1 # Estimating the impact of disruptions due to COVID-19 on HIV

2 # transmission and control among men who have sex with men in

3 # China

4 Ross. D. Booton[1, 2, *, §], Gengfeng Fu[3, *], Louis MacGregor[1], Jianjun Li[3], Jason J. Ong[4, 5, 6],

5 Joseph D. Tucker[4, 5, 7, 8], Katy M.E. Turner[1], Weiming Tang[4, 7, 8], Peter Vickerman[1], Kate M.

6 Mitchell[2]

7

8 [1]University of Bristol, Bristol, United Kingdom

9 [2]MRC Centre for Global Infectious Disease Analysis, Department of Infectious Disease Epidemiology, Imperial

10 College London, London, United Kingdom

11 [3]Jiangsu provincial center for disease control and prevention, Nanjing, Jiangsu province, China

12 [4]Social Entrepreneurship to Spur Health (SESH) Global, Guangzhou, China

13 [5]Faculty of Infectious and Tropical Diseases, London School of Hygiene & Tropical Medicine, London, United

14 Kingdom

15 [6]Central Clinical School, Monash University, Melbourne, Australia

16 [7]University of North Carolina Project-China, Guangzhou, China

17 [8]University of North Carolina at Chapel Hill, Chapel Hill, United States

18 *Considered joint first author*

19 §*Correspondence: Dr. Ross D. Booton, Bristol Veterinary School, University of Bristol, Bristol, BS40 5DU,*

20 *rdbooton@gmail.com*

21

22 E-mail addresses of authors:

23 RDB: rdbooton@gmail.com

24 GF: fugf@jscdc.cn

25 LM: louis.macgregor@bristol.ac.uk

26 JL: babbittlee@jscdc.cn

27 JJO: Jason.Ong@monash.edu

28 JDT: jdtucker@med.unc.edu

29 KMET: katy.turner@bristol.ac.uk

30 WT: Weiming_tang@med.unc.edu

31 PV: peter.vickerman@bristol.ac.uk

32 KMM: kate.mitchell@imperial.ac.uk

33

34 Keywords:

35 COVID-19 pandemic, men who have sex with men, modeling, HIV transmission, key and vulnerable

36 populations, People's Republic of China

37 Word count:

38 Abstract: 344. Main text: 3604.

Abstract

Introduction The COVID-19 pandemic is impacting HIV care globally, with gaps in HIV treatment expected to increase HIV transmission and HIV-related mortality. We estimated how COVID-19-related disruptions could impact HIV transmission and mortality among men who have sex with men (MSM) in four cities in China.

Methods Regional data from China indicated that the number of MSM undergoing facility-based HIV testing reduced by 59% during the COVID-19 pandemic, alongside reductions in ART initiation (34%), numbers of sexual partners (62%) and consistency of condom use (25%). A deterministic mathematical model of HIV transmission and treatment among MSM in China was used to estimate the impact of these disruptions on the number of new HIV infections and HIV-related deaths. Disruption scenarios were assessed for their individual and combined impact over 1 and 5 years for a 3-, 4- or 6-month disruption period.

Results Our China model predicted that new HIV infections and HIV-related deaths would be increased most by disruptions to viral suppression, with 25% reductions for a 3-month period increasing HIV infections by 5-14% over 1 year and deaths by 7-12%. Observed reductions in condom use increased HIV infections by 5-14% but had minimal impact (<1%) on deaths. Smaller impacts on infections and deaths (<3%) were seen for disruptions to facility testing and ART initiation, but reduced partner numbers resulted in 11-23% fewer infections and 0.4-1.0% fewer deaths. Longer disruption periods of 4 and 6 months amplified the impact of combined disruption scenarios. When all realistic disruptions were modelled simultaneously, an overall decrease in new HIV infections was always predicted over one year (3-17%), but not over 5 years (1% increase-4% decrease), while deaths mostly increased over one year (1-2%) and 5 years (1.2 increase – 0.3 decrease).

Conclusions The overall impact of COVID-19 on new HIV infections and HIV-related deaths is dependent on the nature, scale and length of the various disruptions. Resources should be directed to ensuring levels of viral suppression and condom use are maintained to mitigate any adverse effects of COVID-19 related disruption on HIV transmission and control among MSM in China.

Introduction

Globally, 37.9 million people are living with HIV (PLWH) [1], with men who have sex with men (MSM) disproportionally affected [2]. In China, a recent systematic review indicated an HIV prevalence of 5.7% (95% CI:5.4-6.1%) among MSM, with increasing HIV prevalence in this group over time (2001-2018) [3]. Efforts to manage the HIV epidemic in China have been made increasingly difficult by the emergent COVID-19 pandemic [4,5], having significant potential to affect the HIV care continuum and patterns of sexual risk behaviour in numerous settings worldwide [6–10]. Close examination of this syndemic is a key issue for global public health [11].

Among PLWH in China - who already face high levels of HIV stigma, psychological distress, and suboptimal adherence to antiretroviral therapy (ART) [4] - the COVID-19 pandemic has presented further barriers to HIV control [5]. Quarantine and social distancing reduce access to routine HIV testing which reduces the identification and treatment of new HIV infections [12]. Timely linkage to HIV services and initiation of ART have been affected during the COVID-19 pandemic, with many hospitals designated for treatment of COVID-19 suspending taking on new patients with HIV [4]. The COVID-19 pandemic has hindered ART, due to hospital visits being restricted from city lockdowns/traffic controls [4]. In February 2020, a survey in China found 32.6% of PLWH were at risk of ART discontinuation and about half (48.6%) did not know where to get ART in the near future [13]. These gaps in HIV treatment could lead to increased HIV-related deaths and higher risk of HIV transmission. Conversely, MSM in other countries have reported having fewer sexual partners during periods of COVID-19-related lockdown, which may temporarily reduce HIV transmission [7].

Mathematical modelling can be used to capture the complexity of these changes and estimate the impacts of COVID-19 on HIV epidemiology. One modelling study of PLWH in Africa projected that a 6-month interruption in ART supply across 50% of the population on treatment could lead to a 60% increase in HIV-related deaths over a 1-year period [14]. Another modelling study on low-and-middle-income countries (LMIC) projected that HIV-related deaths would increase by 10% over the next five years, with the greatest impact on mortality estimated to be from ART interruptions [15]. However, neither of these studies

104   used observed COVID-19 impact data to inform their modelled disruptions, which is

105   essential for obtaining reliable projections for the true scale of COVID-19 disruptions.

106

107   To our knowledge no COVID-19 impact modelling has been published focussing on key

108   populations, who are the main groups affected by HIV [16]. In addition, no model projections

109   have to date incorporated observed data from the COVID-19 disruption. In this study, we

110   addressed this by collating data on the impact of COVID-19 and resulting lockdown

111   measures on HIV testing and treatment among PLWH, sexual risk behaviour and condom use

112   among MSM in China. We used a deterministic model of HIV transmission and treatment

113   among MSM in China to estimate the impact of these disruptions on new HIV infections and

114   HIV-related deaths. We identified where HIV prevention and treatment efforts should be

115   focussed to help mitigate potential adverse effects of COVID-19.

116

Methods

Observed disruptions due to COVID-19 in China

119   Estimates of changes in HIV testing (among MSM), treatment initiation and viral load

120   suppression (among all PLWH) came from surveillance data from Jiangsu province (HIV

121   testing/clinics), from the first quarter of 2019 and 2020 [17]. Estimates of changes in number

122   of sexual partners and consistency of condom use came from an online survey conducted

123   among MSM (N=731) across 31 provinces in China between 18/05/2020-02/06/2020, during

124   the COVID-19 pandemic. From these data, we estimated the following percentage changes

125   due to the disruption caused by COVID-19, compared to the pre-COVID period (before

126   01/01/2020):

127

128   I.   The number of MSM undergoing facility-based HIV testing in the first quarter of

129   2019 was 6436 compared to 2641 in 2020, a reduction of 59% (95% CI:58-60%).

130   II.   The number of PLWH initiating ART in the first quarter of 2019 was 315 compared

131   to 208 in 2020, a reduction of 34% (95% CI:29-39%).

132   III.   There was no change in viral suppression (VS) among PLWH. 95.3% (940/986; 95%

133   CI:93.8-96.6%) of viral load tests showed VS in the first quarter of 2019, with similar

134   numbers in 2020 (96.0%, 928/967; 95% CI:94.5-97.1%). The proportion of diagnosed

135   PLWH who had a viral load test was similar in both years: 4.7% in the first quarter of

136   2019 and 4.3% in the first quarter of 2020. Note most viral load tests in this region are

137   conducted in the 3rd/4th quarter.

138 IV. 62% (313/506) of MSM reported reduced numbers of sexual partners compared to the

139   pre-pandemic period (among those who had male partners in the last six months).

140 V. 25% (126/506) of MSM used fewer condoms with their partners compared to the pre-

141   pandemic period.

142

143 **Mathematical model**

144 We used a model of HIV testing/transmission/treatment among MSM in China which was

145 previously developed to evaluate the long-term impact of an HIV self-testing intervention in

146 four cities (Guangzhou/Shenzhen/Jinan/Qingdao) [18]. All individuals within the model are

147 categorised by infection status, risk (≤/>two male anal sex partners in the last three months),

148 anal sex role (always insertive/versatile/always receptive), infection stage

149 (acute/CD4>500/351-500/200-350/<200 cells/µl), and diagnosed/ART status. Uninfected

150 MSM enter the population upon sexual debut and leave through migration or non-HIV/HIV-

151 related death. Those not on ART move into more advanced stages of infection, while those

152 on ART do not; their mortality is modelled as a function of infection stage at ART initiation

153 (Fig.S2).

154

155 Both facility-based and self-testing are modelled, and MSM are distinguished by whether or

156 not they have previously tested. Those on ART who drop out re-enter the diagnosed

157 compartments. HIV transmission occurs via anal sex between MSM at a rate which depends

158 on HIV disease stage/ART coverage/VS/total partners/total sex acts/sexual role/condom

159 efficacy and use. The model was calibrated to MSM city-level HIV epidemics, parameterised

160 using demographic/behaviour data from CDC/trials, calibrated to local

161 city/province/national-level estimates ("fitting metrics") of HIV prevalence/ART

162 coverage/diagnosis/incidence/population size [18]. The model was solved in R.3.5.1.

163 Model/schematics (Figs.S2-3), parameters/fitting metrics (Table S6) and fitting metrics

164 (Fig.S1) are given in the supplement.

165

166 **Base case scenario (no COVID-19)**

167 The model was run for five years until 01/01/2025 using the fitted model parameters, with all

168 parameters constant at their 2019 values from 01/01/2020 onwards. These base case runs

169 predicted the non-COVID-19 trajectory of HIV prevalence and care for each city.

170

171 **COVID-19-related disruption scenarios**

172 Disruption scenarios were implemented from 01/01/2020 and run for 3 months, after which

173 all parameters were reset to their original pre-COVID-19 values. Comparisons of these

174 scenarios with the base case were made over one (01/01/2021) and five years (01/01/2025).

175

176 The following *observed* disruption scenarios were based on the observed disruptions –

177 reductions in:

178   A. facility-based HIV testing (59%)

179   B. ART initiation (34%)

180   C. number of sexual partnerships (31–62%)

181   D. condom use (12.5–25%)

182

183 Although data from Jiangsu province suggested no disruption to VS, disruptions in ART

184 provision have been reported to the WHO [19]. We explored an additional *hypothetical*

185 scenario where VS was reduced by 10% (consistent with reductions in ART access among

186 MSM in United States [7]) and 25% (consistent with disruptions to ART uptake reported

187 among PLWH in China [4]):

188   E. Reduction in VS of 10/25%

189

190 The data on sexual partnerships and condom use estimated the proportion of MSM having

191 fewer partnerships/using condoms less frequently (not of their overall reductions). We

192 sampled partnership and condom use parameters from uniform distributions with bounds of

193 half-reported to full-reported reductions. Reductions in condom use were modelled as a

194 reduction in the proportion of sex acts in which a condom is used. Reductions in HIV testing

195 and ART initiations were modelled as reductions in the facility-based HIV testing rate and

196 ART initiation rate, and reductions in partner numbers were modelled as reductions in

197 numbers of partners per year (applied across all risk groups). VS reductions were modelled as

198 increases in infectiousness and HIV-related mortality among those on ART, assuming a

199 proportion (10%/25%) of virally suppressed MSM stop taking ART, having the same

200 infectiousness and HIV-related mortality as individuals not on ART. No reduction in HIV

201 self-testing rates were modelled, in line with local observations in Jiangsu.

202

203 We assessed the impact of each disruption (A,B,C,D,E) separately, and also assessed the
204 combined impact of these disruptions occurring simultaneously (±scenario-E). The impacts
205 of disruptions lasting 3, 4 and 6 months were assessed.

206

207 The outcome measures used to assess the disruption caused by COVID-19 were total and
208 relative percentage change in new infections and HIV-related deaths, compared to the base
209 case, non-COVID-19 scenario. These impacts were evaluated over 1-year (01/01/2020-
210 01/01/2021) and 5-years (01/01/2020-01/01/2025). All impact measures were expressed as
211 median values and 95% credible intervals (95% CrI), across the 100 selected parameter sets
212 in each city, and across the 400 parameter sets from all cities.

213

214 We analysed the sensitivity of these scenarios (A,B,C,D,E) to different magnitudes of
215 disruption (0,25,50,75,100%) over 1 and 5 years with a 3-month disruption. We plot the %
216 change in new HIV infections and HIV-related deaths as a function of each individual
217 disruption parameter.

218

Results

220 The percentage change in impact measures (new HIV infections and HIV-related deaths) did
221 not vary between each city, with greater within-city variation across the scenarios. Therefore,
222 all results are presented as the overall impact across four cities (Table S1,
223 Guangzhou/Shenzhen/Jinan/Qingdao), with results for each city in the supplement (Tables
224 S2-5).

225

Single and combined 3-month disruptions

227 Realistic disruptions to facility-based HIV testing, ART initiation and condom use were each
228 estimated to lead to an increase in new HIV infections among MSM (Fig.1a, Tables S1-S5).
229 Disruptions to condom use (scenario-D) lasting 3 months were predicted to lead to the largest
230 overall relative increase in HIV infections, of 7.8% (95% CrI:4.5-13.8%) over one year
231 (Fig.1a), with relative increases of 2.3% (1.7-2.9%) and 1.7% (1.2-2.4%) predicted over 1
232 year for realistic 3-month disruptions to facility-based HIV testing (scenario-A) and ART
233 initiations (scenario-B), respectively. Reductions in numbers of sexual partners (scenario-C)
234 were predicted to reduce HIV infections, by a median 16.2% (11.1-23.2%) over one year
235 among MSM following a 3-month disruption.

236

237   A hypothetical 10%/25% reduction in VS (E10/E25) would lead to increased numbers of

238   HIV infections. 25% reductions in VS increased new HIV infections by 7.4% (4.7-14.0%)

239   over one year given a 3-month disruption.

240

241   The effect of each disruption scenario on the relative percentage change in HIV infections

242   was always smaller over five years than after one year (but not the absolute difference in HIV

243   infections, which generally increased over 5 years), with a more rapid decrease in effect over

244   5 years seen for disruptions to partnership numbers, condom use and VS (Fig.1a).

245

246   When all of the observed disruptions (A+B+C+D) were modelled simultaneously, a decrease

247   in new HIV infections was always predicted over one year (median 8.7%, (2.8%-17.2%)), but

248   over 5 years this impact reduced to a 1.6% (-0.6%-4.3%) decrease in new HIV infections due

249   to the disruptions to HIV testing (increase 1.7%, 1.2%-2.4%) and ART initiation (increase

250   1.1%, 0.7-1.8%) having a longer-lasting effect on ART outcomes, with ART taking longer

251   post-disruption to return to pre-disruption levels.

252

253   HIV-related deaths were also predicted to increase following disruptions to HIV testing/ART

254   initiations/condom use/VS (scenarios-A,B,D,E), and decrease following disruptions to

255   partnerships (scenario-C) (Fig.1b, Tables S1-S5). Small impacts (<1%) on HIV-related

256   deaths were predicted over one year for 3-month disruptions to HIV testing, partner numbers

257   or condom use. Larger increases in HIV-related deaths were predicted to occur following 3-

258   month disruptions to ART initiations – a 1.8% (1.5-2.0%) increase over one year–and,

259   especially, VS – a 10.1% (7.6-12.7%) increase over one year following a 25% VS reduction.

260   The observed disruptions together (A+B+C+D) resulted in 1.5% (1.1-1.8%) more HIV-

261   related deaths over one year and 0.6% (-0.3-1.2%) over five years.

262

263   Including reductions of 10%/25% in levels of VS alongside the other, observed scenarios

264   (A+B+C+D+E10, A+B+C+D+E25) always led to an increase in new HIV infections, and,

265   particularly, an increase in HIV-related deaths, over a 1- or 5-year time horizon, compared to

266   the observed scenarios (A+B+C+D) alone (Figs.1a,b).

267

268   **Sensitivity in disruption duration**

269　　When comparing the impacts of two combined disruption scenarios (A+B+C+D and

270　　A+B+C+D+E25) for disruptions lasting 3/4/6 months, we found impacts on both new HIV

271　　infections and HIV-related deaths were approximately linear, with a 4-month disruption

272　　leading to around 34% greater impact than a 3-month disruption, and a 6-month disruption

273　　around two times the impact of a 3-month disruption, over both the 1- and 5-year time

274　　horizons (Fig.2).

275

276　　**Impact in different cities**

277　　The absolute numbers of predicted additional/prevented infections and deaths varied for each

278　　city (Tables S2-S5), related to differing MSM population sizes, but the percentage changes in

279　　infections and deaths did not vary substantially between cities (Fig.3, Tables S2-S5). For

280　　example, for scenario A+B+C+D, the overall predicted reduction in new HIV infections over

281　　one year varied from 8.7% (-2.8-17.2%) in Qingdao to 9.1% (2.5-15.0%) in Jinan, with far

282　　greater within-city than between-city uncertainty (Fig.3).

283

284　　Over 5 years, realistic 3-month disruptions to HIV testing, ART initiations, sexual risk

285　　behaviour and condom use (scenario A+B+C+D) would lead to on average 3 fewer new HIV

286　　infections but 1 additional HIV-related death among MSM in Jinan and Qingdao, 6 fewer

287　　infections and 3 additional deaths in Guangzhou, and to 18 fewer HIV infections but 9

288　　additional HIV-related deaths among MSM in Shenzhen.

289

290　　The combined hypothetical scenario (A+B+C+D+E) lasting for 3 months, over 5 years,

291　　would lead to an average 3 additional new HIV infections in Guangzhou, 7 in Shenzhen but

292　　no change in Jinan and Qingdao, with 11 additional HIV-related deaths in Guangzhou, 33 in

293　　Shenzhen and 3 in Jinan and Qingdao.

294

295　　**Sensitivity in disruption magnitude**

296　　Over 1 or 5 years, with a 3-month disruption, the relationship between the magnitude of the

297　　disruption (0,25,50,75,100%) and the projected impact was always linear (Fig.S4-5, Table

298　　S7-8), with higher values of % disruption leading to increases in new HIV infections and

299　　HIV-related deaths for four disruption parameters (facility testing/ART initiation/condom

300　　use/VS) but not for partnership disruption, (fewer infections and deaths).

301

302   For a 3-month disruption evaluated over a 1-year, theoretical disruption scenarios A-E50

303   (affecting 50% of MSM) increased new HIV-infections by 1.8%, 2.4%, -16.7% (decrease),

304   15.8% and 11.3% respectively, and increased HIV-related deaths by 0.1%, 2.5%, -0.4%

305   (decrease), 0.5% and 18.2% respectively (Fig.S4, Table S7). If disruption scenarios affected

306   100% of MSM (A-E100), then new HIV-infections were projected to increase to 3.7%, 4.9%,

307   -30.2% (decrease for 95% affecting MSM – the model requires >0 partnerships), 38.7% and

308   29.3% respectively. Scenarios A-E100 would also cause HIV related deaths to increase to

309   0.3%, 5.3%, -0.8% (decrease – for 95% disruption), 1% and 35.7% respectively.

310

Discussion

312   Available data in this analysis suggests that the COVID-19 pandemic and measures

313   undertaken against it have resulted in reduced rates of HIV testing and treatment among

314   MSM in this region of China but have not so far had an impact on VS rates. Survey data also

315   suggested MSM in China had fewer partners and used condoms less often during the

316   COVID-19 pandemic. Using these data in our modelling analysis, simulating realistic 3-

317   month disruptions to HIV testing, ART initiation, condom use and partner numbers, we

318   found fewer new HIV infections are projected to occur among MSM in China over 2020 (9%

319   fewer) than would have occurred in the absence of the COVID-19 pandemic, with a smaller

320   decrease (2%) seen over 5 years. This decrease was largely due to reductions in sexual

321   partner numbers counteracting a reduction in ART initiations and condom use. Our models

322   do suggest these disruptions will lead to small increases in HIV-related deaths (2% over 1

323   year and 1% over 5 years). When we also evaluated potential reductions in VS of 25%

324   alongside these observed disruptions, we predicted a 4% decrease in new HIV infections and

325   10% increase in HIV-related deaths over one year. When evaluating the effects of each

326   individual disruption separately, new HIV infections were most adversely affected by

327   disruptions in condom use and VS, and HIV-related deaths by reductions in VS. Therefore,

328   our results suggest HIV prevention and treatment efforts should focus on maintaining use of

329   condoms and VS among MSM in China to mitigate short- and long-term adverse effects of

330   the COVID-19 disruption.

331

332   Although disruptions to VS had consequences for HIV incidence/mortality, data from Jiangsu

333   [17] indicated no change in VS among PLWH due to COVID-19 disruption. Other surveys

334   among PLWH in China indicate disruptions to ART access [4] which could lead to

335   reductions in VS. It is critically important to quantify such reductions in treatment access and

336   VS among MSM in China, and we suggest that future surveys should focus their efforts on

337   determining the true scale of the disruption to VS, which is likely to be delayed and could

338   occur after observed treatment disruptions.

339

340   The length of disruption is also critical in determining the longer-term impacts of COVID-19.

341   Throughout our main analysis we used a disruption length of 3 months, with sensitivity

342   analyses (with longer 4/6-month disruptions) demonstrating a linear relationship between the

343   duration of disruption and the change in both new HIV infections and HIV-related deaths,

344   with a doubling in disruption duration leading to a doubling in the impact. When assessing

345   the combined impact of the observed disruptions, the direction of the linear relationship was

346   different for HIV-related deaths (positive – longer duration gave more deaths) and new HIV

347   infections (negative – longer duration gave fewer new infections).

348

349   The absolute numbers of new HIV infections and HIV-related deaths varied between the four

350   cities in China modelled, due to the different population sizes, epidemiology and care cascade

351   in each city (reflected in data used for calibration [18]). However, the percentage change in

352   impact measures did not vary between each city, with much greater within-city variation.

353   This result is surprising, considering each city has different future projected HIV prevalence

354   (5.0 – 12.2% in 2036, based on data specific to these cities [20] in Booton et al. [18]) and are

355   in two different provinces (Guangdong/Shandong). Therefore, the impact predicted in this

356   study is likely to be applicable to MSM within any city/region in China.

357

358   We may compare our results to other modelling studies predicting the potential impact of

359   COVID-19 related disruption on HIV prevention and treatment. Jewell et al. [14] used

360   multiple African models of 3 month disruptions affecting 50% from 01/04/2020, reporting

361   increases in HIV incidence of <1% from the suspension of HIV testing (*compared to our*

362   *prediction of* 1-2% for *50% reductions* in facility testing, scenario-A50, all scenarios in Table

363   S7), <2% from no new ART initiations (2-4%, scenario-B50), 2-9% from the interruption of

364   condom availability (12-33%, scenario-D50), 4-89% from ART interruption (9-31% for 50%

365   reduction in VS, scenario-E50). Suspension of testing for 50% increased deaths by <1%

366   (<1%, scenario-A50), ART initiation <2% (2-3%, scenario-B50) and condom availability 0%

367   (0-1%, scenario-D50) with ART interruption causing an increase of 17-62% (14-25%,

368   scenario-E50). Our results align well with these estimates, considering the different

369   methodology/definitions of disruption/population (all adults/children, compared to solely

370   MSM) and underlying models and data (different settings/treatment/condom use). This is a

371   major strength of our study, the use of early data from China, to estimate data-driven (rather

372   than theoretical) magnitudes of COVID-19-related disruptions. Another major strength of this

373   study was performing our analysis on four separate cities from two distinct regions within

374   China. In addition, our analysis involves various scenarios and the effects of combining these

375   enables us to better understand the relative impact of different disruptions.

376

377   Generalising our results to LMIC should be done with consideration of the differences

378   between China and the respective country. Early estimates of COVID-19 impacts on

379   testing/treatment/sexual risk behaviour were available as China was the first centre of the

380   COVID-19 pandemic, and as more data becomes available, other LMIC countries may report

381   different survey data. Our modelling analysis was able to highlight which of these disruptions

382   are likely to have the biggest negative impacts on HIV incidence and deaths, indicating

383   disruptions which should be prioritised for monitoring and mitigation in other countries.

384

385   Our analysis has some limitations which should be acknowledged. Not all of the disruption

386   estimates were MSM specific, and MSM may have had more substantial disruption when

387   compared to other populations (MSM facility testing was reduced by 59%, compared to 29%

388   for the entire population [17]). Therefore, we may have underestimated the disruption to ART

389   initiations. The survey data only gave semi-quantitative estimates of disruptions to

390   partnerships and condom use i.e. proportion of MSM having fewer partners and not the

391   overall reduction in partner numbers. We accounted for this by exploring uncertainty in the

392   reduction and sampling from a wider distribution of estimates. Further, the disruption

393   estimates for testing/ART initiations/VS came from Jiangsu, different to the cities we model

394   (Guangdong/Shandong), and estimates for disruptions to partner numbers/condom use came

395   from 31 provinces, meaning we may not have fully captured the impact of COVID-19 in each

396   city. Finally, we have not modelled the direct impacts of COVID-19 infection. Future

397   extensions work could include modelling the potential characteristics of co-infection between

398   HIV and COVID-19.

399

Conclusions

400

401 The COVID-19 emergency is impacting HIV care worldwide, as face-to-face consultations
402 and laboratory testing are reduced, drug and condom manufacture and transport are
403 interrupted, and lockdowns affect peoples' ability to access testing or collect medicines. Gaps
404 in HIV treatment could lead to increased deaths from HIV and further HIV transmission,
405 placing further burdens upon healthcare systems. The overall impact of COVID-19 on new
406 HIV infections and HIV-related deaths is expected to be low to moderate for MSM in China,
407 but this is dependent on the scale and length of the various disruptions. Resources should be
408 urgently directed to ensuring VS and condom use remain high in order to mitigate any
409 adverse effects of COVID-19 disruption on HIV transmission and control among MSM in
410 China.

411

Competing interests

412

413 KMM has received an honorarium from Gilead for speaking outside of the submitted work.
414 All other authors have no competing interests.

415

Authors' contributions

416

417 Conception and design of the study: RDB, GF, JJO, JDT, KMET, WT, PV, KMM.
418 Acquisition of data: GF, JL, WT. Mathematical modelling: RDB, LM, KMET, PV, KMM.
419 Coding and simulations: RDB. Analysis and interpretation of results: RDB, GF, LM, JL, JJO,
420 JDT, KMET, WT, PV, KMM. Writing and drafting of the manuscript: RDB, GF, LM, JL,
421 JJO, JDT, KMET, WT, PV, KMM. Approval of the submitted manuscript: RDB, GF, LM,
422 JL, JJO, JDT, KMET, WT, PV, KMM.

423

Acknowledgements

424

437

438   **Additional files**

439   Additional file 1: Supplement **Supplement.docx**

440   Information on file format. Further details of the mathematical model and full results.

441

442

443   **List of abbreviations**

444   HIV human immunodeficiency virus

445   COVID-19 the disease caused by the SARS-CoV-2 (2019-nCoV) coronavirus.

446   PLWH people living with HIV

447   MSM men who have sex with men

448   ART antiretroviral therapy

449   LMIC low- and middle-income countries

450   VS viral suppression

451   CrI credible interval

452   CI confidence interval

453   CDC centre for disease control

454

455   **References**

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516 **Figures**
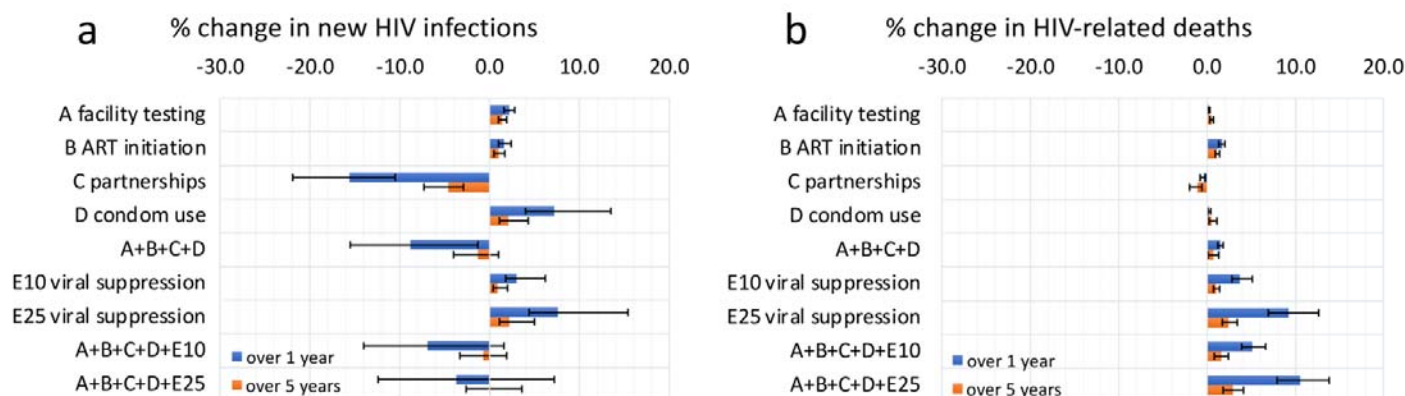
517

518 **Figure 1:** The percentage change in (a) new HIV infections and (b) HIV-related deaths under disruption

519 scenarios evaluated over a 1- and 5-year time horizon (blue and orange respectively) in four cities in China.

520 Bars indicate median values, while error bars show the 95% credible intervals for each scenario and time

521 horizon. Scenarios are as follows: A) Reduction in facility-based HIV testing (59%), B) Reduction in ART

522 initiation (34%), C) Reduction in number of sexual partnerships (31 – 62%), D) reduction in condom use (12.5 –

523 25%) E10) Reduction in viral suppression of 10%, E25) Reduction in viral suppression of 10%.

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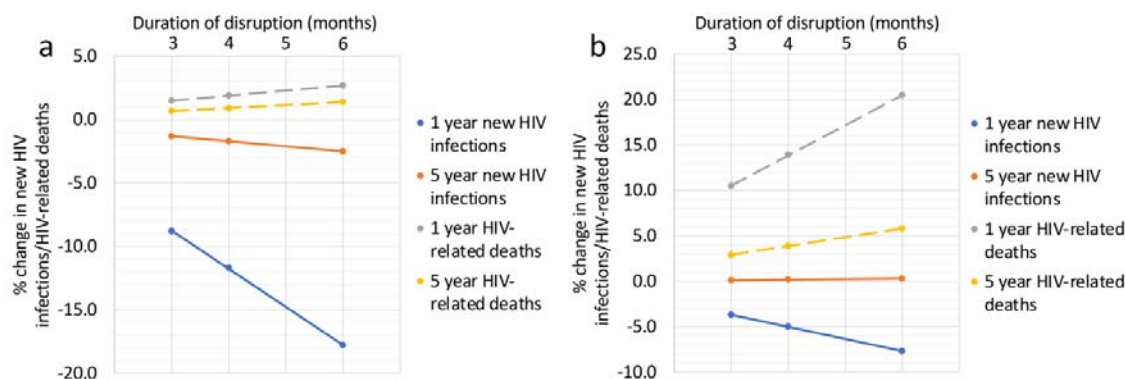
525

526 **Figure 2:** The percentage change in new HIV infections and HIV-related deaths for scenarios (a) A+B+C+D

527 and (b) A+B+C+D+E25 for varying disruption periods (3, 4 and 6 months) and time horizons (1- and 5-year) in
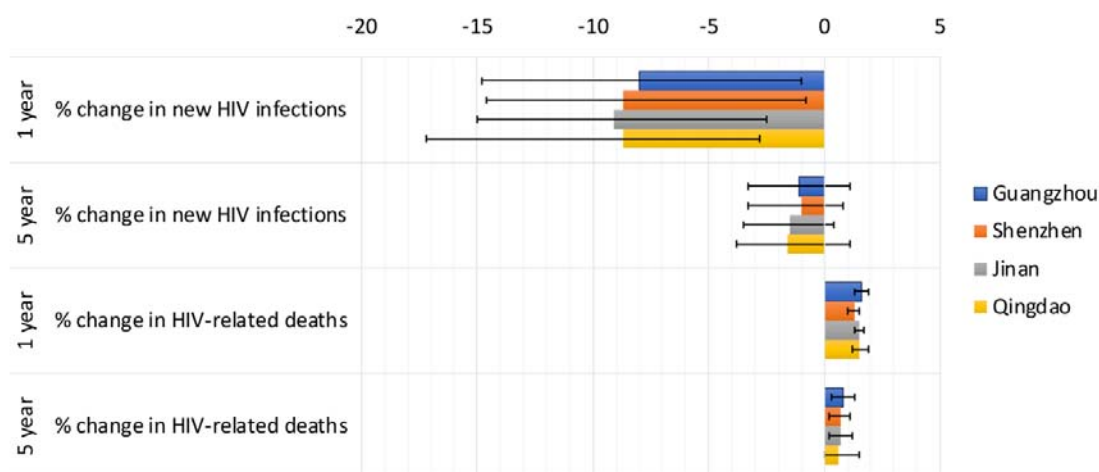
528 four cities in China. Dots indicate median values.

Figure 3: The percentage change in new HIV infections and HIV-related deaths for scenario A+B+C+D for different cities (Guangzhou, Shenzhen, Jinan and Qingdao), and time horizons (1- and 5-year). Bars indicate median values and error bars show the 95% credible intervals.