Evaluation of a decentralised model of care on case isolation and patient outcomes during the 2018–20 Ebola outbreak in the Democratic Republic of the Congo: a retrospective observational study

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Summary

Background Partway into the 2018–20 Ebola outbreak in the Democratic Republic of the Congo (DR Congo), a new strategy of decentralised care was initiated to address delays in care seeking, improve community acceptance, and reduce the risk of Ebola virus disease (EVD) transmission through early case isolation. Unlike centralised EVD facilities (transit and treatment centres), which operated in parallel to the existing health-care system and focused exclusively on EVD, decentralised facilities were integrated into existing health-care structures with which communities were already familiar, and designed to continue providing health care for patients with other non-EVD illnesses. Here we aim to assess the strategy of decentralised care by comparing admission delays and patient outcomes among the three types of EVD facilities (decentralised, transit, and treatment).

Methods We performed a retrospective analysis of routinely collected data from all individuals admitted to EVD facilities (12 treatment, nine transit, and 21 decentralised facilities) at any point during the Ebola outbreak from July 27, 2018, to June 24, 2020 in DR Congo. We used multivariate mixed-effect regression to model admission delays (the number of days between symptom onset and admission to an EVD facility) and patient outcomes (survived or died), as functions of facility type at first admission and date of admission, while controlling for a variety of other covariates.

Findings Over the course of the outbreak 60 465 patients were admitted to EVD facilities, of which 2289 (3·8%) were confirmed to be EVD positive. Covariate-adjusted admission delays were somewhat higher among patients presenting to transit facilities (adjusted rate ratio 1·14 [95% CI 0·95–1·32]) or treatment facilities (1·18 [1·00–1·36]) compared with decentralised facilities. Similarly, compared with decentralised facilities, adjusted case-fatality risks were slightly higher among patients presenting to transit facilities (adjusted risk ratio 1·04 [0·82–1·26]) or treatment facilities (1·03 [0·82–1·24]).

Interpretation As was observed during the 2013–16 west Africa outbreak and the 2020 outbreak in the Equateur province of DR Congo, patients suspected of EVD that presented to decentralised facilities had modestly shorter admission delays than patients presenting to centralised facility types. Case-fatality risks were slightly lower among patients presenting to decentralised facilities; however, this finding was not statistically significant and so it is difficult to assess the generalisability.

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For the French translation of the abstract see Online for appendix 1

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Introduction

The 2018–20 epidemic of Ebola virus disease (EVD) in the Democratic Republic of the Congo (DR Congo) was the largest EVD outbreak in that country's history (3470 cases and 2287 deaths),[1] second globally only to the 2013–16 outbreak in west Africa (over 28 000 cases and 11 000 deaths).[2] Centred in the eastern provinces of North Kivu and Ituri (a region plagued by long-standing armed conflict and associated humanitarian crises[3]) the outbreak unfolded in a context of insecurity and political instability.[4] Conditions during the EVD outbreak were further exacerbated by an even deadlier outbreak of measles (leading to more than 300 000 cases in 2019 alone),[5] and ongoing outbreaks of malaria and cholera.[6]

As was the case during the 2013–16 west Africa Ebola outbreak,[2] EVD response efforts during the 2018–20 outbreak in DR Congo were sometimes met with mistrust and opposition.[7] Security-related incidents, including direct attacks on EVD response personnel and facilities, were heavily reported over the course of the outbreak, contributing to delays and temporary suspensions of response activities, and possibly hundreds

Research in context

Evidence before this study

We searched PubMed using the query "(Ebola* AND decentral*) OR (Ebola* AND community) OR (Ebola* AND delay) OR (Ebola* AND CFR)", covering the period from Jan 1, 1976 to April 30, 2024, without language restrictions, and screened for related citations. A variety of community-based interventions were deployed during the 2013–16 west Africa Ebola outbreak, including community-based education, surveillance, and isolation programmes, with qualitative evidence generally suggesting favourable perceptions among members of affected communities. In Sierra Leone, the Ebola virus disease (EVD) response involved the construction of 55 Community Care Centres (CCCs)—relatively small, temporary facilities where patients suspected of EVD could be isolated and tested closer to their home communities—as part of a strategy to decentralise and improve access to care. Evaluations of the CCC strategy, and a study from 2024 on the deployment of decentralised EVD facilities during the 2020 Ebola outbreak in the Equateur province of DR Congo, reported reduced admission delays at decentralised facilities compared to centralised facility types.

Added value of this study

To our knowledge our study represents the largest-scale analysis to date of a decentralised approach to Ebola care. We analysed 60 465 admissions (2289 of which were confirmed to be EVD positive) to 42 different EVD facilities (21 centralised and 21 decentralised) during the 2018–20 Ebola outbreak in DR Congo. For comparison, the study on the 2020 DR Congo outbreak analysed data from 2359 admissions, and the Sierra Leone study analysed data from 699 admissions. The size of our dataset enabled us to examine, for the first time, whether reductions in admission delays seen at decentralised facilities translated into improved patient outcomes in the form of reduced case fatality. Decentralised Ebola facilities deployed during the 2018–20 outbreak in DR Congo, which were integrated into the local health system, reported lower admission delays than the centralised facility types (transit and treatment centres). Case-fatality risks were slightly lower among patients presenting to decentralised facilities, but this finding was not statistically significant, which limits our confidence about its generalisability.

Implications of all the available evidence

Community-based response initiatives to Ebola outbreaks, including decentralised care, can be effective at enhancing community involvement, building trust, and increasing compliance with public health measures. In three different Ebola outbreaks (2013–16 west Africa, 2018–20 DR Congo, and 2020 DR Congo), decentralised EVD facilities have been associated with earlier case detection and isolation, which are known to reduce EVD transmission. With new effective treatment options that became available during the 2018–20 outbreak in DR Congo, early detection and access to treatment might also eventually contribute to limiting case fatality.

of additional cases.[4] Some community members perceived that the influx of resources to combat EVD was primarily benefiting elites, or that EVD response efforts ignored other ongoing health crises.[7–9] Response efforts were also challenged by a reluctance among some to present to EVD facilities for testing and isolation, sometimes out of fear of being misdiagnosed and isolated far from home (the discharge protocol for suspected cases required two negative PCR test results at least 48 h apart, necessitating that patients spend at least 3 days in isolation once admitted), or of nosocomial transmission, or simply because of the time and costs associated with travelling to a centralised facility.[8] With early isolation being key to limiting EVD transmission, efforts toward community dialogue and engagement were quickly recognised as an essential component of the EVD response.[10] However, even months into the epidemic, a large proportion of EVD deaths were occurring in the community among people who never reached an EVD facility (a situation that was also seen during the west Africa outbreak),[2] and many individuals who did reach an EVD facility arrived too late in the disease course for treatments to be effective.[11]

Beginning in early 2019, about 6 months into the outbreak, a new strategy of decentralised care was initiated[12] to address delays in care seeking, improve community acceptance, and reduce the risk of nosocomial EVD infections. Unlike the centralised EVD facilities (known as transit centres and treatment centres), which operated in parallel to the existing health-care system and focused exclusively on EVD, decentralised EVD centres were integrated into existing health-care facilities with which communities were already familiar, and designed to continue providing health care for patients with other non-EVD illnesses. Facilities were reinforced to ensure triage and immediate supportive care by experienced health workers (with adequate personal protective equipment and training) and collection and transport of samples to a centralised or field laboratory. As was the case for transit centres, patients testing positive for EVD at a decentralised facility would be transferred to a centralised treatment centre for subsequent care (occasionally with an intermediate stay at a transit centre for temporary isolation and further testing). However, unlike transit and treatment centres which focused exclusively on EVD, patients testing negative for EVD at decentralised facilities could remain onsite for treatment of other illnesses. Thus, the decentralised strategy in DR Congo aimed to improve patient outcomes through early access to diagnosis and

treatment for all diseases and reduce the risk of EVD transmission through early case isolation. The decentralised strategy in DR Congo built on related community-based approaches implemented during the 2013–16 west Africa Ebola outbreak, including the establishment of Community Care Centers (CCCs) in Sierra Leone, which were relatively small isolation facilities established closer to affected communities, with a greater focus on community engagement and collaboration.[13] Evidence from the west Africa outbreak suggests that CCCs and related initiatives had high levels of community acceptance and led to more rapid case isolation.[13,14]

Here we aim to compare patient characteristics and outcomes among the three types of EVD facilities (decentralised, transit, and treatment), focusing specifically on whether decentralised facilities saw reduced admission delays (the number of days between symptom onset and admission) compared to the two centralised facility types, and whether such reductions translated into improved patient outcomes in the form of reduced EVD case fatality. Studies from the west Africa Ebola outbreak[13] and the 2020 outbreak in the Equateur province of DR Congo[15] found that decentralised EVD facilities tended to report shorter admission delays than centralised facility types. Our study aims to extend these analyses to a larger dataset with a sufficient sample size of EVD-positive cases to additionally compare patient outcomes between decentralised and centralised facility types.

Methods

Study design and data sources

We conducted a retrospective observational study of routinely-collected data from all individuals admitted to Ebola facilities at any point during the 2018–20 Ebola outbreak in DR Congo, which spanned the eastern provinces of North Kivu, South Kivu, and Ituri (appendix 2 p 10). These data were collected for clinical purposes as part of the emergency response, not in the context of research. Our study was conducted with the approval and collaboration of the DR Congo Ministry of Public Health–National Institute of Biomedical Research.

Throughout the outbreak, individuals suspected of EVD were identified using both passive and active case finding, including notifications from health-care facilities, community-based surveillance programmes, screening at points of entry to the country and between regions, and daily follow-up with contacts of known individuals with EVD. Alerts from these sources were investigated by rapid intervention teams, and people who met the WHO definition for a suspected EVD case were offered transportation to an EVD facility for testing and isolation. Individuals with suspected EVD could also self-present to any of the three EVD facility types. Standardised patient data was recorded in Excel spreadsheets (a data dictionary is in appendix 2 pp 15–21) by data managers at each EVD facility (12 treatment, nine transit, and 21 decentralised facilities), based on clinical and epidemiological data collected in case notification forms by rapid intervention teams (and reviewed at admission by clinicians), and data from medical files and laboratory results updated throughout the period of isolation. Data on patient sex (female or male) was likewise taken from case notification forms completed by rapid intervention teams (and reviewed at admission by clinicians). Data from each facility were compiled on a weekly basis into a centralised case management database. The final version of this compiled database, reflecting all patients admitted to an EVD facility at any point in the outbreak (July 27, 2018, to June 24, 2020), was the primary data source for our analyses. We used no additional inclusion or exclusion criteria for the patients included in our study. In instances where a key variable was missing from the case management database for an EVD-positive patient (eg, symptom onset date, admission date, sex, age, vaccination status, and outcome), we populated the missing variable, where possible, using a separate dataset of all EVD-positive cases (ie, including community deaths). In 95 cases where province of residence was missing, we inferred the likely province of residence based on the province of the corresponding EVD facility. In instances where a variable of interest contained an implausible value, such as a negative delay from admission to treatment, we replaced the implausible value with a missing value as described in appendix 2 (p 2).

Statistical analysis

Our two outcomes of interest were admission delay (ie, the number of days between the date of symptom onset and the date of first admission to an EVD facility) and final patient outcome (survived or died).

We modelled the relationship between time from symptom onset to admission (ie, admission delay) and a variety of predictor variables using generalised linear mixed-effect models (GLMMs) with a negative binomial error distribution and a random intercept term for EVD facility. For the random intercept term, we aggregated the two facilities with the fewest admissions (the decentralised facilities Butsiri [seven admissions] and Kayna [24 admissions]) into a single level to avoid problems with the subsequently described imputation algorithm (the two facilities in question were both decentralised facilities, and both located in the same health area). Our predictor variables of interest (all modelled as fixed effects) were facility type at first admission (decentralised, transit, or treatment), date of admission in months (continuous), age group (<2, 2–9, 10–19, 20–29, 30–39, 40–49, 50–59, or >60 years), sex (male or female), and province of residence (North Kivu, South Kivu, Ituri, or other). The other province category grouped 52 patients from nine provinces (Haut-Uele, Kasaï, Kasaï-Central, Kinshasa, Kongo-Central, Lomami,

See Online for appendix 2

Maniema, Tanganyika, and Tshopo). We scaled the date of admission by its standard deviation to avoid instabilities in the model fitting algorithm, then back-transformed parameter estimates to the original scale (months). To avoid potential biases due to patterns of missing data[16] we used multiple imputation. Specifically, we used the mice R package[17] to multiply-impute missing values using predictive mean matching, a non-parametric approach, and pool parameter estimates and statistical results from the imputed datasets. Missing values were imputed using all other terms included in the model (including the random intercept term, facility) except for facility type, which is inherently colinear with facility. We used the avg_comparisons function in the marginaleffects R package[18] to calculate adjusted rate ratios (ARRs) corresponding to the marginal effect of each predictor on the response, and the D1 function in the mice package to implement multivariate Wald tests, dropping one parameter at a time from the full model. Alongside p values from Wald tests we present the corresponding test statistic (F) and two independent degrees of freedom (df1 and df2). For the sake of completeness, we also present results of univariate analyses based only on complete cases (ie, excluding patients with missing values in either the response or relevant predictor), using likelihood ratio tests (LRTs) to assess statistical significance. Alongside p values from LRTs we present the corresponding test statistic (the difference in deviances between the full and reduced model, or D) and degrees of freedom (df).

To understand factors influencing case-fatality risk (CFR) we modeled patient outcome (survival or death) as

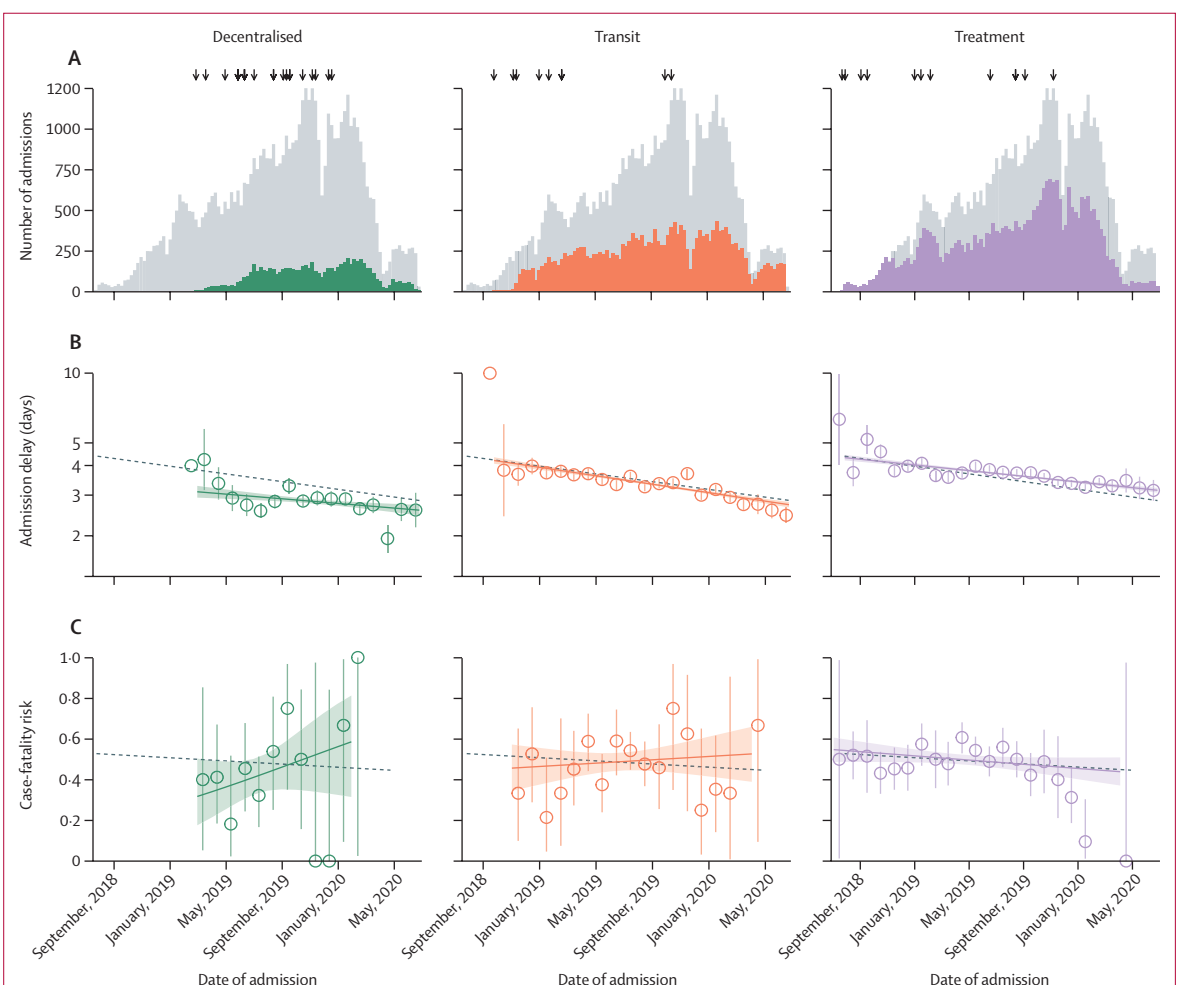

Figure 1: **Weekly number of admissions to Ebola virus disease facilities (A), temporal trends in onset to admission delay (B), and case-fatality risk (C) over the course of the outbreak, by facility type (decentralised, transit, or treatment)**

(A) Coloured bars represent the number of weekly admissions to the given facility type, grey bars represent the total number of weekly admissions independent of facility type, and arrows indicate the opening of new facilities. (B–C) Points represent means calculated over 1-month intervals, and vertical bars represent the associated 95% CIs. Best fit solid lines and 95% CIs (shading) are based on univariate generalised linear models. The dashed best fit lines show the temporal trend in the relevant variable for all patients independent of facility type. Confidence intervals and best fit lines are based on a negative binomial distribution for admission delays (B), and a binomial distribution for case fatality (C). Note that the y-axis in B has a logarithmic scale.

	All patients (n=60 465)			EVD-positive patients (n=2289)		
	Decentralised facility (n=7228)	Transit facility (n=22 208)	Treatment facility (31 029)	Decentralised facility (n=124)	Transit facility (n=499)	Treatment facility (n=1666)
Province of residence						
North Kivu	6119 (84·7%)	21 109 (95·1%)	24 297 (78·3%)	113 (91·1%)	467 (93·6%)	1376 (82·6%)
South Kivu	4 (0·1%)	10 (<0·1%)	368 (1·2%)	0	0	7 (0·4%)
Ituri	1101 (15·2%)	1065 (4·8%)	6340 (20·4%)	11 (8·9%)	32 (6·4%)	283 (17·0%)
Other	4 (0·1%)	24 (0·1%)	24 (0·1%)	..	..	..
Sex						
Female	3470 (48·0%)	11 047 (49·7%)	15 183 (48·9%)	59 (47·6%)	274 (54·9%)	974 (58·5%)
Male	3755 (52·0%)	11 144 (50·2%)	15 820 (51·0%)	65 (52·4%)	225 (45·1%)	692 (41·5%)
Unknown	3 (<0·1%)	17 (0·1%)	26 (0·1%)	0	0	0
Vaccinated, rVSV						
Yes	1383 (19·1%)	2442 (11·0%)	6009 (19·4%)	40 (32·3%)	163 (32·7%)	369 (22·1%)
No	4282 (59·2%)	18 004 (81·1%)	14 301 (46·1%)	67 (54·0%)	304 (60·9%)	677 (40·6%)
Unknown	1563 (21·6%)	1762 (7·9%)	10 719 (34·5%)	17 (13·7%)	32 (6·4%)	620 (37·2%)
Age group, years						
<2	546 (7·6%)	1699 (7·7%)	2254 (7·3%)	6 (4·8%)	30 (6·0%)	121 (7·3%)
2–9	1581 (21·9%)	4603 (20·7%)	6047 (19·5%)	8 (6·5%)	54 (10·8%)	140 (8·4%)
10–19	1716 (23·7%)	4620 (20·8%)	6327 (20·4%)	22 (17·7%)	64 (12·8%)	206 (12·4%)
20–29	1561 (21·6%)	5099 (23·0%)	6902 (22·2%)	30 (24·2%)	116 (23·2%)	415 (24·9%)
30–39	909 (12·6%)	2963 (13·3%)	4214 (13·6%)	30 (24·2%)	95 (19·0%)	322 (19·3%)
40–49	447 (6·2%)	1544 (7·0%)	2355 (7·6%)	17 (13·7%)	69 (13·8%)	205 (12·3%)
50–59	228 (3·2%)	830 (3·7%)	1381 (4·5%)	7 (5·6%)	42 (8·4%)	142 (8·5%)
>60	230 (3·2%)	846 (3·8%)	1498 (4·8%)	4 (3·2%)	29 (5·8%)	113 (6·8%)
Unknown	10 (0·1%)	4 (<0·1%)	51 (0·2%)	0	0	2 (0·1%)
Received investigational treatment						
Yes	..	..	..	77 (62·1%)	370 (74·1%)	1148 (68·9%)
No	..	..	..	6 (4·8%)	19 (3·8%)	114 (6·8%)
Unknown	..	..	..	41 (33·1%)	110 (22·0%)	404 (24·2%)
Outcome, initial EVD facility						
Sent back home, not a case	5021 (69·5%)	18 555 (83·6%)	25 956 (83·7%)	..	..	..
Transferred to health facility	683 (9·4%)	2579 (11·6%)	2699 (8·7%)	..	..	..
Transferred to a different EVD facility	1226 (17·0%)	624 (2·8%)	29 (0·1%)	119 (96·0%)	446 (89·4%)	18 (1·1%)
Died	48 (0·7%)	251 (1·1%)	1236 (4·0%)	5 (4·0%)	52 (10·4%)	819 (49·2%)
Cured	1 (<0·1%)	1 (<0·1%)	828 (2·7%)	0	1 (0·2%)	824 (49·5%)
Unknown	96 (1·3%)	124 (0·6%)	145 (0·5%)	0	0	3 (0·2%)
Lost to follow-up	153 (2·1%)	74 (0·3%)	136 (0·4%)	0	0	2 (0·1%)
Outcome, final						
Cured	..	..	..	71 (57·3%)	255 (51·1%)	834 (50·1%)
Died	..	..	..	51 (41·1%)	243 (48·7%)	829 (49·8%)
Unknown	..	..	..	2 (1·6%)	1 (0·2%)	3 (0·2%)
Onset to admission delay, days*	2 (1–3)	2 (1–4)	3 (1–5)	3 (1–5)	3 (1–5)	4 (2–7)
Onset to treatment delay, days†	..	..	..	4 (2–6)	4 (3–6)	5 (3–7)
Length of initial stay, days‡	2 (2–3)	2 (1–2)	2 (2–3)	0 (0–1)	1 (0–1)	8 (2–18)
RT-PCR cycle threshold at admission§	..	..	..	29·6 (5·0)	28·0 (5·4)	27·6 (4·7)

Data are n (%), median (IQR), or mean (SD). EVD=Ebola virus disease. rVSV=recombinant vesicular stomatitis virus. *Excludes 106 patients with admission delays less than zero days or greater than 40 days and 1101 patients with missing data (among EVD-positive subset excludes three patients with admission delays of less than zero days or greater than 40 days and 17 patients with missing data). †Based on 1228 EVD-positive patients that received treatment and had known treatment start date, excludes 14 patients with onset to treatment delay less than zero days or greater than 40 days. ‡Excludes 57 patients with lengths of initial stay less than zero days and 592 patients with missing data (among EVD-positive subset excludes four patients with an initial stay of less than zero days and 19 patients with missing data). §Excludes 779 patients with missing data in the EVD-positive subset.

Table 1: **Summary of patient characteristics and outcomes by type of facility first admitted to**

a function of a variety of predictors using GLMMs with binomial error structure (ie, logistic regression) and a random intercept term for EVD facility (this time with no aggregation of facility levels). Our predictor variables of interest (all modelled as fixed effects) were facility type at first admission (decentralised, transit, or treatment), date of admission (continuous), age group (<2, 2–9, 10–19, 20–29, 30–39, 40–49, 50–59, or >60 years), sex (male or female), province of residence (North Kivu, South Kivu, or Ituri), number of days between symptom onset and admission (continuous), RT-PCR cycle threshold at admission (continuous), whether the patient had previously received an EVD vaccine (yes or no), and whether the patient received an investigational EVD treatment (yes or no). Our statistical analysis of CFR was the same as the approach described for onset to admission delay, with univariate analyses based on complete cases and multivariate analyses with multiple imputation of missing data. For analyses of CFR we present risk ratios instead of rate ratios. For the multivariate analysis, missing values were imputed using all other terms included in the model, except for the random intercept term facility. The facility term could not be included in the imputation because several facilities had no non-missing data for the RT-PCR cycle threshold at admission variable (and could not be easily aggregated to overcome this issue), so we included facility type instead (whereas the imputation for the admission delay models used facility but not facility type). All statistical analyses were performed with R version 4.4.0.[19]

	Missing data	Univariate analysis		Multivariate analysis	
		Rate ratio (95% CI)	p value	Adjusted rate ratio (95% CI)	p value
Facility type	0/60 465	..	<0·0001	..	0·074
Decentralised	..	..	..	..	..
Transit	..	1·27 (1·08–1·46)	..	1·14 (0·95–1·32)	..
Treatment	..	1·35 (1·17–1·54)	..	1·18 (1·00–1·36)	..
Date of admission, months	195/60 465 (0·3%)	0·98 (0·98–0·98)	<0·0001	0·98 (0·98–0·99)	<0·0001
Age group, years	65/60 465 (0·1%)	..	<0·0001	..	<0·0001
<2	..	..	..	..	..
2–9	..	0·96 (0·93–0·99)	..	0·95 (0·92–0·98)	..
10–19	..	1·01 (0·98–1·04)	..	1·00 (0·97–1·04)	..
20–29	..	1·11 (1·07–1·14)	..	1·09 (1·06–1·13)	..
30–39	..	1·18 (1·14–1·22)	..	1·16 (1·13–1·20)	..
40–49	..	1·36 (1·31–1·41)	..	1·34 (1·29–1·39)	..
50–59	..	1·49 (1·42–1·55)	..	1·46 (1·40–1·53)	..
>60	..	1·57 (1·50–1·64)	..	1·56 (1·49–1·62)	..
Sex	46/60 465 (0·1%)	..	0·079	..	0·27
Female	..	..	..	..	..
Male	..	1·01 (1·00–1·03)	..	1·01 (0·99–1·02)	..
Province	0/60 465	..	<0·0001	..	<0·0001
North Kivu	..	..	..	..	..
South Kivu	..	1·18 (0·91–1·44)	..	1·12 (0·88–1·37)	..
Ituri	..	1·27 (1·22–1·32)	..	1·26 (1·21–1·31)	..
Other	..	1·35 (1·03–1·67)	..	1·38 (1·06–1·71)	..

Data are n/N (%) unless otherwise stated.

Table 2: **Summary of statistical models for the onset to admission delay outcome among all patients admitted to Ebola virus disease facilities over the course of the outbreak**

Role of the funding source

Employees of the study funder, Médecins Sans Frontières (TN and FR), and its research affiliate Epicentre (PMB, AC, RMC, and EG), were involved in study design, data collection, data analysis, data interpretation, and writing of the report.

Results

Over the course of the outbreak (July 27, 2018, to June 24, 2020), 60 465 patients were admitted to EVD facilities (figure 1A), of which 2289 (3·8%) were confirmed to be EVD positive. Of the total admissions, 7228 (12·0%) were first admitted to a decentralised facility, 22 208 (36·7%) to a transit facility, and 31 029 (51·3%) to a treatment facility (table 1). Among the 58 176 non-EVD cases a primary diagnosis was available for 11 409 patients (19·6%). The most common diagnosis among these patients was malaria, accounting for 5574 (48·9%) of 11 409 non-EVD cases with known diagnosis (appendix 2 p 11).

Of the 60 465 patients admitted to EVD facilities over the course of the outbreak, time from symptom onset to admission was missing for 1207 (2·0%) patients, date of admission was missing for 195 (0·3%) patients, age was missing for 65 (0·1%) patients, and sex was missing for 46 (0·1%) patients. Of the 2289 confirmed EVD cases, final outcome (survived or died) was missing for six (0·3%) patients, date of admission was missing for six (0·3%) patients, age was missing for two (0·1%) patients, time from symptom onset to admission was missing for 20 (0·9%) patients, RT-PCR cycle threshold at admission was missing for 779 (34·0%) patients, vaccination status was missing for 669 (29·2%) patients, and treatment status was missing for 555 (24·2%) patients.

The mean time between symptom onset and admission to an EVD facility declined steadily over the course of the outbreak (LRT: D=404·3, df=1, p<0·0001), from a modelled (univariate) mean of 4·1 days (95% CI 3·8–4·4) in July, 2018, to 2·8 days (2·6–3·0) as of June 2020 (figure 1B; dashed line). Admission delays were lower at decentralised facilities (mean 2·8 days [2·5–3·0]) than transit facilities (mean 3·5 days [3·1–4·0]; ARR 1·14 [95% CI 0·95–1·32]) and treatment facilities (mean 3·8 days [3·4–4·2]; ARR 1·18 [1·00–1·36]), an effect that was statistically significant in univariate analyses (univariate LRT: D=15·6, df=2, p<0·0001) but not statistically significant in multivariate analyses

(multivariate Wald test: F=2·6, df1=2, df2=58175, p=0·074).

Based on our multivariate analysis, time from symptom onset to admission declined with increasing admission date (ARR: 0·98 per month [95% CI 0·98–0·99]), generally increased with age (table 2), and was greater for patients residing in South Kivu (1·12 [0·88–1·37]), Ituri (1·26 [1·21–1·31]), and other provinces (1·38 [1·06–1·71]) compared with individuals residing in North Kivu (table 2; figure 2). Admission delays were not statistically significantly associated with facility type or patient sex (table 2; figure 2).

Among the 2283 patients confirmed to be EVD positive with known outcome there were 1123 deaths, yielding an overall CFR of 49·2% (95% CI 47·1 to 51·3). Monthly CFR values were close to the overall mean throughout most of the outbreak, reaching a high of 58·9% (52·3 to 65·2) in April, 2019, and declining only in the last few months of the outbreak to a low of 24·4% (12·4 to 40·3) in January, 2020 (figure 3G; appendix 2 p 8). The overall

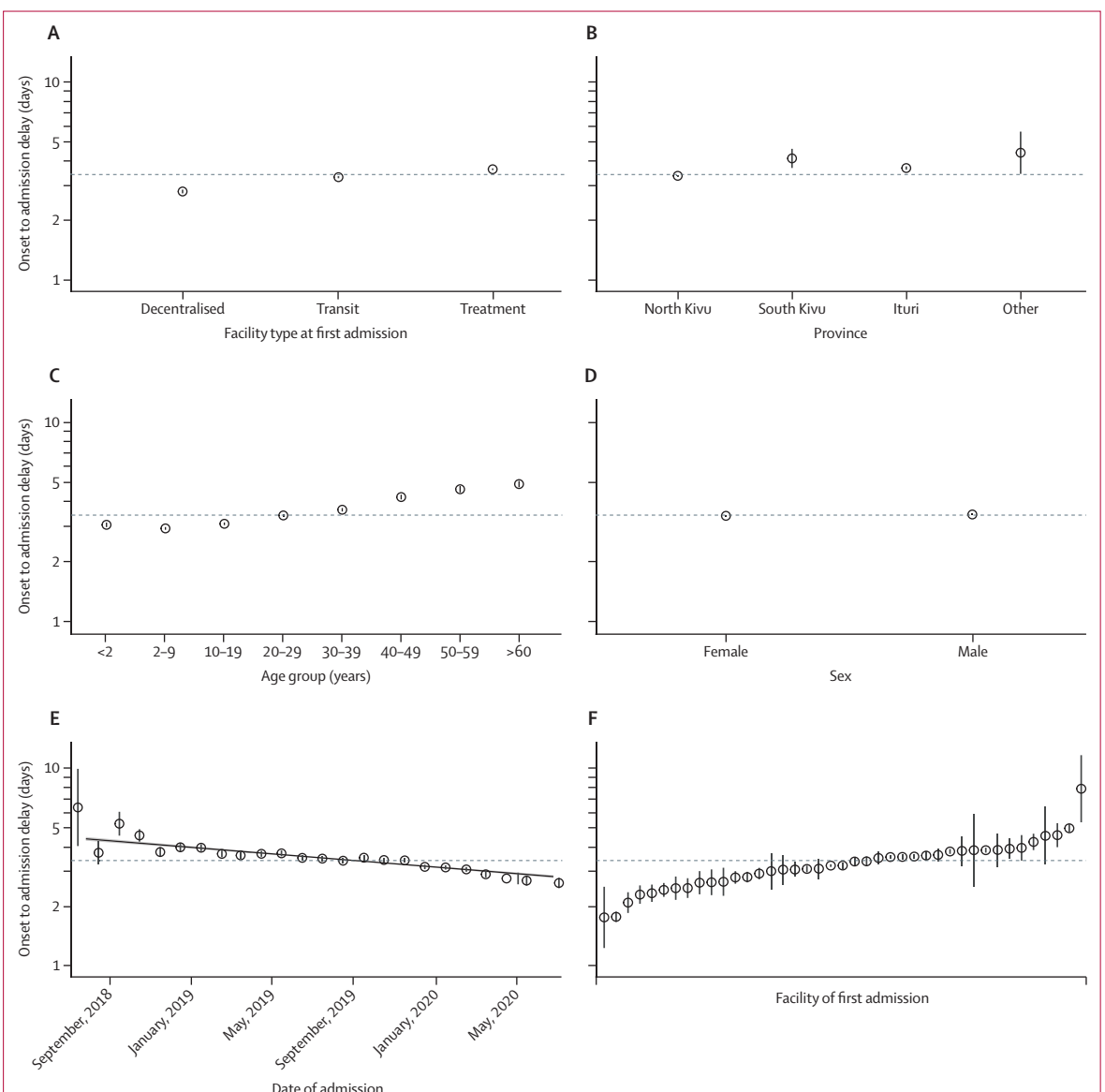

Figure 2: **Mean onset to admission delay (non-adjusted) and corresponding 95% negative binomial CIs by facility type at first admission (A), province (B), age group (C), sex (D), date of admission (E), and facility of first admission (F)**

Note that the y-axis has a logarithmic scale. For graphical clarity point estimates for date of admission are aggregated by calendar month. The best fit line and corresponding 95% CIs for the date of admission term (E) are based on a univariate generalised linear mixed-effect model with negative binomial error (fit to the original, unaggregated data). The dashed horizontal line indicates the mean onset to admission delay among all patients. (F) Each point represents a facility and facilities are ordered by mean onset to admission delay. One of the 42 facilities (the decentralised facility Butsiri) is omitted because onset to admission delays were missing for all patients (n=7).

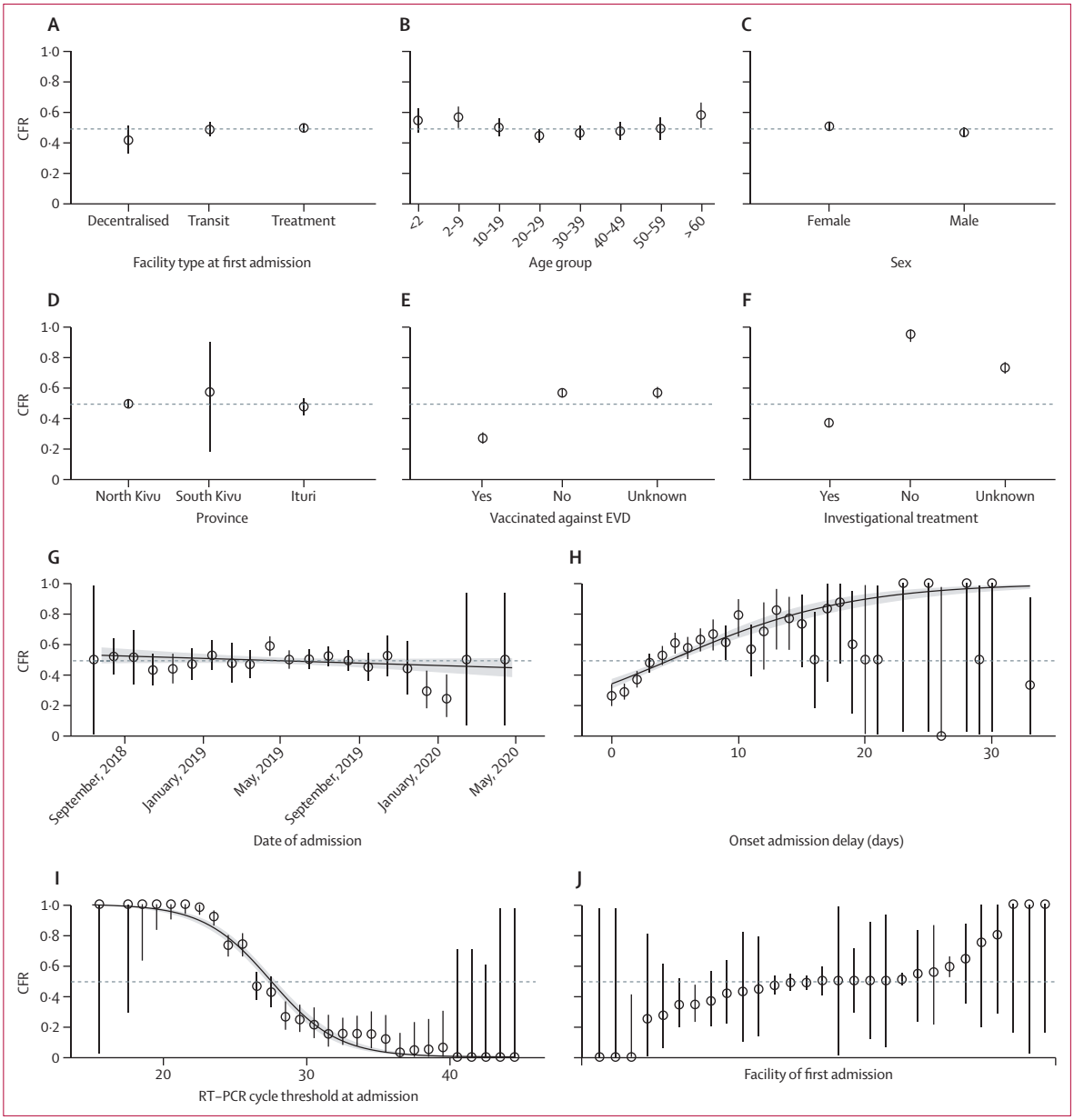

Figure 3: **Non-adjusted mean CFR among EVD-positive patients and corresponding binomial 95% CIs by facility type at first admission (A), age group (B), sex (C), province (D), vaccination status (E), investigational treatment status (F), date of admission (G), onset admission delay (H), RT-PCR cycle threshold at admission (I), and facility of first admission (J)**

For graphical clarity point estimates for some continuous variables are aggregated: date of admission (month) and RT-PCR cycle threshold (rounded to nearest integer). Best fit lines and corresponding 95% CI bands for continuous variables (G–I) are based on univariate generalised linear mixed-effect models with binomial error (ie, logistic regression), always fit to original, unaggregated continuous variables. The dashed horizontal lines indicate the mean CFR among all EVD-positive patients. (J) Each point represents a facility. CFR=case fatality risk. EVD=Ebola virus disease.

temporal trend in CFR was slightly negative at –0·8% per month (–2·0 to –0·3); although, this effect was not statistically significant (univariate LRT: D=2·0, df=1, p=0·16). The CFR among patients first admitted to decentralised facilities (42% [33 to 51]) was somewhat lower than at transit (49% [44 to 53]; ARR 1·04 [95% CI 0·82–1·26]) or treatment facilities (50% [47 to 52]; ARR 1·03 [0·82–1·24]; figure 2B); although, again this difference was not statistically significant in univariate analyses (LRT: D=2·2, df=2, p=0·34) or multivariate analyses (Wald test: F=0·058, df1=2, df2=457, p=0·94). CFR increased strongly with the time between symptom onset and admission to an EVD facility, from 27% (20 to 34) among patients admitted on the same day as symptom onset to 70% (63 to 76) among patients admitted ten or more days after symptom onset (appendix 2 p 7; figure 3H).

Based on our multivariate analysis, CFR varied significantly among age groups (table 3), significantly increased with increasing time from symptom onset to admission (ARR 1·02 per day; 95% CI 1·01–1·03), decreasing RT-PCR cycle threshold at admission (0·89 per cycle [0·89–0·90]), and was significantly higher among individuals that had not been vaccinated (1·25 [1·13–1·37]) relative to vaccinated individuals, and among those who did not receive investigational treatment (1·63 [1·44–1·83]) relative to treated individuals (table 3; figure 3). CFR was not statistically significantly associated with facility type at admission, date of admission, sex, or province of residence (table 3; figure 3). A supplementary analysis suggested that the relationship between CFR and time from symptom onset to admission depended on whether a patient received one of the investigational treatments: the relationship was strongest among patients that received treatment (all treatments combined), weaker but still apparent among patients with unknown treatment status, and not apparent among patients that did not receive an investigational treatment (appendix 2 p 12).

We conducted supplementary analyses to identify potential cases of nosocomial transmission (appendix 2 p 3). We identified four patients that were discharged from an EVD facility as non-EVD cases and then readmitted within 30 days and confirmed to be EVD-positive, with no other evidence of exposure to Ebola. In all four cases the initial facility of potential exposure was a treatment facility (ie, none were transit or decentralised facilities; appendix 2 p 4).

	Missing data	Univariate analysis		Multivariate analysis	
		Risk ratio (95% CI)	p value	Adjusted risk ratio (95% CI)	p value
Facility type	0/2289	..	0·341	..	0·94
Decentralised	..	..	..	..	..
Transit	..	1·16 (0·88–1·45)	..	1·04 (0·82–1·26)	..
Treatment	..	1·18 (0·91–1·45)	..	1·03 (0·82–1·24)	..
Date of admission, months	6/2289 (0·3%)	0·99 (0·98–1·00)	0·155	1·00 (0·99–1·01)	0·86
Age group, years	2/2289 (0·1%)	..	0·016	..	0·005
<2	..	..	..	..	..
2–9	..	1·04 (0·84–1·24)	..	0·95 (0·78–1·13)	..
10–19	..	0·91 (0·75–1·08)	..	0·97 (0·80–1·13)	..
20–29	..	0·81 (0·67–0·95)	..	1·02 (0·86–1·18)	..
30–39	..	0·85 (0·70–1·00)	..	1·04 (0·87–1·20)	..
40–49	..	0·87 (0·70–1·03)	..	1·10 (0·92–1·28)	..
50–59	..	0·89 (0·71–1·08)	..	1·17 (0·97–1·37)	..
>60	..	1·06 (0·84–1·27)	..	1·25 (1·03–1·47)	..
Sex	0/2289	..	0·062	..	0·92
Female	..	..	..	..	..
Male	..	0·92 (0·84–1·00)	..	1·00 (0·94–1·07)	..
Province	0/2289	..	0·892	..	0·16
North Kivu	..	..	..	..	..
South Kivu	..	1·19 (0·41–1·98)	..	0·46 (-0·03–0·95)	..
Ituri	..	1·00 (0·85–1·16)	..	0·98 (0·88–1·09)	..
Onset to admission delay, days	20/2289 (0·9%)	1·07 (1·06–1·08)	<0·0001	1·02 (1·01–1·03)	<0·0001
RT-PCR cycle threshold	779/2289 (34·0%)	0·87 (0·86–0·88)	<0·0001	0·89 (0·89–0·90)	<0·0001
Vaccinated	669/2289 (29·2%)	..	<0·0001	..	<0·0001
Yes	..	..	..	..	..
No	..	2·12 (1·80–2·44)	..	1·25 (1·13–1·37)	..
Received investigational treatment	555/2289 (24·2%)	..	<0·0001	..	<0·0001
Yes	..	..	..	..	..
No	..	2·83 (2·36–3·30)	..	1·63 (1·44–1·83)	..

Data are n/N (%) unless otherwise stated.

Table 3: **Summary of statistical models for the died or survived outcome among Ebola virus disease-positive patients**

Discussion

During the 2018–20 Ebola outbreak in DR Congo, patients first presenting at decentralised EVD facilities had modestly shorter mean admission delays, and a slightly lower CFR (although not statistically significant) compared with individuals first presenting at one of the two centralised facility types (transit and treatment facilities). Reduced admission delays among EVD-positive patients correspond to faster case isolation, thereby reducing the potential for further EVD transmission.[20] Among EVD-negative patients, who accounted for 96% of admissions to any EVD facilities, reducing admission delays is also desirable from a broader health care perspective. The 2018–20 EVD outbreak was exacerbated by concomitant outbreaks of measles, cholera, and malaria,[5,6] diseases for which early diagnosis and treatment are also beneficial. The mobilisation of resources toward Ebola response efforts often strains local health-care systems, disrupting the delivery of other primary health services.[21] By reducing admission delays, and responding to health needs beyond just Ebola, decentralised facilities could play an important role in ensuring the continuum of care for all patients, regardless of EVD status.

Whereas the importance of rapid case identification for limiting EVD transmission is generally well established, current evidence for the relationship between admission delays and EVD case fatality is mixed. Intuitively, we would expect shorter delays between symptom onset and admission to an EVD facility should lead to earlier treatment and therefore improved patient outcomes, but several studies of the 2013–16 Ebola outbreak in west Africa found either no relationship between admission delay and case fatality,[22,23] or even that shorter admission delays were associated with higher EVD case fatality.[24] Part of the explanation for this lack of advantage associated with early admission might be the lack of

effective treatment options that were available during the 2013–16 outbreak. The most promising treatments at the time, such as the monoclonal antibody cocktail ZMapp and the small interfering RNA TKM-Ebola, were not generally associated with a statistically reduced case fatality.[25]

In contrast to the 2013–16 Ebola outbreak in west Africa, effective treatment options did finally become available during the 2018–20 outbreak in DR Congo, and correspondingly, early admission to an EVD facility was strongly associated with increased survival. In the PALM clinical trial, a study of four investigational treatments conducted during the 2018–20 outbreak in DR Congo, the monoclonal antibody treatments MAb114 and REGN-EB3 were associated with a 76% (95% CI 39–90) and 79% (47–92) increase, respectively, in the covariate-adjusted odds of survival to 28 days, relative to ZMapp.[26] Among all patients combined, the PALM study reported an increase in the odds of death of 11% (5–16) for each additional day of delay between symptom onset and admission to a treatment centre.[26] Supplementary analyses from our own study suggest that the survival advantage associated with early admission was limited to the subset of patients that received one of the investigational treatments (appendix 2 p 12).

At the time of the introduction of decentralised facilities, echoing concerns raised during the 2013–16 west Africa outbreak,[27] there was concern that isolating patients in local facilities, outside of the standard Ebola referral pathway, could increase the risk of breaches in infection prevention and control (IPC) protocols.[12] The prevention of nosocomial infections requires concerted effort, and the 2018–20 outbreak reaffirmed that major gaps still exist in DR Congo, particularly related to IPC measures within local health facilities.[28] In the face of these challenges, proponents of the decentralised approach asserted that provision of support for decentralised care was an opportunity to improve IPC at the local level. In supplementary analyses we found no evidence of nosocomial transmission at decentralised facilities, and only a few potential cases of nosocomial transmission at the centralised facility types (appendix 2 pp 3–4). Importantly, there does not appear to be a higher risk of death among EVD-positive patients first admitted to a decentralised facility, suggesting rapid access to appropriate care and transfer to treatment facilities.

As was the case in the 2013–16 west Africa Ebola outbreak, response efforts during the 2018–20 outbreak in DR Congo were multifaceted, and evolved over time. For instance, the implementation of decentralised EVD facilities during the 2018–20 outbreak in DR Congo was part of an effort that also re-emphasised contact tracing, safe and dignified burials, health promotion, and greater engagement with affected communities. The multi-faceted nature of response efforts, and the understandable focus during Ebola outbreaks on emergency response rather than scientific research, makes it difficult to evaluate causal effects associated with different interventions.[29] Although our analysis adds to a growing body of evidence that decentralisation can help reduce admission delays, the steady decline in admission delays that occurred over the course of the outbreak, independently within all facility types, suggests that other drivers were also important. Ending Ebola outbreaks depends on many response components working in concert.[2]

Our study has several important limitations. First, as noted earlier, it is inherently difficult to isolate causal effects associated with different interventions in retrospective analyses of Ebola outbreaks, where response efforts are dynamic and multifaceted. Second, we did not have access to data on potential confounding variables such as underlying health conditions or education levels, which could be causally related to our two outcomes of interest. Our analyses nonetheless controlled for typical confounders including sex, age, province, and EVD facility (and additional covariates in analyses of case fatality). Another limitation is that our main explanatory variable of interest, the facility type that people suspected of EVD first presented to, might in some cases be causally associated with other patient characteristics. For instance, people that presented with the most severe EVD-like symptoms might have been preferentially offered transportation to treatment facilities rather than decentralised or transit facilities. All else being equal, we might expect this pattern to lead to relatively higher observed admission delays and case fatality for patients first admitted to treatment facilities (ie, because patients with more severe symptoms are likely to be further along in the course of the disease), but such a pattern would not necessarily indicate that treatment facilities were inferior in terms of patient outcomes. A fourth limitation of our study relates to data quality and missing data. Three of the covariates included in our analyses on case fatality (RT-PCR cycle threshold values, vaccination status, and treatment status) had relatively high rates of missing data, with rates of missingness varying over time and by facility. We believe that our multivariate analysis with multiple imputation of missing data was the best possible approach for analysing data of this nature, but nonetheless, some prudence is warranted in not overinterpreting results from this analysis.

In the 6 years since the 2018–20 Ebola epidemic started in DR Congo, seven additional Ebola outbreaks have occurred, including five in DR Congo, one in Guinea, and one in Uganda. While the threat of new Ebola outbreaks remains high, response teams have more tools than ever before with which to respond. Our results add to evidence from two other Ebola outbreaks (the 2013–16 west Africa outbreak, and the 2020 outbreak in the Equateur province of DR Congo) that decentralised EVD strategies can be associated with earlier case detection and isolation,[13,15] which are important factors

for limiting EVD transmission. With new effective treatment options that became available during the 2018–20 outbreak in DR Congo, early detection and access to treatment might also eventually contribute to limiting case fatality.

Contributors

All authors contributed to the conceptualisation and design of the work. PMB and AC curated the data. PMB did the formal analysis and prepared the figures. PMB, AC, RMC, and EG wrote the first draft of the manuscript. All authors contributed to the acquisition of data and to the critical review and editing of the early and final versions of the manuscript. PMB and AC accessed and verified the data. All authors had full access to all data in the study and had final responsibility for the decision to submit for publication.

Equitable partnership declaration

The authors of this paper have submitted an equitable partnership declaration (appendix 3). This statement allows researchers to describe how their work engages with researchers, communities, and environments in the countries of study. This statement is part of *The Lancet Global Health*'s broader goal to decolonise global health.

Declaration of interests

We declare no competing interests.

Data sharing

All data belong to the Ministry of Health of DR Congo, who authorised access to the dataset for this collaborative research. Further request for data access must be presented to and approved by the Ministry of Health. Requests should be addressed to Steve Ahuka-Mundeke (amstev04@yahoo.fr; amstev4@gmail.com).

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See **Online** for appendix 3