 17]. Early referral and surgery are advised to avoid morbidity and mortality. The odds ratio for death for patients with travel time over one hour from the referral hospital was 3.6 (95% confidence interval). Patients who were more than one hour away from the receiving institution (RCWMCH) experienced a higher mortality, indicating that distance travelled from referral hospital negatively impacts patient outcome. Resultant delays to definitive care may contribute to increased rates of morbidity and mortality in neonates reliant on surgical intervention for survival. Patient pathology from this distance of more than 100 km included necrotizing enterocolitis, spontaneous intestinal perforation and gastrochisis which were conditions among the top 5 causes of mortality. It stands to reason that distance and primary pathology both impact on survival outcomes post-surgery. This may be evident by significant increase in development of morbidities as a result of delayed transfer and receiving patients who are critically ill at time of admission. Efficient referrals and neonatal transport systems are essential interventions to reduce neonatal mortality [6, 16, 19]. Paediatric surgical services, with early referral and improvement of neonatal transport systems need to be prioritized.

Seventy four percent (54/73) of patients had post-operative complications. These include but not limited to abdominal compartment syndrome, anastomotic leak, and sepsis. This may be related to the extremist condition that some of these patients arrived in, related to primary pathology, associated comorbidity, and delays in transfer for definitive are as a result of transport or ICU space limitations. Neonates born outside the tertiary center’s where definitive management is undertaken have a worse reported outcome in LMIC [2, 3, 14–16, 18]. Delayed presentation is an independent risk factor that predicts the morbidity and mortality.

**Abdominal compartment syndrome (ACS)** was mostly encountered in patients with necrotizing enterocolitis requiring re operation. Consideration should be made at initial surgery if patients’ abdomen should have been left open, especially patients with necrotizing enterocolitis who ended up with necrotic bowel on the second look procedure as a result of abdominal compartment syndrome. Acute abdominal risk factors especially in NEC, perforation, strangulated inguinal hernia, ileus and volvulus; this group of patients being at increased risk of ACS because of distended oedematous bowel associated with systemic inflammatory response syndrome and organ dysfunction [18, 30]. Identifying at risk groups, careful patient selection, intra operative decision-making and a low threshold for reexploration in such patients to ensure better outcomes and avoid ACS. Considerations for staged procedures and abdominal pressure monitoring to

| Condition                              | Study cohort (%) | LIC (%) [1, 6, 34–37] | MIC (%) [1, 4, 6, 17, 18, 34, 35] | HIC (%) [1, 19, 34, 35, 38] |
|----------------------------------------|-----------------|------------------------|----------------------------------|-----------------------------|
| Necrotising enterocolitis              | 28              | 19–53                  | 32–50                            | 15–30                       |
| Spontaneous intestinal perforation     | 29              | 15–70                  | 22–32                            | 19                           |
| Gastrochisis                           | 18              | 90–63                  | 31–42                            | 1–4                         |
| Oesophageal atresia                    | 9               | 20–80                  | 15–10                            | 3                            |
| Malrotation                            | 9               | 50                     | 37                               | 3–9                         |
| Congenital diaphragmatic hernia        | 9               | 20–60                  | 42–50                            | 10–30                       |
| Intestinal atresia                     | 8               | 50                     | 47                               | 3                            |
| Anorectal malformation                 | 5               | 31                     | 11–20                            | 3–10                        |
| Inguinal hernia                        | 3               | 5                      | 0.2                              | 0                            |
| Total                                  | 83              | (11%)                  |                                  |                              |

LMIC low-to-middle income countries, HIC high income countries, N number, ARM anorectal

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Table 2: Comparison of neonatal mortality between study cohort and other settings for various surgical conditions
eliminate deleterious consequences of increase intra-abdominal pressure and progression to abdominal compartment syndrome [18]. Implementation of strategies to allow early recognition and reduce the deleterious consequences of ACS need to be addressed [18].

Anastomotic leaks were observed mostly in patients with intestinal atresia. Better selection of patients for primary anastomosis and those that would have had a better outcome with stoma formation needs to be held in balance with the poor outcome of especially premature neonates with proximal stomas due to high intestinal losses and fluid/electrolyte replacement in context with high rates of central line associated blood stream infection (CLABSI). Patients in the study had systemic sepsis, inotropic support with organ system failure. There were multiple confounding factors to their break down. Anastomosis leaks may be reduced by opting either for abbreviated surgery with planned relook surgery when patient has been optimized or the creation of stomas. There would be less chance of anastomotic leak whether intra-abdominal or intra thoracic if consideration for staged procedures in patients with sepsis and organ support was instituted.

Sepsis is an important cause of death in neonates and children under 5 years of age globally at 7% [31]. Fifteen percent of our patients died, due to sepsis, a frequency at least 2–3 times higher in LMIC than HIC. Infection causes 4–56% of all neonatal mortality in LMICs [12, 16, 31]. Patients who had initial perforated bowel, necrotic or ischaemic bowel which resulted in early sepsis with influence on mortality were 49% of the cohort who died. This included intestinal perforation and intra-abdominal soiling (36%), ischaemic bowel (31%) and necrotic diseased bowel (33%).

Preoperative risk factors for sepsis: Neonates requiring surgery are more often premature or have very low birth weight (VLBW) and require interventions such as central venous catheterisation more frequently. They also have prolonged hospital stay due to underlying congenital anomalies or prematurity, which may further predispose to development of morbidity, especially nosocomial sepsis. There were 41% of patients in the cohort with respiratory failure with 10% complicated by ventilator associated pneumonia resulting in death. Intra-operative risk factors for sepsis: Demise from sepsis in cases such as bowel perforation due to incarcerated inguinal hernia might have been related to inadequate sepsis source control at the index procedure as well as sepsis-related organ complications such as respiratory failure and acute kidney injury. This might also hold true for the other abdominal surgery’s such as intestinal atresia, volvulus, NEC, and spontaneous intestinal perforation if intra-abdominal contamination is not controlled. Further study is needed to see if intra-operative factors resulting in sepsis could be reduced. Post-operative risk factors for sepsis: Mortality was caused by sepsis in 74% with these organisms cultured: Enterococcus spp., Klebsiella pneumoniae, Acinetobacter baumanii and Candida albicans. Culture-proven wound infection was accounted for by Streptococcus pneumoniae and Staphylococcus aureus. Sources of sepsis included line sepsis with the highest percentage followed wound sepsis from surgical sites, infective endocarditis and anastomotic leak. Early identification of at-risk patients for wound break down and anastomotic leak by setting in place monitoring and intervention strategies is required. This may also include decision making intra operatively regarding stoma creation or versus primary anastomosis. Programs to improve infection prevention, stringent transmission-based precaution, education and adjustments or modifications to clinical practice is required to address post-surgical sepsis in neonates [32]. Central lines and sepsis: Central lines were inserted in 89% of patients, especially in patients with ultra-short bowel syndrome who needed long term total parenteral nutrition (such as intestinal atresia, necrotizing enterocolitis, gastroschisis with atresia and malrotation with volvulus). Forty eight percent of patients had culture-proven sepsis from the central line. Surgical site infection: This is higher in neonates due to underlying co-morbidities, prematurity, prolonged requirements for total parenteral nutrition and immature immune system of neonates [24]. Improvement in prevention of sepsis and improved infection control are therefore an absolute necessity if we are to improve outcomes in surgical neonates.

Disease-specific mortality in patients with NEC, SIP and gastroschisis were associated with higher mortality rates compared to the rest of the conditions. The rest of the other conditions had significantly lower comparative mortality rates. Sepsis was the largest contributor to mortality in NEC, SIP and gastroschisis, and typically complicated with anastomotic leaks and organ failure. Abdominal compartment syndrome resulting in patient deterioration and in some instances bowel ischaemia, anastomotic leak and central line sepsis had a contribution to mortality.

Overall RCWMCH neonatal post-operative mortality at 30 days post-surgery was 11% with an increase to 23% by 12 months. This late doubling of mortality requires further investigation to see if it is related to poor follow-up or other underlying conditions or comorbidities such as chromosomal abnormalities or other organ dysfunction such as the poor neurological outcomes frequently seen following surgical management of necrotizing enterocolitis for example [9, 25, 33]. This was not assessed as part of the study.

Conclusion

This study identified the 30-day neonatal post-operative mortality rate at RCWMCH, a MIC free-standing tertiary paediatric hospital, to be 11% which was lower compared
to LIC post-surgery outcomes but inferior to other MIC for some disease conditions, and higher than HIC mortality. Mortality in patients with necrotizing enterocolitis and intestinal atresia was the highest. Gram-negative sepsis was a major contributing factor in the development of morbidity and mortality in our cohort, with sepsis accounting for 74% of deaths, often associated with anastomosis leak, as well as CLABSI. Abdominal compartment syndrome was another significant preventable cause of death.

**Limitations of this study**

The retrospective nature of the study affected availability of information from files which was often poor due to quality of record-keeping. This study analyzed post-operative mortality. Patients who did not survive to surgery were not included. Risk factors for pre- and post-operative mortality overlap but there may be a few differences. However, further prospective multi centre studies will be required to investigation the overall neonatal mortality for the various surgical conditions.

**Recommendations**

There need to be ongoing efforts to improve the quality of surgical care for children in low and middle-income countries to prevent mortality and morbidity across multiple congenital and infection-related neonatal conditions. Prevention and improvement strategies for infection control are imperative if we are to improve outcomes in our surgical neonates. Better central venous line care needs to be instituted as this is a contributor to sepsis. Programmes to improve infection prevention practice in African neonatal units are urgently required. Implementation of transmission-based precautions, health care worker education, and changes to clinical practices could potentially contain infection outbreaks. Considerations need to be made to reduce ACS by leaving the abdomen open after laparotomy for peritonitis with planned relook for definitive closure. Early referral and definitive management to allow a better prognosis. This was evident in those patients who were transferred from areas more than an hour away. We need improvements in timeous transfer for definite surgical procedure through infrastructural and organizational logistics. Addressing intensive care bed capacity for regional hospital transfer. Recognize specific group of patient’s pathologies at increased risk for mortality with early intervention and sepsis control measures in place. This is especially the case for patients with necrotizing enterocolitis and gastrochisis. Improved surgical technique. Improved communication with the multidisciplinary team, including with paediatricians, fetal medicine specialist and obstetricians. This resulting in coordinated delivery and transfer of patients timeously for their definitive intervention. The mortality at 6 and 12 months was significant and would need to be assessed in detail in future further studies to define the cause and associated factors.

**References**

1. Wright NJ (2019) Management and outcomes of gastrointestinal congenital anomalies in low, middle and high income countries: protocol for a multicentre, international, prospective cohort study. BMJ Open 9:e030452
2. Poley MJ, Werner BF, Brouwer JV et al (2007) Cost-effectiveness of neonatal surgery. Pediatric Surg Int 24:119–127. https://doi.org/10.1007/s00383-007-2045-0
3. Sebastian OE, Obinna V et al (2016) Challenges of management and outcome of neonatal surgery in Africa: a systematic review. Pediatric Surg Int. https://doi.org/10.1007/s00383-016-3861-x
4. Chirdan LB, Ngiloi PJ, Elhalaby EA (2012) Neonatal surgery in Africa. Semin Pediatr Surg 21(2):1. https://doi.org/10.1053/j.semptdsurg.2012.01.007
5. Chirdan LB, Ngiloi PJ, Elhalaby EA (2012) Neonatal surgery in Africa. Semin Pediatr Surg 21(1):51–159. https://doi.org/10.1053/j.semptdsurg.2012.01.007
6. Ilori IU, Ituen AM, Eyo SC (2013) Factors associated with mortality in neonatal surgical emergencies in a developing tertiary hospital in Nigeria. Open J Pediatr 3:231–235. https://doi.org/10.4236/ojped.2013.33040
7. United Nations Inter-agency Group for Child Mortality Estimation (UN IGME), ‘Levels & Trends in Child Mortality: Report 2018, Estimates developed by the United Nations Inter-agency Group for Child Mortality Estimation’, United Nations Children’s Fund, New York, 2018. https://www.unicef.org/media/47626/file/UN-IGME-Child-Mortality-Report-2018.pdf
8. Pongou R (2013) Why is infant mortality higher in boys than in girls? A new hypothesis based on preconception environment and evidence from a large sample of twins. Demography 50(2):421–444. https://doi.org/10.1007/s13524-012-0161-5
9. Amponsah G (2010) Challenges of anaesthesia in the management of the surgical neonates in Africa. Afr J Paediatr Surg 7(3):134–139. https://doi.org/10.4103/01896725.70410
10. Peters RT, Ragab H, Columb M et al (2017) (2017) Mortality and morbidity in oesophageal atresia. Mortality and morbidity in oesophageal atresia. Pediatr Surg Int 33(9):989–994. https://doi.org/10.1007/s00383-017-4124-1
11. Ekenze SO, Anyanwu PA, Ezomike UO, Oguoru T (2010) Profile of pediatric abdominal surgical emergencies in a developing country. Int Surg 95(4):319–324 (PMID: 21309414)
12. Shakyta VC, Agrawal CS, Shreshtha P et al (2010) Management of jejunoileal atresias: an experience at eastern Nepal. BMC Surg 10:35. https://doi.org/10.1186/1471248210-35
13. Vukadin M, Savic D, Malikovic A et al (2015) Analysis of prognostic factors and mortality in children with esophageal atresia, Indian J Pediatr 82(7):586–590. https://doi.org/10.1007/s12098-015-1730-6
14. Ekenze SO, Ibeziako SN, Ezomike UO (2007) (2007) Trends in neonatal intestinal obstruction in a developing country, 1996–2005. World J Surg 31(12):2405–2409. https://doi.org/10.1007/s00268-007-9206-0
15. Manso J, Ameh E, Canvassar N et al (2012) Gastrochisis: a multi-centre comparison of management and outcome. Afr J Paediatr Surg 9(1):17–22. https://doi.org/10.4103/0189-6725.93296
16. Sagers RT, Ballot DE, Grieve A (2020) An analysis of neonates with surgical diagnoses admitted to the neonatal intensive care
unit at Charlotte Maxeke Johannesburg Academic Hospital, South Africa. S Afr Med J 110(6):497–501. https://doi.org/10.7196/SAMJ.2020.v110i6.14326

17. Manchanda V, Sarin YK, Ramji S (2012) Prognostic factors determining mortality in surgical neonates. J Neonatal Surg 1(1):3

18. Withers A, Cronin K, Mabaso M, Brisighelli G, Gabler T, Harrison D, Patel N, Westgarth-Taylor C, Loveland J (2021) Neonatal surgical outcomes: a prospective observational study at a Tertiary Academic Hospital in Johannesburg, South Africa. Pediatr Surg Int. https://doi.org/10.1007/s00383-021-04881-7

19. Bradnock TJ, Marven S, Owen A et al (2011) Gastroschisis: one-year outcomes from national cohort study. BMJ 343:d6749. https://doi.org/10.1136/bmj.d6749

20. Adams MM, Alexander GR, Kirby RS, Wingate MS (2010) Perinatal epidemiology for public health practice, 1st edn. Springer, New York, p 2009

21. Davis AL, Carcillo JA, Kirby RS, Wingate MS (2014) Surgical site infections in infants admitted to the neonatal intensive care unit. J Pediatr Surg 49(3):381–384. https://doi.org/10.1016/j.jpedsurg.2013.08.001

22. Eltayeb AA (2010) Delayed presentation of anorectal malformations: the possible associated morbidity and mortality. Pediatr Surg Int 26:801–806. https://doi.org/10.1007/s00383-010-2641-2

23. Akbilgic O, Langham MR, Walter AI et al (2018) A novel risk classification system for 30-day mortality in children undergoing surgery. PLoS ONE 13(1):e0191176

24. Wilkinson JD, Pollack MM, Glass NL et al (1987) Mortality associated with multiple organ system failure and sepsis in pediatric intensive care unit. J Pediatr 111:324

25. Division of Paediatric Surgery. (2017) Annual Report. Red Cross War Memorial Children’s Hospital Cape Town South Africa.

26. The Millennium Development Goals Report 2015. UNDP. www.unDP.org/.../themillennium-development-goals-report-2015.html. Accessed 18Aug 2022

27. WHO Sepsis Technical Expert Meeting - Meeting report. Geneva: World Health Organization; 2018. https://creativecommons.org/licenses/by-nc-sa/3.0/igo

28. Dramowski A, Madide A, Bekker A (2015) Neonatal nosocomial bloodstream infections at a referral hospital in a middle-income country: burden, pathogens, antimicrobial resistance and mortality. Paediatr Int Child Health 35(3):265–272. https://doi.org/10.1179/2046905515Y.0000000029

29. Gom S, Grieve A, Velaphi S (2019) Characteristics and outcomes of neonates with gastroschisis managed in a public tertiary hospital in a developing country. S Afr J Child Health 13(4):168173. https://doi.org/10.7196/SAJCH.2019.v13i4.1588

30. Schier IAM, Giuffrè M, Piro E, Ortolano R, Siracusa F, Pinello G, La Placa S, Corsello G (2014) Predictive factors of abdominal compartment syndrome in neonatal age. Am J Perinatol 31(1):49–54. https://doi.org/10.1055/s-0033-1334447

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