OBJECTIVE: Pediatric neurosurgical cases have been identified as an important target for impacting health disparities in Uganda, with over 50% of the population being less than 15 years of age. The objective of the present study was to evaluate the effects of the Duke-Mulago collaboration on pediatric neurosurgical outcomes in Mulago National Referral Hospital.

METHODS: We performed retrospective analysis of all pediatric neurosurgical cases who presented at Mulago National Referral Hospital in Kampala, Uganda, to examine overall, preprogram (2005–2007), and postprogram (2008–2013) outcomes. We analyzed mortality, presurgical infections, postsurgical infections, length of stay, types of procedures, and significant predictors of mortality. Data on neurosurgical cases was collected from surgical logbooks, patient charts, and Mulago National Referral Hospital’s yearly death registry.

RESULTS: Of 820 pediatric neurosurgical cases, outcome data were complete for 374 children. Among children who died within 30 days of a surgical procedure, the largest group was less than a year old (45%). Postinitiation of the Duke-Mulago collaboration, we identified an overall increase in procedures, with the greatest increase in cases with complex diagnoses. Although children ages 6–18 years of age were 6.66 times more likely to die than their younger counterparts preprogram, age was no longer a predictive variable postprogram. When comparing pre- and postprogram outcomes, mortality among pediatric patients within 30 days after a neurosurgical procedure increased from 4.3% to 10.0%, mortality after 30 days increased slightly from 4.9% to 5.0%, presurgical infections decreased by 4.6%, and postsurgery infections decreased slightly by 0.7%.

CONCLUSIONS: Our data show the provision of more complex neurological procedures does not necessitate improved outcomes. Rather, combining these higher-level procedures with essential pre- and postoperative care and continued efforts in health system strengthening for pediatric neurosurgical care throughout Uganda will help to address and decrease the burden throughout the country.

INTRODUCTION

Pediatric global health, including the millennium development goals aimed at children, has predominantly focused on issues such as infectious diseases, premature births, and nutrition.1,2 Surgical conditions, including neurosurgical conditions, largely have not been a major factor in global health efforts; however, an estimated 85% of children will have a surgically treatable condition by the age of 15 years.3 The landmark The Lancet study on global surgery showed that surgical conditions significantly contribute to the global burden of disease in low-income and middle-income countries (LMICs) and that treating these conditions can be just as, if not more, cost-effective than traditional public health programs, such as immunizations and other interventions considered part of a global health regiment.3-5 Hence, improving surgical care...
access and quality of care received is a critical component to improve the health of persons in resource-poor settings.

Pediatric neurosurgical cases have been identified as an important target for impacting health disparities in Uganda, with over 50% of the population being less than 15 years of age. The most common type of pediatric neurosurgical case is hydrocephalus, with approximately 80,000–375,000 new cases each year in Sub-Saharan Africa. Although CURE Hospital in Uganda specializes in pediatric neurosurgical needs and has made significant progress in developing accessible and affordable treatments for hydrocephalus and treating complex pediatric brain tumor cases and other neurosurgical conditions, the demand for pediatric neurosurgical treatment far outweighs CURE Hospital’s capacity of approximately 1000 cases per year. Furthermore, surgeries at CURE Hospital are only accessible to those within a limited catchment area in Uganda, therefore, it is essential for more hospitals to be able to provide critical neurosurgical care for the large pediatric population.

Despite the need for pediatric neurosurgical care, there were only 5 neurosurgeons to serve Uganda’s population of 30 million individuals in 2009, and even national referral and regional hospitals lack adequate equipment that would allow these neurosurgeons to deliver standard neurosurgical care. To overcome the lack of neurosurgeons within Uganda, the Duke University Medical Center and the Duke Global Health Institute established a program, the Duke-Mulago collaboration, in 2007 at Mulago National Referral Hospital in Kampala, Uganda, to address the neurosurgical need with a 2-pronged approach: 1) providing essential equipment to provide basic neurosurgical services, and 2) expanding the neurosurgical training through a twinning approach. In this twinning approach, a multidisciplinary team from Duke University, which included neurosurgeons, anesthesiologists, nurses, biomedical engineers, Certified Registered Nurse Anesthetists, and other health care workers, were paired with their Ugandan counterparts to impart new skills and share best practices during training camps. Outcomes data from the pre- and postprogram initiative have shown that this program increased both the number and complexity of cases in Mulago National Referral Hospital. However, an analysis focusing on the pediatric patient population at Mulago National Referral Hospital has not been conducted.

Given the large pediatric population in Uganda, it is imperative to understand the effects of this program on pediatric cases. These outcomes data would not only enable us to understand the quality of care patients are receiving, but it would also inform future measures for improving the program. Furthermore, this information would provide insight into the feasibility and efficacy of implementing this program in other hospitals in developing countries. Therefore, the objective of this study was to evaluate the effects of the Duke-Mulago collaboration on pediatric neurosurgical outcomes in Mulago National Referral Hospital.

METHODS

Setting
Mulago National Referral Hospital serves as a national referral hospital and teaching hospital for Uganda and provides medical care to the largest catchment area of Kampala, the capital city (i.e., 1.5 million people). Likewise, Mulago National Referral Hospital provides the most comprehensive specialty services in the country, and nearly all patients with neurosurgical needs are referred to the hospital for care. Because of the high volume of referrals, limited infrastructure, and human resources available to meet the demand, neurosurgical patients are met with long queues and sometimes leave the hospital without needed procedures or wait for weeks for surgery. The status of Mulago National Referral Hospital as a teaching hospital addresses this need by attracting visiting surgeons from abroad to perform neurosurgical camps providing care to those in the queues that would likely have not received an operation.

Data Collection
This study is a retrospective analysis examining the impact of the Duke-Mulago collaboration on pediatric neurosurgical outcomes, including mortality and hospital discharges. All pediatric patients between birth and 18 years of age who underwent a neurosurgical procedure from fiscal year (FY) 2005 to FY 2013 were included in the study (FY is defined as August of year prior to July of stated year). Two distinct time periods, pre- and postprogram, were distinguished based on the Duke-Mulago collaboration initiation in FY 2008. The preprogram period included pediatric neurosurgical procedures between FY 2005 and FY 2007, and the postprogram period included procedures between FY 2008 and FY 2013. Research ethics approval was obtained from the Makerere University School of Medicine Research and Ethics Committee, Duke University Health System Institutional Review Board, and Mulago National Referral Hospital Institutional Review Board.

Data on neurosurgical cases, defined as all cases performed by a neurosurgeon at Mulago National Referral Hospital, were collected from 3 primary sources: surgical logbooks, patient charts, and Mulago National Referral Hospital’s yearly death registry, which includes all deaths occurring in the hospital. Data from surgical logbooks included date of operation, patient’s name, age, sex, hospital ward, inpatient number, type of anesthesia used, diagnosis, and operation. Data from inpatient medical charts included death or discharge, date of death/discharge, admission date, infection prior to surgery, infection postsurgery, any antibiotics used during their stay, any radiographic results documented, Glasgow Coma Scale score at admission, and additional details to provide context for future analyses. Data collected from the death registry included death or discharge, date of death/discharge, admission date, and other relevant documented outcome measures.

Data between the 3 sources were matched by patient name, inpatient number, age, and sex. All data were doubly entered into a Microsoft Excel (Microsoft Corp., Redmond, Washington, USA) spreadsheet to decrease the likelihood of human error. Discordant entries were rechecked against the physical hospital documents and updated accordingly. When writing on either the surgical logbooks or medical charts became difficult to interpret, a staff member of Mulago National Referral Hospital was asked to interpret the writing. If they were unable to, that data point was labeled as missing.
Data Analysis
Data analysis was performed using SAS 9.4 (SAS Institute Inc., Cary, North Carolina, USA) and stored in spreadsheets in Microsoft Excel 2014. Demographic data and clinical characteristics were compared between children who died within 30 days, children who died after 30 days, and children who were discharged after a neurosurgical procedure. Mortality after a neurosurgical procedure and clinical characteristics was compared between program periods (i.e., pre- vs. postprogram) using \( \chi^2 \) statistics for categorical variables and \( t \) test statistics for continuous variables. We evaluated significant predictors of mortality between the program periods through a multivariate model, including the child’s age, sex, and diagnosis on hospital admission. Diagnosis categories were collapsed because of small cell sizes into ventriculoperitoneal shunts, myelomeningoceles or encephaloceles, tumors, including posterior fossa and spinal tumors, and other, including infections, spine, aneurysms, chiari malformations, cerebrospinal fluid leak, peripheral nerve tumors, and extracranial lesions. Length of stay and infection prior or after surgery were not included in the multivariate model because of missing data. Statistical significance for all results was evaluated at \( P < 0.05 \).

RESULTS
Overall Descriptive Results
In Mulago National Referral Hospital between FY 2005 and FY 2013, there were 820 neurosurgical procedures performed, 820 (43.7%) were among children less than 18 years of age. Of the 820 children, outcome data were complete for 374 children. Of the 374 children, 29 died within 30 days, 18 died after 30 days, and 327 were discharged from the hospital. Outcome status by age group was significantly different (\( P = 0.01 \)). Among children who died within 30 days of a surgical procedure, 45% were less than 1 year of age, 31% were between the ages of 1 and 5 years, and 14% were older children between the ages of 15 and 18 years of age (Table 1). Similar results were found among children who died more than 30 days after a surgical procedure, with the exception of a higher percentage of children between the ages of 11 and 15 years, where 17% died. A greater percentage of males died in the hospital after a neurosurgical procedure compared with boys who were discharged; however, the difference was not statistically significant. The type of diagnosis on hospital admission also varied by hospital outcome, with a greater percentage of children who died after a surgical procedure being admitted for shunts, myelomeningoceles, and tumors. The difference in median lengths of stay between the 3 outcome groups was significantly different (\( P < 0.0001 \)). Among children who died within 30 days after a surgical procedure, the median length of stay was 4.0 days compared with 76.5 days among children who died after 30 days and 7.0 days among children who were discharged.

Comparison of Pre- and Postprogram Outcomes
Mortality among pediatric patients within 30 days after a neurosurgical procedure increased from 4.3% to 10.0% (\( P = 0.25 \)) between the pre- and postprogram periods (Table 2). Mortality after 30 days increased slightly from 4.9% to 5.0%. Presurgical infections decreased by 4.6% (\( P = 0.11 \)), whereas postsurgery infections decreased slightly by 0.7% when comparing the pre- or postprogram periods (\( P = 0.88 \)). The median length of stay decreased by 1 day with a larger interquartile range (5 vs. 8, respectively); however, the finding was nonsignificant (\( P = 0.81 \)).

The type of neurosurgical procedure differed between the pre- and postprogram periods (Figure 1). An increase in all types of procedures was observed with the exception of infections or other procedure types. The greatest increase in type of procedure during the postprogram time was for more complex diagnoses, including tumors and traumas.

Predictors of Mortality
Predictors of pediatric mortality after neurosurgical procedures included age and type of diagnosis on admission (Table 3). During the preprogram period, older children between the ages of 6 and 18 years were 6.66 times more likely to die (95% confidence

| Table 1. Outcome for Pediatric Admissions in Mulago National Referral Hospital |
|-------------------------------------------------|------------------------------|---------------------------------|---------------------------------|------------------|
| Characteristic                                  | Died Within 30 Days (n = 29) | Died Over 30 Days (n = 18)     | Discharged (n = 327)            | \( P \) Value    |
| Age (years)                                     | 0.01                          |                                 |                                 |                  |
| <1                                              | 44.8 (13)                     | 44.4 (8)                        | 67.9 (222)                      |                  |
| 1–5                                             | 31.0 (9)                      | 22.2 (4)                        | 10.1 (33)                       |                  |
| 6–10                                            | 6.9 (2)                       | 5.6 (1)                         | 8.3 (27)                        |                  |
| 11–15                                           | 3.5 (1)                       | 16.7 (3)                        | 6.7 (22)                        |                  |
| 15–18                                           | 13.8 (4)                      | 11.1 (2)                        | 7.0 (23)                        |                  |
| Sex                                             | 0.72                          |                                 |                                 |                  |
| Male                                            | 62.1 (18)                     | 61.1 (11)                       | 55.4 (181)                      |                  |
| Female                                          | 37.9 (11)                     | 38.9 (7)                        | 44.6 (145)                      |                  |
| Diagnosis                                       | 0.61                          |                                 |                                 |                  |
| Shunt                                           | 34.5 (10)                     | 38.9 (7)                        | 37.6 (123)                      |                  |
| Myelomeningocele                                | 31.0 (9)                      | 22.2 (4)                        | 36.7 (120)                      |                  |
| Tumor                                           | 20.7 (6)                      | 11.1 (2)                        | 3.7 (12)                        |                  |
| Tumor posterior fossa                           | 6.9 (2)                       | 16.7 (3)                        | 1.2 (4)                         |                  |
| Trauma                                          | 0.0 (0)                       | 0.0 (0)                         | 9.8 (32)                        |                  |
| Infection                                       | 3.5 (1)                       | 5.6 (1)                         | 3.9 (13)                        |                  |
| Encephalocele                                    | 3.5 (1)                       | 5.6 (1)                         | 3.1 (10)                        |                  |
| Other*                                          | 0.0 (0)                       | 0.0 (0)                         | 3.6 (13)                        |                  |
| Length of stay post surgery                     | <0.0001                       |                                 |                                 |                  |
| Median ± SD                                     | 4.0 ± 7.7                     | 76.5 ± 125.3                    | 7.0 ± 13.1                      |                  |

Values are number of patients (%) or as otherwise indicated.
*Includes chiari, cerebrospinal fluid leak, peripheral nerve, wound, spine, extracranial lesion, and spinal tumor.
interval [CI], 1.85–24.04; \( P = 0.004 \) than their younger counterparts, and children with a neurosurgical procedure other than myelomeningoceles or encephaloceles or tumors were less likely to die than children receiving a shunt procedure (odds ratio, 0.23; 95% CI, 0.07–0.74; \( P = 0.03 \)). During the postprogram period, age was no longer a predictive variable while adjusting for sex and diagnosis type. Children receiving a procedure for tumors were 2.91 times more likely to die (95% CI, 1.20–7.05; \( P = 0.0003 \)) than children receiving a procedure for a shunt.

**DISCUSSION**

Hospital outcomes of mortality or being discharged after a neurosurgical procedure among pediatric patients differed by age group, length of stay after surgery, and pre- and postprogram periods. Significant predictors of mortality included age and diagnosis type on admission, which were driven mainly by increased treatment of pediatric trauma. Clearly, treating pediatric patients with neurosurgical needs is a complex problem that may differ by the age and condition of the child.

**Caseload**

In our data hydrocephalus patients constituted most cases in patients less than 5 years of age, with trauma being the main diagnosis for those older than 5 years of age. Neonatal infection is the primary driver of hydrocephalus development in children less than 5 years of age within Sub-Saharan African countries.20 Within Uganda, it has been proven that an effective approach to treatment of hydrocephalus is third ventriculostomy, with choroid plexus cauterization as an alternative to the traditional shunt procedure.9 Regarding pediatric trauma, patients are admitted with traumatic brain injuries because of road traffic accidents; therefore, the surgical approach requires an ability to handle intracranial hemorrhage and provide decompressive operations.20 This difference in etiology related to age is important to note because the approach for adequate neurosurgical management of hydrocephalus is very different than trauma.

Demonstrated in our data is the increase in the number of pediatric surgical cases performed, which was driven mainly by an increased treatment of pediatric trauma. Importantly, the other procedure that increased after the collaboration was tumor operations. This increase serves as a proxy measure for increased

![Figure 1. Pediatric neurosurgical procedures in Mulago National Referral Hospital, 2005–2013. Preprogram included neurosurgical procedures between fiscal years 2005 and 2007. Postprogram included neurosurgical procedures between fiscal years 2008 and 2013.](image-url)
complexity of cases performed because proper treatment of pediatric brain tumor patients is highly complex. The only published article on brain tumors at Mulago National Referral Hospital detailed that pediatric patients suffer from pituitary tumors, meningiomas, and craniopharyngiomas, all of which require specialized surgical approaches for tumor resection. Moreover, research at CURE Hospital suggests that most pediatric brain tumors in the region go unrecognized, and the ones that do seek treatment have delayed presentation with visible diagnosis, further increasing the complexity of the tumor cases. The increase in treatment of pediatric brain tumor patients points to an area of success for this collaboration. Initially, the collaboration, described in detailed elsewhere, began with complex pediatric neurosurgical patients being treated solely during the biannual neurosurgical camps with operations led by Duke neurosurgeons. As the collaboration flourished, these complex operations shifted toward being led by Ugandan neurosurgeons during the camps, and currently Ugandan neurosurgeons and Ugandan neurosurgical resident trainees perform most of the complex operations independently.

Mortality
Postoperative mortality rate (POMR) has been touted as an indicator for safe surgical and anesthesia care, for usage in LMICs where collection of data is difficult. We used this metric to compare the pre- and postprogram POMRs to determine the impact of the Duke-Mulago collaboration. Paradoxically, our data suggest that the collaboration has negatively impacted the POMR because it increased from 7.4% within the preprogram period to 13.6% within the postprogram period. Although this is counterintuitive, it makes sense when looking at the increased complexity of the cases performed paired with the pre- and postoperative care remaining standard regardless of case complexity. Studies show that the surgical operation itself, patient comorbidities, and pre- and postoperative patient management significantly contribute to mortality. The collaboration’s mentorship model creates an environment where the skills necessary to perform complex operations are slowly transferred over multiple complex patient cases before that type of case is tried independently. Therefore, it usually takes multiple camps before particularly complex cases can be handled outside of the camps. This provides neurosurgeons with the necessary skills, techniques, and equipment to perform highly complex operations safely and effectively. Given that the collaboration’s main focus is on access and provision of the operation itself, it is clear from the data that more emphasis is needed on adequate pre- and postoperative management of patients. This aspect of the collaboration has already begun, with an increased emphasis on training patient’s families and also all nursing staff on proper management of complex neurosurgical pediatric patients.

Infections
A key element for pre- and postoperative management of patients is infection control. Although we were unable to collect the etiology of postoperative infections in our data, surgical site infection is a frequent complication after surgery in Sub-Saharan Africa. Poor infection control and management of existing infections preoperatively has been linked with poor surgical outcomes, including mortality. This holds true for postoperative infections from surgical site infections, pneumonia, and catheter-associated infections. To combat the issue of infections fully within this context, increased vigilance must be maintained to increase hand-washing practices in the wards, maintenance of proper sterile techniques within the operating rooms, and infection control mechanisms postoperatively, such as proper maintenance and early removal of indwelling urinary catheters.

Study Limitations
Inherent to the retrospective nature of the data in this study, study limitations exist that hinder complete evaluation of the outcomes for pediatric neurosurgical patients. Mulago National Referral Hospital uses paper documentation for all hospital proceedings, and these records are at times improperly stored. Additionally, charts are lost, damaged by water, have illegible handwriting, or have important pages missing. These factors in tandem with the fact that neurosurgical patients’ charts are not properly filed led to a large amount of missing data for this study. To combat this issue, multiple sources of information were used, and an extensive search of the medical records department was performed to gather as much data as was available. Bias may be present in our study given that outcome data were available for 374 of the 820 pediatric neurosurgical operations during our follow-up period. However, we assumed the missing data files with the outcome data during our follow-up period were missing at random because factors regarding recordkeeping were the same pre- and postprogram. Nonetheless, the lack of outcome data highlights the need for further research to obtain a more complete data sample.

We used only basic in-hospital outcome metrics as our primary outcomes because of the lack of follow-up and inconsistent documentation within charts of other important mortality and morbidity outcome metrics. A prospective database is now currently being implemented to improve variable collection for more robust outcome metrics for evaluations.

CONCLUSIONS
Pediatric surgery in Sub-Saharan Africa is increasingly being recognized as an important public health problem and contributor to the overall global burden of disease. Although this awareness is encouraging, performing more surgeries or providing a higher level of complexity regarding pediatric surgeries alone is not the answer. As our data show, the provision of more complex neurological procedures does not necessitate improved outcomes. Rather, combining these higher-level procedures with essential pre- and postoperative care will be critical. Increased focus on pre- and postoperative care linked with continued efforts in health system strengthening for pediatric neurosurgical care throughout Uganda will help to address and decrease the burden throughout the country. Similarly, this approach can serve as a representation of a working model for other Sub-Saharan African countries dealing with the same problems.
REFERENCES


