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Research Letter | Public Health

Modeling Contact Tracing Strategies for COVID-19 in the Context of Relaxed Physical Distancing Measures

Alyssa Bilinski, MS; Farzad Mostashari, MD; Joshua A. Salomon, PhD

Introduction

Confirmed coronavirus disease 2019 (COVID-19) cases have increased in the United States following the relaxation of strong lockdown measures.[1] Contact tracing, which entails identifying and monitoring people who have been in close contact with individuals with confirmed diagnoses and encouraging them to self-isolate and quarantine, is recommended as a key component of COVID-19 control strategies.[2-4] We used a mathematical model to examine the potential for contact tracing to reduce the spread of severe acute respiratory syndrome coronavirus 2 (SARS-CoV-2) in the context of relaxed physical distancing, under different assumptions for case detection, tracing, and quarantine efficacy.

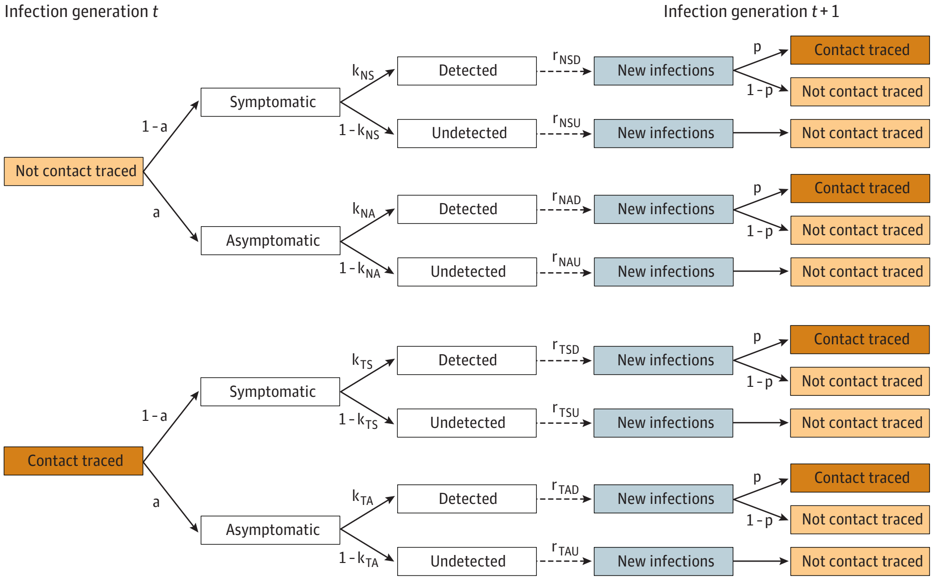
+ Supplemental content

Author affiliations and article information are listed at the end of this article.

Methods

In this mathematical modeling study, we developed a simple deterministic branching model of SARS-CoV-2 transmission (**Figure 1**; eAppendix in the Supplement). Individuals with infection transmit to others based on symptom status, detection of infection, and whether they are traced contacts of a known infected person. We varied the fraction of symptomatic infections detected in the community from 10% to 90%, the fraction of contacts successfully traced from 10% to 90%, the efficacy of isolation and quarantine among traced contacts from 30% to 90%, and whether testing included all identified contacts or only those with symptoms. We quantified the outcomes of contact tracing strategies as percentage reductions in the effective reproductive number (R_t; the mean number of secondary infections from each infection) compared with a scenario without contact tracing. This

Figure 1. Model Structure and Parameters



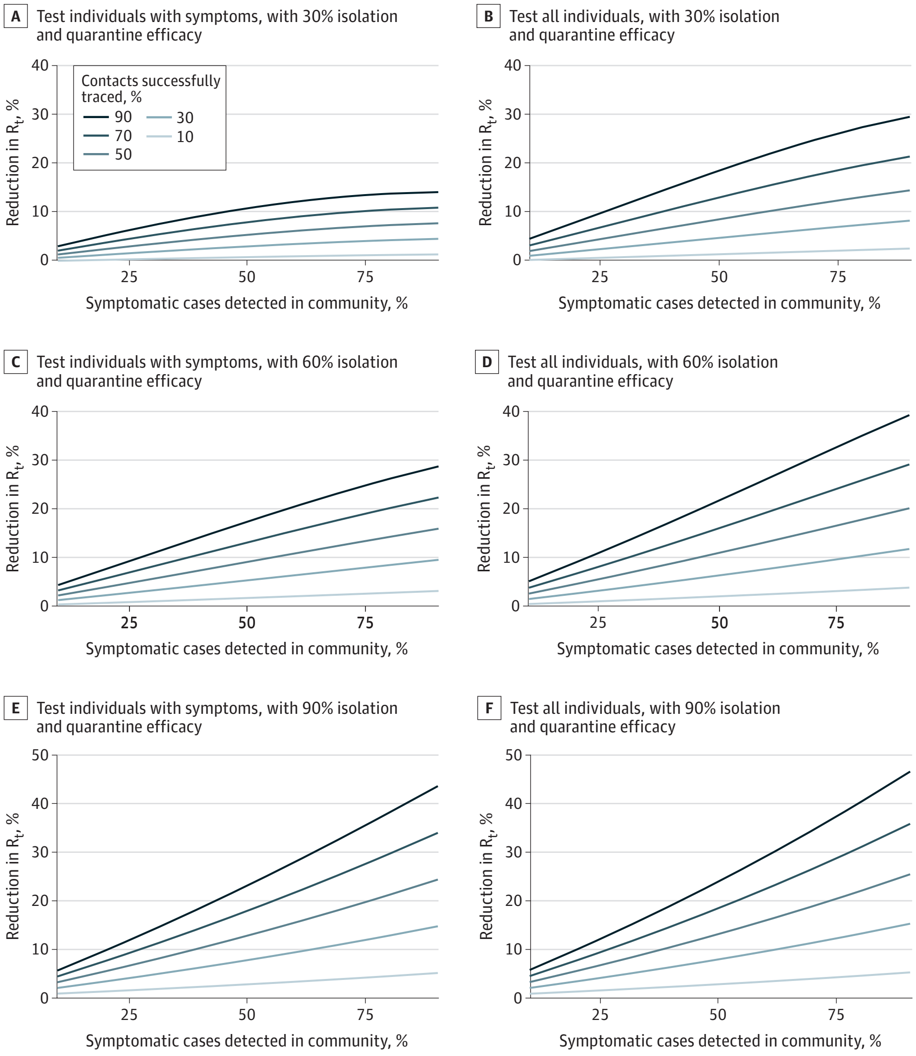
Parameter definitions: *a* is the fraction of infections that are asymptomatic; *k*, the fraction of infections that are detected; *r*, the number of secondary infections from each infection; and *p*, the fraction of cases that are successfully contact traced. For parameters indexed by subscripts: *T* is contact traced; *N*, not contact traced; *S*, symptomatic; *A*, asymptomatic; *D*, detected; and *U*, undetected. Parameter values are reported in the eAppendix in the Supplement.

measure is invariant to the starting R_t, which enables comparisons across program scenarios that do not require calibration to specific epidemiological settings. All analyses were conducted using R version 4.0.2 (R Project for Statistical Computing). Because this study did not qualify as human participants research under the Common Rule definition, no institutional review board approval was sought.

Results

When community detection of symptomatic index cases and tracing of contacts were less than 50%, simulated contract tracing programs did not reduce R_t by more than 10% (**Figure 2**). In scenarios with rates of detection and tracing that were both greater than 50%, testing asymptomatic contacts increased the program benefit by a median factor of 1.28 (range, 1.04-2.07), with a larger relative increase when isolation and quarantine efficacy were lower. The contact tracing scenario with the greatest benefit reduced R_t by 46%.

Figure 2. Reductions in the Effective Reproductive Number (R_t) Associated With Contact Tracing Strategies Under Varying Assumptions Regarding Key Program Features


A Test individuals with symptoms, with 30% isolation and quarantine efficacy

B Test all individuals, with 30% isolation and quarantine efficacy

C Test individuals with symptoms, with 60% isolation and quarantine efficacy

D Test all individuals, with 60% isolation and quarantine efficacy

E Test individuals with symptoms, with 90% isolation and quarantine efficacy

F Test all individuals, with 90% isolation and quarantine efficacy

Outcomes measured as percentage reductions in R_t in the contact tracing scenario relative to R_t without contact tracing. Isolation and quarantine efficacy refers to the level of reduction in transmission rates from traced, undetected contacts. Modeled estimates of relative reductions do not depend on current levels of R_t.

In sensitivity analyses, if the percentage of infections without symptoms was lower (20% vs base case of 40%), the benefit of contact tracing was greater, by a median factor of 1.22 (range, 1.04-1.41). In secondary analyses, we estimated the total combined benefit of improving case detection and contact tracing against the counterfactual of detecting only 20% of symptomatic infections and no contact tracing; the maximum combined benefit of tracing with higher detection was a 57% reduction in R_t.

We calculated the degree to which contract tracing efforts could compensate for relaxed physical distancing and maintain R_t less than 1.0, which is the critical threshold needed for new infections to decline. As an example, if strict physical distancing decreased R_t from 2.5 to 0.9 and a contact tracing strategy could reduce R_t by 40%, containment remained possible if physical distancing measures were applied at only 52% of the effectiveness of strict measures.

Discussion

To support efforts to control COVID-19, contact tracing must be implemented alongside prompt and extensive community case detection, and a high proportion of contacts must be reached. Similar to other models,[5,6] our estimates imply that contact tracing could support partial relaxation of physical distancing measures but not a full return to levels of contact before lockdown.

The benefits of contact tracing depend substantially on adherence to isolation and quarantine among individuals who are traced, which could be enhanced through policy measures such as voluntary out-of-home accommodations, income replacement, and social supports. Prompt testing, diagnosis, and notification of individuals with infection are needed to ensure that contacts can be traced and quarantined early enough to prevent transmission. Testing contacts without symptoms could improve program benefits by identifying new cases to trace and potentially improving quarantine adherence.

Limitations of this analysis include lack of network or household structure or explicit consideration of high-risk venues. Nevertheless, by examining a range of scenarios that reflect key uncertainties and program features, we provided benchmarks to aid in developing evidence-based mitigation and containment strategies.

ARTICLE INFORMATION

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Corresponding Author: Joshua A. Salomon, PhD, Center for Health Policy and Center for Primary Care and Outcomes Research, Stanford University School of Medicine, 615 Crothers Way, Encina Commons, Room 118, Stanford, CA 94305 (salomon1@stanford.edu).

Author Affiliations: Interfaculty Initiative in Health Policy, Graduate School of Arts and Sciences, Harvard University, Cambridge, Massachusetts (Bilinski); Aledade Inc, Bethesda, Maryland (Mostashari); Center for Health Policy and Center for Primary Care and Outcomes Research, Stanford University School of Medicine, Stanford, California (Salomon).

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Concept and design: All authors.

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Additional Information: The code for the analysis is available at https://github.com/abilinski/contact_tracing.

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SUPPLEMENT.

eAppendix. Supplementary Methods

eReferences.

Supplementary Online Content

Bilinski A, Mostashari F, Salomon JA. Modeling contact tracing strategies for COVID-19 in the context of relaxed physical distancing measures. *JAMA Netw Open*. 2020;3(8):e2019217. doi:10.1001/jamanetworkopen.2020.19217

eAppendix. Supplementary Methods
eReferences.

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Table S1. Model parameter values.

Parameter	**Value**	**Notes**
Fraction of infections that are asymptomatic (a)	40%	Estimates vary across studies.[1–4] Alternative value of 20% examined in sensitivity analysis.
Fraction of cases detected Symptomatic, not contact traced (k_{NS})	varies	Values between 10% and 90% examined. Estimates on the fraction of symptomatic cases that are detected vary considerably across locations, due to testing capacity, epidemic intensity and other factors.[5]
Asymptomatic, not contact traced (k_{NA})	5%	Assumed to be negligible based on current US testing guidelines[6]
Symptomatic, contact traced (k_{TS})	90%	Assumption, reflecting referral to testing for traced contacts
Asymptomatic, contact traced (k_{TA})	90%	Assumption, reflecting referral to testing. Applies only in contact tracing strategies that include testing for asymptomatic people.
Number of secondary infections from each infection (r)	computed	See **Table S2** for details.
Fraction of cases successfully traced (p)	varies	Values between 10% and 90% examined. New York City results imply around 33% of contacts reached, adjusting for those who do not report any contacts.[7] Massachusetts has reported an increase from 40-50% to 90% of contacts reached.[8.] The UK has set a tracing target of 80%[9] and Santa Clara County, CA a target of 90%.[10]
Duration of infectiousness Presymptomatic (d_P) Symptomatic (d_S) Asymptomatic (d_A)	 1.5 days 4 days 5.5 days	Durations inferred from temporal dynamics of viral shedding.[11]
Relative infectiousness of asymptomatic infection compared to symptomatic infection (v_A)	0.7	Estimates vary across studies (e.g. 1.0,[11] 0.66,[12] 0.5,[13] 0.25[14])
Relative infectiousness of presymptomatic infection compared to symptomatic infection	1	Inferred from studies indicating substantial presymptomatic transmission.[11,12]

(v_P)		
Relative number of secondary infections from detected infections compared to undetected infections (q)	0.5	Limited empirical data, rationale for reduced secondary transmission includes: potentially increased likelihood of adherence to self-isolation, targeting of confirmed cases for public health support.[15]
Average daily rate of transmission for symptomatic cases not traced (b)	Calibrated	Values calibrated to produce baseline R_t=1. Note that relative reductions in secondary infections, the primary outcome in this study, are invariant to the R_t level, so this calibration is only used in further application of primary results to estimate potential for containment with relaxed physical distancing.
Isolation and quarantine efficacy (e)	Varies	Values ranged from 30% to 90%. Isolation and quarantine efficacy is approximately the product of how much infectious time remains when the contact is notified, and the degree of adherence to isolation and quarantine measures. Estimates of adherence have ranged considerably in previous studies (0-94%)[16], including 70%[12] and 90%[17] in previous COVID-19 analyses. Remaining infectious time is difficult to measure, but likely less than 1.[17,18] A prior modeling study used efficacy estimates of 25% for a 'low-feasibility setting' and 75% for a 'high-feasibility setting.'[19]

Table S2. Estimation of secondary infections.

Category	Formula
Not contact traced, symptomatic, detected	$r_{NSD} = bd_P v_P + bd_S q$
Not contact traced, symptomatic, undetected	$r_{NSU} = bd_P v_P + bd_S$
Not contact traced, asymptomatic, detected	$r_{NAD} = bv_A d_A q$
Not contact traced, asymptomatic, undetected	$r_{NAU} = bv_A d_A$
Contact traced, symptomatic, detected	$r_{TSD} = (1\text{-}e)bd_P v_P + (1\text{-}e)bd_S q$
Contact traced, symptomatic, undetected	$r_{TSU} = (1\text{-}e)bd_P v_P + (1\text{-}e)bd_S$
Contact traced, asymptomatic, detected	$r_{TAD} = (1\text{-}e)bv_A d_A q$
Contact traced, asymptomatic, undetected	$r_{TAU} = (1\text{-}e)bv_A d_A$

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