

Developing an Antimicrobial Strategy for Sepsis in Malawi

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Thesis submitted in accordance with the requirements of the Liverpool School of Tropical Medicine for the degree of Doctor in Philosophy by Joseph Michael Lewis

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4.3.1 Study population

Figure 4.1 shows flow through the study. 225 participants were recruited in 20 months between 19th February 2017 and 2nd October 2018. Participants were recruited, in general, soon after arrival in hospital, a median (IQR) of 1.5 (0.8-2.6) hours after fist attendance. In total, 4 participants (2%) were lost to follow up over the 180-day study period; 5 participants (2%) withdrew; and 7 participants (3%) transferred out of the study area before 180 days. Four of the five participants who withdrew gave a reason for their wish to withdraw, all that they no longer wished the inconvenience of being involved in the study. 15/225 (7%) participants had their final study visit before 180 days, and so were not included in the 180-day outcome analysis.

4.3.2 Symptoms and health-seeking behaviour

Table 4.1 shows the baseline characteristics of the recruited participants. They were young (median [IQR] age 36 [28-44]) and predominantly HIV-infected. Of those who were HIV-infected, the majority (117/143 [82%]) were on ART, almost exclusively the Malawian first-line regimen of efavirenz, lamivudine and tenofovir, and 88/117 (75%) had been taking ART for more than three months. Figure 4.2 shows the presenting symptoms of the participants. Almost all (221/225 [98%] of participants) experienced subjective fever. Participants had been unwell for some time, a median (IQR) of 7 (3-14) days; 32/225 (14%) of participants had been unwell for more than 4 weeks. 18/225 (8%) of participants had been admitted to hospital within the last 4 weeks. Over half (123/225 [55%]) of participants had sought care for their current illness (Table 4.2), most commonly (101/123 [82%] of participants) at a government health centre, a median (IQR) of 2 (1-6) days previously. 60/225 (27%) of all participants had received an antimicrobial for their current illness: 7/60 (12%) of all prehospital antimicrobials were antimalarials, the remainder antibacterial, most commonly co-trimoxazole or ciprofloxacin. Prehospital intravenous or intramuscular antimicrobials were administered in 16/60 (27%) participants receiving antimicrobials: ceftriaxone (n=6), benzylpenicillin (n=4), gentamicin (n=3) and artesunate (n=3).

Table 4.1: Participant Characteristics

Variable	Value
Demographics	
Age (years)	36 (28-44)
Male sex	114/225 (51%)
HIV/TB status	
HIV Reactive	143/225 (64%)
HIV Non Reactive	70/225 (31%)
HIV Unknown	12/225 (5%)
Ever treated for TB	37/225 (16%)
Of those, current TB treatment	10/37 (27%)
ART status*	
Current ART	117/143 (82%)
Months on ART	29 (4-73)
ART regimen: EFV/3TC/TDF	110/117 (94%)
ART regimen: other	7/117 (6%)
Current CPT [†]	98/141 (70%)
Tobacco/alcohol use	
Never tobacco	196/225 (87%)
Ex tobacco	17/225 (8%)
Current tobacco	12/225 (5%)

Table 4.1: Participant Characteristics (*continued*)

Variable	Value
Current alcohol	51/225 (23%)
Education	
Primary incomplete or complete	97/225 (43%)
Secondary school complete	48/225 (21%)
Some secondary education	47/225 (21%)
College or higher	17/225 (8%)
No formal schooling	16/225 (7%)
Employment	
Unemployed	82/225 (36%)
Currently employed	65/225 (29%)
Self-employed	56/225 (25%)
Student	21/225 (9%)
Retired	1/225 (0%)
Toilet facilities	
Pit latrine with slab +/- foot rest	104/225 (46%)
Hanging toilet/latrine	59/225 (26%)
Pit latrine with slab and cover +/- foot rest	45/225 (20%)
Flush Toilet (any type)	14/225 (6%)
No toilet	2/225 (1%)
Composting toilet	1/225 (0%)
Main water source	
Piped outside dwelling	69/225 (31%)
Tube well/borehole	64/225 (28%)
Public tap/standpipe	51/225 (23%)
Piped into dwelling	30/225 (13%)
Unprotected well/spring	5/225 (2%)
Surface water (including rainwater collection)	4/225 (2%)
Tube well with powered pump	2/225 (1%)
Electricity	
Electricity available in house	119/225 (53%)
Main cooking fuel	
Charcoal	161/225 (72%)
Wood	61/225 (27%)
Electricity	3/225 (1%)
Animals at home?	
Any animal	71/225 (32%)
Poultry	46/71 (65%)
Dogs	18/71 (25%)
Goats	12/71 (17%)
Dogs	18/71 (25%)
Other	11/71 (15%)

Table 4.1: Participant Characteristics (*continued*)

Variable	Value
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Note:

ART = Antiretroviral therapy, CPT = Co-trimoxazole preventative therapy, EFV: Efavirenz, 3TC: Lamivudine, TDF: Tenofovir. Numeric values are median (IQR)) unless otherwise stated.

* ART status includes HIV reactive only as denominator

† Missing CPT data for two participants.

Table 4.2: Prehospital healthcare seeking and antimicrobial exposure

Variable	Value
Pre-hospital healthcare seeking	
Sought care prior to attendance at hospital	123/225 (55%)
At health centre	101/123 (82%)
At hospital	16/123 (13%)
At private doctor	8/123 (7%)
Somewhere else	1/123 (1%)
Days prior to today that participant sought care	2 (1-6)
Prehospital antimicrobial exposure	
Received any antimicrobial prior to attendance at hospital	60/225 (27%)
Co-trimoxazole	12/60 (20%)
Ciprofloxacin	10/60 (17%)
Amoxicillin	9/60 (15%)
Ceftriaxone	6/60 (10%)
Metronidazole	5/60 (8%)
Benzylpenicillin	4/60 (7%)
Artesunate	3/60 (5%)
Gentamicin	3/60 (5%)
Erythromycin	2/60 (3%)
LA	2/60 (3%)
SP	2/60 (3%)
Azithromycin	1/60 (2%)
Flucloxacillin	1/60 (2%)
Days prior to today that antimicrobials started	2 (1-5)
Method of transport to hospital	
Minibus	78/225 (35%)
Taxi	65/225 (29%)
Private car/truck	42/225 (19%)
Ambulance	37/225 (16%)
Other	2/225 (1%)
Walk	1/225 (0%)
Cost (MWK) of transport to hospital	1000 (275-3000)

Note:

LA = Lumefantrine-artemether, SP = Sulfamethoxazole-pyrimethamine, MWK = Malawian Kwacha. Numeric values are median (IQR)) unless otherwise stated.

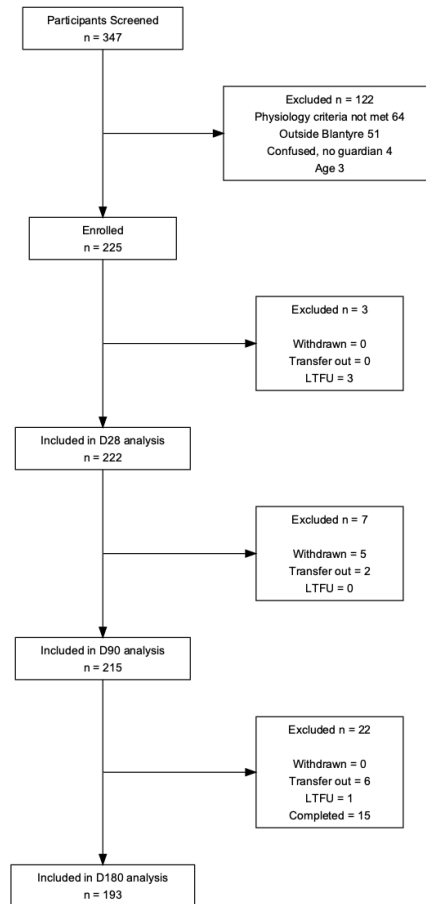


Figure 4.1: Study recruitment and follow up.

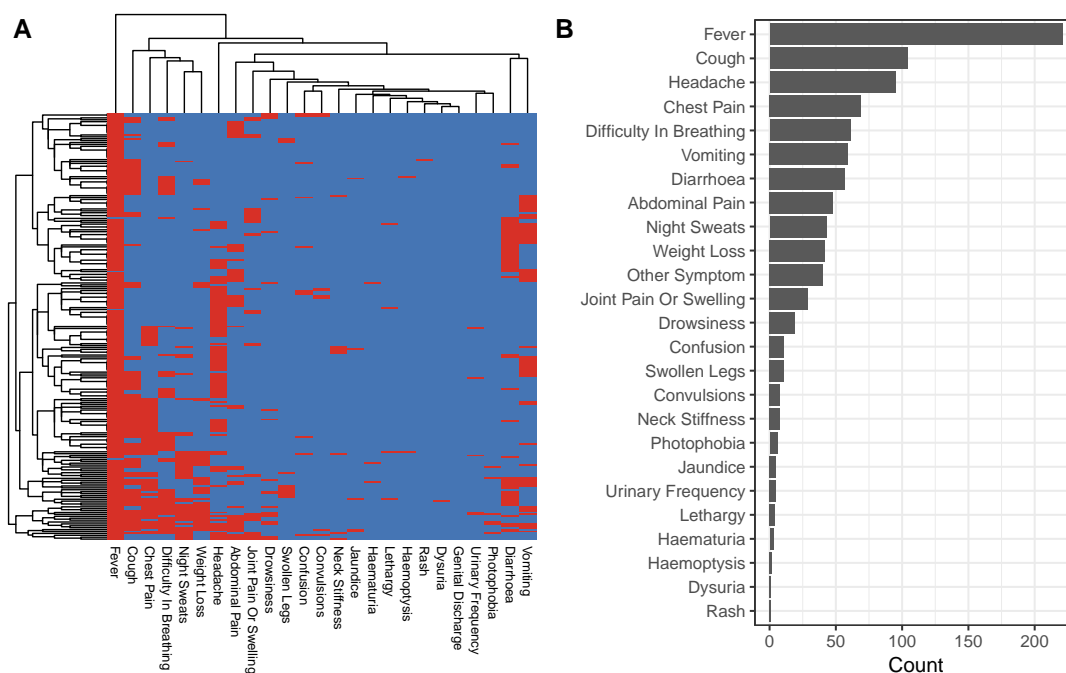


Figure 4.2: Symptoms of recruited participants. A: Row and column clustered heatmap of participant symptoms. Each row represents a patient. Red = presence, blue = absence. B: Frequency of occurrence of symptoms

4.3.3 Admission physiology and laboratory investigations

Admission vital signs and laboratory investigations are shown in Table 4.3. Despite high ART coverage (117/143 [82%]) amongst HIV-infected participants for a median of 29 months, the median (IQR) CD4 count was low at 98 (31-236) cells μL^{-1} . 108/141 (70%) of participants had a CD4 count below 200 cells μL^{-1} . CD4 count was similar in participants who had started ART more than 6 months ago as compared to less than three months ago (median [IQR] 99 [27-260] vs 93 [39-137] cells μL^{-1} respectively) and 42/83 (51%) of participants who had been taking ART for more than 6 months had a CD4 count of less than 100 cells μL^{-1} , and would fulfil a WHO definition of immunological failure.

Table 4.3: Admission physiology, haematology and biochemistry

Variable	Value
Admission physiology	
Temperature ($^{\circ}\text{C}$)	38.5 (37.9-39.0)
Heart rate (min^{-1})	121 (102-132)
Systolic blood pressure (mmHg)	99 (85-119)
Diastolic blood pressure (mmHg)	66 (56-76)
Respiratory rate (min^{-1})	34 (32-38)
Oxygen saturation (%)	96 (94-98)
GCS	
15	204/225 (91%)
11-14	16/225 (7%)
< 11	5/225 (2%)
Admission CD4 count	
CD4 count* (μL^{-1})	98 (31-236)
Admission haematology	
Haemoglobin ($\times 10^9 \text{ g dL}^{-1}$)	10.8 (8.2-13.2)
White cell count ($\times 10^9 \text{ L}^{-1}$)	6.5 (4.4-11.4)
Neutrophil count ($\times 10^9 \text{ L}^{-1}$)	4.0 (2.1-7.5)
Platelet count ($\times 10^9 \text{ L}^{-1}$)	218 (146-297)
Admission biochemistry	
Sodium (mmol L^{-1})	134 (130-137)
Potassium (mmol L^{-1})	4.0 (3.6-4.4)
Bicarbonate (mmol L^{-1})	19 (17-22)
Chloride (mmol L^{-1})	101 (97-104)
Urea (mmol L^{-1})	4.8 (3.5-8.0)
Creatinine (mmol L^{-1})	76 (59-103)
Lactate (mmol L^{-1})	3.4 (2.3-5.2)

Note:

GCS = Glasgow coma scale. Numeric values are median (IQR)) unless otherwise stated.

* CD4 count includes only HIV-infected participants; 2 values were missing.

4.3.4 Aetiology

In total, 51% (114/225) of the 225 participants had at least one infectious agent identified (Table 4.4), most commonly tuberculosis (76/225 [34%]) followed by bloodstream infection (24/225 [11%]) and malaria (21/225 [9%]). Table 4.5 shows the availability of test and proportion of positive tests across the cohort, stratified by HIV status. 2/225 patients (1%) had a missing aerobic blood culture; the remaining 223 patients had a total of 259 blood cultures performed. 15/259 (6%) blood cultures grew at least one contaminant, but 26 blood cultures from 24 patients were positive for a total of 28 pathogenic bacteria (Figure 4.3): *Salmonella* Typhi was the most commonly isolated pathogenic bacterium, and seemed to show an association with HIV-negative participants: all (8/8) of the participants from whom *S. Typhi* was isolated and whose HIV status was known were HIV noninfected. Of the 18 Gram negative bacteria isolated, 3/18 (17%) were cefpodoxime resistant on AST via disc diffusion testing, and likely ESBL producers: one *K. pneumoniae* and one *E. coli* (both from the same blood culture and same patient) and one *Acinetobacter baumannii*. Both *Staphylococcus aureus* isolates were oxacillin sensitive. The one *Streptococcus pneumoniae* cultured was penicillin intermediate on AST.

Lumbar puncture and CSF culture was carried out in 44 participants: 5/44 (11%) of samples grew a contaminant and no pathogenic bacteria were recovered from any sample. 4/44 (9%) had a detectable cryptococcal antigen (CRAG) in CSF. Malaria testing was missing for 6/225 (3%) of participants, but of the remainder, a positive malaria test was more likely in the HIV-uninfected (12/69 [17%] vs 6/138 [4%], $p = 0.01$ on pairwise Fisher's exact test). Positive aerobic blood culture showed no statistically significant association with HIV, nor did positive CSF testing, though in the latter case numbers were small and all positive tests (all positive CRAG) were in fact in the HIV-infected (Table 4.5).

Testing for TB, with the exception of sputum Xpert testing, was restricted to HIV-infected participants. Sputum Xpert was carried out in 44/225 (20%) of participants, and was more commonly carried out in the HIV-infected: 35/143 [24%] of HIV-infected participants had sputum testing performed vs 8/70 (11%) of HIV uninfected ($p = 0.07$ by Fisher's exact test). 53 sputum samples were sent in total from the 44 patients, and 8/44 (18%) diagnoses of TB made, all except one in HIV-infected participants. One sample identified a rifampicin resistance gene; the remainder of infections were rifampicin-sensitive.

155 participants were eligible for urinary lipoarabinomannan (uLAM) and mycobacterial blood culture testing, being either HIV-infected ($n=143$) or of unknown HIV status ($n=12$). Urine was available for 145/155 (94%) of those eligible, and 74/145 (51%) of samples were positive for uLAM. 150/155 (97%) of eligible participants had blood samples collected and cultured

Table 4.4: Final diagnosis of all participants

Diagnosis	Proportion of participants
Tuberculosis	76/225 (34%)
Bloodstream infection	24/225 (11%)
Malaria	21/225 (9%)
Meningitis	4/225 (2%)
No diagnosis	111/225 (49%)

Table 4.5: Positive diagnostic tests for all participants, stratified by HIV status.

Test	HIV status			All	p
	Positive	Negative	Unknown		
Number of participants	143	70	12	225	-
TB diagnostics					
Urinary LAM	70/136 (51%)	-	4/9 (44%)	74/145 (51%)	-
Sputum Xpert	7/35 (20%)	1/8 (12%)	0/1 (0%)	8/44 (18%)	0.835
TB blood culture	7/128 (5%)	-	1/10 (10%)	8/138 (6%)	-
Other diagnostics					
Aerobic blood culture	13/141 (9%)	9/70 (13%)	2/12 (17%)	24/223 (11%)	0.647
CSF culture or CRAG	4/31 (13%)	0/12 (0%)	0/1 (0%)	4/44 (9%)	0.445
Malaria RDT	6/138 (4%)	12/69 (17%)	3/12 (25%)	21/219 (10%)	0.007

Note:

LAM = Lipoarabinomannan, CSF = Cerebrospinal fluid, CRAG = Cryptococcal antigen, RDT = Rapid diagnostic test. p-values are chi-squared test across the three HIV status strata, and hence may be different from the pairwise exact Fisher's tests presented in the text. Urinary LAM and TB blood culture were not carried out in HIV negative participants.

for mycobacteria. 12/150 (8%) grew contaminants and are excluded from the denominators in Table 4.5; of the remainder 8/138 (6%) grew mycobacteria, all *M. tuberculosis*.

Figures 4.5 and 4.4 show the overlap of positive tests from the different diagnostic modalities. Of the 114 patients with at least one positive diagnostic test, 90/114 (79%) had only one positive diagnostic test. The exceptions to this were mycobacterial blood culture and sputum Xpert: patients who had TB diagnosed by these tests tended to also have a positive uLAM. 2/4 (50%) of patients with positive CSF testing (all of whom had detectible CRAG) had also grown *Cryptococcus neoformans* in aerobic blood culture. 111/225 (49%) of patients remained with no diagnosis.

4.3.5 Treatment

At least one antimicrobial drug was received by 95% (214/225) of the cohort during their admission (Table @ref:(time-to-ab-table)), most commonly an antibacterial (207/225 [92%]), but also a significant minority received antitubercular therapy (63/225 [28%]). Of those

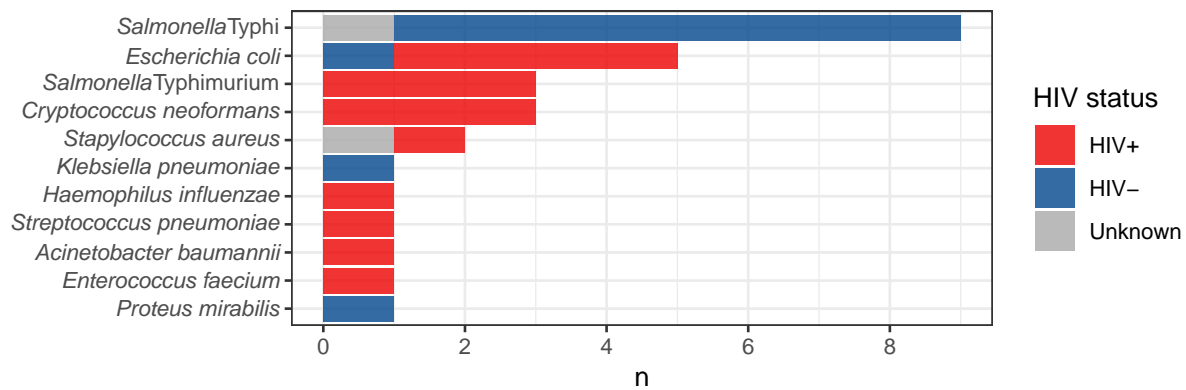


Figure 4.3: Pathogenic isolates recovered from aerobic blood culture. 26 blood cultures in 24 participants were positive for 28 pathogens in total

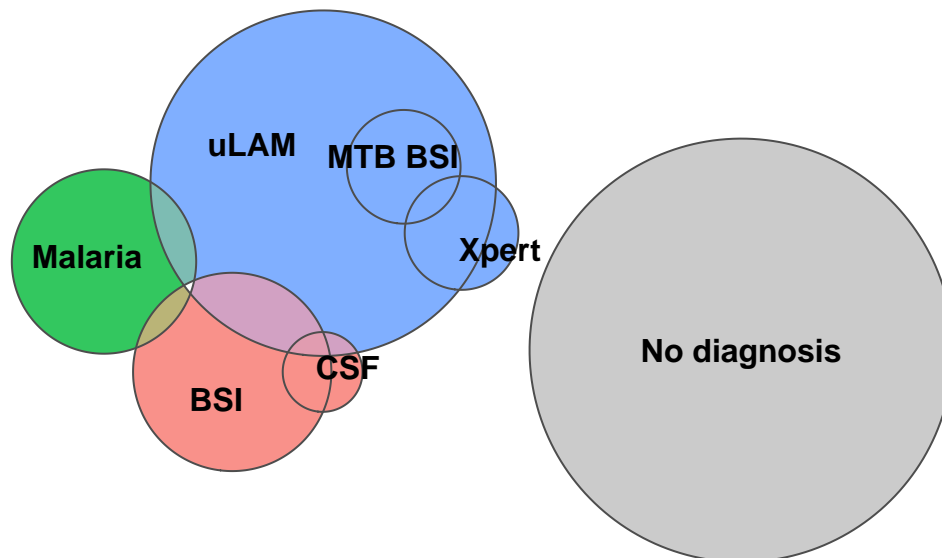


Figure 4.4: Venn diagram showing overlap of positive diagnostic tests; culture of blood and CSF shown in red, malaria in green and TB diagnostics in blue. The CSF variable includes either a positive culture for a pathogenic bacteria or positive cryptococcal antigen, BSI a positive aerobic culture of pathogenic bacteria from blood and MTB BSI a positive mycobacterial culture of tuberculosis from blood. BSI: Bloodstream infection, CSF: Cerebrospinal fluid, CRAG: Cryptococcal antigen, mRDT: Malaria rapid diagnostic test, MTB BSI: Mycobacterium tuberculosis bloodstream infection, uLAM: urinary lipoarabinomannan.

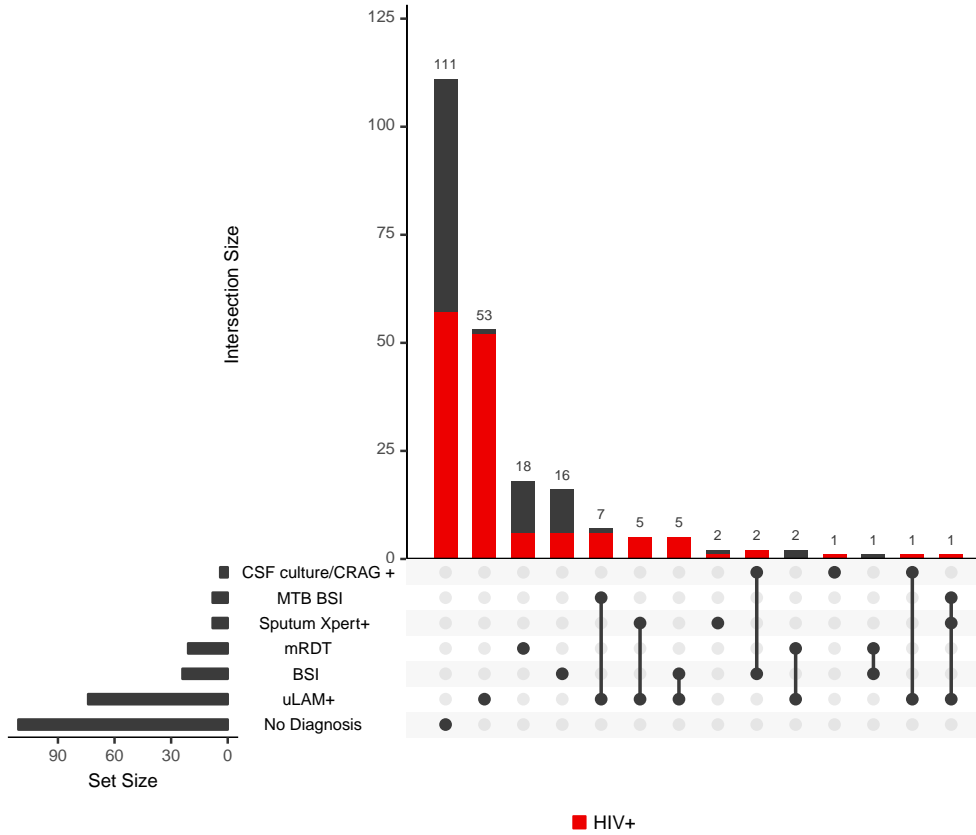


Figure 4.5: UpSet plot of overlap of positive diagnostic tests, showing that for the majority of participants, one test alone is positive. Red colour indicates HIV-infected; black is a composite of HIV-negative and unknown. The CSF variable in includes either a positive culture for a pathogenic bacteria or positive cryptococcal antigen, BSI a positive aerobic culture of pathogenic bacteria from blood and MTB BSI a positive mycobacterial culture of tuberculosis from blood. BSI: Bloodstream infection, CSF: Cerebrospinal fluid, CRAG: Cryptococcal antigen, mRDT: Malaria rapid diagnostic test, MTB BSI: Mycobacterium tuberculosis bloodstream infection, uLAM: urinary lipoarabinomannan.

Table 4.6: Door-to-antimicrobial times.

Antimicrobial class	No. participants	Median [IQR] time (hours)
Antibacterial	207/225 (92%)	5.3 (3.7-10.8)
Antitubercular	63/225 (28%)*	120.9 (63.7-171.0)
Antifungal	26/225 (12%)	47.7 (27.9-73.9)
Antimalarial	12/225 (5%)	4.5 (3.1-21.7)

* 10/63 participants who received antitubercular agents during admission were taking them prior to admission; they are excluded from the calculation of median door-to-antimicrobial time for this class.

receiving antitubercular therapy, 16% (10/63) were taking the medication prior to admission, and the remainder were initiated on therapy during admission. The first antibacterial agent administered was most often ceftriaxone, in 87% (181/207) of cases but ciprofloxacin (18/207 [9%] of participants), amoxicillin (6/207 [3%]) and metronidazole (2/207 [1%]) were also used. Median door to antimicrobial time was 5.3 (IQR 3.7-10.8) hours for antibacterials and 4.5 (IQR 3.1-21.7) hours for antimalarials but longer for antifungals at 47.7 (IQR 27.9-73.9) hours and longer still for antitubercular therapy at 120.9 (IQR 63.7-171.0). Cumulative incidence curves for administration of the different antimicrobial classes are shown in Figure 4.6A-D.

Of all participants, 85% (192/225) received any intravenous fluid in the first 6 hours of enrollment to the study; of these, most received 0.9% saline (160/192 [83%] of those receiving fluid) but 5% dextrose (91/192 [57%]) were also used; Ringer's lactate (6/192 [6%]) and blood (2/192 [1%]) were rarely administered. Of the 192 patients who were administered any fluid, a median of 1.5L (IQR 1-2L) was administered over the 6hr study period; fluid administration as a function of time is shown in Figure 4.6E.

4.3.6 Outcome

Median hospital stay was 4 (IQR 1-9) days. Mortality of the cohort was 18% (95% CI 13-23%) at 28 days, 24% (95% CI 18-30%) at 90 days and 31% (95% CI 25-38) at 180 days, and higher in HIV-infected participants at each time point (Table 4.7), though not statistically significant on pairwise Fisher's exact test (HIV-infected vs noninfected 19% vs 13%, [p = 0.14] at 28 days, 27% vs 17%, [p = 0.44] at 90 days and 36% vs 21% [p = 0.29] at 180 days). Kaplan-meier estimation of the survival function (Figure 4.7) showed a precipitous decline in survivorship to around day 30 but also continuous mortality thereafter, to the end of the study period. Stratifying the analysis by HIV status revealed that early deaths (within the first 1-2 weeks) occur at similar rates in the two groups before the curves diverge; log-rank test suggested a significant difference in survival function between the two groups (p = 0.03).

Health related quality of life measures, as assessed by EQ-5D-3L, are shown in Figure 4.8 for

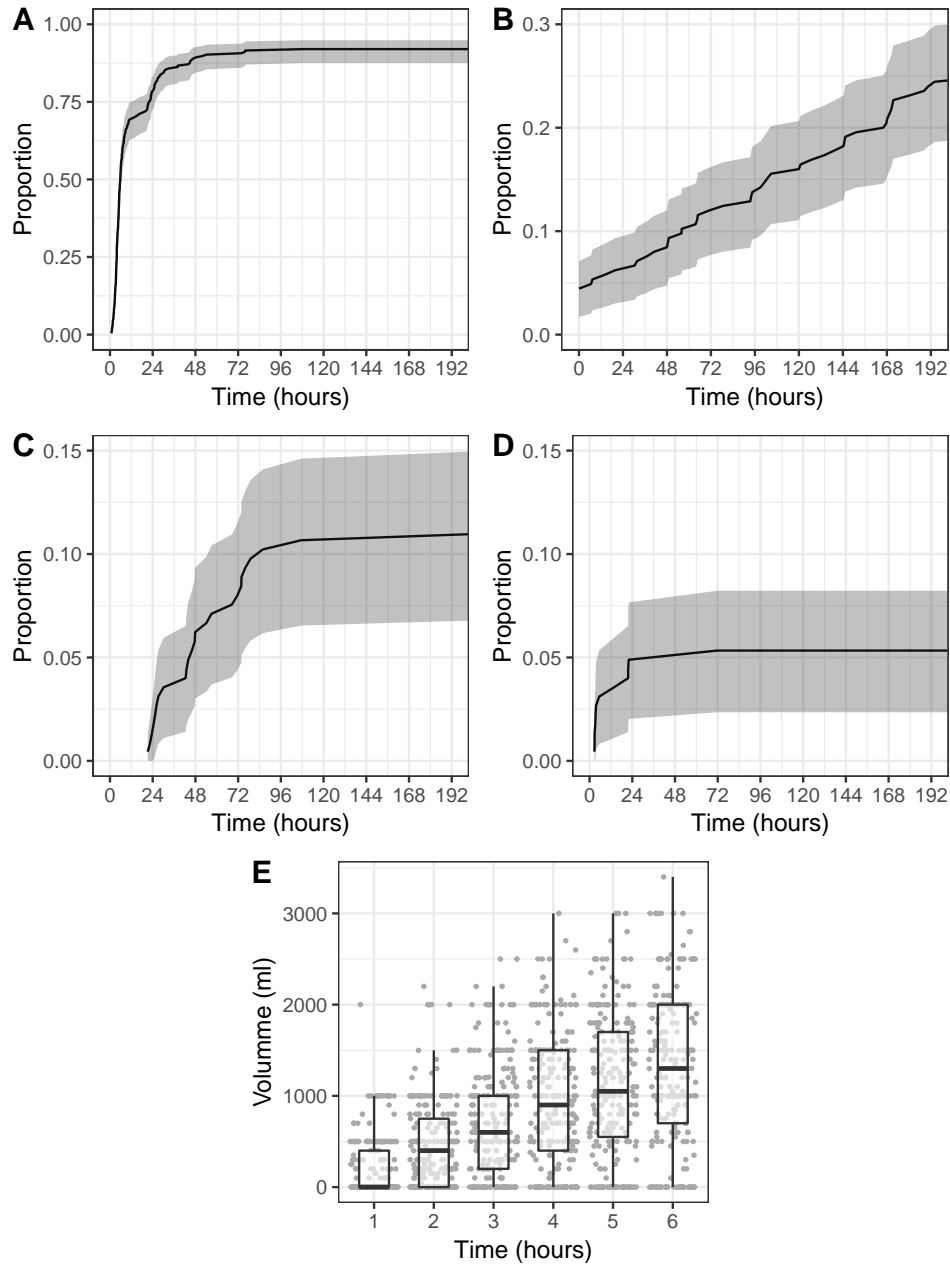


Figure 4.6: Timing of antimicrobial and fluid administration. A-D: Cumulative incidence of administration of antibacterial (A), antitubercular (B), antifungal (C) and antimalarial (D) agents as a function of time since arrival at hospital in hours. E: Total volume of administered intravenous fluid as a function of time since enrollment to study in hours. Boxplots show median, quartiles box and 1.5 times interquartile range as whiskers. Points are jittered around the hour at which they were measured to show distribution.

Table 4.7: Day 28, 90 and 180 mortality stratified by HIV status

	HIV+		HIV-		HIV Unknown		Total	
	n	Mortality	n	Mortality	n	Mortality	n	Mortality
Day 28	143	19% (13-26)	67	13% (6-24)	12	25% (5-57)	222	18% (13-23)
Day 90	139	27% (19-35)	64	17% (9-29)	12	25% (5-57)	215	24% (18-30)
Day 180	125	36% (28-45)	58	21% (11-33)	11	27% (6-61)	194	31% (25-38)

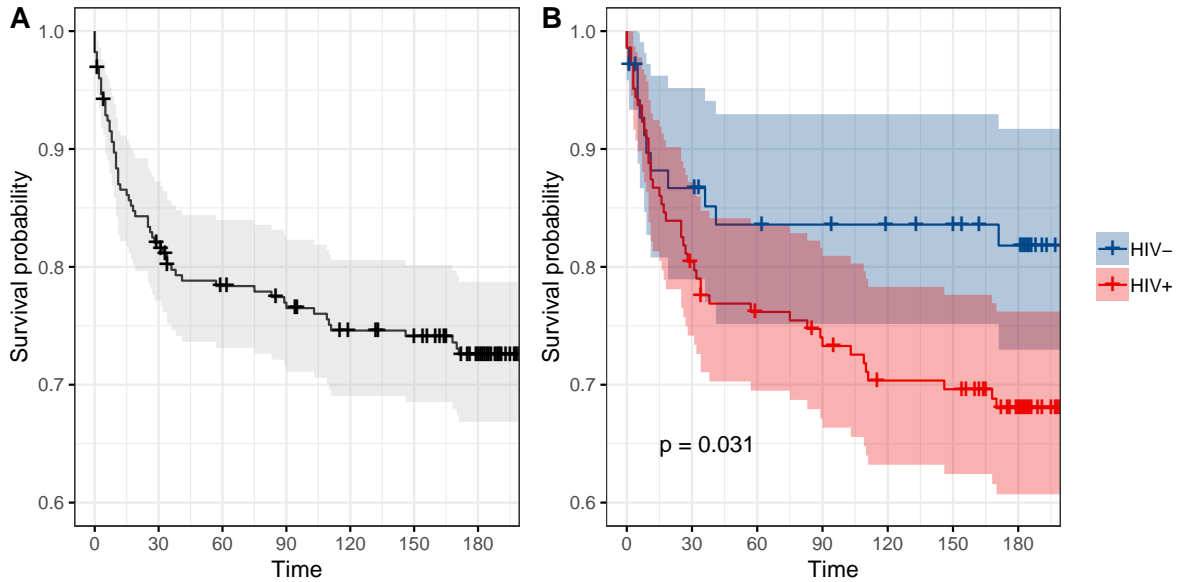


Figure 4.7: Kaplan-Meier survival curves of all included participants (A) and stratified by HIV status (B). Crosses indicate censoring. p value from log-rank test comparing survival of HIV-infected to HIV-noninfected participants shown ($p = 0.03$).

participants with sepsis and the community cohort as a comparator. Acutely, participants with sepsis reported were significantly disabled, reporting at least moderate impairment across all domains in the majority of cases, and over 90% of participants reporting at least moderate impairment in activities of daily living and experiencing at least moderate pain or discomfort. However, recovery following treatment in survivors was rapid. The mean EQ-5Q utility score (a measure of the weight compared to a health state compared to 1, perfect health) of healthy community controls was 0.910 (SD 0.102) at enrollment, significantly higher than participants with sepsis at enrollment (utility score 0.496 (SD 0.251), $p = < 0.0001$ versus community scores by t-test), but comparable to participants with sepsis at their 12 week assessment (0.913 (SD 0.147), $p = 0.903$ versus community enrollment scores).

4.4 Logistic regression - determinants of 28 day mortality

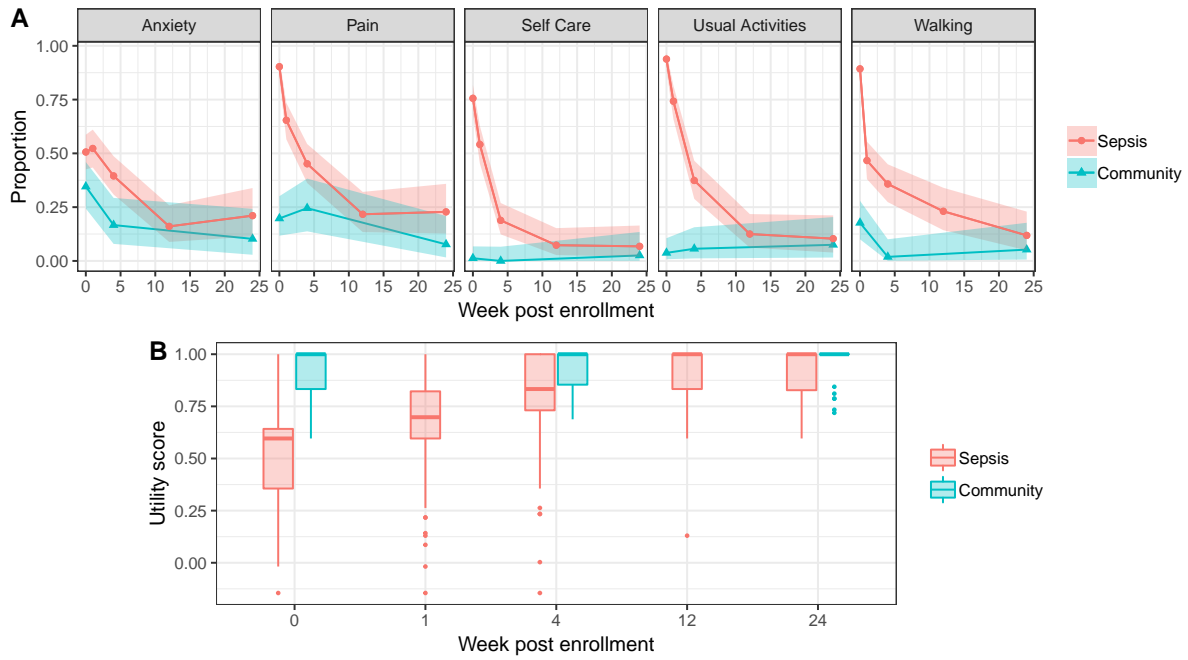


Figure 4.8: Health-related quality of life following sepsis admission, compared to community controls, showing a return to usual quality of life by 12 weeks following admission. A: proportion of participants across each of the five domains of the EQ-5D questionnaire who report at least moderate impairment. B: EQ-5D utility score derived using the Zimbabwean tariff set. The utility score is interpreted as the weight attached to a health state compared to perfect health, which is assigned a value of 1. By 12 weeks there is no statistically significant difference between sepsis and baseline community participant utility scores ($p = 0.90$ by t-test).

Table 4.8: Bivariate associations with death by 28 days

Variable	Died	Survived	p
Host Variables			
Age (years)	36.4 (31.5-46.0)	35.9 (27.4-42.9)	0.252
Male sex	19/39 (49%)	93/183 (51%)	0.861
HIV Infected	27/36 (75%)	116/174 (67%)	0.433
CD4 count (μL^{-1})	28.5 (9.5-124.5)	103.0 (43.5-251.0)	0.007
Severity Variables			
Haemoglobin ($\times 10^9 \text{ g dL}^{-1}$)	9.1 (6.0-10.4)	11.0 (8.6-13.4)	<0.001
Temperature ($^{\circ}\text{C}$)	38.1 (37.7-38.8)	38.5 (38.0-39.0)	0.024
Heart rate (min^{-1})	123.0 (104.5-138.5)	120.0 (102.0-131.0)	0.510
Systolic BP (mmHg)	89.0 (76.0-120.5)	99.0 (86.5-118.5)	0.154
Diastolic BP (mmHg)	60.0 (51.5-80.5)	67.0 (57.0-75.5)	0.136
Mean arterial BP (mmHg)	70.7 (61.2-94.8)	78.7 (67.0-89.2)	0.123
Respiratory rate (min^{-1})	34.0 (32.0-36.5)	34.0 (32.0-38.0)	0.681
Oxygen saturation (%)	95.0 (89.5-97.0)	97.0 (95.0-98.0)	0.017
GCS	15.0 (15.0-15.0)	15.0 (15.0-15.0)	0.044
Lactate (mmol L^{-1})	4.6 (3.0-10.6)	3.2 (2.1-4.5)	0.001
White cell count ($\times 10^9 \text{ L}^{-1}$)	5.9 (3.5-11.0)	6.9 (4.5-11.5)	0.165
Platelet count ($\times 10^9 \text{ L}^{-1}$)	181.5 (86.8-300.8)	223.0 (148.0-296.5)	0.291
Sodium (mmol L^{-1})	131.0 (127.0-137.8)	134.0 (130.0-137.0)	0.280
Potassium (mmol L^{-1})	4.0 (3.4-4.5)	4.0 (3.6-4.4)	0.683
Chloride (mmol L^{-1})	101.0 (96.0-104.8)	101.0 (98.0-104.0)	0.846
Bicarbonate (mmol L^{-1})	17.0 (14.0-21.0)	20.0 (17.0-22.0)	0.007
Urea (mmol L^{-1})	7.8 (4.5-14.3)	4.5 (3.2-7.0)	<0.001
Creatinine (mmol L^{-1})	90.0 (60.0-185.0)	73.0 (59.0-96.0)	0.100

Chapter 5

Early response to resuscitation in sepsis

Chapter 6

Gut mucosal carriage of ESBL-E in Blantyre, Malawi

Chapter 7

Whole genome sequencing of ESBL *E. coli* carriage isolates

Placeholder

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7.2.3 Statistical analysis

7.3 Results

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7.3.2 Phylogroup, MLST and core genome phylogeny of study isolates

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7.3.4.2 Quinolone resistance

7.3.4.3 Aminoglycoside resistance

7.3.4.4 Chloramphenicol, co-trimoxazole, tetracycline and other resistance determinants

7.3.4.5 Clustering and lineage association of AMR determinants

7.3.5 Plasmid replicons

7.3.6 Testing metadata associations: SNP distance, hierBAPS sequence clusters and ESBL-clusters

7.3.6.1 Hierarchical BAPS clustering of core gene pseudosequences

7.3.6.2 ESBL-clusters

7.3.6.3 Assessing for healthcare-associated lineages

7.3.6.4 Assessing for within-patient conservation of lineage or MGE

7.4 Discussion

References