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RESEARCH ARTICLE

Prevalence and risk factors for Q fever, spotted fever group rickettsioses, and typhus group rickettsioses in a pastoralist community of northern Tanzania, 2016–2017

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Abstract

Background: In northern Tanzania, Q fever, spotted fever group (SFG) rickettsioses, and typhus group (TG) rickettsioses are common causes of febrile illness. We sought to describe the prevalence and risk factors for these zoonoses in a pastoralist community. **Methods:** Febrile patients ≥ 2 years old presenting to Endulen Hospital in the Ngorongoro Conservation Area were enrolled from August 2016 through October 2017. Acute and

Sustainable Development Goals: Good Health and Well-being.

The findings and conclusions in this report are those of the authors and do not necessarily represent the official position of the US Centers for Disease Control and Prevention. Use of trade names and commercial sources is for identification only and does not imply endorsement by the US Department of Health and Human Services or the Centers for Disease Control and Prevention.

†Deceased

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convalescent blood samples were collected, and a questionnaire was administered. Sera were tested by immunofluorescent antibody (IFA) IgG assays using *Coxiella burnetii* (Phase II), *Rickettsia africae*, and *Rickettsia typhi* antigens. Serologic evidence of exposure was defined by an IFA titre $\geq 1:64$; probable cases by an acute IFA titre $\geq 1:128$; and confirmed cases by a ≥ 4 -fold rise in titre between samples. Risk factors for exposure and acute case status were evaluated.

Results: Of 228 participants, 99 (43.4%) were male and the median (interquartile range) age was 27 (16–41) years. Among these, 117 (51.3%) had *C. burnetii* exposure, 74 (32.5%) had probable Q fever, 176 (77.2%) had SFG *Rickettsia* exposure, 134 (58.8%) had probable SFG rickettsioses, 11 (4.8%) had TG *Rickettsia* exposure, and 4 (1.8%) had probable TG rickettsioses. Of 146 participants with paired sera, 1 (0.5%) had confirmed Q fever, 8 (5.5%) had confirmed SFG rickettsioses, and none had confirmed TG rickettsioses. Livestock slaughter was associated with acute Q fever (adjusted odds ratio [OR] 2.54, 95% confidence interval [CI] 1.38–4.76) and sheep slaughter with SFG rickettsioses case (OR 4.63, 95% CI 1.08–23.50).

Discussion: Acute Q fever and SFG rickettsioses were detected in participants with febrile illness. Exposures to *C. burnetii* and to SFG *Rickettsia* were highly prevalent, and interactions with livestock were associated with increased odds of illness with both pathogens. Further characterisation of the burden and risks for these diseases is warranted.

KEYWORDS

Q fever, rickettsioses, zoonoses

INTRODUCTION

Q fever and spotted fever group (SFG) rickettsioses are important causes of febrile illness in Tanzania [1, 2]. Typhus group (TG) rickettsioses are also implicated in febrile illness, although less frequently [1]. *Coxiella burnetii* is the causative agent of Q fever and human transmission occurs predominantly through inhalation of contaminated aerosols or consumption of infected, unpasteurized dairy products [3]. The role of ticks in the transmission of *C. burnetii* to humans is ambiguous [2]. *Rickettsia africae* and *Rickettsia conorii* are the causative agents of SFG rickettsioses. *Rickettsia africae* is transmitted by *Amblyomma* spp. ticks that feed on domestic livestock whereas *R. conorii* is transmitted by *Rhipicephalus sanguineus* ticks that are frequently found on dogs; both can infect humans directly through bites [4]. Rodents are the hosts for *Rickettsia typhi* and the rat flea, *Xenopsylla cheopis*, is the primary vector mediating human infection with TG rickettsioses [5].

There are gaps in the understanding of the epidemiology, risk factors for acute illness and serologic exposure, and clinical impact of these zoonotic diseases in sub-Saharan Africa [2, 6, 7]. Q fever, SFG rickettsioses, and TG rickettsioses share non-specific presenting symptoms and signs including fever, headache, and myalgia [8, 9]. Limited diagnostic capacity and low awareness of zoonoses among healthcare providers contribute to underdiagnosis [10].

Studies from sub-Saharan Africa indicate highly variable levels of serologic exposure to *C. burnetii* and SFG *Rickettsia* by location [1, 6, 11]. Frequent, close contact with livestock and their tick ectoparasites has been associated with the risk of Q fever and SFG rickettsioses [6, 7, 12]. Handling animal abortion materials, slaughtering animals, and consuming raw or locally fermented dairy products have been

associated with Q fever [13–15]. There have been few studies of seroprevalence or acute illness in populations that are likely to be highly exposed to these infections such as livestock-dependent pastoralists.

We describe the prevalence and identify factors associated with serologic evidence of exposure and acute illness due to *C. burnetii*, SFG *Rickettsia*, and TG *Rickettsia* among individuals presenting to a rural hospital in northern Tanzania that serves a predominantly pastoralist population.

METHODS

Study site

Participants were recruited at Endulen Hospital, a 110-bed facility serving the predominantly pastoralist population in the Ngorongoro Conservation Area (NCA) of northern Tanzania. The NCA is a multiple land use area for conservation of wildlife, tourism, and livestock-keeping (predominantly cattle, sheep, and goats) by the local, pastoralist community that consists predominantly of individuals identifying as Maasai [16]. There is bimodal seasonal variability with wet seasons typically occurring October through December and March through May [17]. Further details of the foundational study focused on brucellosis including the study site and participant population have been published previously [18].

Enrolment

Patients seeking care in the outpatient department of Endulen Hospital were screened for eligibility from August 2016 through October 2017. Screening occurred ~4–5 days each

week on a total of 259 (61.4%) of 422 days in the study period. Eligible individuals were aged ≥ 2 years with reported fever within the past 72 h or with a tympanic temperature of $\geq 38.0^{\circ}\text{C}$ at presentation. Eligible patients were approached by a study team member to obtain written informed consent to participate in the study. After enrolment, blood was drawn for serology and a study team member administered a structured questionnaire including closed-ended questions related to demographic data, clinical characterisation of illness, recent illness, occupation, and livestock-related activities, but not including capture of direct dog or tick exposures, during the past month and past year (Supplementary Methods S1). Four to six weeks after enrolment, study team members conducted home visits to collect convalescent-phase blood samples from participants.

Laboratory testing

Serum was separated and stored at 4°C at Endulen Hospital prior to transport to Kilimanjaro Clinical Research Institute (KCRI) the next day at $4\text{--}10^{\circ}\text{C}$. At KCRI, sera were stored at -70°C then shipped on dry ice to the Rickettsial Zoonoses Branch, US Centers for Disease Control and Prevention (US CDC) for immunofluorescent antibody (IFA) testing. All sera were tested by IFA IgG assays using *C. burnetii* (Nine Mile strain) Phase I and Phase II antigens for Q fever, *R. africae* (Z9-Hu strain) antigen for SFG rickettsioses, and *R. typhi* (Wilmington strain) for TG rickettsioses. Paired acute and convalescent serum samples were tested concurrently using the same reagent lot. Samples were tested using doubling dilutions to determine the last dilution at which antibody was detected or a result of $<1:32$ recorded if no antibody was detected.

Outcome definitions

US Council of State and Territorial Epidemiologists case definitions for Q fever and SFG rickettsioses were used with the modification that all participants were considered to have a clinically compatible syndrome based upon their presentation with fever [19, 20]. Henceforth, exposure is defined as serologic evidence of exposure to a pathogen of interest. Exposure to *C. burnetii* was defined by a single IFA titre of $\geq 1:64$ to Phase II antigen in either the acute or convalescent sample [1]. Probable acute Q fever was defined by a single IFA titre of $\geq 1:128$ to phase II antigen [19]. Confirmed acute Q fever was defined by a ≥ 4 -fold rise in IFA titre to *C. burnetii* Phase II antigen between acute and convalescent serum samples [19]. Chronic Q fever was defined by an IFA titre of $\geq 1:1024$ to *C. burnetii* Phase I antigen [21].

For SFG *Rickettsia* and TG *Rickettsia*, exposure was defined by an IFA titre to $\geq 1:64$ in either the acute or convalescent sample using *R. africae* and *R. typhi* antigens, respectively [1]. Probable illness was defined by an IFA titre $\geq 1:128$ in either the acute or convalescent sample [20]. Confirmed illness was defined by a ≥ 4 -fold rise in IFA titre

to SFG rickettsioses antigen between acute and convalescent serum specimens [1, 20].

Statistical analysis

Data were entered using the OpenText Teleform System (Open Text, Waterloo, Ontario, Canada) into an Access database (Microsoft Corporation, Redmond, WA, USA). Data were analysed using R version 4.1.1 (R Foundation for Statistical Computing, Vienna, Austria). We chose independent variables for analyses through literature review and based on dataset variables from the primary study. Logistic regression models were used to identify associations between selected independent variables and the outcome variables of exposure to *C. burnetii*, acute Q fever, exposure to SFG *Rickettsia*, and SFG rickettsioses. For the risk factor analyses for acute Q fever, individuals with illness that met probable and confirmed case definitions were considered as cases. For the risk factor analyses for SFG rickettsioses, only individuals with illness that met confirmed case definitions were considered as cases and analyses were restricted to individuals with paired sera.

For models of exposure to *C. burnetii* and SFG *Rickettsia*, variables defining animal-related activities such as direct animal contact, contact with animal products, or consumption of animal products in the preceding year were analysed (Tables 2 and 4). For analyses of acute Q fever and SFG rickettsioses, variables describing animal-related activities in the preceding month were analysed, aligning with the 7–32 day incubation period for Q fever and the 6- to 10-day incubation period for SFG rickettsioses [22, 23] (Tables 3 and 5).

Data regarding participants' consumption of raw dairy products were only available for the preceding month, and data regarding exposure to livestock abortions were only available for the preceding year. These variables and time periods were used in all analyses. Data on participant occupation were grouped to compare high- and low-risk occupations based on likelihood of livestock and tick exposure. Farmers, livestock attendants, or persons who worked with wildlife were classified as engaging in high-risk occupations and all other reported occupations were classified as low risk. January, February, June, July, August, and September were classified as dry season months, and all other months as wet season [17].

Univariable models were explored for all outcomes modelled. Variables with likelihood ratio test (LRT) $p \leq 0.2$ in the univariable model were considered for inclusion in multivariable models. Correlations between plausibly correlated independent variables (e.g., milking cattle, milking goats, milking sheep) were assessed using a matrix of Pearson's product moment correlation coefficients (Tables S1–S3). For variable pairs with Pearson's correlation coefficients >0.5 , a single variable from the set of correlated variables with univariable LRT $p \leq 0.2$ was selected to represent an animal-related exposure or activity in multivariable models. Multivariable models were created by initially fitting maximal models and simplifying by removing variables with LRT $p > 0.05$, with terms with the largest LRT p -values removed first. Interactions between

season and abortion associated risks were considered. Variables were excluded from multivariable models if a small number of observations in any category caused convergence problems.

Research ethics

This study was conducted in accordance with the Declaration of Helsinki. It was approved by the Tanzania National Institute for Medical Research National Health Research Ethics Review Committee (NIMRIHQ/R.8cIV01 11/708), Kilimanjaro Christian Medical University College Research Ethics Committee (698), University of Glasgow College of Medical, Veterinary and Life Sciences Ethics Committee (200150140), and the University of Otago Human Ethics Committee (Health) (H17/052). Written informed consent was obtained from all participants ≥ 18 years old or their guardians if < 18 years old; minors aged 13–17 years also provided assent.

RESULTS

Sociodemographic and characteristics of study participants

A total of 228 participants with complete questionnaires and diagnostic test data were included in analyses (Figure 1). The

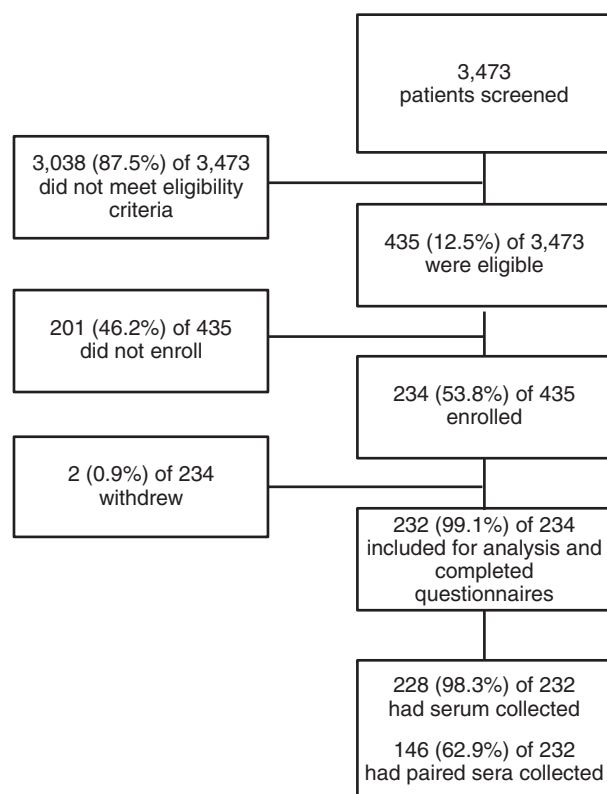


FIGURE 1 Flow chart showing the steps in the screening, enrolment, and data collection from the study population of individuals with febrile illness seeking care in the outpatient department of Endulen Hospital from August 2016 through October 2017.

median (interquartile range) age of participants was 27 (16–41) years and 99 (43.4%) were male. Of all participants, 146 (62.9%) had results of paired acute and convalescent serum sample testing. Further details of the study population and the frequency of potential risk factors for study outcomes are given in Tables 1–5. Distributions of age, sex, and season of presentation are shown in Figures S1–S3.

Prevalence of exposure, probable, and confirmed illness

Of 228 participants, 117 (51.3%) had exposure to *C. burnetii* and 74 (32.5%) had probable acute Q fever. Of 146 participants with paired sera, 1 (0.7%) had confirmed acute Q fever. Of 220 participants with Phase I antibody results, 1 (0.5%) had chronic Q fever. Of 228 participants, 176 (77.2%) had exposure to SFG *Rickettsia* and 134 (58.8%) had probable SFG rickettsioses. Of 146 participants with paired sera, 8 (5.5%) had confirmed SFG rickettsioses. Of 228 participants, 11 (4.8%) had exposure to TG *Rickettsia* and 4 (1.8%) had probable TG rickettsioses. Among 146 participants with paired serum samples, none had confirmed TG rickettsioses.

Univariable and multivariable logistic regression

Logistic regression models are presented for the outcome variables of exposure to *C. burnetii*, acute Q fever (probable and confirmed cases), exposure to SFG *Rickettsia*, and SFG

TABLE 1 Demographic and clinical characteristics of study participants, Endulen Hospital, Tanzania, 2016–2017.

Variable	Study participants (N = 228)		
	n/N (%)	Median age in years (IQR)	Male (%)
All study participants	228	27 (16–41)	99 (43.4)
Q fever			
<i>C. burnetii</i> exposure	117/228 (51.3)	24 (17–38)	52 (44.4)
Probable acute case	74/228 (32.5)	24 (16–39)	35 (47.3)
Confirmed acute case	1/146 (0.7)	24	0 (0)
Confirmed chronic case	1/220 (0.5)	11	1 (100.0)
Spotted fever group Rickettsioses			
SFG <i>Rickettsia</i> exposure	176/228 (77.2)	29 (18–42)	79 (44.9)
Probable case	134/228 (58.8)	30 (18–44)	64 (47.8)
Confirmed case	8/146 (5.5)	26 (22–42)	3 (37.5)
Typhus group Rickettsioses			
TG <i>Rickettsia</i> exposure	11/228 (4.8)	20 (17–31)	3 (27.3)
Probable case	4/228 (1.8)	18 (14–26)	2 (50.0)
Confirmed case	0/146 (0)	-	-

Abbreviations: IQR, interquartile range; SFG, spotted fever group; TG, typhus group.

TABLE 2 Univariable and multivariable logistic regression analyses for factors associated with *C. burnetii* exposure among febrile study participants, Endulen Hospital, Tanzania, 2016–17.

Variable	Level	Exposure to <i>C. burnetii</i>		<i>C. burnetii</i> unexposed		Univariable logistic regression			Multivariable logistic regression		
		n/N	%	n/N	%	OR	95% CI	p-Value	aOR	95% CI	p-Value
Herding livestock (y)		45/108	41.7	38/110	34.5	1.35	0.78–2.35	0.28			
	Cattle	32/108	29.6	27/110	24.5	1.29	0.71–2.37	0.40			
	Goats	38/108	34.9	33/110	30.0	1.22	0.69–2.16	0.50			
	Sheep	37/108	34.3	31/110	28.2	1.33	0.75–2.37	0.33			
Herding livestock with dogs (y)*		12/108	11.1	12/110	10.9	1.02	0.43–2.41	0.96			
Milking animals (y)*		44/115	38.3	38/108	35.2	1.14	0.66–1.97	0.63			
	Cattle	39/115	33.9	33/108	30.6	1.17	0.66–2.05	0.59			
	Goats	31/115	27.0	26/108	24.1	1.16	0.64–2.14	0.62			
	Sheep	11/115	9.6	13/108	12.0	0.77	0.32–1.81	0.55			
Slaughtering animals (y)*		97/116	83.6	86/110	78.2	1.42	0.73–2.81	0.30			
	Cattle	72/116	62.1	79/110	71.8	0.64	0.36–1.12	0.12			
	Goats	85/116	73.3	78/110	70.9	1.12	0.63–2.02	0.69			
	Sheep	63/116	54.3	66/110	60.0	0.79	0.47–1.34	0.39			
Assisting animal births (y)*		30/115	26.1	27/110	24.5	1.08	0.59–1.99	0.79			
	Cattle	22/115	19.1	18/110	16.4	1.21	0.61–2.42	0.59			
	Goats	25/115	21.7	22/110	20.0	1.11	0.58–2.13	0.75			
	Sheep	16/115	13.9	20/110	18.2	0.73	0.35–1.49	0.38			
Handling animal waste (y)*		54/116	46.6	62/110	56.4	0.67	0.40–1.14	0.14			
	Cattle	44/116	37.9	47/110	42.7	0.82	0.48–1.39	0.46			
	Goats	43/116	37.1	45/110	40.9	0.85	0.50–1.45	0.55			
	Sheep	38/116	32.8	45/110	40.9	0.70	0.41–1.21	0.20			
Handling aborted products (y)*		18/116	15.5	3/110	2.7	6.55	2.14–28.58	0.003	6.36	2.05–28.02	0.004
	Cattle	11/116	9.5	3/110	2.7	3.74	1.13–16.86	0.05			
	Goats	13/116	11.2	2/110	1.8	6.82	1.82–44.27	0.01			
	Sheep	9/116	7.8	1/110	0.9	9.17	1.68–170.53	0.04			
Handling animal placenta (y)*		31/114	27.2	27/110	24.5	1.15	0.63–2.10	0.65			
	Cattle	19/114	16.7	17/110	15.5	1.09	0.54–2.25	0.81			
	Goats	24/114	21.1	21/110	19.1	1.13	0.59–2.19	0.71			
	Sheep	18/114	15.8	19/110	17.3	0.90	0.44–1.82	0.77			
Handling animal carcass (y)*		10/116	8.6	6/107	5.6	1.59	0.57–4.82	0.39			
	Cattle	3/116	2.6	13/107	12.1	0.92	0.17–5.07	0.92			
	Goats	8/116	6.9	3/107	2.8	2.57	0.72–11.97	0.17			
	Sheep	9/116	7.8	4/107	3.7	2.17	0.68–8.19	0.21			
Handling animal hides (y)*		11/117	9.4	8/109	7.3	1.31	0.51–3.51	0.58			
	Cattle (m)	6/7	85.7	5/8	62.5	3.60	0.33–86.54	0.33			
	Goats (m)	7/9	77.8	3/7	42.9	4.67	0.58–50.86	0.16			
	Sheep (m)	4/6	66.7	3/5	60.0	1.33	0.10–17.65	0.82			
Aborted animals (y)*		49/107	45.8	37/103	35.9	1.51	0.87–2.63	0.15			
	Cattle	22/89	24.7	18/101	17.8	1.51	0.75–3.08	0.25			
	Goats	41/104	39.4	22/98	22.4	2.25	1.22–4.21	0.01			
	Sheep	27/98	27.6	25/103	24.3	1.19	0.63–2.24	0.59			
Consumption of raw dairy (m)*		28/117	23.9	21/110	19.1	1.33	0.71–2.54	0.38			
Age (years)		-	-	-	-	0.99	0.98–1.01	0.37			
Sex (male)		52/117	44.4	47/111	42.3	1.09	0.64–1.84	0.75			
High risk occupation		46/116	39.7	21/111	28.8	1.62	0.94–2.84	0.08			
Season (dry)		77/117	65.8	53/111	47.7	2.11	1.24–3.61	0.01	2.16	1.25–3.77	0.006

Note: Bold indicates variables included in multivariable analyses. Asterisk denotes question answered as yes or no. All variables with (y) notation refer to the performance of or exposure to the stated activity in the 12 months prior to presentation. All variables with (m) notation refer to the performance of or exposure to the stated activity in the 1 month prior to presentation. High risk occupation includes farmers, livestock attendants and those who worked with wildlife. All animal-related activities include cattle, sheep and goats in all cases and other species for specific questions.

Abbreviations: aOR, adjusted odds ratio; CI, confidence interval.

TABLE 3 Univariable and multivariable logistic regression analyses for factors associated with acute Q fever among febrile study participants, Endulen Hospital, Tanzania, 2016–17.

Variable	Level	Q fever		No Q fever		Univariable logistic regression			Multivariable logistic regression		
		n/N	%	n/N	%	OR	95% CI	p-Value	aOR	95% CI	p-Value
Herding livestock (m)*		21/67	31.3	47/151	31.1	1.01	0.54–1.87	0.97			
	Cattle	16/67	23.9	32/151	21.2	1.17	0.58–2.29	0.66			
	Goats	18/67	26.9	41/151	27.2	0.99	0.51–1.87	0.97			
	Sheep	18/67	26.9	40/151	26.5	1.02	0.52–1.93	0.95			
Herding livestock with dogs (m)*		8/67	11.9	15/151	9.9	1.23	0.47–2.99	0.66			
Miking animals (m)*		14/74	18.9	40/154	26.0	0.67	0.33–1.29	0.24			
	Cattle	9/73	12.3	32/150	21.3	0.52	0.22–1.11	0.11	0.43	0.17–0.97	0.052
	Goats	8/73	11.0	27/150	18.0	0.56	0.23–1.25	0.17			
	Sheep	2/73	2.7	13/150	8.7	0.30	0.05–1.11	0.12			
Slaughtering animals (m)*		41/74	55.4	61/154	39.6	1.89	1.08–3.34	0.026	2.54	1.38–4.76	0.003
	Cattle	27/73	37.0	41/153	26.8	1.60	0.88–2.90	0.12			
	Goats	34/73	46.6	54/153	35.3	1.60	0.91–2.82	0.11			
	Sheep	22/73	30.1	41/153	26.8	1.18	0.63–2.17	0.60			
Assisting animal births (m)*		11/77	14.3	19/154	12.3	1.24	0.54–2.73	0.60			
	Cattle	6/72	8.3	12/153	7.8	1.07	0.36–2.88	0.90			
	Goats	8/72	11.1	17/153	11.1	1.00	0.39–2.37	1.00			
	Sheep	3/72	4.2	12/153	7.8	0.51	0.11–1.67	0.31			
Handling animal waste (m)*		25/74	33.8	59/154	38.3	0.82	0.46–1.46	0.51			
	Cattle	17/74	23.0	43/152	28.3	0.76	0.39–1.42	0.40			
	Goats	19/74	25.7	46/152	30.3	0.80	0.42–1.47	0.48			
	Sheep	16/74	21.6	46/152	30.3	0.64	0.32–1.20	0.17			
Handling aborted products (m)*		5/74	6.8	11/154	7.1	0.94	0.29–2.70	0.92			
	Cattle	4/73	54.8	6/153	3.9	1.42	0.35–5.13	0.60			
	Goats	5/73	6.8	6/153	3.9	1.80	0.50–6.18	0.35			
	Sheep	4/73	5.4	4/153	2.6	2.16	0.50–9.38	0.29			
Handling animal placenta (m)*		9/74	12.2	19/154	12.3	0.98	0.40–2.24	0.97			
	Cattle	6/72	8.3	9/152	5.9	1.44	0.47–4.17	0.50			
	Goats	6/72	8.3	18/152	11.8	0.68	0.24–1.70	0.43			
	Sheep	3/72	4.2	13/152	8.6	0.46	0.10–1.50	0.24			
Handling animal carcass (m)*		4/74	5.4	6/154	3.8	1.41	0.35–5.09	0.60			
	Cattle	0/73	0.0	4/150	2.7	-	-	-			
	Goats	4/73	5.5	5/150	3.3	1.68	0.41–6.54	0.45			
	Sheep	3/73	4.1	5/150	3.3	1.24	0.25–5.21	0.77			
Handling animal hides (m)*		4/74	5.4	8/154	5.2	1.04	0.27–3.43	0.95			
	Cattle	3/3	100.0	8/12	66.7	-	-	-			
	Goats	4/5	80.0	6/11	54.5	3.33	0.34–77.29	0.34			
	Sheep	3/3	100.0	4/8	50.0	-	-	-			
Aborted animals (y)*		27/66	40.9	59/144	41.0	1.00	0.55–1.80	0.99			
	Cattle	13/56	23.2	27/134	20.1	1.20	0.55–2.50	0.637			
	Goats	22/64	34.4	41/138	29.7	1.24	0.65–2.32	0.51			
	Sheep	18/61	29.5	34/140	24.3	1.31	0.66–2.54	0.44			
Consumption of raw dairy (m)*		18/74	24.3	31/153	20.3	1.26	0.64–2.43	0.49			
Age (years)		-	-	-	-	1.00	0.98–1.01	0.64			
Sex (male)		35/75	47.3	64/154	41.6	1.26	0.72–2.21	0.41			
High risk occupation		28/74	37.8	50/153	32.7	1.25	0.70–2.23	0.44			
Season (dry)		54/74	73.0	76/154	49.4	2.77	1.54–5.15	0.001	3.14	1.70–6.02	0.001

Note: Bold indicates significant variables included in multivariable analyses. Asterisk denotes question answered as yes or no. All variables with (y) notation refer to the performance of or exposure to the stated activity in the 12 months prior to presentation. All variables with (m) notation refer to the performance of or exposure to the stated activity in the 1 month prior to presentation. Acute Q fever includes those with probable and confirmed cases. High risk occupation includes farmers, livestock attendants, or worked with wildlife. All animal related activities include cattle, sheep and goats in all cases and other species for specific questions.

Abbreviations: aOR, adjusted odds ratio; CI, confidence interval.

TABLE 4 Univariable and multivariable logistic regression analyses for factors associated with spotted fever group (SFG) *Rickettsia* exposure among febrile study participants, Endulen Hospital, Tanzania, 2016–17.

Variable	Level	Exposure to SFG <i>rickettsia</i>		SFG <i>rickettsia</i> unexposed		Univariable logistic regression			Multivariable logistic regression		
		n/N	%	n/N	%	OR	95% CI	p-Value	aOR	95% CI	p-Value
Herding livestock (y)*		68/167	40.7	15/51	29.4	1.65	0.85–3.32	0.15			
	Cattle	53/167	31.7	6/51	11.8	3.49	1.50–9.56	0.007	4.12	1.74–11.47	0.003
	Goats	56/167	33.5	14/51	27.5	1.33	0.68–2.74	0.42			
	Sheep	55/167	32.9	13/51	25.5	1.44	0.72–3.00	0.32			
Herding livestock with dogs (y)*		18/167	10.8	6/51	11.8	0.91	0.36–2.62	0.84			
Milking animals (y)*		66/172	38.4	16/51	31.4	1.36	0.71–2.71	0.36			
	Cattle	62/172	36.0	10/51	19.6	2.31	1.12–5.17	0.03			
	Goats	47/172	27.3	10/51	19.6	1.54	0.74–3.48	0.27			
	Sheep	18/172	10.5	6/51	11.8	0.88	0.34–2.54	0.79			
Slaughtering animals (y)*		145/174	83.3	38/52	73.1	1.84	0.87–3.79	0.10			
	Cattle	119/174	68.4	32/52	61.5	1.35	0.70–2.56	0.36			
	Goats	130/174	74.7	33/52	63.5	1.70	0.87–3.27	0.12			
	Sheep	100/174	57.5	29/52	55.8	1.07	0.57–2.00	0.83			
Assisting animal births (y)*		47/173	27.2	10/52	19.2	1.57	0.75–3.53	0.25			
	Cattle	34/173	19.7	6/52	11.5	1.88	0.79–5.21	0.19			
	Goats	38/173	22.0	9/52	17.3	1.34	0.62–3.16	0.47			
	Sheep	30/173	17.3	6/52	11.5	1.61	0.67–4.50	0.32			
Handling animal waste (y)*		88/174	50.6	28/52	53.8	0.88	0.47–1.63	0.68			
	Cattle	71/174	40.8	20/52	38.5	1.10	0.59–2.11	0.76			
	Goats	68/174	39.1	20/52	38.5	1.03	0.55–1.96	0.94			
	Sheep	63/174	36.2	20/52	38.5	0.91	0.48–1.74	0.77			
Handling aborted products (y)*		18/174	10.3	3/52	5.8	1.88	0.61–8.28	0.33			
	Cattle	13/174	7.5	1/52	1.9	4.12	0.79–75.71	0.10			
	Goats	13/174	7.5	2/52	3.8	2.02	0.53–13.19	0.33			
	Sheep	8/174	4.6	2/52	3.8	1.20	0.29–8.15	0.82			
Handling animal placenta (y)*		48/172	27.9	10/52	19.2	1.63	0.78–3.66	0.20			
	Cattle	31/172	18.0	5/52	9.6	2.07	0.82–6.32	0.13			
	Goats	36/172	20.9	9/52	17.3	1.26	0.58–2.98	0.56			
	Sheep	31/172	18.0	6/52	11.5	1.69	0.70–4.71	0.25			
Handling animal carcass (y)*		13/172	7.6	3/51	5.9	1.31	0.40–5.88	0.69			
	Cattle	3/172	1.7	3/51	5.9	0.28	0.05–1.58	0.13			
	Goats	10/172	5.8	1/51	2.0	3.09	0.57–57.33	0.29			
	Sheep	12/172	7.0	1/51	2.0	3.75	0.71–69.16	0.13			
Handling animal hides (y)*		17/174	9.7	2/52	3.8	2.71	0.74–17.45	0.14			
	Cattle (m)	10/23	43.5	1/2	50.0	3.33	0.11–104.48	0.44			
	Goats (m)	9/14	64.3	1/2	50.0	1.80	0.06–52.70	0.70			
	Sheep (m)	6/10	60.0	1/2	50.0	-	-	-			
Aborted animals (y)*		67/161	41.6	19/49	38.8	1.13	0.59–2.19	0.72			
	Cattle	32/143	22.4	8/47	17.0	1.41	0.62–3.51	0.43			
	Goats	50/155	32.3	13/47	27.7	1.25	0.62–2.64	0.55			
	Sheep	40/153	26.1	12/48	25.0	1.06	0.51–2.31	0.87			
Consumption of raw dairy (m)*		40/175	22.9	9/52	17.3	1.42	0.66–3.32	0.40			
Age (years)		-	-	-	-	1.04	1.01–1.06	0.001	1.04	1.02–1.06	0.001
Sex (male)		79/176	44.9	20/52	38.5	1.30	0.70–2.48	0.41			
High risk occupation		70/175	40.0	8/52	15.4	3.67	1.71–8.83	0.0002			
Season (dry)		98/176	55.7	32/52	61.5	0.79	0.41–1.47	0.45			

Note: Bold indicates significant variables included in multivariable analyses. Asterisk denotes question answered as yes or no. All variables with (y) notation refer to the performance of or exposure to the stated activity in the 12 months prior to presentation. All variables with (m) notation refer to the performance of or exposure to the stated activity in the 1 month prior to presentation. High risk occupation includes farmers, livestock attendants, or worked with wildlife. All animal related activities include cattle, sheep and goats in all cases and other species for specific questions.

Abbreviations: aOR, adjusted odds ratio; CI, confidence interval.

TABLE 5 Univariable logistic regression analyses for factors associated with spotted fever group (SFG) rickettsioses among febrile study participants, Endulen Hospital, Tanzania, 2016–17.

Variable	Level	SFG rickettsioses		No SFG rickettsioses		Univariable logistic regression		
		n/N	%	n/N	%	OR	95% CI	p-Value
Herding livestock (m)*		2/8	25.0	42/132	31.8	0.71	0.10–3.25	0.69
	Cattle	1/8	12.5	30/132	22.7	0.49	0.03–2.88	0.51
	Goats	2/8	25.0	35/132	26.5	0.92	0.13–4.23	0.93
	Sheep	2/8	25.0	34/132	25.8	1.44	0.72–3.00	0.32
Herding livestock with dogs (m)*		0/8	0.0	13/132	9.8	-	-	-
Milking animals (m)*		1/8	12.5	29/138	21.0	0.54	0.03–3.19	0.57
	Cattle	1/8	12.5	22/136	16.2	0.74	0.04–4.46	0.78
	Goats	1/8	12.5	17/136	12.5	1.00	0.05–6.13	1.00
	Sheep	1/8	12.5	8/136	5.8	2.29	0.12–15.32	0.46
Slaughtering animals (m)*		6/8	75.0	59/138	42.8	4.02	0.89–28.09	0.10
	Cattle	2/8	25.0	40/136	29.4	0.80	0.11–3.64	0.79
	Goats	5/8	62.5	50/136	36.8	2.87	0.67–14.46	0.16
	Sheep	5/8	62.5	36/136	26.5	4.63	1.08–23.50	0.043
Assisting animal births (m)*		2/8	25.0	16/138	11.6	2.54	0.35–12.17	0.28
	Cattle	1/8	12.5	9/135	6.7	2.00	0.10–13.15	0.54
	Goats	2/8	25.0	12/135	9.9	3.42	0.47–16.85	0.16
	Sheep	0/8	0.0	8/135	5.9	-	-	-
Handling animal waste (m)*		2/8	25.0	50/138	36.2	0.59	0.08–2.66	0.52
	Cattle	1/8	12.5	39/136	28.7	1.10	0.59–2.11	0.76
	Goats	2/8	25.0	37/136	27.2	0.89	0.13–4.07	0.89
	Sheep	1/8	12.5	35/136	25.7	0.41	0.02–2.43	0.42
Handling aborted products (m)*		0/8	0.0	9/138	6.5	-	-	-
	Cattle	0/8	0.0	4/136	3.0	-	-	-
	Goats	0/8	0.0	7/136	5.1	-	-	-
	Sheep	0/8	0.0	5/136	3.7	-	-	-
Handling animal placenta (m)*		2/8	25.0	15/138	10.9	2.73	0.38–13.16	0.24
	Cattle	1/8	12.5	7/134	5.2	2.07	0.82–6.32	0.16
	Goats	2/8	25.0	12/134	8.9	3.39	0.46–16.71	0.16
	Sheep	0/8	0.0	9/134	6.7	-	-	-
Handling animal carcass (m)*		0/8	0.0	5/138	3.6	-	-	-
	Cattle	0/8	0.0	2/134	1.5	-	-	-
	Goats	0/8	0.0	5/134	3.7	-	-	-
	Sheep	0/8	0.0	4/134	3.0	-	-	-
Handling animal hides (m)*		0/8	0.0	7/138	5.1	-	-	-
	Cattle	0/8	0.0	6/138	4.3	-	-	-
	Goats	0/8	0.0	6/138	4.3	-	-	-
	Sheep	0/8	0.0	3/138	2.2	-	-	-
Aborted animals (y)*		3/8	37.5	50/131	38.2	0.97	0.19–4.14	0.97
	Cattle	1/6	16.7	23/119	19.3	0.83	0.04–5.51	0.87
	Goats	3/8	37.5	37/127	29.1	1.46	0.29–6.26	0.62
	Sheep	2/7	28.6	29/124	23.4	1.31	0.18–6.44	0.75
Consumption of raw dairy (m)*		1/8	12.5	28/137	20.4	0.56	0.03–3.31	0.59
Age (years)		-	-	-	-	1.00	0.95–1.04	0.85
Sex (male)		3/8	37.5	64/138	46.4	0.69	0.14–2.94	0.63
High risk occupation		3/8	37.5	49/136	36.0	1.08	0.21–4.58	0.92
Season (dry)		3/8	37.5	77/138	55.8	1.32	0.31–6.64	0.71

Note: Bold indicates significant variables in univariable regression analysis and was included in attempted multivariable modelling. Asterisk denotes question answered as yes or no. All variables with (y) notation refer to the performance of or exposure to the stated activity in the 12 months prior to presentation. All variables with (m) notation refer to the performance of or exposure to the stated activity in the 1 month prior to presentation. High risk occupation includes farmers, livestock attendants, or worked with wildlife. All animal related activities include cattle, sheep and goats in all cases and other species for specific questions.

Abbreviations: CI, confidence interval; OR, odds ratio.

rickettsioses. Regression models of exposure to TG *Rickettsia* and TG rickettsioses were not performed due to small numbers of outcomes.

Exposure to *C. burnetii* and Q fever

The results of univariable and multivariable risk factor analyses for exposure to *C. burnetii* and acute Q fever are given in Tables 2 and 3. Pearson's correlation coefficients between animal-related activities undertaken within the past year and past month that were evaluated in *C. burnetii* relevant models are given in Tables 2, S1, and S2. The final model for exposure to *C. burnetii* identified increased odds of exposure among those who reported handling the products of livestock abortion events within the prior year compared with those who did not (adjusted odds ratio [aOR] 6.36, 95% confidence interval [CI] 2.05–28.02) and among those who presented to the hospital during the dry season compared with the wet season (aOR 2.16, 95% CI 1.25–3.77). The final model for acute Q fever, which included probable and confirmed cases, showed increased odds of disease among those who slaughtered animals within the prior month compared with those who did not (aOR 2.54, 95% CI 1.38–4.76) and among those who presented to the hospital during the dry season compared with the wet season (aOR 3.14, CI 1.70–6.02). There were decreased odds of acute Q fever among those who milked cattle within the prior month compared with those who did not (aOR 0.43, CI 0.17–0.97).

Exposure to SFG *Rickettsia* and SFG rickettsioses

The results of univariable and multivariable risk factor analyses for exposure to SFG *Rickettsia* and SFG rickettsioses are given in Tables 4 and 5. Pearson's correlation coefficients between animal-related activities undertaken within the past year that were evaluated in SFG *Rickettsia* relevant models are given in Table S3. The multivariable logistic regression model of exposure to SFG *Rickettsia* identified increased odds of exposure among those who herded cattle within the prior year compared with those who did not (aOR 4.12, 95% CI 1.74–11.47) and with age, with increased odds of exposure per year of age (aOR 1.04, 95% CI 1.02–1.06; Table 4). No multivariable model is presented for the SFG rickettsioses outcome as none were a better fit than univariable models. In univariable models of SFG rickettsioses, the only statistically significant association ($p < 0.05$) identified was slaughtering sheep (OR 4.63, 95% CI 1.08–23.50; Table 5). No significant associations were identified between herding livestock with dogs and exposure to SFG *Rickettsia* or SFG rickettsioses.

DISCUSSION

We found high levels of exposure to *C. burnetii* and SFG *Rickettsia* among febrile patients seeking outpatient care at a hospital that serves a predominantly pastoralist population

in northern Tanzania. For acute Q fever and SFG rickettsioses, large proportions of the study population met probable case definitions, although confirmed case numbers were smaller. In contrast, exposure to TG *Rickettsia* was low, observed in <5% of participants. Livestock-related activities were associated with increased odds of exposure to *C. burnetii* and SFG *Rickettsia*. Hospital presentation during the dry season was associated with increased odds of exposure to *C. burnetii* and acute Q fever. Our findings add to the growing evidence that *C. burnetii* and SFG *Rickettsia* are important causes of disease in northern Tanzania that warrant further study particularly among livestock-keeping populations.

Livestock-related activities were associated with exposure to *C. burnetii*, and SFG *Rickettsia*. Handling aborted livestock products was associated with exposure to *C. burnetii* in this population, likely due to the localization of the bacteria to the uterus and products of conception in infected animals [9]. Participants who herded cattle had higher odds of exposure to SFG *Rickettsia* compared with those who did not herd cattle. This is consistent with associations between human SFG *Rickettsia* seropositivity and cattle contact described in southern Tanzania and plausibly explained by a cattle ectoparasite acting as source of infection for humans in these Tanzanian contexts [12]. The odds of exposure to SFG *Rickettsia* increased with each year of participant age (aOR 1.04, CI 1.02–1.06). This could be due to the accumulation of exposure probability over time. Slaughtering animals was associated with increased odds of acute Q fever in this study population. This association is consistent with the findings from studies of nomadic pastoralists in northeast Kenya and abattoir workers in Australia [14, 24]. Previous studies have shown specific increased risk associated with slaughter of pregnant animals due to release of *C. burnetii* from the animal's uterus [23, 25]. In this study population, milking animals was protective against acute Q fever; this association merits further study.

Many of the livestock-related activities associated with exposure to *C. burnetii* or SFG *Rickettsia* could also be plausibly associated with human tick-contact from close and frequent contact with animals. IFA testing is a group-specific tool detecting antibody to antigens of all SFG *Rickettsia*, thus we cannot differentiate which *Rickettsia* species was associated with exposure in this study population. Most cases of SFG rickettsioses in returning travellers from sub-Saharan Africa are attributed to *R. africae* that is transmitted by livestock-associated ticks. In this study dataset, the only variable measuring contact with dogs, or their ticks, related to the use of dogs for herding. Herding with dogs was not associated with exposure to either *C. burnetii* or SFG *Rickettsia* or on outcomes of acute Q fever or SFG rickettsioses. Previous work in Tanzania found no association between dogs and SFG *Rickettsia* exposure, but did find an association between SFG *Rickettsia* exposure and livestock density within a community [12]. Together, these findings suggest that *R. africae* rather than *R. conorii* may be the more frequent cause of SFG *Rickettsia* exposure in Tanzania. In many cases, human interactions with livestock and dogs may be correlated due to the use of dogs for livestock herding and the co-distribution of these animals at the population and activity level. Further study is needed to disentangle the specific SFG

Rickettsia pathogens in Tanzania and further understand risk factors for human exposure to tick vectors.

Presentation to the hospital during the dry season was associated with increased odds of exposure to *C. burnetii* and of acute Q fever. *Coxiella burnetii* is highly stable in the environment and infectious aerosols may be created from environmentally persisting bacteria long after the release of bacteria from an infected animal [26]. Aerosolized transmission of *C. burnetii* between infected herds, and from livestock or their environments to humans is known to be associated with windborne transmission and open landscapes where aerosols or spore-like particles are more likely to be dispersed during dry seasons [27]. The risk of *C. burnetii* infection in rural areas is highest within 5–10 km of farms with infected animals [28]. Understanding the mechanics of transmission is key to inform context-specific approaches to preventing human cases and minimise disease.

The proportions of participants seropositive for *C. burnetii* and SFG *Rickettsia* in this predominantly pastoralist population were 51.3% and 77.2%, respectively. The prevalence of serologic exposure to *C. burnetii* was higher in this northern Tanzanian population compared with other studies in sub-Saharan Africa that have demonstrated seroprevalence of 1%–32% [6]. Exposure to SFG *Rickettsia* in this study population was similar to that seen in previous studies in rural areas of southwestern Tanzania and Senegal [12, 29]. Further understanding of the immune response to and long-term persistence of antibodies against *C. burnetii* and SFG *Rickettsia* is necessary to maximise epidemiologic and clinical inference from antibody detection. There are limited data on long-term antibody persistence after natural infection by *C. burnetii*, and the role of antibodies in protection against *C. burnetii* disease is unknown. In rickettsial infections, it is thought that antibodies play a minor role in clearance of primary infection [30]. Host factors, pathogen factors, and exposure profiles including the timing and frequency of pathogen exposure may all play a role in the progression from pathogen exposure to acute illness with *C. burnetii* and SFG *Rickettsia*, and further study of these determinants is needed.

Laboratory diagnosis of Q fever and SFG rickettsioses is challenging due to the need for both acute and convalescent sera to confirm diagnosis. In Tanzania, patients with unexplained fever rarely receive empiric treatment for Q fever or rickettsial infections [5, 30]. Doxycycline, an accessible antimicrobial in many low- and middle-income countries, including Tanzania, effectively treats acute Q fever and SFG rickettsioses [1]. However, clinical management algorithms for fever applied in Tanzania focus predominantly on malaria and invasive bacterial disease. Tetracyclines are not included in local or national guidelines for febrile illness, and receive scant attention in international guidelines for the empiric treatment of severe febrile illness or sepsis [32–34]. Untreated Q fever and rickettsial disease are not without risk of severe illness and death [3, 8, 11, 35]. Our findings support re-evaluation of guidelines and algorithms for the assessment and management of patients with severe febrile illness in this setting [1, 31].

We acknowledge the limitations to our study. We were unable to directly measure exposure to ectoparasites and used proxy variables for vector exposure such as activities involving close animal contact. We also had little data on the interactions of participants with rodents and dogs, animals known to harbour ectoparasites capable of transmitting SFG and TG *Rickettsia*, limiting our ability to explore any risks associated with these animals. We lacked clinical data on many symptoms and signs associated with the diseases investigated, potentially contributing to misclassification of cases. Our study population is biased towards those with increased hospital-based health-seeking behaviour and may not be generalizable to the wider population. The case definitions used in this study were adapted from those used principally for diagnosis in the United States and these definitions may not be appropriate for populations with more frequent serologic exposure to the study pathogens. It is plausible that high levels of serologic exposure to *C. burnetii* and *Rickettsia* spp. in this population reduced the specificity of probable acute disease case definitions, leading to over-estimation of the prevalence of probable cases. Delayed hospital presentation for acute illness may have reduced the probability of detecting seroconversion and thus a likely under-estimation of the prevalence of confirmed illness.

CONCLUSIONS

We demonstrate that exposure to *C. burnetii* and SFG *Rickettsia* was common among patients seeking care for fever in a predominantly pastoralist area of rural northern Tanzania, and that substantial proportions of participants met criteria for probable acute illness due to these two pathogens. Direct interactions with livestock conferred increased odds of both exposure and acute illness with *C. burnetii* and SFG *Rickettsia*. Further understanding of the complex interactions between humans, livestock, and ectoparasites is needed to disentangle the epidemiology of these pathogens, improve clinical management, and ultimately develop disease prevention strategies for Q fever and SFG rickettsioses.

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CONFLICT OF INTEREST STATEMENT


All authors declare no conflicts of interest.

DATA AVAILABILITY STATEMENT


The data used and analysed during the current study are available from <http://dx.doi.org/10.5525/gla.researchdata.1568>.

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REFERENCES

- Prabhu M, Nicholson WL, Roche AJ, Kersh GJ, Fitzpatrick KA, Oliver LD, et al. Q fever, spotted fever group, and typhus group rickettsioses among hospitalized febrile patients in northern Tanzania. *Clin Infect Dis*. 2011;53(4):e8–e15.
- Honarmand H. Q fever: an old but still a poorly understood disease. *Interdiscip Perspect Infect Dis*. 2012;2012:1–8.
- Raoult D, Marrie T, Mege J. Natural history and pathophysiology of Q fever. *Lancet Infect Dis*. 2005;5(4):219–26.
- Socolovschi C, Gaudart J, Bitam I, Huynh TP, Raoult D, Parola P. Why are there so few *Rickettsia conorii conorii*-infected *Rhipicephalus sanguineus* ticks in the wild? *PLoS Negl Trop Dis*. 2012;6(6):e1697.
- Raoult D, Roux V. Rickettsioses as paradigms of new or emerging infectious diseases. *Clin Microbiol Rev*. 1997;10(4):694–719.
- Vanderburg S, Rubach MP, Halliday JEB, Cleaveland S, Reddy EA, Crump JA. Epidemiology of *Coxiella burnetii* infection in Africa: a OneHealth systematic review. *PLoS Negl Trop Dis*. 2014;8(4):e2787.
- Carugati M, Kilonzo KG, Crump JA. Fever, bacterial zoonoses, and one health in sub-Saharan Africa. *Clin Med*. 2019;19(5):375–80.
- Jensenius M, Fournier PE, Kelly P, Myrvang B, Raoult D. African tick bite fever. *Lancet Infect Dis*. 2003;3(9):557–64.
- Angelakis E, Raoult D. Q fever. *Vet Microbiol*. 2010;140(3–4):297–309.
- Zhang HL, Mnzava KW, Mitchell ST, Melubo ML, Kibona TJ, Cleaveland S, et al. Mixed methods survey of zoonotic disease awareness and practice among animal and human healthcare providers in Moshi, Tanzania. *PLoS Negl Trop Dis*. 2016;10(3):e0004476.
- Salje J, Weitzel T, Newton PN, Varghese GM, Day N. Rickettsial infections: a blind spot in our view of neglected tropical diseases. *PLoS Negl Trop Dis*. 2021;15(5):e0009353.
- Heinrich N, Dill T, Dobler G, Clowes P, Kroidl I, Starke M, et al. High Seroprevalence for spotted fever group Rickettsiae, is associated with higher temperatures and rural environment in Mbeya region, southwestern Tanzania. *PLoS Negl Trop Dis*. 2015;9(4):e0003626.
- Wardrop NA, Thomas LF, Cook EAJ, De Glanville WA, Atkinson PM, Wamae CN, et al. The Sero-epidemiology of *Coxiella burnetii* in humans and cattle, Western Kenya: evidence from a cross-sectional study. *PLoS Negl Trop Dis*. 2016;10(10):e0005032.
- Njeru J, Henning K, Pletz MW, Heller R, Forstner C, Kariuki S, et al. Febrile patients admitted to remote hospitals in northeastern Kenya: seroprevalence, risk factors and a clinical prediction tool for Q-fever. *BMC Infect Dis*. 2016;16(1):244.
- Cadmus SI, Akporube KA, Ola-Daniel F, Adelakun OD, Akinseye VO. Seroprevalence and associated factors of brucellosis and Q-fever in cattle from Ibarapa area, Oyo state, south-western Nigeria. *Pan Afr Med J* [Internet]. 2020;36:370 [cited 2023 Apr 26]. Available from: <https://www.panafrican-med-journal.com/content/article/36/370/full>
- UNESCO World Heritage Centre. UNESCO World Heritage Centre. Ngorongoro Conservation Area. [cited 2023 Jun 11]. Available from: <https://whc.unesco.org/en/list/39/>
- National Bureau of Statistics, Tanzanian Ministry of Finance and Planning. Tanzania in Figures [Internet]. Dodoma, Tanzania. 2021; 2022 Jun [cited 2023 Jun 11] p. 88. Available from: https://www.nbs.go.tz/nbs/takwimu/references/2021_Tanzania_in_Figure_English.pdf
- Bodenham RF, Lukambagire AS, Ashford RT, Buza JJ, Cash-Goldwasser S, Crump JA, et al. Prevalence and speciation of brucellosis in febrile patients from a pastoralist community of Tanzania. *Sci Rep*. 2020;10(1):7081.
- Centers for Disease Control and Prevention. Q Fever (*Coxiella burnetii*) 2009 case definition [Internet]. 2021 [cited 2023 Jul 14]. Available from: <https://ndc.services.cdc.gov/case-definitions/q-fever-2009/>
- Centers for Disease Control and Prevention. Spotted Fever Rickettsiosis (including Rocky Mountain Spotted Fever) (SFR, including RMSF) 2020 Case Definition [Internet]. 2021 [cited 2023 May 16]. Available from: <https://ndc.services.cdc.gov/case-definitions/spotted-fever-rickettsiosis-2020/>
- Anderson A, Bijlmer H, Fournier PE, Graves S, Hartzell J, Kersh GJ, et al. Diagnosis and management of Q fever—United States, 2013: recommendations from CDC and the Q fever working group. *MMWR Recomm Rep Morb Mortal Wkly Rep Recomm Rep*. 2013;62(RR-03):1–30.
- Todkill D, Fowler T, Hawker JL. Estimating the incubation period of acute Q fever, a systematic review. *Epidemiol Infect*. 2018;146(6):665–72.
- Raoult D, Fournier PE, Fenollar F, Jensenius M, Prioe T, De Pina JJ, et al. *Rickettsia africae*, a tick-borne pathogen in travelers to sub-Saharan Africa. *N Engl J Med*. 2001;344(20):1504–10.

24. Woldeyohannes SM, Gilks CF, Baker P, Perkins NR, Reid SA. Seroprevalence of *Coxiella burnetii* among abattoir and slaughterhouse workers: a meta-analysis. *One Health*. 2018;6:23–8.
25. Garner MG, Longbottom HM, Cannon RM, Plant AJ. A review of Q fever in Australia 1991–1994. *Aust N Z J Public Health*. 1997;21(7):722–30.
26. Eldin C, Mélenotte C, Mediannikov O, Ghigo E, Million M, Edouard S, et al. From Q fever to *Coxiella burnetii* infection: a paradigm change. *Clin Microbiol Rev*. 2017;30(1):115–90.
27. Salifu SP, Bukari ARA, Frangoulidis D, Wheelhouse N. Current perspectives on the transmission of Q fever: highlighting the need for a systematic molecular approach for a neglected disease in Africa. *Acta Trop*. 2019;193:99–105.
28. Clark NJ, Soares Magalhães RJ. Airborne geographical dispersal of Q fever from livestock holdings to human communities: a systematic review and critical appraisal of evidence. *BMC Infect Dis*. 2018;18(1):218.
29. Mediannikov O, Diatta G, Fenollar F, Sokhna C, Trape JF, Raoult D. Tick-borne rickettsioses, neglected emerging diseases in rural Senegal. *PLoS Negl Trop Dis*. 2010;4(9):e821.
30. Osterloh A. The neglected challenge: vaccination against rickettsiae. *PLoS Negl Trop Dis*. 2020;14(10):e0008704.
31. Crump JA, Morrissey AB, Nicholson WL, Massung RF, Stoddard RA, Galloway RL, et al. Etiology of severe non-malaria febrile illness in northern Tanzania: a prospective cohort study. *PLoS Negl Trop Dis*. 2013;7(7):e2324.
32. World Health Organization. IMAI district clinician manual: hospital care for adolescents and adults: guidelines for the management of common illnesses with limited resources. Vol 1. Geneva, Switzerland: World Health Organization; 2011. p. 2.
33. World Health Organization. IMAI district clinician manual: hospital care for adolescents and adults: guidelines for the management of common illnesses with limited resources. Vol 2. Geneva, Switzerland: World Health Organization; 2011. p. 2.
34. World Health Organization. Pocket book of hospital care for children: guidelines for the management of common childhood illnesses [Internet]. Pocketbook of hospital care for children. 2nd ed. Geneva: World Health Organization; 2013 [cited 2022 Dec 15]. Available from: <https://apps.who.int/iris/handle/10665/81170>
35. Cherry CC, Kersh GJ. Pediatric Q fever. *Curr Infect Dis Rep*. 2020; 22(4):1–7.

SUPPORTING INFORMATION

Additional supporting information can be found online in the Supporting Information section at the end of this article.

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