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The impact of earthquakes in Latin America on the continuity of HIV care: A retrospective observational cohort study

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ABSTRACT

Objectives: As earthquakes occur frequently in Latin America and can cause significant disruptions in HIV care, we sought to analyze patterns of HIV care for adults at Latin American clinical sites experiencing a significant earthquake within the past two decades.
Study design: Retrospective clinical cohort study.
Methods: Adults receiving HIV care at sites experiencing at least a "moderate intensity" (Modified Mercalli scale) earthquake in the Caribbean, Central and South America network for HIV epidemiology (CCASAnet) contributed data from 2003 to 2017. Interrupted Time Series models were fit with discontinuities at site-specific earthquake dates (Sept. 16, 2015 in Chile; Apr. 18, 2014 and Sept. 19, 2017 in Mexico; and Aug. 15, 2007 in Peru) to assess clinical visit, CD4 measure, viral load lab, and ART initiation rates 3- and 6-months after versus before earthquakes.
Results: Comparing post-to pre-earthquake periods, there was a sharp drop in median visit (incidence rate ratio [IRR] = 0.79, 95% confidence interval [CI]: 0.68–0.91) and viral load lab (IRR = 0.78, 95% CI: 0.62–0.99) rates per week, using a 3-month window. CD4 measurement rates also decreased (IRR = 0.43; 95% CI: 0.37–0.51), though only using a 6-month window.
Conclusions: Given that earthquakes occur frequently in Latin America, disaster preparedness plans must be more broadly implemented to avoid disruptions in HIV care and attendant poor outcomes.

1. Background

Large-scale disasters expose health disparities and social inequities pre-existing in societies, as persons of lower socioeconomic status and those with multiple medical comorbidities often suffer greater disease severity and mortality rates [1]. Though natural disasters are typically associated with structural and financial damage [2], they also negatively impact morbidity and mortality in people with chronic medical conditions [3]. For example, prior retrospective studies have shown that, following earthquakes, patients with type 2 diabetes may suffer increases in their hemoglobin A1c, and those with chronic obstructive pulmonary disease (COPD) may have 2.5 times more frequent exacerbations. In addition, higher incidence of emergency room visits for dialysis and diabetes-related concerns was seen following hurricanes, and an increase in COPD-related emergency room visits following wildfires [4].

Despite classification of HIV as a chronic condition [5] and knowledge that disruptions in care lead to worse outcomes [6], little is known

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about the impact that natural disasters may have on HIV care continuity [7–9]. According to the United Nations Office for Disaster Risk Reduction, 15 million people in Latin America and the Caribbean were affected by earthquakes between the years 2000–2022, with an associated 229,000 deaths and $57.2 billion dollars' worth of damage [10]. For instance, in 2007, an earthquake in Peru caused significant damage to local healthcare facilities, major road blockages and impaired transportation which severely limited the ability to provide healthcare services. Chapin et al. [11] showed that facilities with an emergency disaster plan in place were more likely to continue operations within 48 h of the earthquake. All facilities reported consistent access to HIV medications throughout the disaster but did not assess HIV-related outcomes.

The impact of the 2010 earthquake in Haiti on HIV services was previously described by Waldorf et al. [7], demonstrating immediate declines in HIV testing, antiretroviral therapy (ART) initiation and distribution of ART at PEPFAR-supported clinics. Services recovered to pre-earthquake levels within 6 months post-earthquake. In addition, authors of this group report here that the earthquake which struck Mexico in 2017 led to closure of the large HIV clinic and pharmacy at the Instituto Nacional de Ciencias Médicas y Nutrición Salvador Zubirán (INCMNSZ) in Mexico City for 48 h. No disaster plan was in place, and the response was improvised, including an informal agreement with Centro Nacional para la Prevención y Control del VIH y el sida (CENSIDA) to ensure ART provision regardless of insurance type and psychological support to patients and staff in the weeks that followed the earthquake. This experience inspired our group to assess the impact of earthquakes on HIV care at clinical centers in the Caribbean, Central and South America network for HIV epidemiology (CCASAnet), including INCMNSZ, as these centers did not have disaster preparedness plans in place at the time of the 2017 earthquake in Mexico. We therefore sought to quantify the impact of local earthquakes on the rates of four HIV-related outcomes at CCASAnet clinical centers: clinical visits, CD4 and viral load measures, and ART initiations.

2. Methods

CCASAnet is the Latin American regional member of the International epidemiology Databases to Evaluate AIDS (IeDEA) network and includes HIV clinical care sites in Argentina, Brazil, Chile, Haiti, Honduras, Mexico and Peru. Data were collected from the United States Geological Survey (USGS) Earthquake Catalogue [12] for earthquakes (i) considered to be of at least moderate intensity ($\geq$level-5 Modified Mercalli intensity (MMI) [13]) and (ii) centered $\leq$300 km from a CCASAnet clinical site between January 1, 2000 and June 26, 2018, the date of the query). According to the USGS, an earthquake with a MMI of 5 would be "felt by nearly everyone; many awakened," and damages could include "some dishes, windows broken." [13] Based on latitude and longitude, distances between the epicenters and CCASAnet sites were calculated using the Haversine Formula [14]. Geographic Information System (GIS) shapefiles were extracted from the USGS Earthquake Catalogue for 94 earthquakes satisfying these initial conditions. A "shakemap" was then constructed for each earthquake with CCASAnet locations superimposed (Supplemental Fig. S1), from which the MMI at the site was estimated using point-in-polygon analysis [15]. Moderate-to-high intensity earthquakes were identified for sites in Mexico, Peru, Chile, Haiti, and Honduras. However, the site in Honduras had insufficient clinical data for analysis and the 2010 earthquake in Haiti has been extensively studied elsewhere with respect to several outcomes [7,16], so these two were excluded from the current analysis. We analyzed four remaining earthquakes experienced by three CCASAnet clinic sites in Mexico (Instituto Nacional de Ciencias Médicas y Nutrición Salvador Zubirán, Mexico City), Peru (Instituto de Medicina Tropical Alexander von Humboldt, Universidad Peruana Cayetano Heredia, Lima), and Chile (Fundación Arriarán, Santiago) during the study period.

Patient data for 6-month periods before and after the associated earthquakes were collected from the sites and sent to the CCASAnet data coordinating center at Vanderbilt University Medical Center per CCASAnet standardized protocols (more information available at http://www.ccasanet.org) where statistical analyses were performed. The number of patients in care for each site was first estimated per day, based on last evidence of engagement in care or the close of the study period, as determined by their most recent clinical visit or lab value from patient records. Daily estimates were then aggregated into weekly estimates; for sensitivity, we report models based on the minimum, maximum, and median numbers of patients in care weekly (Table 1). However, since results did not vary substantially between them, only the models based on the median patients in care are interpreted in the text.

We examined four HIV-related outcomes: numbers of clinical visits, CD4 and viral load measures, and ART initiations per person per week. Interrupted time series (ITS) models with discontinuities aligned at the date of the earthquake (Aug. 15, 2007 in Peru, Apr. 18, 2014 in Mexico, Sept. 16, 2015 in Chile and Sept. 19, 2017 in Mexico) were fit for each outcome. These were Poisson regression models defined like

$$\log(Y) = \beta_0 + \beta_1 Week + \beta_2 AfterQuake + \beta_3 Week \times AfterQuake + \log(P),$$

where the count of the outcome (Y) is modeled as a function of the number of weeks since the earthquake (*Week*), an indicator of the after-earthquake time period (*AfterQuake*), and an interaction between them (*Week* × *AfterQuake*). To obtain the per-patient rate of the outcome, the number of patients in care (P) is included as an offset.

The ITS models quantified the altered trajectories of the four outcomes after vs. before the earthquakes. Primary interpretations from the ITS models were two-fold: (i) did the outcome rates change in the immediate aftermath of the earthquake and (ii) if so, how quickly did they return to pre-earthquake levels? These questions were answered with the incidence rate ratio (IRR) and by the ratio of incidence rate ratios (IRRR) from the ITS models, respectively. First, for the immediate change in incidence rates of outcomes after vs. before the earthquakes, measured as the IRR, we obtained and exponentiated estimates of the main effect for the post-earthquake period (β_2). Second, for the week-on-week change in the rate of the outcome following vs. before the earthquake, measured as the IRRR, we obtained and exponentiated estimates of the interaction effect between the weekly rate of change and an indicator for the post-earthquake period (β_3). Both measures are presented with their 95% confidence intervals (95% CI). We also examined multiple time horizons over which changes in outcomes may have occurred: 3 months (for near-term effects) and 6 months (for longer-term effects) before and after the earthquakes.

R Statistical Software (R Core Team 2019. R Foundation for Statistical Computing, Vienna, Austria) was used for all analyses. All study activities were performed in compliance with the principles and regulations for the ethical treatment of human subjects in research set forth in the Declaration of Helsinki.

3. Results

Using a 3-month window pre- and post-earthquake (Table 1), we observed a sharp immediate drop in the weekly rate of clinical visits (IRR = 0.79; 95% CI: 0.68, 0.90). That is, the expected number of patient visits at a clinic dropped from 9.1 to 7.2 visits per 100 people in care from the pre-to post-earthquake periods. There was also a significant drop in the weekly rate of viral load measures at clinics immediately following the earthquakes (IRR = 0.78; 95% CI: 0.62, 0.99), with the expected number of viral load measures per 100 people in care dropping from 3.4 to 2.7. There were no significant shifts in the weekly rates of CD4 measures taken (IRR = 0.82; 95% CI: 0.66, 1.04) or of patients initiating new ART regimens (IRR = 0.78; 95% CI: 0.31, 2.00). Further, in the period after the earthquakes, the week-on-week change in the rate of clinical visits increased slightly over change in the period before the

Table 1
Interrupted Time Series models with discontinuities aligned at the time of an earthquake quantified altered trajectories of the numbers of clinical visits, CD4 measurements, viral loads, and ART initiations per patient per week in three- and 6-month windows after vs. before the earthquakes.

	Patients in care per week		
	Minimum	Median	Maximum
	3 months pre- and post-quake		
Clinical visits			
(Intercept)	9.12 (8.68, 9.58)	9.10 (8.67, 9.56)	9.09 (8.65, 9.55)
Week	**0.99** (0.98, 0.99)	**0.99** (0.98, 0.99)	**0.99** (0.98, 0.99)
Post-quake (IRR)	**0.78** (0.68, 0.90)	**0.79** (0.68, 0.91)	**0.79** (0.68, 0.91)
Week-by-Post-quake period (IRRR)	**1.02** (1.01, 1.03)	**1.02** (1.01, 1.03)	**1.02** (1.01, 1.03)
CD4 measurements			
(Intercept)	3.44 (3.17, 3.72)	3.43 (3.17, 3.72)	3.43 (3.16, 3.71)
Week	0.99 (0.98, 1.00)	0.99 (0.98, 1.00)	0.99 (0.98, 1.00)
Post-quake (IRR)	0.82 (0.65 1.03)	0.82 (0.66, 1.04)	0.83 (0.66, 1.04)
Week-by-Post-quake period (IRRR)	1.01 (1.00, 1.03)	1.01 (1.00, 1.03)	1.01 (1.00, 1.03)
Viral loads			
(Intercept)	3.42 (3.16, 3.70)	3.41 (3.15, 3.70)	3.41 (3.15, 3.69)
Week	0.99 (0.98, 1.00)	0.99 (0.98, 1.00)	0.99 (0.98, 1.00)
Post-quake (IRR)	**0.78** (0.62, 0.98)	**0.78** (0.62, 0.99)	**0.78** (0.62, 0.99)
Week-by-Post-quake period (IRRR)	1.01 (1.00, 1.03)	1.01 (1.00, 1.03)	1.01 (1.00, 1.03)
ART initiations			
(Intercept)	0.26 (0.19, 0.34)	0.26 (0.19, 0.34)	0.26 (0.19, 0.34)
Week	0.98 (0.95, 1.02)	0.98 (0.95, 1.02)	0.98 (0.95, 1.02)
Post-quake (IRR)	0.78 (0.30, 1.99)	0.78 (0.31, 2.00)	0.79 (0.31, 2.01)
Week-by-Post-quake period (IRRR)	1.01 (0.95, 1.07)	1.01 (0.95, 1.07)	1.01 (0.95, 1.07)
	6 months pre- and post-quake		
Clinical visits			
(Intercept)	8.94 (8.64, 9.24)	8.93 (8.64, 9.24)	8.92 (8.63, 9.23)
Week	1.00 (1.00, 1.00)	1.00 (1.00, 1.00)	1.00 (1.00, 1.00)
Post-quake (IRR)	**0.65** (0.59, 0.72)	**0.66** (0.59, 0.72)	**0.66** (0.60, 0.73)
Week-by-Post-quake period (IRRR)	**1.01** (1.01, 1.01)	**1.01** (1.01, 1.01)	**1.01** (1.01, 1.01)
CD4 measurements			
(Intercept)	4.01 (3.81, 4.22)	4.00 (3.82, 4.22)	4.00 (3.80, 4.21)
Week	**0.99** (0.99, 0.99)	**0.99** (0.99, 0.99)	**0.99** (0.99, 0.99)
Post-quake (IRR)	**0.43** (0.37, 0.50)	**0.43** (0.37, 0.51)	**0.43** (0.37, 0.51)
Week-by-Post-quake period (IRRR)	**1.03** (1.02, 1.03)	**1.03** (1.02, 1.03)	**1.03** (1.02, 1.03)
Viral loads			
(Intercept)	3.91 (3.71, 4.12)	3.91 (3.71, 4.11)	3.90 (3.70, 4.11)
Week	**0.99** (0.99, 0.99)	**0.99** (0.99, 0.99)	**0.99** (0.99, 0.99)
Post-quake (IRR)	**0.42** (0.36, 0.50)	**0.42** (0.36, 0.50)	**0.42** (0.36, 0.50)
Week-by-Post-quake period (IRRR)	**1.03** (1.02, 1.03)	**1.03** (1.02, 1.03)	**1.03** (1.02, 1.03)
ART initiations			
(Intercept)	0.24 (0.19, 0.29)	0.24 (0.19, 0.29)	0.24 (0.19, 0.29)
Week	1.00 (0.98, 1.01)	1.00 (0.98, 1.01)	1.00 (0.98, 1.01)
Post-quake (IRR)	0.84 (0.43, 1.64)	0.84 (0.43, 1.65)	0.85 (0.43, 1.66)
Week-by-Post-quake period (IRRR)	1.00 (0.98, 1.02)	1.00 (0.98, 1.02)	1.00 (0.98, 1.02)

Footnotes.
IRR: incidence rate ratio.
IRRR: ratio of incidence rate ratios (for the interaction between two incidence rate ratios).
Bold estimates are statistically significant, with $p < 0.05$.
Poisson models with offsets based on the minimum, median, and maximum number of patients in care weekly at each site are included, but results did not vary substantially between them (IRR/IRRR estimates differed by no more than 0.01). 95% confidence intervals are included for IRR and IRRR estimates in parentheses.

earthquakes (IRRR = 1.02; 95% CI: 1.01, 1.03). In the pre-earthquake period, the rate of clinical visits decreased 1% week-to-week, on average, while it flattened out in the post-earthquake period. The week-on-week change in the rates of CD4 measures (IRRR = 1.01; 95% CI: 1.00, 1.03), viral load measures (IRRR = 1.01; 95% CI: 1.00, 1.03), and ART initiations (IRRR = 1.01; 95% CI: 0.95, 1.07) after the earthquakes were essentially the same as before.

Using a 6-month window pre- and post-earthquake (Table 1), we saw an immediate drop in the weekly rate of clinical visits (IRR = 0.66; 95% CI: 0.59, 0.72) and of viral load measures (IRR = 0.42; 95% CI: 0.36, 0.50) at the clinics following the earthquakes. The corresponding expected numbers of clinical visits and viral load measures per 100 people in care dropped from 8.9 to 5.9 and from 3.9 to 1.6, respectively. In addition, there was a significant immediate drop in the rate of CD4 measures (IRR = 0.43; 95% CI: 0.37, 0.51), leading the expected number of CD4 labs to drop from 4.0 to 1.7 per 100 people in care. Notably, this drop in CD4 was not observed in the model using the shorter 3-month window, while the average weekly rate of patients initiating new ART regimens at the clinics was once again unchanged in the post-earthquake period (IRR = 0.84; 95% CI: 0.43, 1.65). Based on the longer 6-month window, the week-on-week change in the rates of clinic visits (IRRR = 1.01; 95% CI: 1.01, 1.01), CD4 measures (IRRR = 1.03; 95% CI: 1.02, 1.03), and viral loads (IRRR = 1.03; 95% CI: 1.02, 1.03) all increased slightly in the post-earthquake period, while the week-on-week change for the expected number of ART initiations at the clinics still did not change significantly (IRRR = 1.00; 95% CI: 0.98, 1.02).

In Fig. 1, the observed trajectories from the ITS models for the four outcomes are illustrated against their counterfactual trajectories, i.e., the expected trajectories in the post-earthquake period had there not been an earthquake. Sharp drops in the rates of each clinical outcome immediately following the earthquake discontinuity are apparent for all outcomes, though shifts in the week-on-week changes following the earthquake are more apparent with a 6-month than a 3-month window. For clinic visits, CD4 measures, and viral load measures, these shifts all indicated a post-earthquake recovery in the rates of the outcomes, following the immediate drop. Each of these rates was subtly declining week-on-week in the pre-earthquake period but was noticeably increasing post-earthquake.

4. Discussion

Longitudinal analysis of regional earthquakes showed an appreciable impact on the continuity of HIV care when comparing post-to pre-

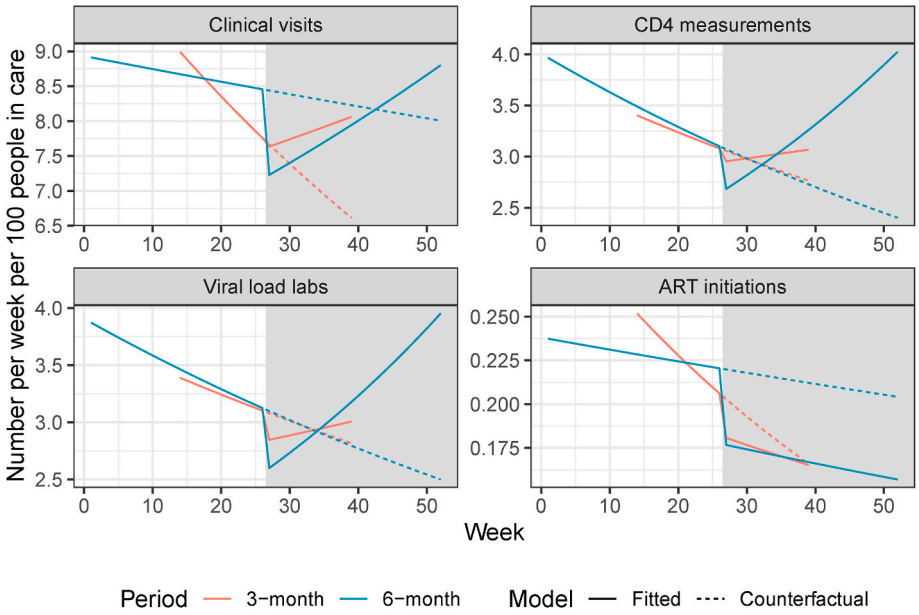

Fig. 1. Interrupted Time Series models with discontinuities at the time of an earthquake to illustrate post-earthquake trajectories (solid lines) for comparison against the pre-quake trajectories (dotted lines) based on the 3- and 6-month windows before and after the events (in red and blue, respectively). (For interpretation of the references to colour in this figure legend, the reader is referred to the Web version of this article.)

earthquake periods within CCASAnet clinical care sites. There were significant drops in clinic visits and viral load measures in the 3-month post-earthquake window, and significant drops in clinic visits, CD4 measures, and viral load measurements in the 6-month post-earthquake window, but with no significant change in ART initiations. Despite these declines, there was a steady recovery in the months following an earthquake, suggesting that most clinics were able to recover pre-earthquake functionality. There were similar findings regarding patients receiving HIV care following the 2010 Haiti earthquake, with immediate declines in HIV testing that largely dissipated by 6 months post-earthquake [7]. Our results differed from those in the 2010 Haiti study in that (i) clinic visits, in addition to testing, were seen to be interrupted, but (ii) access to new ART regimens seemed unimpacted. While we were not able to directly assess the specific factors which contributed to disruptions in care for the CCASAnet clinics following the earthquakes, other publications regarding the 2007 earthquake in Peru, the 2014 earthquake in Mexico and the 2015 earthquake in Chile [11,17,18] suggest that structural damage, displacement of patients, lack of hospital personnel, disruption of pharmacy supply chains, and power outages likely played varying roles.

Despite the face validity of our findings with respect to other clinical natural disaster responses in the region, there are limitations in our measurements and analyses. First, though we utilized USGS data on earthquake intensity relative to clinic locations to assess seismic events most likely to result in disruptions in services, the effects of these events are attributed uniformly to all patients seen at the relevant clinic sites, irrespective of environmental risk or structural challenges specific to individual patient residences (both within and outside the affected areas). This attribution could have resulted in measurement error of our exposure: namely the magnitude, location, and timing of earthquakes relative to barriers to patient care for individual patients. Second, the nature of our ITS models requires that trends in the pre- and post-earthquake periods remain linear with time, which may not strictly have been the case. Because the time periods being modeled are relatively short (a matter of months instead of years or decades), though, this assumption is unlikely to impose unreasonable constraints on modeled trends and associated incidence rates for our outcomes. Still, if there was concern about nonlinearity a more flexible function of time (e.g., a cubic spline) might be considered to relax this assumption. Third, some individuals who were not seen at our clinic sites, and thus were counted as not retained or not receiving clinical services, may simply have migrated or obtained services at HIV clinical care sites outside of our network. Therefore, we may have misclassified individuals with respect to our outcomes due to silent transfers of care, particularly in the aftermath of a traumatic event such as a natural disaster, and over-estimated the negative impact of the earthquakes on continuity of care. However, migration and loss to follow-up rates at clinic sites within CCASAnet have been relatively stable and <10% per year over the same study period in prior analyses [6]. Even so, the detailed clinical data available within our network, in a region with frequent seismic events, enabled a geographically diverse and rigorous longitudinal analysis of the impact of earthquakes on HIV clinical care in a novel manner. Finally, though the current analysis extends only into the pre-COVID-19 era, we believe that restricting our data to this pre-pandemic period renders our inferences less susceptible to bias: i.e., misattribution of clinical care disruption due to COVID-19 to our exposure of interest, earthquakes, cannot occur.

The experience of the authors following the 2017 earthquake in Mexico and the findings of our work speak to the need for Latin American and Caribbean clinical sites to create contingency plans to mitigate the impact of future earthquakes and other natural disasters on HIV clinical care. Such disaster preparedness plans should include strategies for retention in care, including but not limited to the utilization of telehealth technologies and methods for maintaining adequate healthcare staffing and medical supplies to provide care. Lessons learned from the COVID-19 pandemic regarding medical staffing and medical supply shortages may also inform policies regarding natural disaster preparedness [19]. For example, patients should be counseled on how to develop their own disaster preparedness plans, including knowledge of their diagnosis and medications and a disaster "kit" containing back-up supplies of medications, contact information for their providers, insurance information and any other critical items. A patient's plan may also specify a means of maintaining contact with their clinical care site and sharing their disaster plan with friends or family. In addition, contingency plans should also consider infrastructure needed to ensure laboratory access for CD4 and viral load assessments, in addition to supplies of ART. Policymakers at the regional and national level should also be included in such disaster preparedness plans, particularly when

considering how to manage drug or supply shortages, coordination of disparate insurance systems with easing of restrictions between public and private sectors, disease surveillance and coordination of aid. Assistance from HIV advocacy groups may be needed to ensure that the specific needs of people living with HIV are addressed.

5. Conclusion

Earthquakes occur frequently in Latin America and the Caribbean and have potential to disrupt care for chronic conditions like HIV. Here we show that there were short term impacts on the numbers of clinic visits and CD4 and viral load measures over the 3 months post-earthquake, but that these were overcome by 6 months post-earthquake. Our data speak to the need for HIV clinical centers within Latin America and the Caribbean to develop disaster preparedness plans to help mitigate such disruptions in care following natural disasters such as earthquakes.

Ethics approval & consent to participate

Ethical review of the study and waivers of consent were obtained by local Institutional Review Boards (IRB)s of the Instituto Nacional de Ciencias Médicas y Nutrición Salvador Zubirán, Mexico City, Mexico; the Instituto de Medicina Tropical Alexander von Humboldt, Universidad Peruana Cayetano Heredia, Lima, Peru; the Fundación Arriarán, Santiago, Chile; and the Vanderbilt University Medical Center IRB.

Consent for publication

Not Applicable.

Availability of data & materials

The datasets generated and/or analyzed during the current study are not publicly available due to data privacy and ethical standards required by both local site and parent study IRBs but are available from the corresponding author on reasonable request. All data requests must undergo scientific review, via an approved concept sheet and IRB approval of the same (see https://www.ccasanet.org/collaborate/; contact Ms. Hilary Vansell: hilary.vansell@vumc.org).

Authors' contributions

CG: Study concept and design, manuscript draft, approval of final manuscript. SCL: Study concept and design, data management, data analysis, manuscript draft, approval of final manuscript. PB-Z: Data acquisition, study concept approval, manuscript draft, approval of final manuscript. FM: Data acquisition, study concept approval, manuscript draft, approval of final manuscript. CC: Data acquisition, study concept approval, manuscript draft, approval of final manuscript. BC-R: Data acquisition, study concept approval, manuscript draft, approval of final manuscript. DPS: Data acquisition, study concept approval, manuscript draft, approval of final manuscript. VR: Data acquisition, study concept approval, manuscript draft, approval of final manuscript. CCM: Study concept and design, study concept approval, manuscript draft, approval of final manuscript. PFR: Study concept and design, data curation, supervision of analysis, manuscript draft, approval of final manuscript.

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Declaration of competing interest

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Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.puhip.2024.100479.

List of abbreviations

CCASAnet	Caribbean, Central and South America network for HIV epidemiology
HIV	Human Immunodeficiency Virus
ART	Antiretroviral Therapy
USGS	United States Geological Survey
MMI	Modified Mercali intensity scale
ITS	Interrupted Time Series
IRR	Incidence Rate Ratio
IRRR	Ratio of Incidence Rate Ratios
CI	Confidence Interval

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