Monitoring Anesthesia Care Delivery and Perioperative Mortality in Kenya Utilizing a Provider-driven Novel Data Collection Tool

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ABSTRACT

Background: Perioperative mortality rate is regarded as a credible quality and safety indicator of perioperative care, but its documentation in low- and middle-income countries is poor. We developed and tested an electronic, provider report–driven method in an East African country.

Methods: We deployed a data collection tool in a Kenyan tertiary referral hospital that collects case-specific perioperative data, with asynchronous automatic transmission to central servers. Cases not captured by the tool (nonobserved) were collected manually for the last two quarters of the data collection period. We created logistic regression models to analyze the impact of procedure type on mortality.

Results: Between January 2014 and September 2015, 8,419 cases out of 11,875 were captured. Quarterly data capture rates ranged from 423 (26%) to 1,663 (93%) in the last quarter. There were 93 deaths (1.53%) reported at 7 days. Compared with four deaths (0.53%) in cesarean delivery, general surgery (n = 42 [3.65%]; odds ratio = 15.80 [95% CI, 5.20 to 48.10]; $P < 0.001$), neurosurgery (n = 19 [2.41%]; odds ratio = 14.08 [95% CI, 4.12 to 48.10]; $P < 0.001$), and emergency surgery (n = 25 [3.63%]; odds ratio = 4.40 [95% CI, 2.46 to 7.86]; $P < 0.001$) carried higher risks of mortality. The nonobserved group did not differ from electronically captured cases in 7-day mortality (n = 1 [0.23%] *vs.* n = 16 [0.58%]; odds ratio =3.95 [95% CI, 0.41 to 38.20]; $P = 0.24$).

Conclusions: We created a simple solution for high-volume, prospective electronic collection of perioperative data in a lower- to middle-income setting. We successfully used the tool to collect a large repository of cases from a single center in Kenya and observed mortality rate differences between surgery types. **(Anesthesiology 2017; 127:250-71)**

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NONCOMMUNICABLE diseases are an increasing disease burden in many low- and middle-income countries.[1–3] Providing basic surgical and anesthesia care in such countries could avert as many as 1.4 million deaths yearly.[1] It is important to assess current outcomes to identify and remedy unsafe practices or poor quality care along the way to improving surgery and anesthesia in low-resource countries. Perioperative mortality rate (defined as the percentage of patients dying during or shortly after surgery) is a credible quality and safety indicator of perioperative care.[3,4] Perioperative mortality rate (henceforth referred to as "postoperative mortality") data are crucial to direct capacity-building efforts for safe surgical care in low- and middle-income countries.

Postoperative mortality is a principal indicator of the safety of surgery and anesthesia care in a country or health region.[3–5] Risk adjustment for factors such as the American Society of Anesthesiologists (ASA) physical status, age, admission urgency, and type of procedure can refine interpretation of postoperative mortality outcomes.[5] Postoperative mortality is well documented in high-income countries but rarely used as an outcome metric in low- and middle-income countries.[3–5]

What We Already Know about This Topic

- Perioperative mortality is a useful indicator of the quality and safety of anesthesia and surgery, but such data are not readily available in low- to middle-income countries
- A simple electronic data collection tool for tracking postoperative mortality was designed and implemented in a rural Kenyan tertiary care hospital

What This Article Tells Us That Is New

- Prospective real-time collection of postoperative mortality data for 21 months in a lower- to middle-income country showed procedure-specific differences in 7-day mortality
- Mortality was highest in emergency surgery and lowest in cesarean delivery, the most common surgical procedure

Postoperative mortality in high-income settings is ninefold lower than in low- and middle-income countries (0.38 *vs.* 3.44 per 100 admissions, respectively),[5] and postoperative mortality has declined more in high-income countries than in low- and middle-income countries over the past three to four decades.[6] A systematic review of postoperative mortality

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reporting in low- and middle-income countries from 1995 to 1999 revealed a median in-hospital mortality rate of 1.2% for elective procedures and 10.1% for emergency procedures.[7] Studies of postoperative mortality have been limited by several factors, including the following: (1) small sample size; (2) hospital-level surveys instead of patient-level data; (3) focus on a specific surgery, such as cesarean delivery or cleft palate repair; and (4) data collected retrospectively from surgical case logbooks, which are often incomplete.[8–14]

We designed and implemented a simple electronic data collection solution to gather information on anesthesia, surgery, and perioperative outcomes in a prospective, near real-time manner. We present the methodology for creating and implementing this postoperative mortality tool in Kenya and demonstrate 21 months of case-by-case postoperative mortality data from a rural tertiary referral hospital.

Materials and Methods

Study Design

The Vanderbilt University Medical Center (Nashville, Tennessee) and the Kijabe Hospital Institutional Review Boards (Kijabe, Kenya) approved the study without requiring written informed consent. Africa Inland Church Kijabe Hospital is a 285-bed, rural teaching hospital that serves a catchment area of 45 million persons.[15] It was chosen to be the first center for implementation of the data collection tool because of its clinical and educational capacity in surgery and anesthesia. Results of the prototype are intended to support an ongoing project to expand anesthesia and surgery capacity in government and nongovernment hospitals throughout Kenya.

Questionnaire

A case report form was assembled using two guiding principles. First, we included all of the data fields believed to be important for understanding baseline characteristics of surgical care and outcomes in low- and middle-income countries. Second, we limited the number of data fields to make the case report form reasonable to complete by the anesthetist during a typical surgical case. These somewhat competing principles were iteratively applied using a modified Delphi technique with Vanderbilt University (B.S., M.D.M., J.P.W., W.S.S.) and Kijabe Hospital (M.W.N., J.K., M.M.) experts. The result contains five sections of questions, yielding a final case report form with 132 data fields (appendix 1 and 2).

Data Collection Tool

Kenyan anesthetists performed initial data collection using paper forms while we developed the electronic data collection system. We created the electronic system on the Research Electronic Data Capture (REDCap) platform, a free, customizable Web-based data collection instrument that typically requires Internet connectivity for functionality.[16] Internet connectivity can be unreliable in rural Kenya, so we created a version of the REDCap tool supporting offline data capture with asynchronous data upload when an Internet connection was available (appendix 3). During the implementation phase, Kenyan registered nurse anesthetists and student nurse anesthetists received training on principles of quality improvement, real-time data acquisition, data management, and professionalism. We collected data from January 2014 to September 2015, organized into seven 3-month quarters.

Mortality

Data collectors followed patients prospectively from preoperative assessment until 7 days into the postoperative period (appendix 2E). When patients were discharged before day 7, a follow-up telephone call was made to the patient or designated family member. Inpatient mortality data were independently verified using existing in-hospital mortality logs. Cases that were missed, meaning not collected using the REDCap tool, were identified using the surgical logbook (henceforth referred to as "nonobserved"). Key outcome data for nonobserved cases were manually collected retrospectively for the last 6 months of the data collection period. This manual collection of data did not use the REDCap tool.

Statistical Analysis

We described baseline characteristics and demographics using counts and percentages for all of the categorical data. Ear, nose, and throat; endoscopy; gynecology; ophthalmology; oral/maxillofacial; and urology surgeries were grouped together and referred to as "other procedures" under the classification of procedure type. Demographic and clinical characteristics were compared between observed and nonobserved cases in the last two quarters using the Fisher exact test or Kruskal–Wallis test for categoric and quantitative factors, respectively.

Two types of missing data were identified: the nonobserved and, for observed cases, missing mortality status. Both types of missing data can introduce bias in the estimate of postoperative mortality and its association with procedure type and other factors. Missing mortality records and missing records for key covariates were treated using multiple imputation with the chained-equations approach.[17] Specifically, this method was used to account for uncertainty due to missing values for emergency and trauma status, time of procedure (day, night, or weekend), and mortality status at 24 h, 48 h, and 7 days. Records with missing values for other covariates were excluded from analysis. We multiply imputed each of these variables using the remaining variables, including procedure type. One hundred chains were initialized and evaluated for 30 iterations. All subsequent statistical analyses were evaluated using each of the 100 completed data sets. The results of these analyses were combined using Rubin's rules.[18]

Inverse probability weighting was used to compute marginal estimates of 24-h, 48-h, and 7-day postoperative mortality, accounting for the possibility of bias due to missing cases that were not captured in REDCap. Specifically, in the completed second- to third-quarter 2015 case data, the probability of failed capture by the REDCap system was

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estimated using logistic regression, adjusting for procedure type, emergency, trauma, and pediatric status, as well as time of procedure. The fitted model was then used to estimate the probability of failed capture for all of the observed procedure records. The reciprocals of these probabilities were used to weight the estimate of 24-h, 48-h, and 7-day postoperative mortality. All of the mortalities are reported cumulatively, meaning deaths in 24 h were counted in 48-h and 7-day mortality, and deaths in 48 h were counted in 7-day mortality.

The adjusted associations between mortality (24-h, 48-h, and 7-day) and procedure type, emergency, trauma, pediatric status, time of procedure, and date (days from the start of data collection) were assessed using unweighted logistic regression analysis. The effect of procedure date was modeled using a restricted cubic spline with three degrees of freedom and knots spaced evenly along the procedure date quantiles. Probabilities and odds ratios (ORs) were summarized using Wald-type 95% CIs. All of the statistical analyses were implemented using the open-source software package R (v3.2.5; http://www.r-project.org; accessed May 19, 2017) with the add-on package "mice," for multiple imputation.[17,19]

Results

From January 2014 to September 2015, data from 8,419 cases were captured with the REDCap tool, representing 71% of the 11,875 cases recorded on the surgical book at Kijabe Hospital during that period. We excluded 553 cases (6.56%) with missing demographics and procedure type data and entered 7,866 cases into the postoperative mortality analysis (fig. 1). Table 1 gives details of patient, provider, and case demographics. Most patients, 7,444 (94.6%), were healthy, as defined by ASA status equal to I or II. Most cases, 7,635 (97.1%), were performed by Kenyan registered nurse anesthetists as is customary at Kijabe Hospital. Because Kijabe Hospital is a training center, 6,679 (84.9%) of the cases included nurse anesthetist students under the direct supervision of registered nurse anesthetists and anesthesiologists in a task-sharing, anesthesia team model.

Pulse oximetry was used in 7,813 cases (99.3%), blood pressure measurement at least every 5 min in 7,737 (98.4%), and a 3-lead electrocardiogram in 7,517 (95.6%). Only 4,829 cases (61.4%) used end-tidal carbon dioxide monitoring, and only 1,319 (16.8%) reported monitoring of patient temperature (table 1). In 7,822 (99.4%) of the cases, a Safe Surgery Checklist was performed, designed to reduce postoperative mortality.[20]

Overall, 1,702 cases (21.6%) entered into REDCap were missing 7-day mortality data (fig. 1). After a research assistant was hired at the end of the first quarter of 2015 to focus solely on collection of 7-day mortality data, missing data for this statistical element dropped to 5 (0.32%) in the final quarter (fig. 2).

Concerning postoperative mortality, there were 50 mortalities (0.64%) reported at 24 h, 66 (0.87%) at 48 h, and 93 (1.53%) at 7 days after surgery (table 2). Patients who

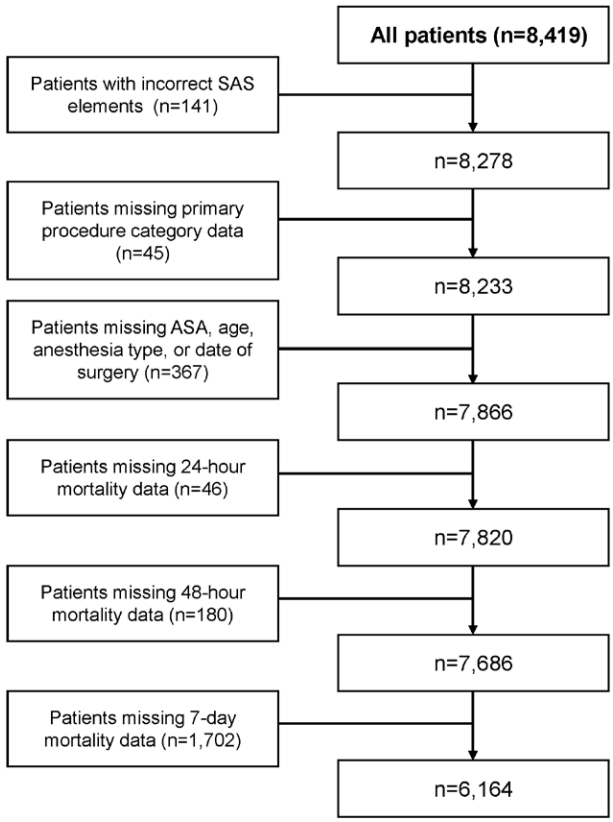

Fig. 1. Number of cases with missing data. A total of 7,866 cases were used for evaluating patient demographics, whereas mortality analyses for 24 h, 48 h, and 7 days were performed on 7,820, 7,686, and 6,164 cases, respectively. ASA = American Society of Anesthesiologists; SAS = surgical Apgar score.

underwent cesarean delivery had the lowest 24-h (n = 2 [0.23%]), 48-h (n = 3 [0.34%]), and 7-day (n = 4 [0.53%]) mortality, whereas patients who underwent general surgery (n = 20 [1.23%], n = 29 [1.83%], and n = 42 [3.65%]) and emergency surgery (n = 13 [1.53%], n = 17 [2.04%], and n = 25 [3.63%]) showed significantly higher 24-h, 48-h, and 7-day mortality, respectively (table 2). Logistic regression analysis for 24-h mortality showed that, as compared with cesarean delivery, general surgery (OR = 10.68 [95% CI, 2.32 to 49.13]; $P = 0.002$), neurosurgery (OR = 8.45 [95% CI, 1.56 to 45.80]; $P = 0.01$), orthopedic surgery (OR = 6.81 [95% CI, 1.31 to 35.40]; $P = 0.02$), and emergency surgery (OR = 4.30 [95% CI, 1.97 to 9.41]; $P = 0.0003$) were associated with higher risk of mortality (table 3). Trauma, pediatrics, and "other surgeries" were not associated with increased risk of 24-h mortality. In addition, the number of days after the start of data collection was also significantly associated with 24-h mortality. Specifically, the OR associated with day 450 *versus* day 0 was 0.55 (95% CI, 0.25 to 1.23; $P = 0.15$). The corresponding OR for day 600 *versus* day 450 was 0.11 (95% CI, 0.02 to 0.71; $P = 0.02$; fig. 3). These associations with mortality were also seen in 48-h and 7-day mortality (table 3).

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Table 1. Patient Demographics

Category	No. (%)
Total no. of patients	7,866
In-room providers	
KRNA	7,635 (97.1)
Anesthesia student	6,679 (84.9)
Clinical officer	140 (1.8)
ASA classification	
ASA I	3,370 (42.8)
ASA II	4,074 (51.8)
ASA III	388 (4.9)
ASA IV	25 (0.3)
ASA V	9 (0.1)
Male	3,948 (50.2)
Age*	
< 1 mo	355 (4.5)
< 3 mo	555 (7.1)
< 3 yr	1,250 (15.9)
< 12 yr	2,075 (26.4)
< 18 yr	2,442 (31.0)
18–65 yr	4,621 (58.7)
> 65 yr	803 (10.2)
Anesthesia type	
General	4,491 (57.1)
Regional/spinal	2,895 (36.8)
MAC	480 (6.1)
Monitors used	
Pulse oximetry	7,813 (99.3)
Blood pressure	7,737 (98.4)
3-lead ECG	7,517 (95.6)
End-tidal carbon dioxide	4,829 (61.4)
Temperature probe	1,319 (16.8)
Peripheral nerve stimulator	147 (1.9)
Safe Surgery Checklist	7,822 (99.4)

*For patients < 18 yr old, the age categories reported contain all of the patients less than the age listed in each line; thus, the summated percentages will be > 100%. Categories for ages < 18 yr, 18 to 65 yr, and > 65 yr equal 100%.

ASA classification = American Society of Anesthesiologists physical status classification; ECG = electrocardiogram; KRNA = Kenyan registered nurse anesthetist; MAC = monitored anesthesia care.

During the study period, 3,456 cases from the surgical logbook were not captured by the REDCap tool (nonobserved). The first 3 months of data collected *via* paper form showed the lowest capture rate, at 26%, whereas after implementation of the electronic tool the average data capture rate was at 77%, increasing to 93% of all cases in the final quarter (fig. 4). Comparison of observed and nonobserved data for the last two quarters revealed that there were more night and weekend cases (28.9 and 40.3% *vs.* 3.5 and 1.1%; $P < 0.001$), emergency cases (52.2 *vs.* 8.6%; $P < 0.001$), and trauma cases (15.6 *vs.* 11.1%; $P = 0.008$) in the nonobserved group than in the observed group. Procedure type distribution also differed between groups, with fewer orthopedic and pediatric cases in the nonobserved group (table 4).

Regression analysis of the nonobserved group revealed general surgery, neurosurgery, and emergency surgery associated with higher 48-h and 7-day mortality as compared with cesarean delivery, similar to the finding with the observed group (table 5). Adjusting for procedure, emergency status, trauma status, and time of surgery (day, night, or weekend), there was no evidence that being in the nonobserved group was associated with 48-h (OR = 3.52 [95% CI, 0.34 to 36.70]; $P = 0.29$) or 7-day (OR = 3.95 [95% CI, 0.41 to 38.20]; $P = 0.24$) mortality. Because there were no deaths in 24-h mortality in the nonobserved group for these quarters, we were unable to perform regression analysis for 24-h mortality.

We used the propensity score model associated with the 2015 quarter 2 and 3 data to compute the likelihood of having been observed for each case in the whole study cohort and used inverse probability weighting to estimate 24-h, 48-h, and 7-day mortality. This revealed an adjusted 24-h mortality of 0.71 (95% CI, 0.54 to 0.92), 48-h mortality of 0.99 (95% CI, 0.78 to 1.24), and 7-day mortality of 1.86 (95% CI, 1.52 to 2.27), as opposed to an unadjusted mortality of 1.58.

Discussion

Kenyan anesthesia providers achieved near real-time, point-of-care collection of key perioperative anesthesia and surgical data using the electronic data collection tool that we developed. Thus, we have enabled near real-time electronic outcomes capture for large surgical populations in a middle-income country. Postoperative mortality at a tertiary referral center in Kenya is lower than previous reports from similar centers. Consistent with previous literature, emergency surgery is associated with higher postoperative mortality than elective cases. Lastly, we documented higher postoperative mortality rates in orthopedics, general surgery, and neurosurgical cases, as compared with cesarean delivery, the most common procedure in low- and middle-income countries.

Prospective Large-scale Data Collection Possible in Low- and Middle-income Countries

Our postoperative mortality data were collected prospectively, in contrast to other reports from hospitals in Africa.[21,22] We collected perioperative data from 8,419 of 11,875 cases, providing richer data to interpret observed surgical outcomes. Through continued education and resource allocation, we were able to reduce nonobserved cases to 7% of total in the last quarter of data collection. We manually collected postoperative mortality data on a subgroup of the nonobserved population and were then able to demonstrate that postoperative mortality outcomes of cases captured in the REDCap tool were representative of the whole surgical population. Although there is a possibility that there are some cases that were performed but not entered in the surgical logbook, based on our clinical experience at Kijabe Hospital, this happens in very rare circumstances. At this hospital there are personnel dedicated to entering such data daily in the surgical logbook, even on weekends, and the likelihood of selection bias affecting our outcomes analysis is extremely low.

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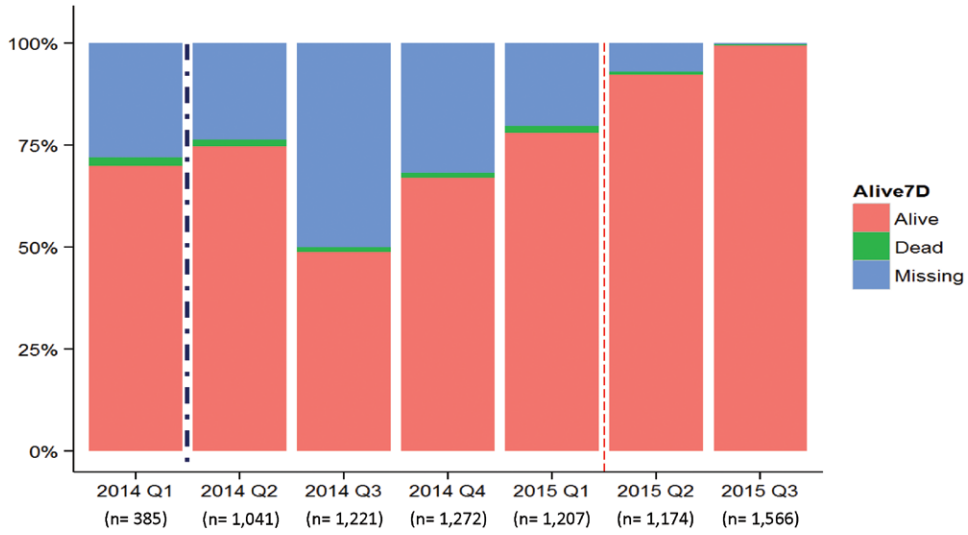

Fig. 2. Nonobserved and 7-day (7D) mortality missing data. This figure shows percentage alive, dead, and missing data for 7-day mortality per quarter. *Black dotted line* between quarters (Q) 1 and 2 in 2014 represents transition from paper form of Research Electronic Data Capture (REDCap) to electronic, whereas *red dotted line* between Q1 and Q2 in 2015 indicates the period when a research assistant dedicated to the collection of 7-day mortality data was hired.

Table 2. Absolute Numbers for 24-h, 48-h, and 7-day Mortality by Procedure Type and Other Categories

	24 h			48 h			7 d		
Surgery Type	Mortality, n (%)*	Alive, n	Missing, n	Mortality, n (%)	Alive, n	Missing, n	Mortality, n (%)	Alive, n	Missing, n
All surgeries	50 (0.64)	7,770	46	66 (0.87)	7,620	180	93 (1.53)	6,071	1,702
By procedure type									
Cesarean delivery	2 (0.23)	876	5	3 (0.34)	870	10	4 (0.53)	758	121
General surgery	20 (1.23)	1,622	4	29 (1.83)	1,586	31	42 (3.65)	1,151	453
Neurosurgery	9 (0.88)	1,025	6	11 (1.08)	1,014	15	19 (2.41)	789	232
Orthopedics	11 (0.73)	1,499	14	12 (0.83)	1,447	65	14 (1.20)	1,162	348
Other surgeries†	8 (0.29)	2,748	17	11 (0.41)	2,703	59	14 (0.63)	2,211	548
By other categories									
Emergency surgery	13 (1.53)	847	5	17 (2.04)	832	16	25 (3.63)	689	151
Pediatrics (age < 18 yr)	18 (0.75)	2,408	16	24 (1.01)	2,375	42	31 (1.66)	1,863	547
Trauma	6 (0.84)	716	7	8 (1.15)	693	28	9 (1.66)	543	178

*Denominator used for calculation of percentage of mortality is the number of patients alive, without taking missing data into account. †Other surgeries include ear, nose, and throat; endoscopy; gynecology; ophthalmology; oral/maxillofacial; and urology surgeries.

Postoperative Mortality at a Tertiary Referral Center in East Africa

Our overall mortality rate is lower than anticipated. Postoperative mortality in low- and middle-income countries ranges from 3.44 to 6.00%.[5,7,21,22] Consistent use of ASA standard monitors, which have been shown to improve perioperative outcomes,[23,24] might reduce mortality in our population. Monitors are less available in most other low-income institutions. For example, pulse oximetry use rates of 12% (Tanzania) to 46% (Uganda) are typical.[25] In addition, Kijabe Hospital is an international training center for both anesthesiology and surgery, attracting skilled practitioners and creating an environment of excellence, which probably influences postoperative mortality. Lastly, the use of the Safe Surgery Checklist in 99.4% of operative cases could have contributed to a lower mortality rate.[20] It is important to note that the quality of the use of the checklist was not assessed in depth in this study; therefore, additional analysis is needed to further investigate this association.[26]

We observed declining mortality late in the study period (fig. 3). Although the exact reason is not known, we speculate the following. First, the Kenyan Registered Nurse Anesthetist workflow was changed in early January 2015 to relieve the anesthetist from clinical care after taking a full night of call. Fewer fatigued providers on the day shift may have lowered mortality.[27,28] Second, during this study we placed significant educational emphasis on the need to monitor patient outcomes and modify clinical practice to improve outcomes. It is possible that emphasis on monitoring and improving outcome metrics engendered increased

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Table 3. Logistic Regression Analysis: Odds Ratio of Mortality at 24 h, 48 h, and 7 Days as Compared with Cesarean Delivery for Entire Study Period

	24 h			48 h			7 d		
Variable	Odds Ratio	95% CI	*P* Value	Odds Ratio	95% CI	*P* Value	Odds Ratio	95% CI	*P* Value
Cesarean delivery	REF	REF	REF	REF	REF	REF	REF	REF	REF
Procedure type									
General surgery	10.68	2.32–49.13	0.002*	10.09	2.86–35.6	0.0003*	15.8	5.20–48.1	< 0.0001*
Orthopedics	6.81	1.31–35.4	0.02*	4.45	1.09–18.1	0.04*	5.79	1.69–19.9	0.005*
Neurosurgery	8.45	1.56–45.8	0.01*	6.45	1.56–26.6	0.01*	14.08	4.12–48.1	< 0.0001*
Other surgeries	3.09	0.60–15.9	0.18	2.67	0.69–10.4	0.16	3.53	1.07–11.7	0.04*
Emergency	4.30	1.97–9.41	0.0003*	3.95	1.97–7.91	0.0001*	4.40	2.46–7.86	< 0.0001*
Pediatrics	1.02	0.52–2.03	0.95	1.05	0.59–1.89	0.86	0.76	0.45–1.28	0.30
Trauma	0.90	0.32–2.53	0.84	1.11	0.44–2.77	0.83	0.79	0.35–1.77	0.57
Date of surgery									
Day 450 *vs*. day 0	0.55	0.25–1.23	0.15	0.43	0.24–0.76	0.003*	0.58	0.38–0.88	0.01*
Day 600 *vs*. day 450	0.11	0.02–0.71	0.02*	0.09	0.03–0.33	< 0.001*	0.13	0.05–0.35	< 0.001*
Time of surgery (N/W)	1.02	0.38–2.76	0.97	1.13	0.47–2.74	0.86	1.18	0.57–2.43	0.66

Cesarean delivery was used as the reference variable because it is the most commonly performed surgical procedure in low- and middle-income countries.
*Data show *P* values < 0.05.
N/W = night or weekend case; REF = reference value.

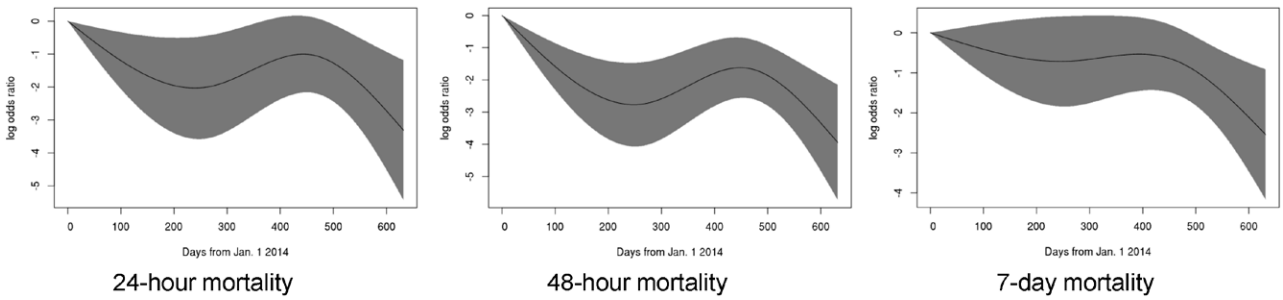

Fig. 3. The effect of date of surgery on the odds of mortality. This figure illustrates the effect of date on the log odds of postoperative mortality rate, relative to the earliest time period point (January 2014). There does not appear to be much effect until roughly March of 2015 (with exception of 48 h), where there is a sharp decline in postoperative mortality rate, adjusting for the effects of all other factors in the multiple regression. The postoperative mortality odds ratio (OR) associated with day 450 *versus* day 0 (January 1, 2014) is 0.55 (95% CI, 0.25–1.23; *P* = 0.15), 0.43 (95% CI, 0.24–0.76; *P* = 0.003), and 0.58 (95% CI, 0.38–0.88; *P* = 0.01), for 24-h, 48-h, and 7-day mortality, respectively. The corresponding OR for day 600 *versus* day 450 is 0.11 (95% CI, 0.02–0.71; *P* = 0.02), 0.09 (95% CI, 0.03–0.33; *P* < 0.001), and 0.13 (95% CI, 0.05–0.35; *P* < 0.001), for 24-h, 48-h, and 7-day mortality, respectively.

vigilance and more diligent care during each case.[29] Third, it is possible that the case mix shifted to healthier patients or lower acuity without being detected in the REDCap tool, independently lowering mortality risk. A future study is needed to prospectively test the possibility that the introduction of an initiative of this type might improve outcomes.

We observed higher mortality in patients undergoing emergency surgery, consistent with previous reports,[4,5,22,30] and postoperative mortality rate was also higher in the general surgery/orthopedics/neurosurgery patient mix compared with cesarean delivery patients. Regional referral hospitals naturally attract nonobstetric patients who have a more guarded prognosis. In addition, delayed presentation for oncologic surgery or fixation of fractures is common in low- and middle-income countries.[31,32] In contrast, the obstetric patient is younger, has fewer comorbidities, and primarily arrives from a short distance, potentially explaining mortality differences. In the future, it will be important to evaluate mortality rates within these surgical specialties among national referral hospitals to see whether the case mix and outcomes are similar.

A standardized set of validated metrics for postoperative mortality rate in low- and middle-income countries does not exist.[4] Weiser *et al.*[33] recommended using day-of-surgery death ratio and in-hospital death ratio as two metrics that could be adopted globally. We chose to report 24-h, 48-h, and 7-day mortality. We believe that the 24-h death ratio functionally represents day-of-surgery ratio for most patients.[4] In addition, we believe that 24-h mortality may

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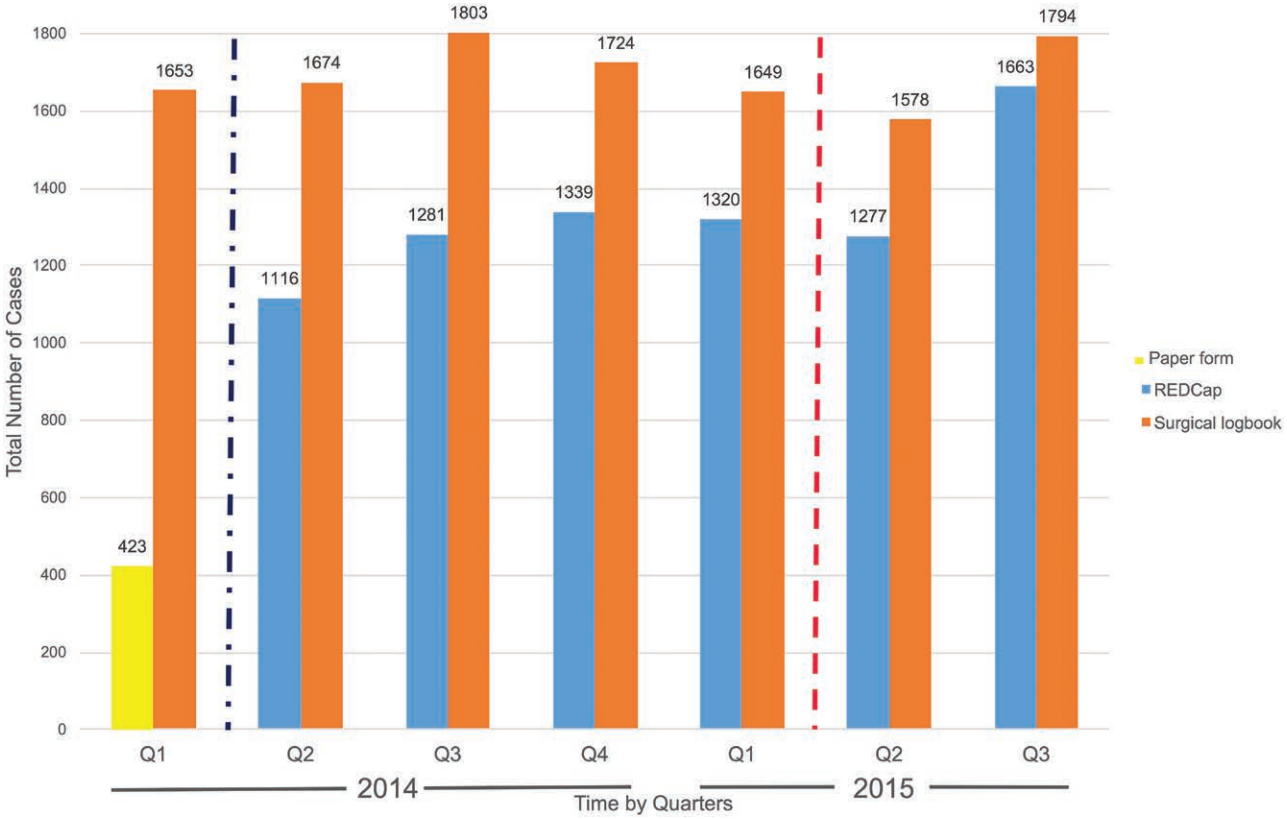

Fig. 4. Number of cases collected with Research Electronic Data Capture (REDCap) tool compared with surgical logbook (non-observed). *Black dotted line* between quarters (Q) 1 and 2 in 2014 represents transition from paper form of REDCap to electronic, whereas *red dotted line* between Q1 and Q2 in 2015 indicates the period when a research assistant dedicated to the collection of 7-day mortality data was hired.

have an advantage in that it takes into account emergency cases that are completed in the evening. For instance, a case that ends at 10:00 PM would only have a 2-h period to consider day-of-surgery mortality, as opposed to a full 24 h postoperatively in our metric. We elected to collect 7-day mortality instead of in-hospital death ratio because we found it challenging to identify date of hospital discharge reliably within our data collection system and current personnel, in a setting where there is no electronic medical record and poor record keeping in general. Instead, having a specific date of follow-up after surgery ensured consistency of reporting. We believe that 7-day mortality will capture a majority of in-hospital mortality, because it is our experience that almost all patients in our setting are discharged by this time point. However, we recognize that future research should address which set of metrics is most valid and reliable in low- and middle-income countries.

Strengths and Limitations

The mechanism by which postoperative mortality was determined in this large cohort was the result of a simple information technology solution coupled with a robust and environment-appropriate data collection education program for the anesthesia providers. Our data collection tool allows for electronic data collection without the need for continuous Internet connectivity. Transmission to a central server makes data analysis and reporting more robust, facilitating data aggregation as other data collection sites come online throughout Kenya. Considering that most postoperative mortality data are derived from review of logbooks or paper data collection, a prospective, electronic solution could be a major step forward.

It would have been ideal to collect data from 100% of cases, but we encountered barriers. Electronic data entry in the perioperative period changes the workflow of anesthesia providers, particularly in low- and middle-income countries, where paper anesthesia charts are the primary record. This additional workload is eased by the presence of students in the theater, but students are not always available. We plan to modify the REDCap tool to produce a simple intraoperative record, along with its other features, minimizing duplication of effort. In addition, data collection and intraoperative charting in general can have the potential to detract from vigilance. This is not unique to our data collection system or the low-resource setting but something that comes with anesthesia practice and knowing what to prioritize. Part of the training that we provide to the data collectors includes emphasizing the precedence that clinical care takes over documentation.

There are several limitations to our study. Kijabe Hospital is a tertiary referral hospital with surgery specialization

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Table 4. Data Summary for Observed *versus* Nonobserved Quarters 2 and 3 of 2015

Variable	Observed (N = 2,740), n (%)	Nonobserved (N = 429), n (%)	*P* Value
Procedure type			< 0.001*
Cesarean delivery	259 (9.5)	154 (35.9)	
General surgery	428 (15.6)	50 (11.7)	
Neurosurgery	297 (10.8)	19 (4.4)	
Orthopedics	548 (20.0)	60 (14.0)	
Other surgery	1,208 (44.1)	146 (34.0)	
Pediatrics	807 (29.5)	47 (11.0)	< 0.001*
Emergency	237 (8.6)	224 (52.2)	< 0.001*
Trauma	303 (11.1)	67 (15.6)	0.008*
Surgery time			< 0.001*
Day	2,495 (91.1)	132 (30.8)	
Night	96 (3.5)	124 (28.9)	
Weekend	30 (1.1)	173 (40.3)	
24-h mortality	9 (0.33)	0 (0)	0.24
48-h mortality	12 (0.44)	1 (0.23)	0.54
7-d mortality	16 (0.58)	1 (0.23)	0.35

Data are presented as absolute number with percentage (%) of total cases in parentheses.

**P* value is significant.

in pediatrics and neurosurgery and extensive, highly supervised anesthesia and surgery training programs. As such, generalizations of these observed outcomes to other health facilities and hospitals should not be made without accounting for practice setting differences. Second, given an average capture rate of approximately 75% of all cases, it is possible that our data set varies from the actual population of cases performed. Although we believe that we have adequately addressed this issue by collecting a sample of nonobserved data and using inverse propensity weighting to estimate postoperative mortality rate and to account for missing data, it is always possible that the true mortality is different from what we observed. Third, as in all nonautomated environments, data entry and accuracy are dependent on the skill and diligence of the data collectors. Although in-hospital mortality data are verified by an independent person using hospital mortality logs and telephone calls to patients and patient families, data quality is still susceptible to human error and bias. As the tool is further modified, data field restrictions are being implemented to improve data quality. Fourth, in October 2014, Kenya's economic status was changed from low income to lower middle income according to the World Bank, which could impact the application of this study to a country that is a low-income country. Lastly, many patients were discharged before postoperative day 7, reducing our 7-day mortality follow-up. We hired a research nurse to collect 7-day follow-up data, reducing missing data in REDCap observed cases to 0.32% (fig. 2). This raised costs, but we demonstrated feasibility with only one additional staff member at a high-volume referral center. This need for additional personnel will have cost implications in smaller and under-resourced hospitals. We have found that, with adequate training, a healthcare worker with diploma-level training is able to accomplish the task. In addition, one worker can cover multiple hospitals, depending on case load, which might alleviate some of the cost burdens.

Future Directions and Conclusions

We plan to expand the scope of this project to include a wide variety of hospitals throughout Kenya, including many government facilities. In addition, we are keen to engage partners in low- and middle-income countries who wish to use the tool that we described, both to enter data and to improve its content based on local experience. By expanding this data collection effort nationally and in other low-income countries, we seek to provide perioperative outcome metrics in

Table 5. Odds Ratio of 48-h and 7-day Mortality for Observed and Nonobserved Cases for Quarters 2 and 3 in 2015

	48 h			7 d		
Variable	Odds Ratio	95% CI	*P* Value	Odds Ratio	95% CI	*P* Value
Cesarean delivery	REF	REF	REF	REF	REF	REF
Procedure type						
General surgery	25.5	3.07–211.2	0.003*	33.7	4.13–274.4	0.001*
Orthopedics	3.58	0.27–46.7	0.33	8.27	0.74–92.7	0.09
Neurosurgery	15.4	1.36–173	0.03*	34.8	3.42–353.6	0.002*
Other						
Emergency	4.99	1.08–23.02	0.04*	6.45	1.72–24.2	0.006*
Pediatrics	1.97	0.54–7.14	0.30	1.19	0.36–3.98	0.78
Trauma	3.83	0.79–18.64	0.10	2.17	0.51–9.23	0.29
Time of surgery (N/W)	1.46	0.23–9.29	0.69	1.07	0.20–5.82	0.94
Observed	3.52	0.34–36.7	0.29	3.95	0.41–38.2	0.24

To assess if being nonobserved affected mortality, we performed a regression analysis only on quarter 2 and quarter 3 data in 2015, the same time period that manual data were collected for the nonobserved group. Cesarean delivery was used as the reference variable because it is the most commonly performed surgical procedure in low- and middle-income countries. Because there was no mortality reported at 24 h in the nonobserved group, we were unable to perform this analysis for 24-h mortality.

**P* values < 0.05 are indicated.

N/W = night or weekend case; REF = reference value.

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diverse hospital settings as baselines against which to evaluate capacity-building efforts. These data are most useful when shared transparently with healthcare system leadership in the government, nongovernmental, and faith-based organization sectors, accompanying an assessment of barriers to providing safe surgery and anesthesia for their representative patient populations. Collection and reporting of perioperative outcome metrics, such as postoperative mortality rate, are vital first steps in the quality improvement cycle so urgently needed for emerging health systems to deliver safe surgery and anesthesia. As a goal in line with the vision of Global Surgery 2030,[3] creating a multinational dataset surrounding perioperative outcomes, particularly for bellwether procedures, could help guide the development and deployment of resources in these settings.

We created a simple solution for high-volume, prospective electronic collection of perioperative medical information in an asynchronous, context-sensitive manner. We successfully used the tool to collect a large repository of cases from a single center in East Africa, demonstrating that 24-h, 48-h, and 7-day mortality data can be measured along with perioperative process data.

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Competing Interests

Dr. McEvoy receives grant funding from Edwards Lifesciences, Irvine, California, for work totally unrelated to this grant. Dr. Vermund reports personal fees from Mead Johnson Nutrition (Glenview, Illinois), World Health Organization (Geneva, Switzerland), National Institutes of Health (Bethesda, Maryland), and several U.S. universities for work totally unrelated to the submitted work. The other authors declare no competing interests.

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Appendix 1. PDF of 132-item case report form. Abbreviations: a = AM; AIC = Africa Inland Church; bpm = beats per minute; CC = milliliter; CO = clinical officer; C-Section = cesarean section; CV = cardiovascular; DA = difficult airway; DD = date; Dias = diastole; ENT = ear, nose, or throat; Epid = epidural; ETT = endotracheal tube; G = gauge (*e.g.*, 25G = 25-gauge needle); GA = general anesthesia; GSW = gunshot wound; HDU = high-demand unit; HH:MM = hours and minutes; HR = heart rate; ICU = intensive care unit; LMA = laryngeal mask airway; MAC = monitored anesthesia care; MD = medical doctor; M-F = Monday to Friday; Misc = miscellaneous; MM = month; MVA = motor vehicle accident; OR = operating room; p = PM; PACU = postanesthesia care unit; POD = postoperative day; REDCap = Research Electronic Data Capture; Resp = respiratory; RN = registered nurse; RSI = rapid sequence intubation; Sat = Saturday; Sun = Sunday; Sys = systole; U/S = ultrasound; v. = *versus*; YOB = year of birth; YYYY = year.

Global Perioperative Outcomes

Please enter your case information below.

TRAINEE INFORMATION

Select highest training level completed:	☐ Physician (MD) ☐ RN ☐ CO
Anesthesia Care Provider	_____ (Initials followed by YOB (Example: MSH1962))
Month of Training	_____
Role	☐ Primary Provider (primary student) ☐ Secondary Provider (assisting student)
Hospital	☐ AIC Kijabe Hospital ☐ University of Nairobi ☐ Other (write name) _____
Please select place of surgical case and write in the name:	☐ Provincial Hospital: (name) _____ ☐ District Hospital: (name) _____ ☐ Sub-District Hospital: (name) _____ ☐ Other: (name) _____
Supervisor (person overseeing you for this case)	_____

PATIENT DEMOGRAPHICS

Medical Record Number	_____
Procedure Date (MM/DD/YYYY)	_____
Country of Patient (write UNK if unknown)	_____
District of Patient (write UNK if unknown)	_____
The patient is from which of the following locations? (select one)	☐ Outpatient ☐ General Ward ☐ ICU ☐ HDU ☐ Burn Unit ☐ Newborn Unit ☐ Casualty ☐ Referral or transfer
Patient Age (select one; if unknown, please estimate)	☐ < 1 mo ☐ ≥1 mo, but < 3 mo ☐ ≥3 mo, but < 3 yrs ☐ ≥3 yrs, but < 12 yrs ☐ ≥12 yrs, but < 18 yrs ☐ ≥18 yrs, but < 65 yrs ☐ ≥65 yrs
Gender	☐ Female ☐ Male
Patient Weight (kg)	☐ < 2 kg ☐ 2-3 kg ☐ 4-10 kg ☐ 10-50 kg ☐ 50-70 kg ☐ 70-100 kg ☐ >100 kg
Physical Status Class	☐ 1 ☐ 2 ☐ 3 ☐ 4 ☐ 5
Patient Contact Information (Phone Number)	_____

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Appendix 1. (Continued)

CASE INFORMATION

Emergency?	☐ yes ☐ no
Trauma (only count if this is 1st operation after trauma event)	☐ Not a trauma case ☐ MVA (car, truck, etc) ☐ Auto v. Pedestrian ☐ Motorcycle ☐ Penetrating injury (knife, GSW) ☐ Blunt trauma (attack, sports, accidental) ☐ Fall-related injury
Length of time since trauma:	☐ _____hours ☐ not a trauma
Transportation mode to hospital:	☐ Ambulance ☐ Private vehicle (car, truck, van) ☐ Motorcycle ☐ Bicycle ☐ Walk
Time	☐ Daytime (normal hours M-F) ☐ Night (5p-7a M-F) ☐ Weekend (Sat/Sun)
Time of surgery (HH:MM)	_____

ANESTHETIC INFORMATION

Anesthetic Type	☐ Local Only ☐ MAC/Sedation with or without local ☐ General ☐ Spinal ☐ Epidural ☐ Combined Spinal-Epid ☐ Other Regional Block ☐ Combined Regional/General
Peripheral Nerve Block Site (if applicable)	☐ Ankle ☐ Axillary ☐ Femoral ☐ Infra/supra-clavicular ☐ Interscalene ☐ Lumbar Plexus ☐ Paravertebral ☐ Popliteal ☐ Saphenous ☐ Sciatic ☐ Other
Localizing technique used:	☐ Nerve stimulator ☐ Ultrasound ☐ Paresthesia ☐ Transarterial ☐ Other
Neuraxial Block Site (if applicable)	☐ Thoracic ☐ Lumbar - L2-3 ☐ Lumbar - L3-4 ☐ Lumbar - L4-5 ☐ Caudal ☐ Not applicable
If SPINAL ANESTHESIA was used, what was the size of the needle?	☐ 25G ☐ 22G ☐ 20G ☐ 18G ☐ spinal not used
If spinal or epidural was used, please record the number of attempts:	☐ 1 ☐ 2 ☐ 3 ☐ 4 or more ☐ unsuccessful, converted to GA
Primary Procedure Type (ask Supervisor if uncertain about which choice is appropriate)	☐ Neurosurgery - intracranial ☐ Neurosurgery - spine ☐ Plastic surgery ☐ Ear, Nose, or Throat (ENT) ☐ Orthopedic - upper extremity ☐ Orthopedic - lower extremity ☐ Orthopedic - spine ☐ Vaginal delivery - normal ☐ Vaginal delivery - high-risk ☐ C-section - elective ☐ C-section - fetal distress ☐ C-section - maternal bleeding ☐ C-section - pre-eclampsia/eclampsia ☐ C-section - other _____ ☐ Gynecology (hysterectomy, ruptured ectopic, ovarian mass) ☐ Gynecology (tubal ligation) ☐ Intra-abdominal - bowel/pancreas/bladder ☐ Intra-abdominal - liver/kidney/vascular ☐ Cardiac or thoracic surgery ☐ Other
Procedure Location	☐ OR ☐ PACU ☐ ICU ☐ Other
Induction Technique	☐ Mask (inhalational) ☐ RSI (IV) ☐ non-RSI (IV)

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Appendix 1. (Continued)

Airway Management Techniques Performed	☐ Room Air Oxygen Only ☐ Supplemental Oxygen Only (cannula, face mask, etc.) ☐ Supraglottic Airway (LMA, etc.) ☐ Direct Laryngoscopy and Intubation ☐ Awake Fiberoptic ☐ Asleep Fiberoptic ☐ Cricothyroidotomy ☐ Other (please describe) _____
Airway Device Used	☐ None ☐ Nasal Cannula or Face Mask ☐ LMA ☐ Oral ETT ☐ Nasal ETT ☐ Double Lumen ETT
Airway Management	☐ 1 attempt ☐ 2 attempts ☐ ≥3 attempts, secured by trainee (unanticipated DA) ☐ ≥3 attempts, secured by supervisor (unanticipated DA) ☐ Airway aborted, patient awakened ☐ Emergency surgical airway
Please select all complications that occurred during the intubation during the induction of anesthesia:	☐ Dental injury ☐ Laceration to lip, tongue, or mouth
Peripheral IV Lines	☐ 1 ☐ 2 ☐ 3 ☐ >3
Was Foley Catheter placed?	☐ Yes ☐ No
Invasive Techniques Performed	☐ Arterial Catheter (landmark) ☐ Arterial Catheter (U/S guided) ☐ Central Venous Catheter (landmark) ☐ Central Venous Catheter (U/S-guided) ☐ None
Invasive Procedure Complication	☐ Hematoma ☐ Pneumothorax ☐ Other ☐ None
Total IV Fluid Given (all types except transfusion; CC)	_____
Types of fluid given (select all that apply)	☐ Normal Saline ☐ Lactated Ringer's ☐ Colloid (albumin, starch) ☐ Blood
Volume Transfused (CC) - Whole Blood	_____
Estimated Blood Loss (CC)	_____
Length of surgery (incision to close; HH:MM)	_____
Length of anesthesia (induction to emergence; HH:MM)	_____

Vital Signs Information

Preop HR (bpm)	_____
Preop_BP (Sys/Dias)	_____
LOWEST Intraop HR (bpm)	_____
HIGHEST Intraop HR (bpm)	_____
LOWEST Intraop BP (Sys/Dias)	_____
HIGHEST Intraop BP (Sys/Dias)	_____

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Appendix 1. (Continued)

FOLLOW-UP & COMPLICATIONS

Postoperative oxygen requirement (within 48 hours of surgery):

- ☐ No oxygen requirement
- ☐ Nasal cannulae
- ☐ Face mask
- ☐ Intubation and spontaneous ventilation
- ☐ Intubation and controlled ventilation (ventilator)

Surgical or Anesthesia Procedure Complications?

- ☐ Yes
- ☐ No

Outcomes - please select all outcomes that occurred for the patient during the hospitalization after surgery. Next to each one selected, please write which postoperative day (e.g. POD2 for post-operative day 2).

- ☐ No complications
- ☐ Intraoperative Death
- ☐ Postoperative Death (< 24 hours)
- ☐ Nervous system: Stroke
- ☐ Nervous system: Seizure
- ☐ Nervous system: Postoperative Delerium
- ☐ Nervous system: Peripheral Nerve Injury
- ☐ CV: Cardiac Arrest
- ☐ CV: Myocardial Ischemia/Infarction
- ☐ CV: Congestive Heart Failure
- ☐ CV: Cardiac Dysrhythmia
- ☐ CV: Severe Hypotension (SBP< 70)
- ☐ Resp: Unplanned Respiratory Arrest
- ☐ Resp: Aspiration
- ☐ Resp: Pulmonary Edema
- ☐ Resp: Bronchospasm
- ☐ Resp: Pneumothorax
- ☐ Airway: Laryngospasm
- ☐ Airway: Difficult Mask Ventilation
- ☐ Airway: Difficult Laryngoscopy/Intubation
- ☐ Airway: Esophageal Intubation
- ☐ Airway: Unplanned Reintubation
- ☐ Airway: Unplanned Tracheotomy
- ☐ Airway: Airway/Dental Injury
- ☐ Misc: Vascular Injury
- ☐ Misc: Wrong Site Surgery
- ☐ Misc: Drug Error
- ☐ Misc: Equipment Problem/Failure
- ☐ Misc: Allergic Reaction
- ☐ Misc: OTHER

Event Comments

Was the patient alive on the day after surgery?

- ☐ Yes
- ☐ No

Was the patient alive 2 days after surgery?

- ☐ Yes
- ☐ No

Was the patient alive 1 week (7 days) after surgery?

- ☐ Yes
- ☐ Uncertain - discharged to home alive before 7 days
- ☐ No - died on post-operative day ____

Other Case Comments _____

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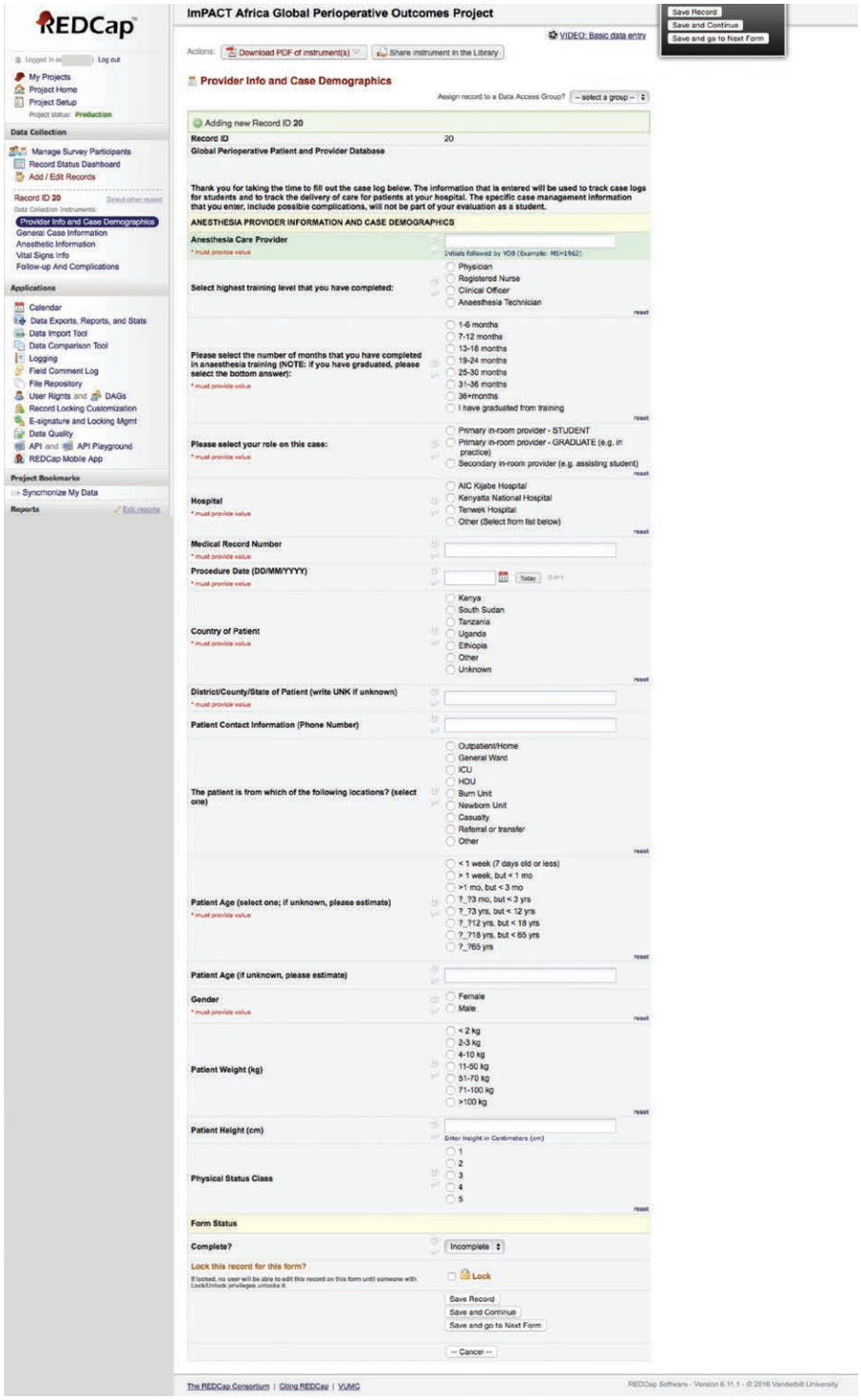
Appendix 2A. REDCap data collection tool: provider and case demographics. Abbreviations: a = AM; AIC = Africa Inland Church; bpm = beats per minute; CC = milliliter; CO = clinical officer; C-Section = cesarean section; CV = cardiovascular; DA = difficult airway; DD = date; Dias = diastole; ENT = ear, nose, or throat; Epid = epidural; ETT = endotracheal tube; G = gauge (*e.g.*, 25G = 25-gauge needle); GA = general anesthesia; GSW = gunshot wound; HDU = high-demand unit; HH:MM = hours and minutes; HR = heart rate; ICU = intensive care unit; LMA = laryngeal mask airway; MAC = monitored anesthesia care; MD = medical doctor; M-F = Monday to Friday; Misc = miscellaneous; MM = month; MVA = motor vehicle accident; OR = operating room; p = PM; PACU = postanesthesia care unit; POD = postoperative day; REDCap = Research Electronic Data Capture; Resp = respiratory; RN = registered nurse; RSI = rapid sequence intubation; Sat = Saturday; Sun = Sunday; Sys = systole; U/S = ultrasound; v. = *versus*; YOB = year of birth; YYYY = year.



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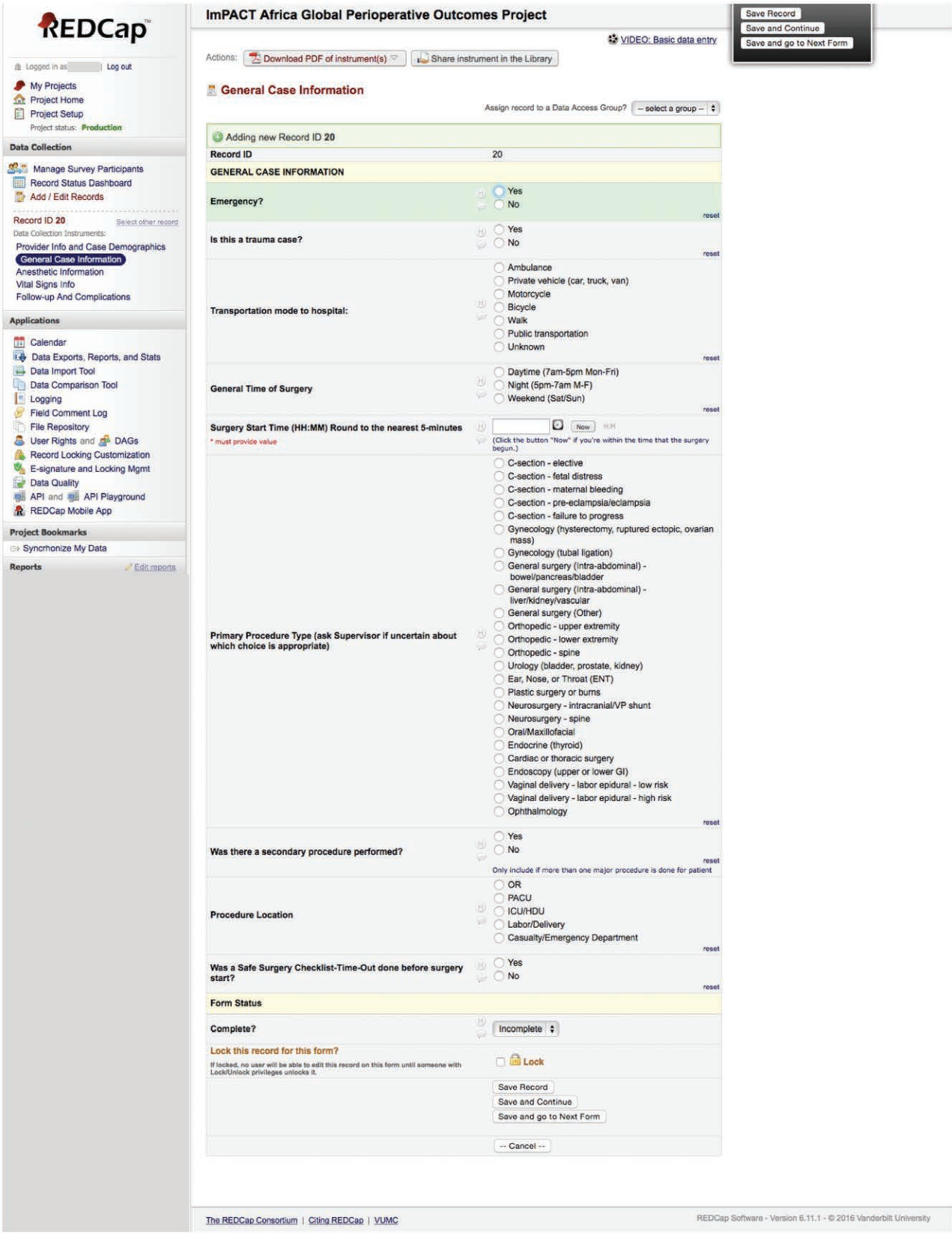
Appendix 2B. General case information.



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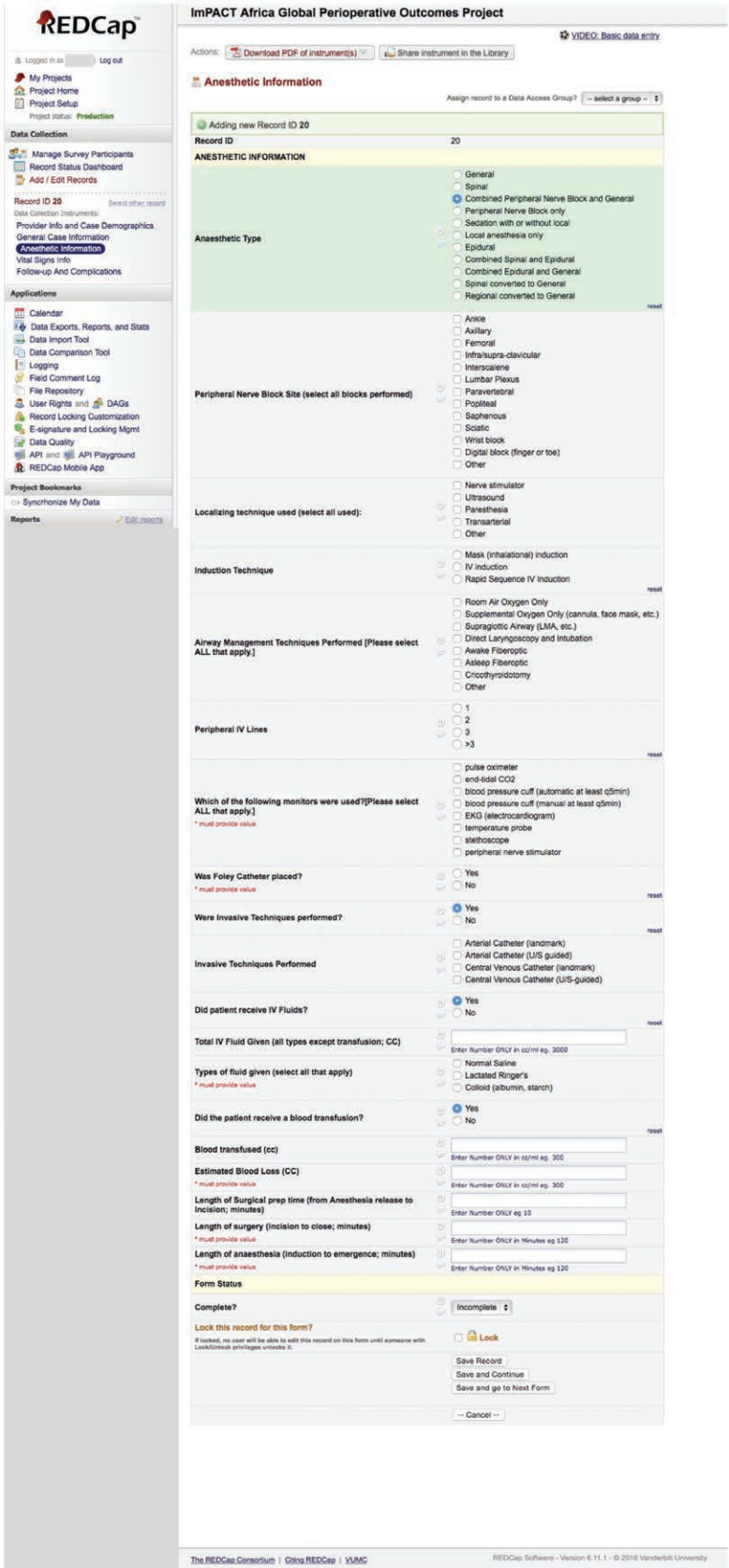
Appendix 2C. Anesthetic information.



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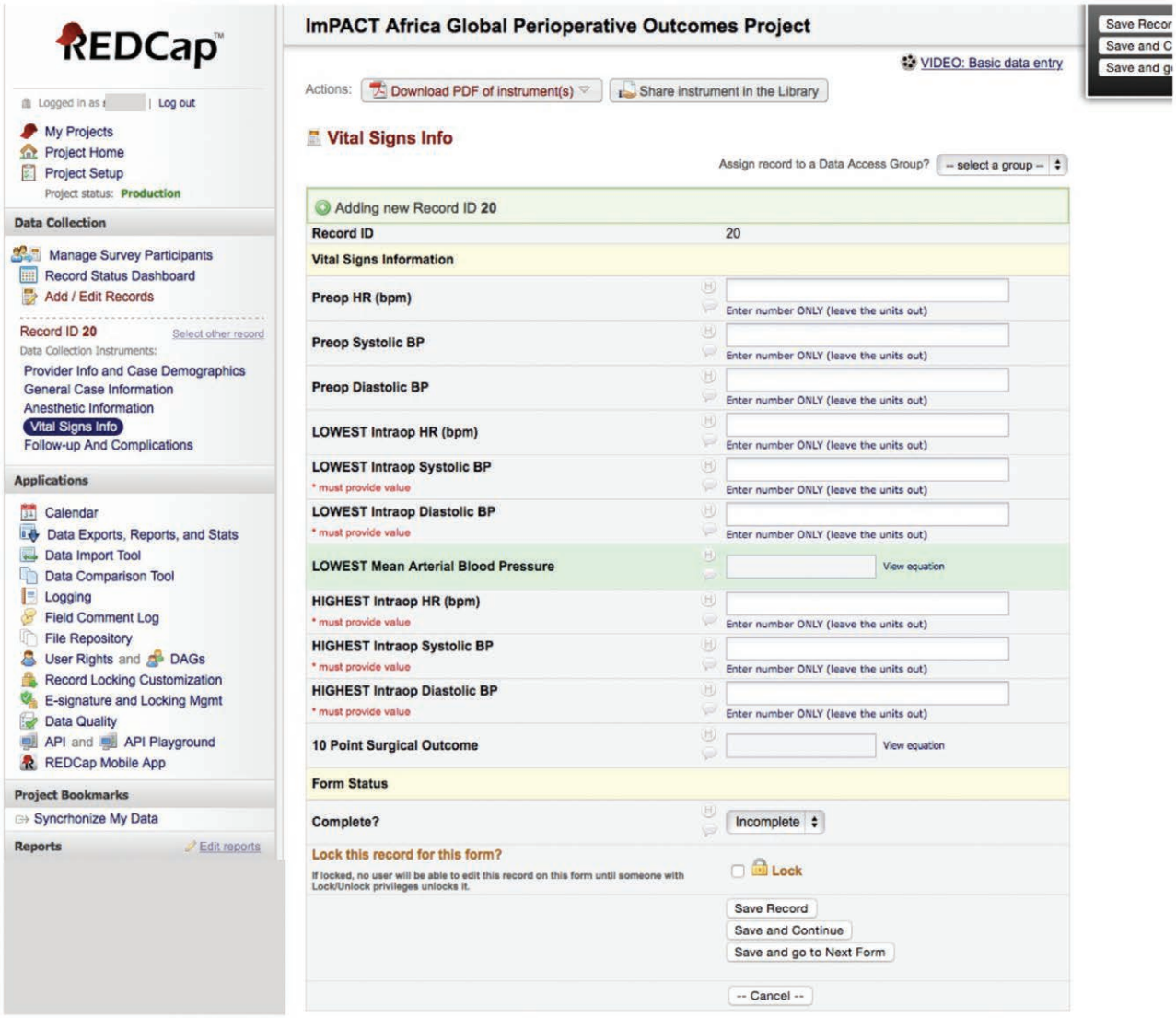
Appendix 2D. Vital signs information.



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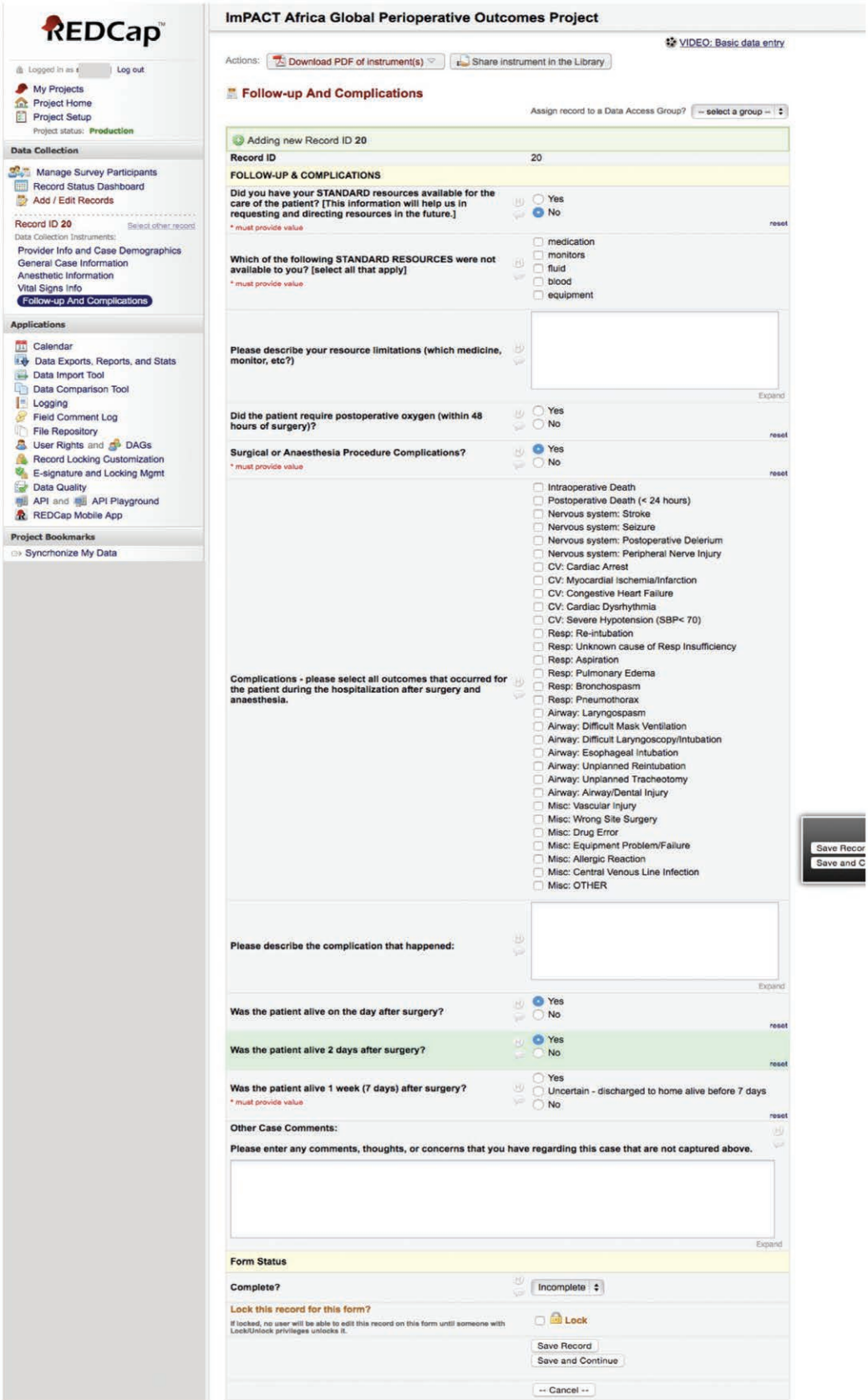
Appendix 2E. Follow-up and complications.



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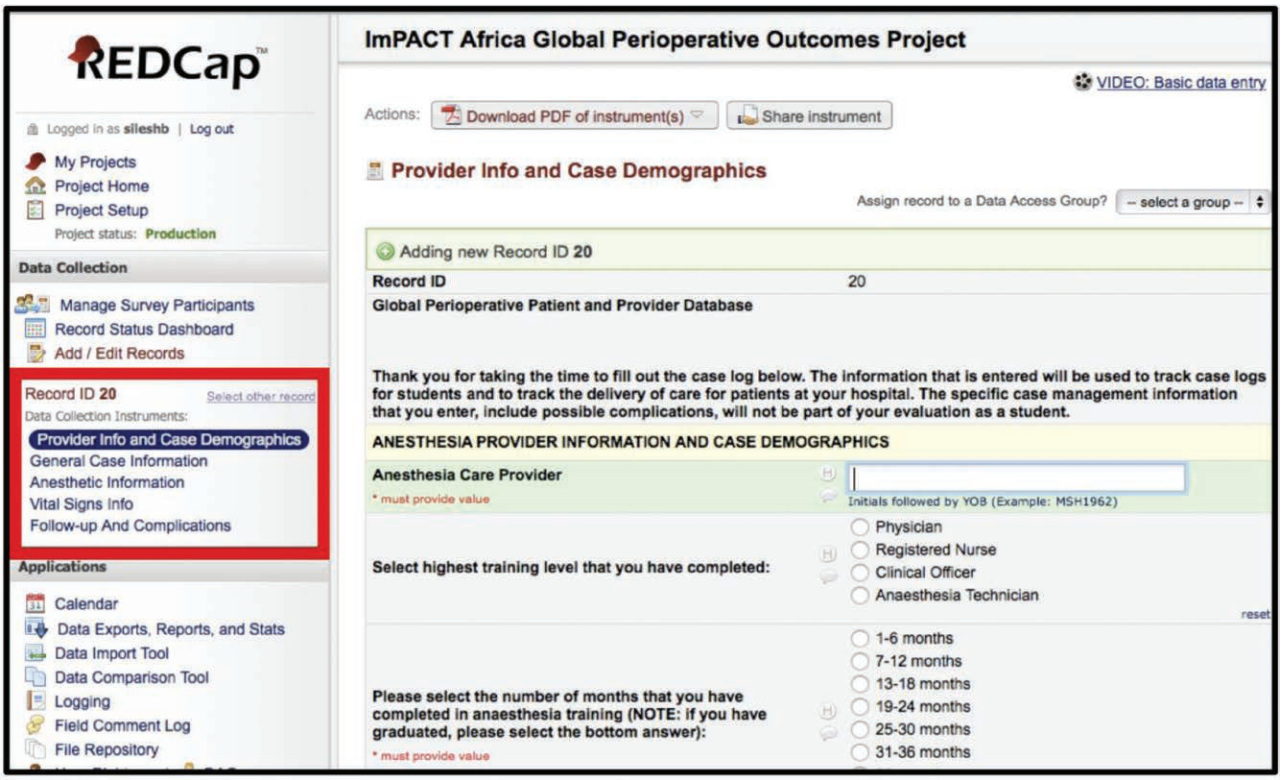
Appendix 3A. Close-up of Research Electronic Data Capture (REDCap) data collection tool. REDCap tool allows the data collector to enter records offline. Record identification (Record ID) number is displayed in the left column, and the user can see which of the five data collection instruments he/she is entering (highlighted in *blue* with *red outlined box*). In the right column, mandatory data points are highlighted with *red text* (*must provide value). Data entry points include free text, radio buttons, check boxes, and calculated data fields. Free text data entry fields are limited in number to provide the most usable structure to the overall dataset.



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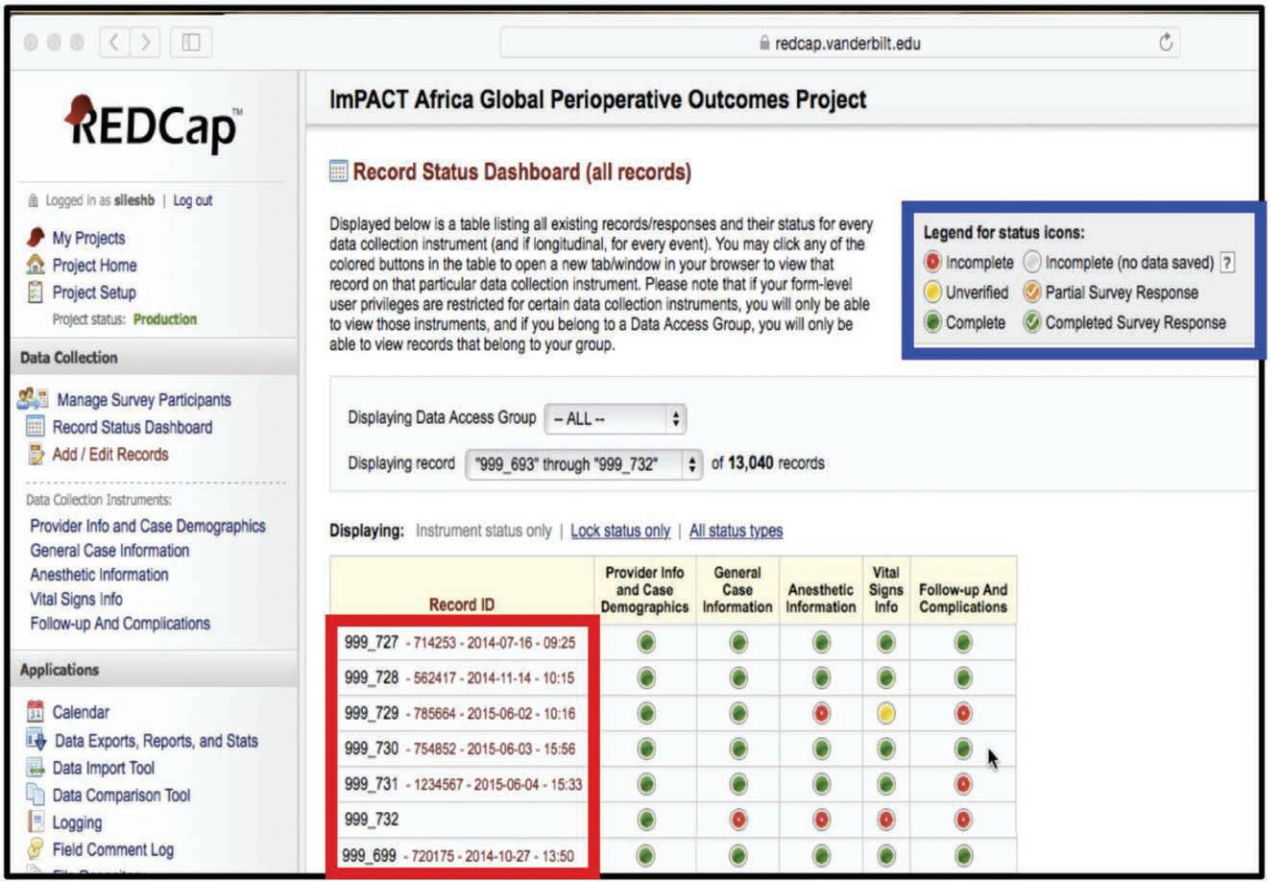
Appendix 3B. Under the Record Status Dashboard, a data collector is able to see, by identification number, all the records entered. The Record ID number includes the date and time of surgery for ease of identifying a particular record (*red box*). Whether all data fields within a form are complete is indicated by the *circles* in the table, with the key being shown in the upper right of the page (*blue box*).



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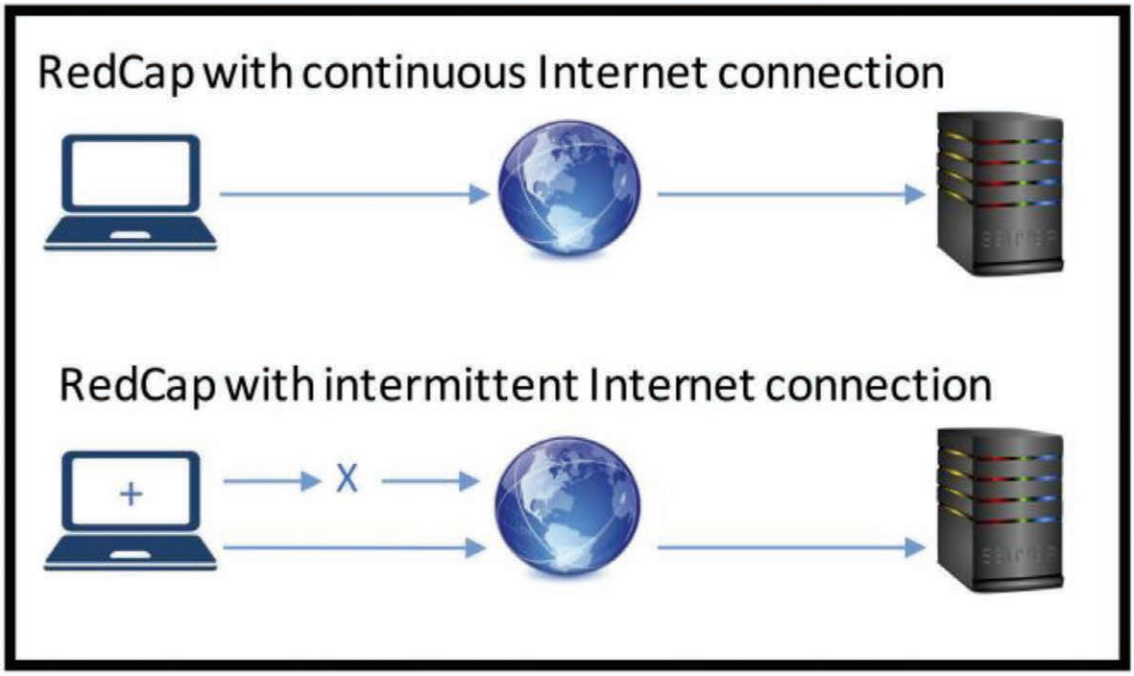
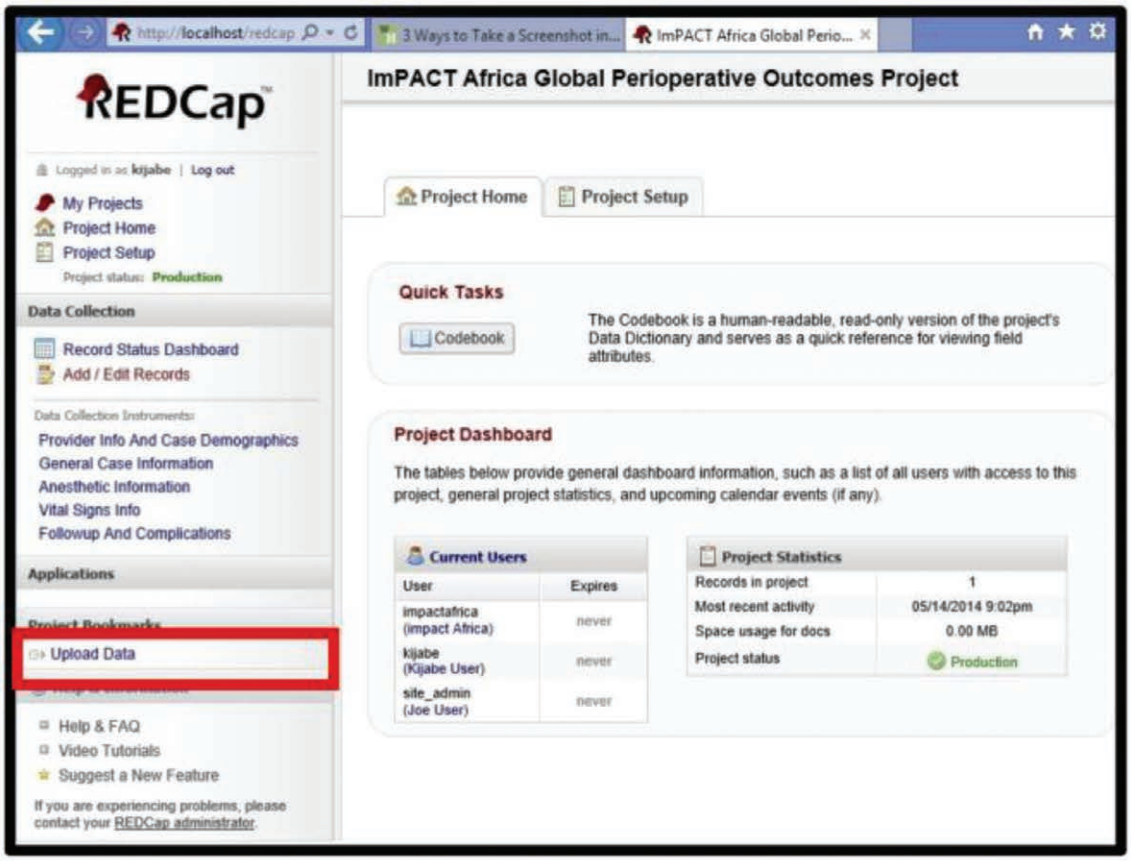
Appendix 3C. The REDCap software was modified so that in the absence of Internet connection (which is a common occurrence in low- and middle-income countries), the laptop will serve as the server and store patient data. Whenever an Internet connection is available, the user can press the upload data button indicated in the red box in the left column, at which point data are uploaded to the main server. If successful, the confirmation message "Data is uploaded successfully" is displayed. Abbreviations: FAQ = frequently asked questions; ID = identification; MB = megabyte; YOB = year of birth.





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