Early Evidence of Effectiveness of Digital Contact Tracing for SARS-CoV-2 in Switzerland

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33   **In the wake of the pandemic of coronavirus disease 2019 (COVID-19), contact tracing has**

34   **become a key element of strategies to control the spread of severe acute respiratory**

35   **syndrome coronavirus 2019 (SARS-CoV-2). Given the rapid and intense spread of SARS-**

36   **CoV-2, digital contact tracing has emerged as a potential complementary tool to support**

37   **containment and mitigation efforts. Early modelling studies highlighted the potential of**

38   **digital contact tracing to break transmission chains, and Google and Apple subsequently**

39   **developed the Exposure Notification (EN) framework, making it available to the vast**

40   **majority of smartphones. A growing number of governments have launched or**

41   **announced EN-based contact tracing apps, but their effectiveness remains unknown.**

42   **Here, we report early findings of the digital contact tracing app deployment in**

43   **Switzerland. We demonstrate proof-of-principle that digital contact tracing reaches**

44   **exposed contacts, who then test positive for SARS-CoV-2. This indicates that digital**

45   **contact tracing is an effective complementary tool for controlling the spread of SARS-**

46   **CoV-2. Continued technical improvement and international compatibility can further**

47   **increase the efficacy, particularly also across country borders.**

48   Contact tracing is a key element of the response to the pandemic of coronavirus disease

49   2019 (COVID-19), caused by severe acute respiratory syndrome coronavirus 2019 (SARS-

50   CoV-2). By August 30, 2020, nearly 25 million diagnosed cases and over 800,000 confirmed

51   deaths had been recorded [1]. Contact tracing is part of a strategy of "test, trace, isolate

52   and quarantine" (TTIQ), which aims to stop recently infected individuals from transmitting

53   SARS-CoV-2 [2]. The capacity for transmission before the onset of symptoms and the short

54   incubation period mean that contact tracing has to be fast to be effective [3,4]. While

55   modelling results showed that rapid, digital contact tracing could be a critical tool for

56   containment and mitigation efforts [5], early efforts to develop and deploy digital

57   applications were hampered by critical limitations imposed by smartphone operating

58   systems and concerns about confidentiality and data protection. The Exposure Notification

59   (EN) framework, jointly developed by Google and Apple, addressed these limitations and

60   enabled the implementation of digital contact tracing applications (apps) in which all

61   proximity contact information, and any decision-making about whether or not to notify a

62   user of an exposure, remain on a user's device, rather than on the server of a central

63   authority. This approach minimizes privacy risks [6], but the restriction of information to

64   users' devices means that data needed to evaluate the effectiveness of EN-based contact

65   tracing apps have to be collected from different sources [7].

66

67   SwissCovid was the first EN-based contact tracing app launched by a governmental public

68   health authority, initially as a pilot to a limited number of users, on May 25, 2020. On June

69   25, 2020 the application was made available to the general population. A growing number

70   of governments have launched or announced EN-based contact tracing apps, but their

71   effectiveness remains unknown. The significance of evaluating the effectiveness of EN-

72   based contact tracing systems was highlighted by the World Health Organization [8] and is

73   considered an ethical requirement for the continued deployment of such systems [9]. Here,

74   we report early findings of the SwissCovid deployment from July 23, 2020 to August 31,

75   2020 (hereafter referred to as the study period).

76

77   **How does SwissCovid work?**

78   The technical details of the SwissCovid system are given in [10], but briefly, SwissCovid uses

79   the EN framework (version 1.2) to estimate proximity between phones. Each phone

80   generates a daily Temporary Exposure Key (TEK), from which fast rotating proximity

81   identifiers (RPI) are derived and exchanged with neighboring phones via Bluetooth Low

82   Energy (BLE) beacons. Upon confirmation of SARS-CoV-2 infection by reverse

83   transcriptase polymerase chain reaction (RT-PCR) testing, authorized Swiss health

84   professionals can generate a single-use validation code (Covidcode), which is provided to

85   the user. The Covidcode is associated with the beginning of the contagious period, which

86   was determined to start 2 days before onset of symptoms [11] for symptomatic patients,

87   and on the day of the test for patients who are asymptomatic at the time of testing. Upon

88   entering a valid Covidcode in the app, TEKs for the contagious period are transmitted from

89   the user's phone to the computer server of the Swiss Federal Office of Public Health (FOPH).

90   All SwissCovid apps regularly contact the server for uploaded TEKs and associated data,

91   and compute the exposure risk for the previous 10 days. To ensure privacy, notifications

92   are shown only on the phone and are not forwarded to a server. During the study period,

93   the notification provided users with the last day of exposure, a reminder that they are

94   entitled to a free RT-PCR test, and directed them to a SwissCovid-specific hotline.

95

96   The BLE beacons, used by SwissCovid to estimate whether two devices have been in close

97   proximity to each other for a period of time, are radio signals, which attenuate with

98   distance. The EN framework application programming interface (API) estimates the amount

99   of time a device has been close enough to other devices of infected individuals, based on

100   three different attenuation intervals. To identify attenuation levels that would best

101   estimate proximity below 1.5 meters, attenuation levels for different controlled and real-

102   life scenarios produced by different devices at different distances and orientation were

103   measured, and subsequently corrected using the per-device calibration values provided by

104   the EN framework. Per-device calibration values take into account varying antenna and

105   chip characteristics that influence sending and receiving powers. These results informed

106   the parameterization of the EN framework so that SwissCovid users are notified if they

107   spent at least 15 minutes in close proximity (1.5 meters) to RT-PCR-confirmed cases.

108

109   **Evaluation of privacy-preserving EN-based digital contact tracing**

110   Digital contract tracing is a new method, and it is therefore crucial to rapidly evaluate and

111   continuously monitor its effectiveness in the field. Digital contact tracing apps aim to

112   prevent secondary transmissions by warning exposed contacts as early as possible [7]. To

113   be an effective intervention, several technical, behavioral and procedural conditions must

114   be met [12] (Figure 1). The app must be used by both the infected index case and exposed

115   contacts (Figure 1, row 1), the index case must enter the Covidcode following a positive RT-

116   PCR test (row 2), the exposed contacts must receive notifications (row 3), and the exposed

117   contacts must respond to the warning in a timely fashion to prevent further transmission

118   (rows 4 and 5). These conditions cannot be assessed directly via the app, due to the

119   voluntary and decentralized nature of the system. Alternative indicators and data sources

120   have therefore been developed or commissioned. In Switzerland, the Federal Statistical

121   Office (FSO) monitors downloads and active use of SwissCovid and publicly releases the

122   relevant number on a daily basis [13,14]. The FOPH updated the clinical registration form

123   for RT-PCR-confirmed cases before the beginning of the study period, and included the

124   SwissCovid app as an option for the reason for the test. In addition, several ongoing

125   research studies collect information about app usage and notifications received on a

126   monthly basis, e.g. Corona Immunitas [15], a nationwide Sars-CoV-2 seroprevalence study

127   with   digital   follow-up   surveys   [16],   and   the   COVID-19   Social   Monitor

128   (https://csm.netlify.app), a regular, longitudinal online-survey on social, economic, and

129   behavioral aspects related to COVID-19, drawn from a representative panel for Switzerland.

130   Furthermore, an ongoing cohort study embedded in contact tracing in the canton of Zurich

131   [17], which   enrolls   RT-PCR-confirmed   cases   and   their   close   contacts,   investigates

132   circumstances of transmissions and risk exposures to SARS-CoV-2, and collects data about

133   use of the app.

134

135   **Downloads and active use of the SwissCovid app**

136   To measure the number of app downloads and active apps, reliable monitoring is already

137   in place (Figure 1, Box 1). By August 31, 2020, the SwissCovid app has been downloaded 2.31

138   million times, and the number of active apps per day has been estimated at 1.59 million

139   (Figure 2A). The number of active users corresponds to 18.5% of the Swiss population (8.6

140   million).

141

142   During the study period, the FOPH reported 8,522 confirmed SARS-CoV-2 cases. During

143   the same time period, the FOPH issued 1,593 (18.7% of confirmed cases) Covidcodes and

144   1,054 (12.4% of confirmed cases, 66.2% of issued Covidcodes) of these Covidcodes were

145   entered in the app by the users (Figure 1, Box 2; Figure 2B). While the decentralized nature

146   makes it impossible to know how many notifications were subsequently generated, the

147   entered Covidcodes triggered 874 phone calls to the SwissCovid hotline, thus providing

148   evidence for actions undertaken by notified contacts (Figure 1, Box 3; Figure 2B).

149

150   The Zurich SARS-CoV-2 Cohort provides additional evidence for SwissCovid app use and

151   notification response among RT-PCR-confirmed cases and their close contacts. From

152   August 7, 2020 to August 28, 2020, this study recruited 96 cases out of 1227 (7.8%)

153   individuals tested RT-PCR-positive in Zurich during the same period. Of the 96 recruited

154   positive cases, 53 (54%) reported that they had used the SwissCovid app, of whom 48

155   entered the Covidcode in the app. Also, in a sample of 82 exposed close contacts of RT-

156   PCR-confirmed cases from the same cohort, 60 of the 82 close contacts (73%) reported

157   that they had used the SwissCovid app. Of those 60 app users, 23 (38%) received an app

158   notification in addition to being identified by the classic contact tracing system.

159

160   **Evidence for app users responding to notifications**

161   Routine public health surveillance data suggest that notified contacts seek SARS-CoV-2

162   testing (Figure 1, Box 4). Information on reason for RT-PCR testing has been collected

163   during the study period and was available for 5,491 (64%) of the 8,522 confirmed cases.

164   Among these, 4,426 reported symptoms compatible with COVID-19, 331 reported outbreak

165   investigation, and 26 reported the SwissCovid app as the reason for the test (Figure 1, Box

166   5). As the information on the reason for the test was only complete for 64% of confirmed

167   cases, the total number of cases that were tested because of the notification by the app is

168   likely higher. To estimate this number, we applied multiple imputation by chained equation

169   [18], accounting for the effect of age and sex on the probability of missing information. This

170   approach yielded a total of 37 cases (95% CI: 29-48) reporting the SwissCovid app as the

171   reason for testing over the period considered. These cases displayed a slightly younger age

172   distribution but a similar sex distribution compared to cases reporting another reason for

173   testing (Figure 2C).

174

175   **Effectiveness of the SwissCovid app**

176   A key measure to quantify the effectiveness of contact tracing at identifying SARS-CoV-2

177   infections is the number of positive contacts per index case. This number depends on

178   several factors, such as the number of contacts traced per index case and the overall

179   dynamics of the epidemic. Two large studies of classic contact tracing for SARS-CoV-2

180   found 23 secondary cases in contacts of 100 index cases (0.23, 95% CI: 0.15-0.32) in Taiwan

181   [19] and 2,169 positive cases in contacts of 5,706 index cases (0.38, 95% CI: 0.37-0.39) in

182   South Korea [20]. To compare the effectiveness of the SwissCovid app to these classic

183   contact tracing studies, we estimated the number of notified positive contacts using the

184   app per index case who entered a Covidcode using the formula $\varepsilon=n/(c\mu)$, where n=37 (95%

185   CI: 29-48) is the imputed total number of confirmed cases that reported the SwissCovid

186   app as the reason for the test, c=1,054 is the number of entered Covidcodes, and μ=18.5%

187   is the proportion of the Swiss population that are active users of the app. Hence, the term

188    $c\mu$ corresponds to the number of index cases entering Covidcodes scaled by the probability

189   that their contacts use the SwissCovid app assuming a homogeneous distribution of the

190   app coverage. We obtained ε=0.19 (95% CI: 0.15-0.25), which is in a similar range to the

191   numbers from the classic contact tracing studies.

192

193   Several factors could affect the estimated effectiveness of the SwissCovid app. Due to

194   clustering of app users, the calculated ε could represent an upper estimate as the uptake

195   of the SwissCovid app in contacts of app users might be higher than the average uptake in

196   the Swiss population. Assuming μ=73%, which is the uptake of the app in contacts of RT-

197   PCR-confirmed cases from the Zurich SARS-CoV-2 Cohort, we obtained ε=0.05 (95% CI:

198   0.04-0.06) as a lower estimate which would still represent a respectable effectiveness of

199   the app at identifying SARS-CoV-2 infections in contacts of index cases. However, a

200   number of factors can also contribute to an underestimate of ε. First, confirmed cases

201   might only report the presence of symptoms as the reason for the test even though they

202   were notified by the app. Second, due to the decentralized and voluntary nature of

203   SwissCovid, there may have been more notified contacts that got infected and self-isolated

204   following the notification, but did not get tested, and are thus missing from the analysis.

205   Third, reported numbers of RT-PCR-confirmed cases using the app for the study period

206   might be slightly higher in reality due to time delays in reporting.

207

208   Reliable, continuous monitoring of app effectiveness indicators is still being improved. Also,

209   citizen reports on social media (e.g. Twitter) have suggested multi-day delays in receiving

210   Covidcodes following positive test results in some instances. Along the same lines, during

211   the study period, only about two thirds of issued Covidcodes have been entered and

212   triggered notifications (Figure 2B). Efforts to streamline procedures and app user

213   interactions with local health authorities - i.e. a direct referral of notified hotline callers to

214   the responsible local authorities - are underway. Our findings illustrate that digital contact

215   tracing can be effective even with low uptake, as suggested by mathematical modeling [21].

216   Because app coverage affects both the number of index cases and their contacts, the total

217   number of SARS-CoV-2 infections that could be identified through digital contact tracing

218   scales with the square of the coverage and could substantially increase with higher uptake

219   (Figure 2D).

220

221   In conclusion, based on the data collected during the initial deployment of the SwissCovid

222   app, we argue that voluntary digital contact tracing can show similar effectiveness at

223   identifying infected partners of index cases as classic contact tracing, provided that both

224   the index case and the exposed contacts use the app. As the effectiveness of digital contact

225   tracing crucially depends on a strong embedding into an efficient testing and contact

226   tracing infrastructure on the ground, apps like SwissCovid represent a helpful

227   complementary tool for controlling the spread of SARS-CoV-2. The strength of evidence

228   for app effectiveness as summarized in Figure 1 illustrates that most indicators have

229   reached at least a "proof-of-principle" stage. That is, the outcome of interest was observed

230   independently in two data sources in all important key indicators. There is, however, still

231   room for improvement. Upcoming improvements in the EN API by Apple and Google will

232   increase the precision in determining risk, and reduce delay in communicating it to users.

233   International interoperability exchanges, planned for October 2020, will increase the

234   effectiveness of the app, in particular in the countries bordering Switzerland. Speed is

235   essential to the effectiveness of TTIQ strategies [4,5]. Reducing the time to quarantine for

236   contacts, as a result of digital contact tracing, should provide an additional, important

237   benefit to COVID-19 mitigation efforts.

238

FIGURES

	Early signal (observed in single data source)	Proof of principle (observed in two independent data sources)	Reliable, valid quantification (regular monitoring in place)	Target reached (targets clearly defined and met by indicators)
1) Apps are downloaded and active			**Box 1**: Regular monitoring through Federal Statistical Office	
2) Covidcodes are issued upon PCR-positive test and entered			**Box 2**: Regular monitoring through Federal Statistical Office	
3) Notifications are received by exposed persons		**Box 3**: Reports from two independent population surveys		
4) Notifications lead to actions in exposed persons (testing, quarantine)		**Box 4**: Mandatory reporting upon PCR+ test		
5) Actions lead to prevention of secondary transmission	**Box 5**: Mandatory reporting upon PCR+ test; contact tracing study			

Accumulation of evidence →

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265

266   **Figure 1: Quality of evidence for SwissCovid app effectiveness**. Row labels: Necessary

267   technical, procedural and behavioral conditions for digital contact tracing to be effective.

268   Columns: Milestones in evidence accumulation. Green boxes indicate available data

269   sources for evidence assessments; quantitative information related to green boxes are

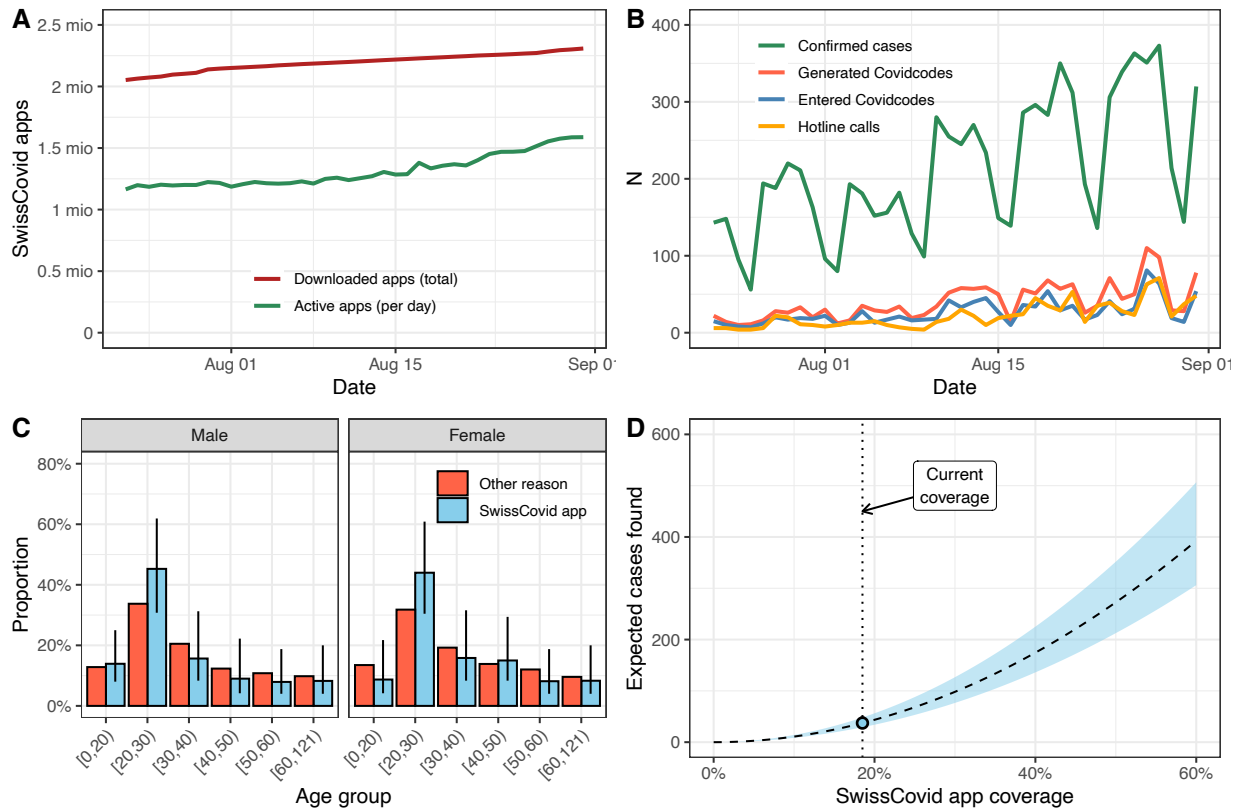270   provided in the main text.

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Figure 2: SwissCovid app measures. (A) Total number of downloaded apps and daily number of active apps. (B) Daily numbers of confirmed SARS-CoV-2 cases, generated Covidcodes, entered Covidcodes and hotline calls. (C) Age distribution of cases stratified by the reason for RT-PCR test (either SwissCovid app or other reason). (D) Expected number of RT-PCR-confirmed cases that were tested because of a notification by the app as a function of hypothetical app coverage during the study period. Error bars and the blue shaded area correspond to 95% confidence intervals.

REFERENCES

1. World Health Organization. Coronavirus disease (COVID-19) - Weekly Epidemiological Update. [cited 4 Sep 2020]. Available: https://www.who.int/docs/default-source/coronaviruse/situation-reports/20200831-weekly-epi-update-3.pdf?sfvrsn=d7032a2a_4

2. Salathé M, Althaus CL, Neher R, Stringhini S, Hodcroft E, Fellay J, et al. COVID-19 epidemic in Switzerland: on the importance of testing, contact tracing and isolation. Swiss Medical Weekly. 2020. doi:https://doi.org/10.4414/smw.2020.20225

3. Aleta A, Martin-Corral D, Piontti AP y, Ajelli M, Litvinova M, Chinazzi M, et al. Modeling the impact of social distancing, testing, contact tracing and household quarantine on second-wave scenarios of the COVID-19 epidemic. Medrxiv. 2020; 2020.05.06.20092841. doi:10.1101/2020.05.06.20092841

4. Kucharski AJ, Klepac P, Conlan AJK, Kissler SM, Tang ML, Fry H, et al. Effectiveness of isolation, testing, contact tracing, and physical distancing on reducing transmission of SARS-CoV-2 in different settings: a mathematical modelling study. Lancet Infect Dis. 2020. doi:10.1016/s1473-3099(20)30457-6

5. Ferretti L, Wymant C, Kendall M, Zhao L, Nurtay A, Abeler-Dörner L, et al. Quantifying SARS-CoV-2 transmission suggests epidemic control with digital contact tracing. Science. 2020;368: eabb6936. doi:10.1126/science.abb6936

309   6. Troncoso C, Payer M, Hubaux J-P, Salathé M, Larus J, Bugnion E, et al. Decentralized Privacy-

310   Preserving Proximity Tracing. arxiv. 2020. Available: https://arxiv.org/abs/2005.12273

311

312   7. Wyl V von, Bonhoeffer S, Bugnion E, Salathé M, Stadler T, Troncoso C, et al. A research agenda

313   for digital proximity tracing apps. Swiss Medical Weekly. 2020.

314   doi:https://doi.org/10.4414/smw.2020.20324

315

316   8. World Health Organization. Ethical considerations to guide the use of digital proximity tracking

317   technologies for COVID-19 contact tracing. [cited 4 Sep 2020]. Available:

318   https://www.who.int/publications/i/item/WHO-2019-nCoV-Ethics_Contact_tracing_apps-

319   2020.1

320

321   9. Gasser U, Ienca M, Scheibner J, Sleigh J, Vayena E. Digital tools against COVID-19: taxonomy,

322   ethical challenges, and navigation aid. Lancet Digital Heal. 2020;2: e425–e434. doi:10.1016/s2589-

323   7500(20)30137-0

324

325   10. Telecommunication SFO of ITS and. SwissCovid Exposure Score Calculation. [cited 4 Sep 2020].

326   Available: https://github.com/admin-ch/PT-System-Documents/blob/master/SwissCovid-

327   ExposureScore.pdf

328

329   11. World Health Organization. Contact tracing in the context of COVID-19. [cited 4 Sep 2020].

330   Available: https://www.who.int/publications/i/item/contact-tracing-in-the-context-of-covid-

331   19

332

333   12. Wyl V von, Hoeglinger M, Sieber C, Kaufmann M, Moser A, Serra-Burriel M, et al. Are COVID-19

334   proximity tracing apps working under real-world conditions? Indicator development and

335   assessment of drivers for app (non-)use. medRxiv. 2020. doi:10.1101/2020.08.29.20184382

336

337   13. Swiss Federal Office of Statistics. Calculation methods for estimating the number of active

338   SwissCovid apps. [cited 4 Sep 2020]. Available:

339   https://www.experimental.bfs.admin.ch/bfsstatic/dam/assets/13667538/master

340

341   14. Swiss Federal Office of Statistics. SwissCovid App Monitoring. [cited 4 Sep 2020]. Available:

342   https://www.experimental.bfs.admin.ch/expstat/en/home/innovative-methods/swisscovid-

343   app-monitoring.html

344

345   15. Corona Immunitas. [cited 4 Sep 2020]. Available: https://www.corona-immunitas.ch/program

346

347   16. Stringhini S, Wisniak A, Piumatti G, Azman AS, Lauer SA, Baysson H, et al. Seroprevalence of

348   anti-SARS-CoV-2 IgG antibodies in Geneva, Switzerland (SEROCoV-POP): a population-based

349   study. Lancet. 2020;396: 313–319. doi:10.1016/s0140-6736(20)31304-0

350

351   17. Zurich Coronavirus Cohort: an observational study to determine long-term clinical outcomes

352   and immune responses after coronavirus infection (COVID-19), assess the influence of virus

353   genetics, and examine the spread of the coronavirus in the population of the Canton of Zurich,

354   Switzerland. [cited 4 Sep 2020]. Available: http://www.isrctn.com/ISRCTN14990068

355

356   18. White IR, Royston P, Wood AM. Multiple imputation using chained equations: Issues and

357   guidance for practice. Stat Med. 2011;30: 377–399. doi:10.1002/sim.4067

358

359   19. Cheng H-Y, Jian S-W, Liu D-P, Ng T-C, Huang W-T, Lin H-H, et al. Contact Tracing Assessment

360   of COVID-19 Transmission Dynamics in Taiwan and Risk at Different Exposure Periods Before and

361   After Symptom Onset. Jama Intern Med. 2020;180. doi:10.1001/jamainternmed.2020.2020

362

363   20. Park YJ, Choe YJ, Park O, Park SY, Kim Y-M, Kim J, et al. Contact Tracing during Coronavirus

364   Disease Outbreak, South Korea, 2020. Emerging Infectous Diseases. 2020. doi:DOI:

365   10.3201/eid2610.201315

366

367   21. Abueg M, Hinch R, Wu N, Liu L, Probert WJM, Wu A, et al. Modeling the combined effect of

368   digital exposure notification and non-pharmaceutical interventions on the COVID-19 epidemic in

369   Washington state. medRxiv. 2020. doi:10.1101/2020.08.29.20184135

370

371