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Private healthcare facilities' participation in Uganda's viral hemorrhagic fever surveillance program: contributions, selective case capture, and underutilized early-warning potential

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Research Article

Keywords: Viral hemorrhagic fever, Disease surveillance, Private healthcare facilities, Uganda, Outbreak detection, Early warning, Ebola virus disease, Crimean–Congo hemorrhagic fever, Integrated Disease Surveillance and Response

Posted Date: November 6th, 2026

DOI: https://doi.org/10.21203/rs.3.rs-11078439/v1

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Additional Declarations: No competing interests reported.

Abstract

Background

Private healthcare facilities are important initial points of contact, especially for patients with undifferentiated febrile illnesses in mixed health systems. However, their contribution to viral hemorrhagic fever surveillance remains to be quantified, particularly in outbreak-prone regions. We assessed their contribution to Uganda's national surveillance system and examined variation by case mix, geography, and outbreak period.

Methods

We conducted a retrospective cross-sectional analysis of all suspected VHF specimen submissions recorded in Uganda's national Result Dispatch System from 1 January 2023 to 14 August 2026, spanning the 2025 Sudan virus disease and 2026 Ebola (Bundibugyo virus, BDBV) outbreaks. Ownership was classified against the national health facility master list. Pre-specified outcomes were test positivity, recorded bleeding, and alive-at-reporting status. Adjusted analyses used generalized linear mixed models with a district-level random intercept, pre-specified sensitivity analyses, and a test of effect modification by Kampala.

Results

Of 7,929 submissions, 504 (6.4%) were private. Private healthcare facilities contributed 21 of 149 VHF-positive submissions and 10 of 32 Ebola-positive submissions. During May–June 2026, they contributed 212 of 1,230 submissions and 10 of 20 Ebola-positive submissions; Ebola positivity was 4.72% versus 0.98% in public submissions (post-hoc comparison; crude odds ratio 4.99, p = 0.0007). Private ownership was associated with overall VHF positivity (adjusted odds ratio [aOR] 3.44, 95% confidence interval [CI] 1.95–6.05), recorded bleeding (4.97, 3.86–6.41), and alive-at-reporting status among known-status records (5.43, 4.09–7.21). Positivity attenuated after reporting-status adjustment (2.40, 1.34–4.28); intervals included 1 in alive-only and pre-2026 analyses. Bleeding remained associated after adjustment for symptom recording (3.85, 2.98–4.97). The alive-at-reporting association was stronger in Kampala but remained elevated elsewhere. All 16 initially significant symptom comparisons remained significant after false discovery rate adjustment.

Conclusions

Private healthcare facilities contributed a small share of submissions but a disproportionate share of detections, recorded VHF-compatible bleeding far more often, and far more often reported patients still alive, unlike the post-mortem case-finding dominating public submissions in the capital. This is

consistent with an underused early-warning role and supports targeted, differentiated integration; establishing any effect on timeliness requires prospective study.

Trial registration

Clinical trial number: not applicable.

Background

Viral hemorrhagic fevers (VHFs), including Ebola disease, Marburg virus disease, Crimean–Congo hemorrhagic fever (CCHF), and Rift Valley fever (RVF), remain among the most consequential epidemic threats in East Africa. Uganda has experienced repeated VHF outbreaks, including the 2025 Sudan virus disease (SVD) outbreak and the 2026 Ebola (Bundibugyo virus, BDBV) outbreak, and has since developed a national surveillance and reference laboratory network to support early detection, diagnostic confirmation, and public health response. Isolation and clinical management of patients with VHF, and quarantine of high-risk contacts, are centralized in government-operated public health facilities (1).

Effective surveillance depends not only on laboratory capacity but on clinical suspicion at the point of care. A large share of health service delivery in Uganda occurs outside government-owned facilities, particularly in urban and peri-urban areas (2), and private facilities, both not-for-profit and for-profit, are often the first point of contact for patients presenting with undifferentiated febrile illness (3). Because early VHF clinical presentations are nonspecific, these facilities occupy a potentially strategic position in the surveillance pathway (4). As out-of-pocket health expenditures continue to drive patients in densely populated urban areas toward accessible private clinics, and as the Ministry of Health advances Universal Health Coverage and the National Health Insurance Scheme, the systematic inclusion of accredited private healthcare facilities in national epidemic surveillance networks becomes increasingly consequential (5).

Despite this clinical footprint, private healthcare facilities' participation in national epidemic surveillance is inconsistent and can be constrained by gaps in clinical suspicion, high staff turnover, infection-prevention measures, outbreak-specific training, fragmented reporting channels, and disincentives stemming from stigma, loss of patient trust, or service disruption, all of which suppress reporting (6). Together, these create potential surveillance blind spots at precisely the point where many patients first seek care.

The contribution of private healthcare facilities to Uganda's VHF surveillance system has not previously been quantified using national routine data spanning successive outbreaks. Existing evidence is drawn largely from facility-level assessments, single-outbreak investigations, and descriptive evaluations. No national analysis has tested whether apparent differences between private and public submissions reflect differences in facility ownership or in the patients and specimens submitted. To address this gap, we analyzed all suspected VHF specimens tested through Uganda's national surveillance network

between 1 January 2023 and 14 August 2026, a period encompassing two distinct Ebola outbreaks. We assessed the contribution of private healthcare facilities to reporting volume, diagnostic yield, pathogen distribution, symptom-defined case capture, and patient status at the time of reporting. We hypothesized that although private healthcare facilities would contribute a small proportion of total notifications, they would act as selective surveillance nodes capturing a clinically distinct cohort. We examined the extent to which that contribution was shaped by case mix, geography, and outbreak context.

Methods

Study design and data source

We conducted a retrospective cross-sectional analysis of routine national VHF surveillance data from Uganda covering 1 January 2023 to 14 August 2026. The analysis used specimen-submission records captured in the Result Dispatch System (RDS), a centralized electronic platform operated by the Uganda Ministry of Health through the Department of National Health Laboratory and Diagnostic Services (NHLDS) and the Central Public Health Laboratories (CPHL). The RDS captures laboratory results for specimens referred through Uganda's national VHF surveillance and specimen-referral network. Specimens from suspected VHF cases are submitted by public and private healthcare facilities and tested at one of three nationally designated reference laboratories: the Uganda Virus Research Institute VHF Laboratory (UVRI VHF), the Central Emergency Response and Surveillance Laboratory (CERSL), and the CPHL Rapid Response Laboratory (RRL), as shown in Fig. 1. This referral network has previously supported rapid laboratory confirmation of VHF index cases, including the 2025 SVD index case (7).

Figure 1: *Specimen referral pathway for viral hemorrhagic fever surveillance in Uganda. Specimens from suspected VHF cases at public and private healthcare facilities are referred through the National Specimen Referral Network (hub system) to three reference laboratories. Results are returned through the Result Dispatch System to submitting facilities and to district and national surveillance teams (dashed arrows). Counts describe 7,929 submissions, not unique patients or numbers of facilities; PNFP, private not-for-profit; PFP, private for-profit; UVRI, Uganda Virus Research Institute; CERSL, Central Emergency Response and Surveillance Laboratory; CPHL, Central Public Health Laboratories*

Case definition and analytic population

Suspected VHF submissions were defined operationally as all records submitted for VHF testing during the study period. Clinical suspicion followed Uganda's national Integrated Disease Surveillance and Response (IDSR) framework and VHF surveillance procedures, informed by WHO AFRO IDSR guidance, which uses standardized alert and suspected-case criteria incorporating acute febrile illness, hemorrhagic manifestations, compatible symptoms, epidemiological linkage, or other clinical or public health suspicion requiring investigation (8). The analytic unit was a single specimen submission. No

formal sample-size calculation was performed; the study size was determined by all eligible VHF specimen submissions recorded in the RDS during the pre-specified study period.

Facility ownership classification and variables extracted

Facility ownership was classified using the facility name recorded in the RDS, against the Uganda Ministry of Health National Health Facility Master List. Facilities were grouped into public, private not-for-profit (PNFP), and private for-profit (PFP) categories. For regression analyses, PNFP and PFP facilities were combined into a single private-facility category because the number of submissions and laboratory-positive detections in the separate private subgroups was small relative to the public sector. Variables extracted from the RDS dataset included the case report date, the sample collection date, patient status at reporting (alive, dead, or unknown), the district of the submitting facility, facility ownership, testing laboratory, laboratory test result, organism tested for or detected, and the presence or absence of 25 recorded clinical symptoms. The symptom variables were fever, vomiting, diarrhea, anorexia, fatigue, abdominal pain, headache, cough, chest pain, joint pain, muscle pain, difficulty breathing, difficulty swallowing, sore throat, conjunctivitis, jaundice, confusion, coma, hiccups, sensitivity to light, skin rash, general weakness, bloody stool, hematuria, and nosebleed or epistaxis. A separate composite variable for bleeding symptoms was also available in the study dataset.

Outcome definitions

Three main outcomes were evaluated. Test positivity was defined as a positive laboratory result for any VHF pathogen recorded in the RDS; confirmed positive results were recorded for Ebola virus, Crimean–Congo hemorrhagic fever virus, and Rift Valley fever virus. Recorded bleeding was defined using the composite bleeding-symptom variable in the dataset. Because the RDS does not document the exclusion of alternative causes, this variable is not equivalent to clinically unexplained bleeding; bleeding subtypes, including bloody stool, hematuria, and epistaxis, were also examined separately.

Alive at reporting was defined, among records with known patient status, as being recorded as alive rather than dead at the time the report was filed. Unknown statuses were excluded from this outcome analysis. Within the VHF program, specimens collected from living patients are generally EDTA whole blood, whereas post-mortem collections predominantly comprise buccal swabs, alone or with blood. However, specimen type and the individual case-finding pathway were not recorded in the analytic extract. Patient status was therefore used as an imperfect proxy for these characteristics in sensitivity analyses, rather than a validated measure of either.

The dataset lacked symptom-onset date, date of first healthcare contact, detailed referral history, and a direct severity measure. Alive-at-reporting status was interpreted as a cross-sectional reporting characteristic, not as a measure of survival, clinical severity, timeliness of detection, or earlier

presentation. The post-hoc May–June 2026 comparison used Ebola-specific positivity; its endpoint differs from the overall VHF-positivity outcome.

Data cleaning and handling of missing data

Direct patient identifiers were removed before creating the analytic dataset. After standardization, the dataset included 97 unique districts. For district-level descriptive summaries, districts with fewer than 20 total submissions were excluded to reduce instability in percentage estimates, yielding a descriptive subset of 33 districts. Records lacking a valid case-report date (59; 0.7%) were excluded only from date-dependent and calendar-year-adjusted analyses. All assigned districts were retained for multilevel regression modeling. Of the 23 records with an UNKNOWN district, one was among the undated records; the remaining 22 were excluded from models including the district random intercept, whereas the single submission with a blank district value was retained and treated as its own district level. Models adjusted for calendar year and containing the district random intercept were therefore fitted on 7,848 of the 7,929 submissions (Additional file 1, Fig. S1). Records with unknown patient status (1,340; 16.9%) were retained in the overall dataset but excluded from the alive-at-reporting analysis, which was fitted on 6,520 records. No imputation was used in the primary analyses; assignments of missing statuses were confined to the sensitivity scenarios described below.

Descriptive and regression analysis

Categorical variables were summarized as counts, proportions, and Wilson 95% confidence intervals (CIs). Two-sided Fisher's exact tests were used to compare public and private submissions. Symptom comparisons were exploratory; Benjamini–Hochberg false-discovery-rate q-values were computed jointly across 25 symptoms and the composite bleeding variable. We compared the number of affirmative symptoms and the proportion of records with no affirmative symptom by ownership, using the Mann–Whitney test for symptom counts. These measures describe symptom recording and do not establish whether a reporting form was fully completed. Specimens tested per positive submission were calculated as the reciprocal of the crude positivity rate and interpreted as a descriptive yield, not as a measure of cost-effectiveness or causal testing efficiency.

Each primary binary-outcome analysis used a generalized linear mixed model (GLMM) with a logit link and district random intercept. The exposure was private versus public ownership, and calendar year was included as a categorical covariate. Models were fitted by maximum likelihood with 10-node adaptive Gauss–Hermite quadrature. The alive-at-reporting primary model additionally adjusted for testing laboratory; laboratory adjustment was a sensitivity specification for positivity and bleeding. Estimates are adjusted odds ratios (aORs) with Wald 95% CIs from the observed Hessian. District variance and the latent-scale intraclass correlation coefficient (ICC) describe clustering. Numerical scores and Hessians were examined for convergence.

Sensitivity analyses

District differences were also controlled for using a district-fixed-effects logistic regression with district-clustered robust standard errors. Clustered inference used an HC0 covariance estimator with a G/(G − 1) adjustment, where G denotes the number of district clusters. Test positivity was further examined after adjustment for reporting status, restricted to alive-at-reporting submissions, excluding 2026, and using Firth-penalized logistic regression for sparse positive outcomes, adjusted for calendar year and Kampala, without a district random intercept. Reporting-status adjustment retained unknown status as a separate category. The bleeding model was additionally adjusted for whether at least one symptom was affirmative and was also fitted restricted to submissions with at least one affirmative symptom. Deterministic missing-status bounds and disaggregation of private ownership into PNFP and PFP were fitted for all three outcomes. These analyses assessed sensitivity to the measured case mix and symptom recording and do not eliminate unmeasured confounding.

For alive-at-reporting status, four deterministic scenarios assigned unknown records to: dead in both sectors; alive in both sectors; private dead/public alive; or private alive/public dead. A post-hoc fractional-outcome analysis assigned an expected alive outcome of 1 to all unknown public statuses and varied a common expected death fraction among unknown private statuses from 0 to 1. The same district, year, and laboratory model was fitted to these expected outcomes, and the thresholds at which the ownership aOR crossed 1.5 and 1 were identified numerically.

The May–June 2026 Ebola-specific comparison was post hoc and is labeled as such throughout.

Geographic, temporal and pathogen-specific analyses

Kampala was examined as a separate geographic stratum because of its high concentration of private healthcare facilities and its distinct surveillance and referral structure compared with many non-capital districts. For test positivity and alive-at-reporting status, crude rates and odds ratios were estimated separately for Kampala and non-Kampala districts. A formal ownership-by-Kampala interaction was assessed for each outcome using a multiplicative interaction term between facility ownership and a Kampala indicator, with adjustment for calendar year (and, for alive-at-reporting, testing laboratory) and robust standard errors clustered at the district level. For crude geographic tabulations, the remaining-submissions group included districts with unknown or blank values. Adjusted geographic models followed the date/district exclusions above and retained the single blank-district record in the non-Kampala indicator group. Kampala-only models used model-based standard errors because Kampala constitutes one district cluster.

Annual and monthly trends in the private-facility submission share were described using the parsed case-report date. Two outbreak-centered calendar groupings were defined for descriptive analysis. Because these analyses used whole calendar months, the categories approximate, rather than exactly reproduce, official epidemiological phase boundaries. Uganda’s 2025 SVD outbreak was declared on 30

January 2025 and declared over on 26 April 2025; the calendar groups were November 2024 to January 2025 (baseline and declaration-month period), February to April 2025 (main outbreak period), and May to August 2025 (post-outbreak period). Uganda's 2026 BDBV outbreak was declared on 15 May 2026. The national announcement on 28 July marked the interruption of local transmission (9); WHO confirmed the end of the outbreak on 27 August 2026 after an additional 42-day monitoring period following the discharge of the last imported patient on 16 July (10). WHO's end-of-outbreak confirmation therefore post-dated the close of the study period. The final 2026 category therefore lies wholly within the outbreak as defined by WHO and is labeled the late-outbreak period. For comparability with the monthly analysis, the 2026 groups were defined as February to April 2026 (pre-outbreak baseline), May to June 2026 (acute outbreak period), and July to 14 August 2026 (late-outbreak period). Laboratory-positive VHF submissions were summarized by pathogen and facility ownership, and the proportional contribution of private healthcare facilities was calculated separately for CCHF, RVF, and Ebola virus detections, with Wilson 95% CIs.

Software

Descriptive summaries, Wilson confidence intervals, Fisher's exact tests, Benjamini–Hochberg adjustment, and temporal summaries were computed in Python 3.12.14 with NumPy 2.3.5, pandas 2.2.3, and SciPy 1.17.0. Generalized linear mixed models were fitted in R 4.3.3 with lme4 1.1–35.1 using 10-node adaptive Gauss–Hermite quadrature. District fixed-effect logistic regression with district-clustered robust standard errors used the sandwich and lmtest packages, and Firth-penalized models used the logistf package. All statistical tests were two-sided, with $p < 0.05$ for unadjusted tests and $q < 0.05$ for the exploratory symptom family.

Reporting

This study is reported in accordance with the STROBE statement and the RECORD extension for studies conducted using observational routinely collected health data. The study design, RDS source, period, eligibility criteria, outcome definitions, and analysis-specific exclusions are described in the Abstract and Methods. The completed checklist is provided in Additional file 1.

Results

Surveillance volume and spatiotemporal distribution

Public facilities contributed 7,425 of 7,929 suspected VHF specimen submissions (93.6%; 95% CI 93.1–94.2%). Private healthcare facilities contributed 504 submissions (6.4%; 95% CI 5.8–6.9%), including 245 from PNFP facilities (3.1%; 95% CI 2.7–3.5%) and 259 from PFP facilities (3.3%; 95% CI 2.9–3.7%), as summarized in Additional file 1 (Table S1). Private healthcare facilities differed markedly from public facilities in case mix: 237 (66.0%) of 359 private submissions with known status were from patients alive at reporting, compared with 1,768 (28.4%) of 6,230 public submissions, and at least one symptom was recorded on 418 (82.9%) of 504 private forms compared with 4,636 (62.4%) of 7,425 public forms.

Private-facility participation varied across the study period: private healthcare facilities contributed 45 of 2,014 submissions in 2023 (2.2%), 52 of 622 in 2024 (8.4%), 130 of 3,348 in 2025 (3.9%), and 269 of 1,886 in 2026 through 14 August (14.3%, a partial year reflecting continued elevated private-facility participation during the 2026 outbreak response). The monthly private-facility share fluctuated throughout the study period, ranging from 0% in multiple months to 45.5% in February 2026 (n = 11); the share exceeded 30% in only two months of the series, and other apparent peaks reflected very small monthly denominators, with a sustained rise to 15–21% during the peak of the 2026 outbreak (May and June 2026; n = 422 and 808, respectively), as shown in Fig. 2a. The 44-calendar-month span contains dated records in 41 months; September–November 2025 have zero recorded submissions and undefined private shares (Additional file 1, Table S10).

Figure 2: *Private-facility share of suspected VHF submissions over time. a Monthly private-facility share, January 2023 to August 2026, with monthly submission volume below. Open circles identify observed months with fewer than 30 submissions. September to November 2025 contain no dated source records and have undefined shares. The dashed line is the full-extract private share (504/7,929; 6.4%). Shaded bands indicate the 2025 Sudan virus disease outbreak (30 January to 26 April 2025) and the 2026 Bundibugyo virus local-transmission interval (15 May to 28 July 2026, ending at the national announcement of interrupted local transmission). b Private share by calendar-month group. These descriptive groups approximate outbreak phases; boundaries and their relation to official dates are specified in Additional file 1, Table S11. Error bars are 95% Wilson confidence intervals. Fractions beneath bars are private/all submissions. August 2026 includes 1 to 14 August only*

District-level private-facility contributions varied substantially. Kampala had the most private submissions overall (n = 376; 74.6% of all private submissions), and its own private-facility share was 7.4% (95% CI 6.7–8.2%; 376 of 5,059 Kampala submissions). Several smaller districts exceeded Kampala's district-level share: Nakaseke led with 40.0% (95% CI 27.0–54.5%; 18 of 45), followed by Luweero at 26.4% (95% CI 16.4–39.6%; 14 of 53), Wakiso at 14.0% (95% CI 8.7–21.8%; 15 of 107) and Mukono at 9.9% (95% CI 6.8–14.2%; 25 of 253). Seventeen of the 33 districts with at least 20 submissions reported no private healthcare facility submissions during the study period. District-level counts are given in Additional file 1 (Table S9).

Surveillance dynamics across the 2025 and 2026 outbreaks

Using the pre-specified calendar-month periods, private healthcare facilities contributed 17 of 206 submissions during the 2025 SVD pre-outbreak baseline and declaration-month period (8.3%; 95% CI 5.2–12.8%), 88 of 1,735 during the outbreak period (5.1%; 95% CI 4.1–6.2%), and 39 of 1,482 during the post-outbreak period (2.6%; 95% CI 1.9–3.6%), as shown in Fig. 2b. None of the 12 Ebola-positive submissions recorded during the 2025 baseline/declaration and main outbreak periods originated from a private facility (Additional file 1, Table S11). By the time the outbreak was declared over, the World Health Organization had recorded 12 confirmed and 2 probable cases nationally (11), with response

activities organized through formal outbreak-control mechanisms that channel highly suspected cases directly to designated treatment units rather than through routine facility-level triage.

Using the same calendar-month period structure, private healthcare facilities contributed 8 of 39 submissions during the 2026 pre-outbreak baseline (20.5%; 95% CI 10.8–35.5%), 212 of 1,230 during the acute outbreak period (17.2%; 95% CI 15.2–19.4%), and 45 of 601 during the late-outbreak period through 14 August (7.5%; 95% CI 5.6–9.9%; Additional file 1, Table S11). Private-facility participation in surveillance was therefore markedly higher during the 2026 outbreak than in 2025. Of the 20 Ebola-positive submissions recorded during the 2026 outbreak period, 10 originated from private healthcare facilities (50.0%; 95% CI 29.9–70.1%). Uganda reported 20 confirmed Ebola cases nationally over the same period (12). Because the surveillance records contain no patient identifiers, we could not determine whether each positive submission corresponded to a distinct confirmed case. Across the full study period, private healthcare facilities accounted for 10 of 32 Ebola virus-positive submissions (31.2%; 95% CI 18.0–48.6%). This regional outbreak was caused by a newly characterized ebolavirus variant (13) and prompted a large joint WHO–Africa CDC continental response (14, 15).

In a post-hoc analysis confined to the 2026 acute outbreak period, private healthcare facilities made 212 (17.2%) of 1,230 submissions but accounted for 10 (50.0%) of the 20 Ebola-positive submissions, 2.9 times the number expected had detections followed submission volume. Test positivity in that period was 10 of 212 private submissions (4.72%; 95% CI 2.6–8.5%) versus 10 of 1,018 public submissions (0.98%; 95% CI 0.5–1.8%; crude OR 4.99; Fisher's exact p = 0.0007), equivalent to 21 specimens tested per positive detection among private submissions compared with 102 among public submissions, as shown in Fig. 3a.

Figure 3: *Ebola-specific positivity, reporting status and overall VHF positivity by ownership. a Post-hoc Ebola-specific comparison for 1 May to 30 June 2026: 10/212 private versus 10/1,018 public submissions; crude odds ratio 4.99, two-sided Fisher p = 0.0007. This is not the overall VHF endpoint. b Dead-at-reporting fractions among submissions with known patient status, by geographic group. Other/unrecorded district includes 23 UNKNOWN and one blank-district submission before restriction to known status. c Overall VHF positivity stratified by recorded status (alive, dead, or unknown). Error bars are 95% Wilson confidence intervals. Fractions are positive/tested in a and c, and dead/known status in b. Tests are two-sided Fisher exact tests.*

Crude diagnostic yield and pathogen-specific contribution

Among 149 laboratory-positive VHF submissions across the full study period, private healthcare facilities contributed 21 positive detections (crude positivity 4.17%; 95% CI 2.7–6.3%) and public facilities contributed 128 (1.72%; 95% CI 1.5–2.0%; crude OR 2.48; Fisher's exact p = 0.0005). This corresponded to approximately 24.0 specimens tested per positive detection among private submissions, compared with 58.0 among public submissions. Private healthcare facilities accounted for 4 of 28 CCHF virus-positive submissions (14.3%; 95% CI 5.7–31.5%), 7 of 89 RVF virus-positive submissions (7.9%; 95% CI

3.9–15.4%) and 10 of 32 Ebola virus-positive submissions (31.2%; 95% CI 18.0–48.6%), as summarized in Additional file 1 (Table S1).

In the primary GLMM (7,848 observations, 97 districts), private ownership was associated with higher overall odds of test positivity after adjusting for calendar year (aOR 3.44; 95% CI 1.95–6.05; p < 0.0001; district variance 3.50, ICC 0.52). The ICC indicated substantial district-level clustering in positivity. The pre-specified fixed-effect sensitivity model yielded a similar overall estimate (aOR 3.40; 95% CI 1.41–8.25; p = 0.0066), and laboratory adjustment gave aOR 3.52 (1.99–6.24). The Firth estimate was 3.38 (Wald 95% CI 2.06–5.57; p < 0.0001); profile penalized-likelihood inference gave CI 2.01–5.48 and p = 0.000017. Excluding the blank-district record yielded an aOR of 3.49 (1.98–6.16). Primary coefficients are provided in Additional file 1 (Tables S3 and S4).

Positivity was 114/2,005 (5.69%) among submissions from patients alive at reporting and 25/4,584 (0.55%) among those recorded as dead. Within these strata, positivity was numerically higher in private submissions, with substantial uncertainty (alive: 7.2% versus 5.5%, Fisher p = 0.30; dead: 1.6% versus 0.5%, p = 0.14; Fig. 3c). The adjusted ownership association attenuated with reporting-status adjustment but remained above 1 (aOR 2.40; 95% CI 1.34–4.28; p = 0.0031). In the alive-only analysis, it was 1.47 (0.78–2.77; p = 0.24), and excluding 2026, it was 2.12 (0.86–5.23; p = 0.10; crude positivity 3.08% versus 1.88%). The intervals in these restricted analyses include 1; they do not establish absence of an association or complete explanation of the pooled association by case mix (Fig. 4; Additional file 1, Table S6).

Figure 4: *Adjusted ownership associations across primary and selected sensitivity models. Odds ratios compare private with public submissions. Orange circles denote primary models; black squares denote sensitivity models. The horizontal axis is logarithmic, and the dashed line marks an odds ratio of 1. Primary models include calendar year and a district random intercept, with additional laboratory adjustment for alive at reporting. Sensitivity specifications include district fixed effects, additional adjustment, restrictions, Firth penalization, deterministic assignments of unknown status, and exclusion of the blank district. Intervals are 95% confidence intervals; the Firth row uses Wald inference.*

Test positivity varied substantially by geography

The crude positivity advantage of private healthcare facilities was geographically concentrated in Kampala. In Kampala, private healthcare facilities contributed 17 positive submissions out of 376 (4.52%; 95% CI 2.8–7.1%), compared with 25 out of 4,683 public submissions (0.53%; 95% CI 0.4–0.8%; crude OR 8.82; Fisher's exact p < 0.0001). Among the remaining submissions, including those with unknown or blank district information, positivity was 4/128 (3.12%; 95% CI 1.2–7.8%) in private healthcare facilities and 103/2,742 (3.76%; 95% CI 3.1–4.5%) in public facilities (crude OR 0.83; Fisher's exact p = 1.00).

The ownership-by-Kampala interaction was elevated (interaction OR 7.58; 95% CI 1.60–35.82; p = 0.011). In separately fitted adjusted strata, the ownership estimate was 4.59 (2.27–9.29; p < 0.0001) in Kampala

and 1.16 (0.31–4.32; p = 0.82) in the remaining model sample. These findings suggest geographic heterogeneity, but the wide non-Kampala interval does not rule out an association. Interaction-model coefficients need not equal the separately fitted stratum estimates because the interaction model shares the effects of other covariates. Kampala is a single district cluster: its separate model uses model-based standard errors, and clustered interaction inference warrants cautious interpretation (Additional file 1, Table S7).

Private-facility submissions were clinically enriched for bleeding and other VHF-compatible symptoms

Recorded bleeding was substantially more frequent among private-facility submissions: 148 of 504 private submissions (29.4%; 95% CI 25.6–33.5%) had bleeding symptoms recorded, compared with 859 of 7,425 public submissions (11.6%; 95% CI 10.9–12.3%; crude OR 3.18; Fisher's exact p < 0.0001). In the primary GLMM, private ownership was strongly associated with higher odds of recorded bleeding (aOR 4.97; 95% CI 3.86–6.41; p < 0.0001; district variance 1.92, ICC 0.37), and the fixed-effect sensitivity model yielded a consistent result (aOR 4.99; 95% CI 2.30–10.86; p < 0.0001).

Much of the broader symptom enrichment reflected how completely the reporting form was filled out rather than differences in clinical presentation. No symptom at all was recorded on 17.1% of private submissions (86 of 504) compared with 37.6% of public submissions (2,789 of 7,425; OR 0.34; p < 0.0001), and private submissions recorded more symptoms on average (mean 3.85, SD 3.11, versus 2.84, SD 3.11; Mann–Whitney p < 0.0001). Among submissions with at least one symptom recorded, however, the mean number of symptoms was nearly identical (4.64, SD 2.82, private versus 4.55, SD 2.79, public). Accordingly, the bleeding association attenuated after adjustment for whether any symptom had been recorded (aOR 3.85; 95% CI 2.98–4.97) and when restricted to submissions with at least one symptom recorded (aOR 3.33; 95% CI 2.55–4.34; n = 5,015), although it remained strong and statistically significant in both.

Bleeding-specific contrasts included bloody stool (4.2% versus 0.8%; p < 0.0001) and epistaxis (1.8% versus 0.5%; p = 0.0015). Other symptoms more frequently affirmative in private submissions included vomiting (36.9% versus 16.8%; p < 0.0001), fever (46.0% versus 28.5%; p < 0.0001), diarrhea (27.8% versus 11.8%; p < 0.0001), fatigue (37.5% versus 29.5%; p = 0.0002), anorexia (30.0% versus 23.0%; p = 0.0005), abdominal pain (31.5% versus 24.8%; p = 0.0010), headache (32.7% versus 26.7%; p = 0.0037), cough (22.0% versus 17.9%; p = 0.0232), sore throat (5.2% versus 2.0%; p < 0.0001), conjunctivitis (4.6% versus 2.1%; p = 0.0016), general weakness (6.3% versus 4.0%; p = 0.0157), sensitivity to light (1.6% versus 0.6%; p = 0.0143) and hiccups (1.0% versus 0.3%; p = 0.0158).

Sixteen of 26 exploratory comparisons had p < 0.05, and all 16 retained q < 0.05 after Benjamini–Hochberg correction. The remaining comparisons—hematuria, joint pain, muscle pain, chest pain, difficulty breathing, difficulty swallowing, jaundice, confusion, skin rash and coma—were not statistically significant. Full counts, CIs, p values, and q values are in Additional file 1 (Table S5).

Private healthcare facilities reported a higher proportion of patients alive at reporting

Among the 6,589 records with known patient status, private healthcare facilities reported 237 of 359 patients as alive (66.0%; 95% CI 61.0–70.7%), compared with 1,768 of 6,230 public-facility patients (28.4%; 95% CI 27.3–29.5%; crude OR 4.90; Fisher's exact $p < 0.0001$).

The primary GLMM included 6,520 observations and 91 district levels and gave an aOR of 5.43 (95% CI 4.09–7.21; $p < 0.0001$; district variance 4.40, ICC 0.57). The model AIC was 4,749.0. The district fixed-effect sensitivity estimate was 5.39 (3.78–7.67; $p < 0.0001$). Because status was more often unknown in private submissions (28.8% versus 16.1%), deterministic scenarios were examined. Assigning all unknown private statuses to dead and all unknown public statuses to alive reversed the association (aOR 0.53; 0.42–0.67); the opposite assignment gave 15.74 (12.42–19.95). Under the two common assignments, it remained above 1: all unknown dead, 3.74 (3.01–4.66); all unknown alive, 4.00 (3.03–5.27) (Additional file 1, Table S6).

In the additional fractional-outcome sensitivity analysis, with all unknown public statuses assigned alive, the aOR crossed 1.5 when 42.2% of unknown private statuses were assigned an expected dead outcome and crossed 1 at 63.3%; at 50% it was 1.28. Crossing 1.5 denotes attenuation, whereas crossing 1 denotes reversal. These thresholds depend on the stated allocation rule and do not estimate the true fraction of deaths among records with unknown status (Additional file 1, Table S6).

The ownership-by-Kampala interaction OR was 6.40 (95% CI 2.90–14.14; $p < 0.0001$). Separately fitted adjusted estimates were 6.27 (4.48–8.78) in Kampala and 2.35 (1.28–4.28; $p = 0.0055$) in the remaining model sample (Additional file 1, Table S7). The association was therefore stronger in Kampala and remained elevated elsewhere. In Kampala, 488/3,982 public records with known status were alive (12.3%; 95% CI 11.3–13.3%), compared with 171/258 private records (66.3%; 95% CI 60.3–71.8%). Among remaining submissions, including unrecorded districts, the corresponding values were 1,280/2,248 (56.9%; 54.9–59.0%) and 66/101 (65.3%; 55.7–73.9%). Thus, 87.7% of known-status public submissions in Kampala were recorded dead, compared with 43.1% in the remaining public group and 34.0% of private submissions overall (Fig. 3b).

Disaggregated and summary estimates

Estimates disaggregated by private subgroup were directionally consistent across all three outcomes, supporting the combination of PNFP and PFP facilities in the main analysis: test positivity aOR 4.19 (95% CI 2.03–8.62) for PNFP and 2.82 (95% CI 1.32–6.05) for PFP; recorded bleeding aOR 5.87 (95% CI 4.24–8.13) and 4.14 (95% CI 2.92–5.87); and alive at reporting aOR 5.65 (95% CI 3.83–8.34) and 5.22 (95% CI 3.53–7.72), as shown in Additional file 1 (Table S8). Adjusted estimates for all three outcomes across every specification are summarized in Additional file 1 (Table S2) and shown in Fig. 4.

Discussion

Private healthcare facilities accounted for 6.4% of suspected VHF submissions in Uganda over three and a half years, yet yielded half of the Ebola virus detections recorded during the 2026 Bundibugyo virus outbreak and 31.2% of Ebola detections across the study period. They recorded VHF-compatible bleeding far more often than public facilities, a difference that persisted even after accounting for how completely reporting forms were filled out, and they submitted specimens from patients who were still alive at the time of reporting at more than twice the public-sector rate. Because the data contain no onset or first-contact dates, patient status at reporting is treated throughout as a recorded status measure rather than a timing measure. On every measure other than volume, private healthcare facilities were disproportionately productive within the surveillance system. This interpretation aligns with established surveillance principles emphasizing usefulness, positive predictive value, timeliness, and representativeness, as well as with WHO guidance advocating the deliberate engagement of non-state providers in national public health priorities (16, 17).

Where the private-facility contribution comes from

The mechanism matters, because it shows where that productivity arises and how it could be extended. Patient status at reporting is an imperfect proxy for specimen type and case-finding channel, neither of which was recorded in the extract: within the program, submissions from living patients are generally EDTA whole blood collected in response to facility-based clinical suspicion, whereas submissions from decedents predominantly comprise buccal swabs collected during community-death and burial-related investigations, which in Uganda are organized through public structures and district rapid-response teams. In Kampala, 87.7% of public-facility submissions with known status came from patients who had already died. Private healthcare facilities therefore appear to contribute detections through a different route: clinical recognition of a patient still alive at the time of reporting, a point in the care pathway at which isolation, treatment and contact tracing can still alter the course of an outbreak. This is an inference from recorded patient status, not a measured difference in timing. That is the substance of the early-warning hypothesis this study raises rather than tests, and it is why the overall crude yield difference is better read as a marker of this channel than as a claim about testing efficiency. Consistent with that reading, the pooled positivity association attenuated after accounting for patient status, although within both patient-status strata, private submissions remained numerically more likely to be positive. This finding is also compatible with private providers occupying an earlier position in the care pathway, where patients may still be ambulatory when clinical suspicion is raised and specimens are submitted, and with health-system referral patterns in which severely ill patients are preferentially concentrated in public referral hospitals (18).

Selective case capture

Selective case capture was supported more directly. Recorded bleeding was strongly associated with private-facility submissions. Part of the broader symptom difference reflected documentation rather than presentation: no symptom at all was recorded on more than a third of public forms, against a sixth of private forms. The bleeding association nevertheless remained large and highly significant after

adjustment for form completion and after restriction to forms with at least one symptom recorded. Private clinicians appear to be genuinely identifying and referring patients whose presentations generate a higher index of suspicion for VHF, even if the magnitude of that effect is smaller than the crude comparison suggests. Importantly, private healthcare facilities also contributed CCHF- and RVF-positive submissions despite their relatively small overall reporting volume. Previous Ugandan investigations have similarly demonstrated that CCHF may be identified during enhanced testing associated with other VHF responses and continues to circulate at the human–animal interface (19, 20). These findings highlight the value of maintaining broad VHF diagnostic awareness across both public and private healthcare facilities rather than focusing surveillance exclusively on the pathogen responsible for a declared outbreak.

Surveillance roles change with outbreak context

The contrast between the two outbreaks shows how much surveillance architecture shapes what any facility type can contribute. No confirmed case during the 2025 SVD outbreak originated from a private submission, whereas private healthcare facilities accounted for 10 of 20 Ebola-positive submissions during the 2026 BDBV outbreak, with positivity roughly five times the public-sector rate. This difference is consistent with changes in triage, referral and outbreak-response pathways. Once an outbreak is recognized, highly suspected patients may increasingly be channeled directly towards designated public isolation and treatment facilities, reducing the apparent contribution of other facilities; conversely, when patients initially present through routine healthcare pathways, private providers have a greater opportunity to trigger investigation, and in 2026 they did so. The substantial contribution of private healthcare facilities during the later outbreak therefore demonstrates the potential fragility of surveillance architectures that rely predominantly on public facilities, particularly where private providers are a key point of first contact. Our findings are consistent with broader evidence that private providers frequently serve as important first points of contact yet remain underrepresented in formal surveillance systems due to weak reporting structures and limited integration with public health authorities (21–23).

Geographic heterogeneity and implications for surveillance policy

Geographic heterogeneity was central to interpreting the contribution of private healthcare facilities. The positivity advantage was concentrated in Kampala and was not evident outside the capital, and the alive-at-reporting difference was far larger in Kampala than elsewhere. This indicates that the private health sector should not be treated as a homogeneous national surveillance category. Differences in facility density, clinical expertise, referral connectivity, access to specimen transport networks, and links with district surveillance systems can plausibly influence the contributions private healthcare facilities can make across different settings.

A differentiated strategy is therefore warranted. Selected high-volume or clinically vigilant private hospitals in Kampala and other urban centers could serve as enhanced sentinel sites for VHF-

compatible syndromes, while less-integrated facilities may require more fundamental support in syndromic recognition, safe referral, infection prevention, notification, and specimen transport. Priority actions include simplifying notification procedures, providing rapid laboratory feedback, linking private healthcare facilities to district surveillance teams, expanding access to the national specimen-referral network, and providing regular training in VHF recognition, infection prevention, isolation, and referral. Uganda's transition towards Universal Health Coverage and the National Health Insurance Scheme provides an opportunity to institutionalize these relationships by incorporating IDSR participation into facility accreditation while reciprocally providing participating private healthcare facilities with training, laboratory referral support and feedback (5, 24). Economic sustainability should also be considered, since experience with private-sector electronic surveillance demonstrates that such systems require defined implementation and maintenance resources (25).

These priorities are supported by recent Ugandan surveillance evaluations. Monthly reporting of surveillance data in 2020–21 showed persistent timeliness gaps, including in Kampala (26), and weekly reporting of epidemic-prone diseases over the same period remained below national timeliness targets, with private healthcare facilities among the poorest-performing facility groups (27). Uganda's scale-up of electronic IDSR demonstrates the feasibility of extending electronic case-based surveillance across districts (28), and a national electronic compendium of public health emergencies provides a model for retaining detection and response metrics for performance improvement (29). During the 2022 SVD outbreak, 60% of patients identified before outbreak recognition had sought care in private health facilities, underscoring their importance as first-contact surveillance points (30), and delayed entry to Ebola treatment units was common early in that outbreak, reinforcing the importance of reducing delays from symptom onset to effective isolation (31). More broadly, a 2024 scoping review found that only 4 of 26 studies using routine private-provider data for health-system governance in low- and middle-income countries addressed epidemic surveillance, highlighting the limited evidence base for the systematic integration of public–private surveillance (32).

Generalizability

The study population is the set of specimens referred into a national VHF testing network, not a sample of febrile patients, and is weighted towards Kampala, which contributed 63.8% of all submissions. Private submissions outside the capital were few, so our estimates describe an urban, capital-centered private sector considerably better than they describe rural private networks. The findings should generalize most readily to other African mixed health systems with a concentrated urban private sector, a centralized VHF reference laboratory network, and outbreak responses that channel suspected cases to designated public treatment units, and least readily to settings where private provision is dispersed and predominantly rural.

Limitations

This study has several limitations that should guide interpretation and future work. First, the analysis relied on routine specimen-submission records without unique patient identifiers, preventing

confirmation that each submission represented a unique clinical episode. Second, patient status was missing more often in private submissions than in public ones. Our bounding analysis quantifies the direction and magnitude of this threat: the association remains stable under both non-differential scenarios evaluated and falls below an adjusted odds ratio of 1.5 only under a differential assignment in which every missing public record is alive and at least 42% of missing private records are deaths; reversal below 1.0 requires at least 63%. Third, differences in symptom recording across sectors mean that symptom-based comparisons partly reflect documentation practices rather than clinical presentation, biasing private–public symptom contrasts away from the null. Fourth, the pooled test-positivity association attenuated after adjustment for reporting status, and its intervals included 1 in the alive-only and pre-2026 analyses, so it should not be interpreted as evidence that private ownership independently improves diagnostic efficiency; the within-outbreak comparison was post hoc and requires replication in future outbreak periods. Fifth, the smaller number of private healthcare facility submissions and their concentration in Kampala limited the precision of pathogen-specific analyses and the generalizability of findings to rural private healthcare facility networks. Finally, the dataset lacked symptom-onset dates, dates of first healthcare contact, detailed referral histories, and direct measures of disease severity, so we make no claim about measured timeliness.

Future studies should prospectively capture symptom onset, first presentation, referral transitions, specimen collection, laboratory receipt, result turnaround, and public health notification, in order to determine whether private-facility integration measurably shortens VHF detection pathways (33). Implementation research should also compare different models of engagement, including sentinel private-facility networks, district-led mentorship and mobile reporting, using performance indicators such as diagnostic yield, timeliness, completeness, referral appropriateness, cost and actionability (34–36).

Conclusions

Private healthcare facilities constituted a small but disproportionately productive component of Uganda’s VHF surveillance system between 2023 and 2026. They delivered half of the Ebola detections of the 2026 Bundibugyo virus outbreak from approximately a sixth of its submissions, recorded hemorrhagic and other VHF-compatible symptoms far more frequently, and far more often submitted specimens from patients who were still alive at the time of reporting, in contrast to the post-mortem case-finding that dominates public submissions in the capital. Their early-warning potential is plausible on this evidence and appears underused, but it is not established by these data.

These patterns were nonetheless strongly context-dependent: the test-positivity advantage was concentrated in Kampala, the alive-at-reporting difference was much larger in Kampala than elsewhere, and the pooled positivity association attenuated after adjustment for reporting status, with intervals including 1 in the alive-only and pre-2026 analyses, so it should not be attributed to ownership itself. The findings therefore support targeted, geographically differentiated integration of private providers into national VHF surveillance rather than uniform expansion or a simple private-versus-public interpretation.

Strengthening the connections among first-contact care, district surveillance, specimen referral and laboratory feedback is likely to improve surveillance performance, but prospective measurement of onset-to-notification and onset-to-confirmation intervals is required before concluding that such integration improves the timeliness of early warning.

Abbreviations

aOR
adjusted odds ratio
AIC
Akaike information criterion
BDBV
Bundibugyo virus
CCHF
Crimean–Congo hemorrhagic fever
CERSL
Central Emergency Response and Surveillance Laboratory
CI
confidence interval
CPHL
Central Public Health Laboratories
DHI
Division of Health Information, Uganda Ministry of Health
EDTA
ethylenediaminetetraacetic acid
GLMM
generalized linear mixed model
ICC
intraclass correlation coefficient
IDSR
Integrated Disease Surveillance and Response
IES & PHE
Department of Integrated Epidemiology, Surveillance and Public Health Emergencies
nAGQ
number of adaptive Gauss–Hermite quadrature points
NHIS
National Health Insurance Scheme
NHLDS
National Health Laboratory and Diagnostic Services
OR

odds ratio
PFP
private for-profit
PNFP
private not-for-profit
RECORD
Reporting of studies conducted using Observational Routinely-collected health Data
RDS
Result Dispatch System
RRL
Rapid Response Laboratory
RVF
Rift Valley fever
SD
standard deviation
SE
standard error
STROBE
Strengthening the Reporting of Observational Studies in Epidemiology
SVD
Sudan virus disease
UHC
Universal Health Coverage
UVRI
Uganda Virus Research Institute
VHF
viral hemorrhagic fever
WHO
World Health Organization

Declarations

Ethics approval and consent to participate

This study used de-identified routine public health surveillance data collected under the mandate of the Uganda Ministry of Health. Ethical approval, including a waiver of the requirement for written informed consent, was granted by the Uganda National Health Laboratory Services Research Ethics Committee (UNHLS-REC). The waiver was granted because the study used existing, routinely collected surveillance records from which direct patient identifiers had been removed. Data access was authorized under a data-sharing agreement with the Uganda Ministry of Health, Division of Health Information (DHI), and the Department of Integrated Epidemiology, Surveillance and Public Health Emergencies (IES & PHE). All

methods were carried out in accordance with the Declaration of Helsinki and relevant national guidelines and regulations.

Consent for publication

Not applicable. This manuscript contains no individual person's data in any form, including individual details, images, or videos.

Trial registration

Clinical trial number: not applicable.

Availability of data and materials

The individual-level surveillance records analyzed in the current study are owned by the Uganda Ministry of Health and are not publicly available because they are derived from a national notifiable disease surveillance system. A de-identified aggregate dataset comprising counts of submissions, positive detections, recorded bleeding, alive-at-reporting status, and records with known patient status by district, facility ownership, and calendar year, together with a data dictionary defining each field, is provided in Additional file 1, Table S12.

Competing interests

The authors declare that they have no competing interests.

Funding

This study received no specific grant from any funding agency in the public, commercial, or not-for-profit sectors, and no funder had any role in the design of the study, the collection, analysis, or interpretation of data, or the writing of the manuscript.

Authors' contributions

AN conceived the study, designed the methodology, curated the data, performed the formal analysis and visualization, and wrote the original draft. JK curated the data, contributed to surveillance activities and interpretation, and reviewed and edited the manuscript. VN contributed to laboratory surveillance, data curation, and interpretation. VKK contributed to surveillance activities and visualization. RK and SS contributed to laboratory surveillance and data curation. AA contributed to methodology, laboratory surveillance, and interpretation. AS and RN contributed to surveillance activities and data management. SB, FK, AO, CM, BK, and IS contributed to interpretation. RW contributed to methodology and interpretation. CD contributed to laboratory surveillance and data curation. EN contributed to data management and surveillance activities. PK and MW supervised the study and contributed to interpretation. WS, HKB, and SNN contributed to conceptualization, methodology, and interpretation. AK, BL, and AM contributed to surveillance coordination and interpretation. AN and SNN accessed and

verified the underlying data. All authors had full access to all data in the study, read and approved the final manuscript, and accept responsibility for the decision to submit for publication.

Acknowledgements

We thank the Uganda Ministry of Health, the Department of National Health Laboratory and Diagnostic Services, and the Central Public Health Laboratories for providing access to the Result Dispatch System data. We acknowledge the contributions of laboratory staff at the Central Emergency Response and Surveillance Laboratory, the Uganda Virus Research Institute VHF Laboratory, and the Central Public Health Laboratories Rapid Response Laboratory. We are grateful to district surveillance officers and healthcare workers across Uganda who reported suspected cases and submitted samples. We also gratefully acknowledge the support of the U.S. Centers for Disease Control and Prevention, whose long-term investment has strengthened Uganda's VHF program across both public and private health facilities, enhancing surveillance, laboratory capacity, and outbreak response.

STROBE reporting checklist. Completed checklist for the reporting of observational studies.

RECORD extension reporting checklist. Completed checklist for studies conducted using observational routinely collected health data.

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Figures

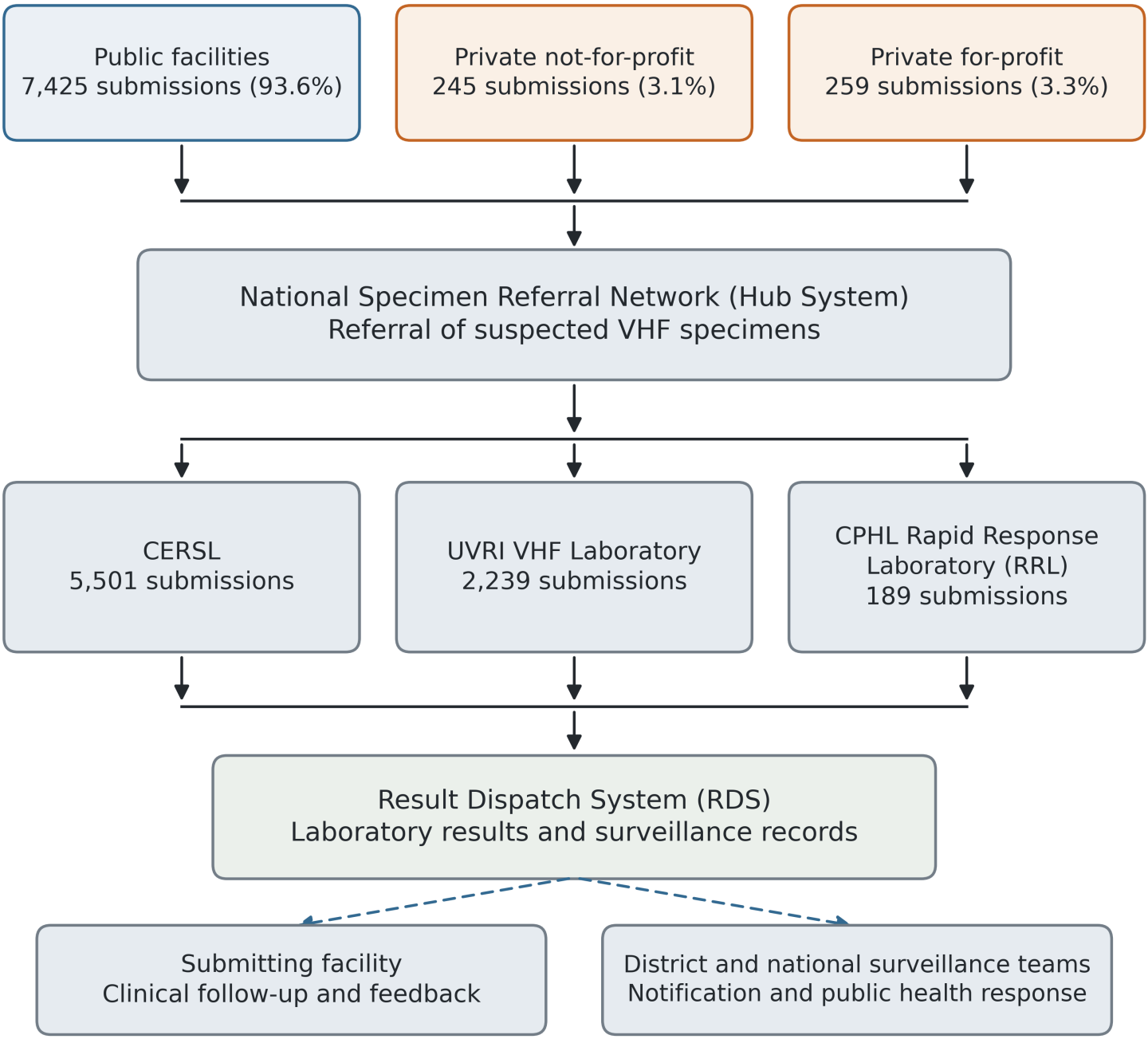


Figure 1

Specimen referral pathway for viral hemorrhagic fever surveillance in Uganda. Specimens from suspected VHF cases at public and private health facilities are referred through the district specimen-referral network to one of three nationally designated reference laboratories. Results are returned through the Result Dispatch System to the submitting facility and to district and national surveillance teams (dashed arrow). Counts are the 7,929 submissions analyzed. PNFP, private not-for-profit; PFP, private for-profit; UVRI, Uganda Virus Research Institute; CERSL, Central Emergency Response and Surveillance Laboratory; CPHL, Central Public Health Laboratories

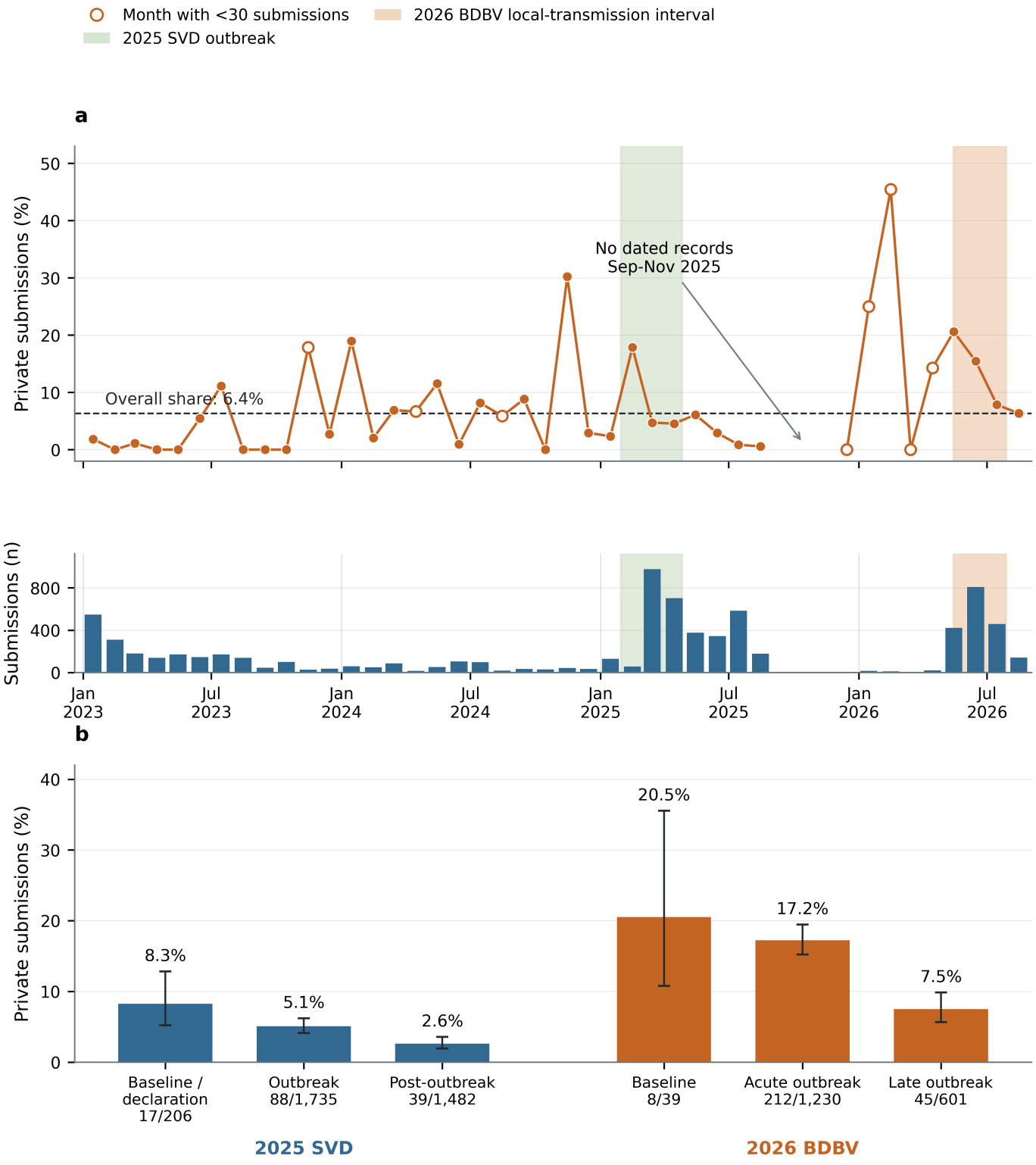


Figure 2

Private-facility share of suspected VHF submissions over time. a Monthly private-facility share, January 2023 to August 2026. Open circles mark months with fewer than 30 submissions, where the share is unstable; gaps indicate months with no submissions. The dashed line marks the overall share across the study period (6.4%). Shaded bands mark the 2025 Sudan virus disease outbreak (30 January to 26 April 2025) and the 2026 Bundibugyo virus outbreak (15 May to 28 July 2026, the period of the national

declaration). The lower panel shows the number of submissions per month on which each share is based. b Private-facility share by pre-specified outbreak period; periods use whole calendar months. Error bars are 95% Wilson confidence intervals; numerators and denominators are given beneath each bar

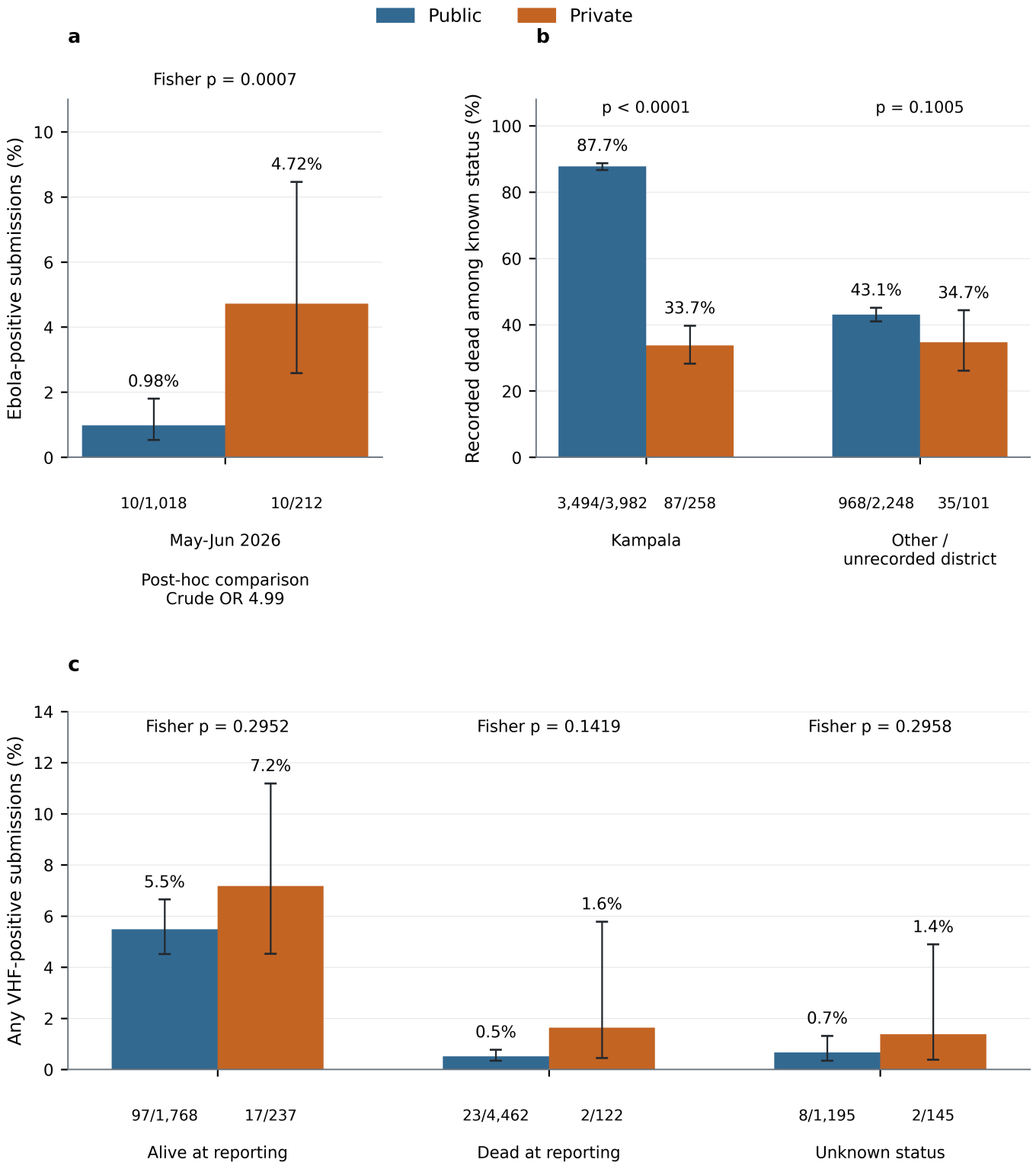


Figure 3

Private-facility contribution to detection and position in the care pathway. a Test positivity by facility ownership within the 2026 acute outbreak period (1 May to 30 June 2026); post-hoc analysis. b Proportion of submissions from patients recorded as dead at the time of reporting, by facility ownership and geographic stratum, among the 6,589 records with known patient status. c Test positivity by patient status at reporting and facility ownership. p-values are from Fisher's exact test comparing private with public submissions. Error bars are 95% Wilson confidence intervals; numerators and denominators are given beneath each bar

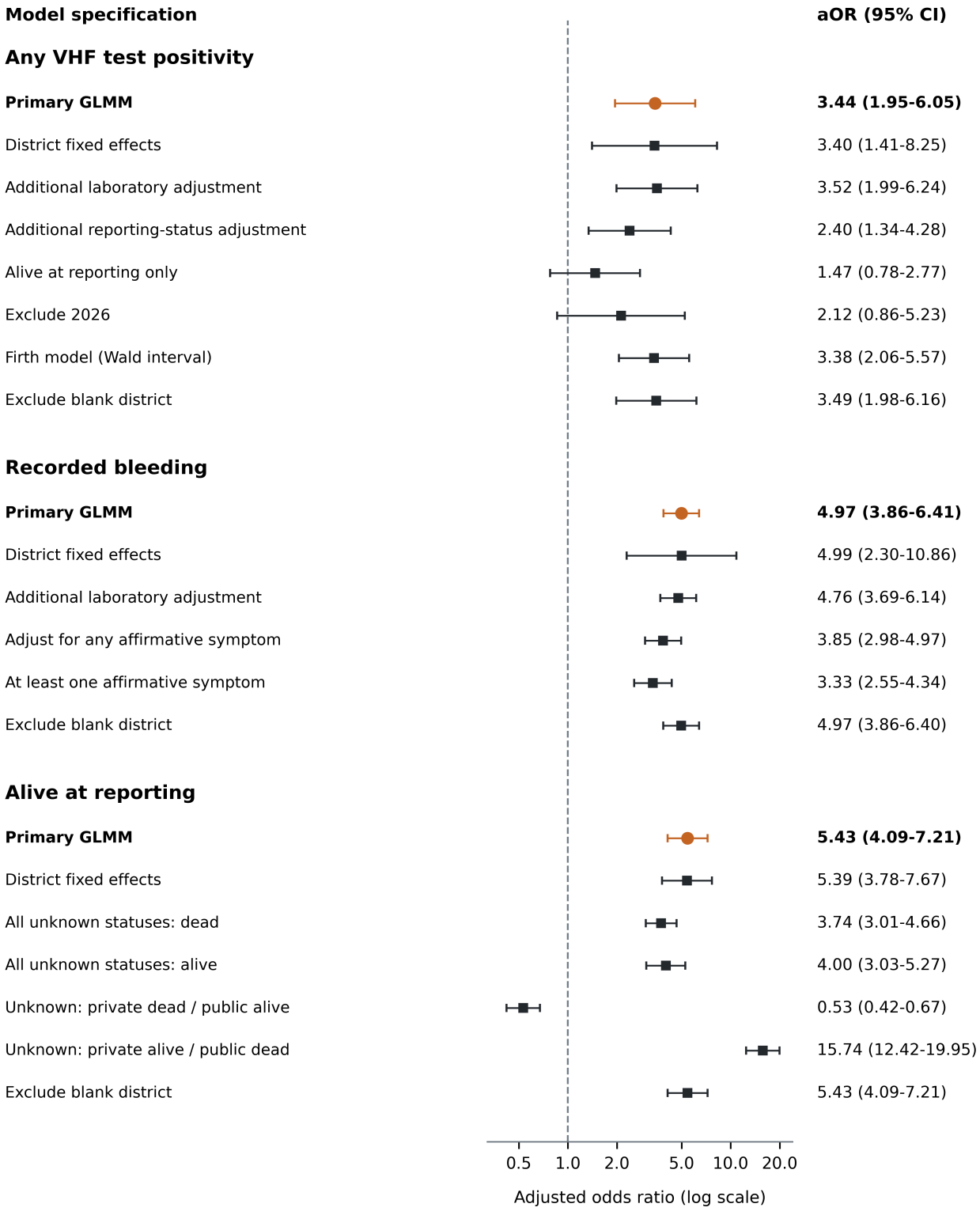


Figure 4

Robustness of the private-versus-public association across model specifications. Odds ratios comparing private with public facility submissions for each of the three outcomes, on a logarithmic scale. Orange circles mark the primary specification for each outcome; black squares mark sensitivity analyses. Primary models are generalized linear mixed models with a district-level random intercept and calendar-year adjustment (n = 7,848 for test positivity and recorded bleeding; n = 6,520 for alive at reporting, which is additionally adjusted for testing laboratory). Full model output is provided in Additional File 1

Supplementary Files

This is a list of supplementary files associated with this preprint. Click to download.

- Additionalfilerevised.pdf
- Supplementaryinformation.docx