2024-01-12

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John Wiley & Sons Ltd.

DOI: 10.1111/tmi.13980

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.

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†Deceased

**Funding information**
Biotechnology and Biological Sciences Research Council (BBSRC), Grant/Award Numbers: BB/L018845, BB/N503563, BB/L018926, BB/L017679; The Royal Society, Grant/Award Number: AA130131; United States (US) National Institute of Child Health and Human Development (NICHD) T32 training grant, Grant/Award Number: 1T32HD094671; Fogarty International Center of the US National Institutes of Health (NIH), Grant/Award Number: D43 TW010543; Economic and Social Research Council; Defence Science & Technology Laboratory; US National Institutes of Health, Grant/Award Numbers: R01AI121378, K23AI116869; Fogarty International Centre and the National Institute of Mental Health, Grant/Award Number: R25TW009337

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 ≥1:64; probable cases by an acute IFA titre ≥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 ≥38.0°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 4–10°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 ≥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 ≥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 ≥1:1024 to *C. burnetii* Phase I antigen [21].

For SFG *Rickettsia* and TG *Rickettsia*, exposure was defined by an IFA titre to ≥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 ≥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 (NIMRlHQ/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 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.

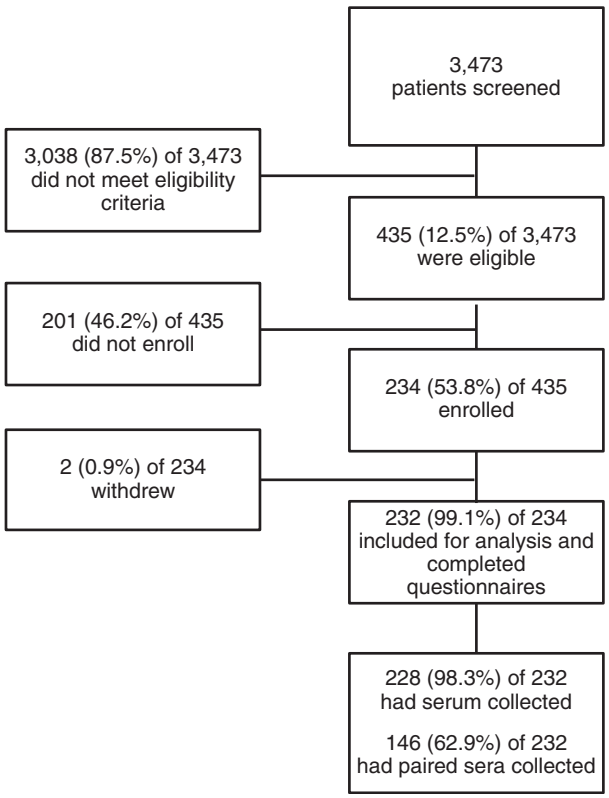


**FIGURE 1** Flow chart showing the steps in the screening, enrolment, and data collection from the study population of individuals with febrile illness seeking care in the outpatient department of Endulen Hospital from August 2016 through October 2017.

## 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.

| | Study participants ($N = 228$) | | |
|---|---|---|---|
| **Variable** | ***n/N* (%)** | **Median age in years (IQR)** | **Male (%)** |
| All study participants | 228 | 27 (16–41) | 99 (43.4) |
| Q fever | | | |
| *C. burnetii* 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 *Rickettsia* 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 *Rickettsia* 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.

| | | Exposure to *C. burnetii* | | *C. burnetii* unexposed | | Univariable logistic regression | | | Multivariable logistic regression | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| **Variable** | **Level** | ***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.

| | | Q fever | | No Q fever | | Univariable logistic regression | | | Multivariable logistic regression | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| **Variable** | **Level** | ***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.

| | | Exposure to SFG *rickettsia* | | SFG *rickettsia* unexposed | | Univariable logistic regression | | | Multivariable logistic regression | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| **Variable** | **Level** | ***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 | | | |
| Miking 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.

| | | SFG rickettsioses | | No SFG rickettsioses | | Univariable logistic regression | | |
|---|---|---|---|---|---|---|---|---|
| **Variable** | **Level** | ***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 | - | - | - |
| Miking 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.

### ACKNOWLEDGEMENTS

We thank the patients and staff at the Endulen Hospital for their participation in this study, and the team at the Kilimanjaro Clinical Research Institute (KCRI) for support in the delivery of this project. We also thank Tanzania Wildlife Research Institute (TAWIRI) and Ngorongoro Conservation Area Authority (NCAA) for approvals to conduct this project within the Ngorongoro Conservation Area.

### FUNDING INFORMATION

This work was funded by the Biotechnology and Biological Sciences Research Council (BBSRC), the Department for International Development, the Economic & Social Research Council, the Medical Research Council, the Natural Environment Research Council and the Defence Science & Technology Laboratory, under the Zoonoses and Emerging Livestock Systems (ZELS) programme (BB/L018845).

Additional support was provided by a Leverhulme - Royal Society Africa Award (AA130131). G.S.M. received support from the United States (US) National Institute of Child Health and Human Development (NICHD) T32 training grant (1T32HD094671) and the Fogarty International Center of the US National Institutes of Health (NIH) (D43 TW010543). R.F.B. received additional funding from the ZELS programme (BB/N503563/1). J.A.C. received additional support from US NIH (R01AI121378), and BBSRC (BB/L018926 and BB/L017679). K.M.T. received additional support from BBSRC (BB/L017679). M.P.R. received additional support from the US NIH (K23AI116869). S.C.G received support from US NIH Research Training Grant funded by the Fogarty International Center and the National Institute of Mental Health (R25 TW009337).

## 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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## SUPPORTING INFORMATION

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

**How to cite this article:** Moorthy GS, Rubach MP, Maze MJ, Refuerzo RP, Shirima GM, Lukambagire AS, et al. Prevalence and risk factors for Q fever, spotted fever group rickettsioses, and typhus group rickettsioses in a pastoralist community of northern Tanzania, 2016–2017. Trop Med Int Health. 2024. https://doi.org/10.1111/tmi.13980