Asymptomatic transmission complicates any public health strategies to combat a pandemic, which proved especially accurate in the case of COVID-19. Although asymptomatic cases are not unique to COVID-19, the high asymptomatic case rate raised many problems for developing effective public health interventions. The current modeling effort explored how asymptomatic transmission might impact pandemic responses in four key areas: isolation procedures, changes in reproduction rate, the potential for reduced transmission from asymptomatic cases, and social adherence to public health measures. A high rate of asymptomatic cases effectively requires large-scale public health suppression and mitigation procedures given that quarantine procedures alone could not prevent an outbreak for a virus such as SARS-CoV-2. This problem only becomes worse without lowering the effective reproduction rate, and even assuming the potential for reduced transmission, any virus with a high degree of asymptomatic transmission will likely produce a pandemic. Finally, there is a concern that asymptomatic individuals will also refuse to adhere to public health guidance. Analyses indicate that, given certain assumptions, even half of the population adhering to public health guidance could reduce the peak and flatten the curve by over 90%. Taken together, these analyses highlight the importance of taking asymptomatic cases into account when modeling viral spread and developing public health intervention strategies.

KEY WORDS: Asymptomatic; pandemic; public health

1. INTRODUCTION

Novel coronavirus cases (COVID-19) increased throughout the world as medical efforts desperately fought to match its speed. A significant challenge from the outset involved identifying new cases and projecting transmission of the virus so that public health policymakers could apply mitigation and suppression strategies. The countries most successful at stemming their outbreaks attributed case improvements to a combination of extensive testing, contact tracing, and subsequent isolation of infected cases (Normile, 2020). Despite the myriad of problems for public health responses, asymptomatic cases and the potential for asymptomatic transmission proved to be among the most intractable problems. Some individuals even went so far as to call asymptomatic transmission the Achilles’ heel of any strategy to control the COVID-19 outbreak (Gandhi, Yokoe, & Havlir, 2020). Given the pervasive challenge of asymptomatic transmission in controlling a pandemic, this discussion will explore the evidence for asymptomatic COVID-19 cases and how various theorized rates should impact public health policy during future pandemics.

The potential for asymptomatic transmission is not unique to COVID-19, and the topic does bring some controversy. Officials from the World Health Organization offered conflicting viewpoints about the potential of, and frequency for, asymptomatic
transmission during the early days of the pandemic (World Health Organization, 2020). Viable virus was collected from individuals who were asymptomatic (Arons et al., 2020), which indicated that the confusion arose from both possibility and description. Specifically, there is a critical distinction between asymptomatic transmission, presymptomatic transmission, and extremely mild symptomatic transmission (cf. Savvides & Siegel, 2020). An individual may contract SARS-CoV-2, the virus responsible for the disease, yet never show any symptoms. There does appear to be scientific consensus on this point.

The debate arises around whether an asymptomatic carrier can infect others with the disease. Conversely, a presymptomatic individual could show no symptoms, yet could be quite contagious (Tindale, Coombe et al., 2020; Tindale, Stockdale et al., 2020). This latter individual will develop symptoms, but during a period of high contagiousness, may not exhibit any symptoms such as fever, cough, or shortness of breath. The current discussion and data demonstration will take this difference into account and draw a critical distinction concerning transmission between individuals who are asymptomatic without ever developing symptoms and individuals who are presymptomatic, indicating that they are asymptomatic at the time of testing but would later become symptomatic. A distinction in description addresses confusion due to terminology, although there is not yet scientific consensus about transmission rates due to asymptomatic COVID-19 patients.

Early evidence cited individual cases of potential asymptomatic carrier transmission based on cases from Chinese patients (Bai et al., 2020; Cai et al., 2020) and a German patient outside the original site of the outbreak (Rothe et al., 2020). Although these individual cases identified the potential for asymptomatic transmission, evidence continued to mount with the question becoming not whether asymptomatic cases exist—but rather what was the rate of asymptomatic transmission? A pair of computational modeling studies provided some insight into this question based on data from existing outbreaks. One study estimated approximately 86% of all infections went undocumented, and while the transmission rate of undocumented cases remained only 55% of documented cases, the greater volume suggested that undocumented cases were responsible for up to 79% of documented cases (Li et al., 2020). Another study explored the epidemiological characteristics of the outbreak and similarly concluded that at least 59% of undocumented cases in Wuhan included asymptomatic and possibly very mild symptomatic cases (Wang et al., 2020). Modeling data from the outbreak in Italy suggested that only 10% of infected individuals were symptomatic (Furukawa, 2020).

Combined case studies and epidemiological modeling suggested a high incidence of asymptomatic transmission, although there was also some empirical evidence based on controlled observations. One study conducted a modeling analysis to determine the asymptomatic proportion of the positive COVID-19 cases from the Diamond Princess, a cruise ship quarantined following an outbreak (Mizumoto, Kagaya, Zarebski, & Chowell, 2020). The cruise ship evidence provided an interesting comparison due to the controlled nature of its environment, and the authors estimated the asymptomatic case proportion as 18% of all cases. A comparable study explored asymptomatic evidence from 565 Japanese citizens repatriated from Wuhan following the original outbreak (Nishiura, 2020). This evidence, similar to the Diamond Princess evidence due to the controlled nature of the sample and subsequent retesting, projected an asymptomatic case rate of 31%. A third study examined the transmission of COVID-19 in Shenzhen, China, and based upon the 921 identified cases along with 1,286 close contacts, at least 20% of cases were asymptomatic (Bi et al., 2020). Precautionary screenings of asymptomatic healthcare workers likewise revealed approximately 57% of individuals were truly asymptomatic (Rivett et al., 2020). Another tightly controlled population, the crew on board the U.S. Aircraft Carrier Theodore Roosevelt, experienced an outbreak affecting 1,271 crew members (26.6% of the crew). In this population, whose health status met U.S. Navy standards for sea duty, 76.9% (978 of 1271) were asymptomatic at the time of their testing (Kasper et al., 2020). This range of evidence supported the potential for asymptomatic COVID-19 cases and demonstrated the wide variance among the observations in their determined rate of asymptomatic cases.

For other diseases, the potential for asymptomatic transmission creates substantial problems in controlling virus and stopping outbreaks. Asymptomatic transmission has been proposed as the most parsimonious explanation about the resurgence of Bordetella pertussis in the United States and the United Kingdom (Althouse et al., 2015). The need to quantify transmissibility in asymptomatic transmission is also not a challenge unique to COVID-19 as the Zika virus presents a similar problem (Moghadas, Shoutkat, et al., 2017). Taken together, these
instances demonstrate how asymptomatic cases and/or transmission severely complicate public health mitigation and suppression strategies for controlling a viral outbreak, especially given the effectiveness of isolation and contact tracing (Hou et al., 2020; Tang et al., 2020). With an effective reproduction number \( R_0 \) of 1.5 and zero transmission prior to symptom onset, simulated outbreaks could be controlled even without a robust contact tracing system (Hellewell et al., 2020).

If the rate of asymptomatic transmission is a critical factor in the success of country-based mitigation strategies (Anderson, Heesterbeek, Klinkenberg, & Hollingsworth, 2020), then public health actions should address this troubling possibility. Previous evidence has demonstrated this need to isolate asymptomatic cases as a means of preventing outbreaks. A modeling study indicated that at least one-third of asymptomatic cases must be isolated to keep the outbreak below 1% of the population (Moghadas, Fitzpatrick et al., 2020). However, this modeling effort only utilized low-end asymptomatic transmission rates of 17.9% and 30.8%, respectively (cf. Byambasuren et al., 2020). These values fall well below other projected ranges of asymptomatic case rates. Epidemiological modeling often allows for some asymptomatic transmission via carriers of the disease, but rarely are the rates so high. Asymptomatic case rates could be between 18% and 79% for COVID-19 based on a variety of empirical observations, although the prevalence of data does appear to support transmission from individuals who are either asymptomatic, presymptomatic, or symptomatic with very mild symptoms (Gaeta, 2020). As such, the present study will explore differences in mitigation versus suppression strategies with given hypothetical rates of asymptomatic transmission. Presymptomatic transmission will be identified as a separate mode of transmission to explore how quarantine procedures might be effective or ineffective with SARS-CoV-2 viral dynamics.

2. CURRENT MODELING EFFORT

The current analysis will explore various simulated asymptomatic transmission rates in a compartmental model. The first step involves addressing assumptions needed to assign values to variables as appropriate for this simulation. Due to the novel nature of this coronavirus, there is no preexisting immunity in the population and no vaccine. The vulnerable population is therefore presumed to be 100%. Given the large vulnerable population and no vaccines at the time of initial outbreak, a simple Susceptible→Infected→Recovered (SIR) epidemiological model was chosen for these simulations (Hethcote, 2000). The primary modification involved three different infected populations with variable \( \beta \) rates to represent the change in contacts following quarantine procedures. One weight represented the presymptomatic infected population, \( \beta_\psi i_\psi(t) \), another weight represented the postsymptomatic infected population, \( \beta_\psi i_\psi(t) \), and a final weight represented the asymptomatic infected population, \( \beta_\psi i_\psi(t) \). This differentiation allows for the model to address how quarantine procedures that might affect a symptomatic population would not affect an asymptomatic population while also allowing for a differentiation of asymptomatic transmission or infection rates during simulation.

Base \( \beta \) rate was derived from existing evidence citing a median basic reproduction number, \( R_0 \), of 2.5 (CDC, 2020) with early estimates ranging between 2.2 and 3.3 (Kucharski et al., 2020; Zhou, Liu et al., 2020). The average incubation period was set as five days from existing research (cf. Backer, Klinkenberg, & Wallinga, 2020; CDC, 2020), which provided the differentiation of prediagnosis and postdiagnosis that parallels a presymptomatic period and symptomatic period. Average duration of the infection has been projected as three or seven days (Woelfel et al., 2020), although the model assumes a total period from beginning to end of 10 days (CDC, 2020). Quarantine procedures in this simulation model are assumed to be perfect, where an individual does not transmit the virus following a positive diagnosis by reducing the corresponding \( \beta \) weight to 0 for the postdiagnosis (quarantined) group. This variable represents another weight that can be manipulated during modeling. Finally, the model begins with a total infected rate of 0.01% of the population, which for the United States, would represent 32,720 cases. The United States reached this total number of positive identifications on 21 March 2020 (Dong, Du, & Gardner, 2020).

3. RESULTS

Results are divided into several sections based on the variables manipulated within the model. The first step involved projecting what the unmitigated pandemic trajectory would be based on current best CDC guidance for COVID-19 pandemic planning (\( R_0 = 2.5, 40\% \) asymptomatic, 10 days to resolution).
Biggs and Littlejohn

Fig 1. Values associated with unmitigated COVID-19 progression. Modeling values are determined based on CDC pandemic planning scenarios as of November 2020 ($R_0 = 2.5$, 40% asymptomatic, 10 days to resolution)

This information provides a baseline for comparison when evaluating how different viral characteristics or public health strategies might influence the pandemic. By the baseline numbers, peak infection rate would occur in 68 days (with Day 1 infection being 0.01% of the population) with 24.11% of the population infected simultaneously. See Fig. 1. The remaining results are divided based upon effectiveness of isolation procedures (3.1), projected changes in base reproduction rate (3.2), reduced transmission from asymptomatic cases (3.3), and social obedience to public health measures (3.4).

3.1. Effectiveness of Isolation Procedures

The first question addresses whether effective isolation procedures would mitigate a pandemic outbreak based on variable rates of asymptomatic cases. This analysis presumes three different rates of efficacy in transmission based on quarantine/self-isolation procedures following symptom onset (0%, 25%, 50%). Zero percent would represent perfect adherence to quarantine procedures where not even healthcare workers contract the virus following symptom onset. Conversely, 50% would represent marginally effective procedures that reduce, but do not eliminate, the potential of spreading the virus following symptom onset. The reduction values represent changes to the basic reproduction number (e.g., 25% indicates a 75% reduction in $R_0$, or $R_0 = 2.00 \times 0.25 = 0.50$). See Fig. 2.

These projections indicate that not even perfect quarantine procedures could effectively break a pandemic with a high rate of asymptomatic transmission. Given the rates of presymptomatic transmission and asymptomatic cases, effective quarantine procedures could reduce peak levels by 53.08% (12.80% maximum peak percentage of population infected versus 24.11% unmitigated). This approach would flatten the curve, but perfect quarantine procedures would not break the pandemic.

3.2. Relationship to Base Reproduction Rate

If effective quarantine procedures for symptomatic patients could not break the pandemic, then additional public health mitigation and suppression strategies would be required. These approaches would require limiting the reproduction rate of the virus through methods such as social distancing, although the question becomes how much the effective reproduction rate would need to be reduced based on some level of asymptomatic cases. This analysis used two variables, differential base reproduction rates between 2.0 and 3.5 (2.0, 2.5, 3.0, and 3.5) to encompass the possible COVID-19 $R_0$ range and different rates of asymptomatic cases (25%, 50%, and 75%) to encompass the possible ranges of asymptomatic cases. These estimates assume effective quarantine
Fig 2. Projected peak total infection rates due to differential effectiveness of isolation procedures (Baseline model parameters: $R_0 = 2.5$, 40% asymptomatic, 10 days to resolution). Four projections indicate the change to $R_0$ as a function of isolation procedures (e.g., 25% indicates a 75% reduction in $R_0$ or $R_0 = 2.00 \times 0.25 = 0.50$)

Table I. Peak Percentage of Population Infected and Days to Peak as Separated by Different $R_0$ Values and Asymptomatic Case Rates

| $R$-naught | 25% | Asymptomatic 50% | 75% |
|------------|-----|------------------|-----|
| $R_0 = 2.0$ | Peak percentagedays to peak | 2.66%|217 days | 7.13%|141 days | 11.61%|111 days |
| $R_0 = 2.5$ | Peak percentagedays to peak | 9.27%|111 days | 15.00%|88 days | 19.91%|76 days |
| $R_0 = 3.0$ | Peak percentagedays to peak | 16.54%|75 days | 22.47%|64 days | 27.28%|58 days |
| $R_0 = 3.5$ | Peak percentagedays to peak | 23.55%|56 days | 29.23%|51 days | 33.68%|47 days |

procedures that reduce $R_0$ to zero once a patient becomes symptomatic. See Table I.

The public health goal would be to reduce the effective reproduction rate to below 1.0, which would stop the pandemic. However, with increasing base reproduction rates, the problem of asymptomatic cases becomes more pervasive. This analysis was conducted presuming perfect quarantine procedures that reduced the effective reproduction rate to zero for all individuals when they became symptomatic. Presymptomatic transmission alone would still drive an outbreak for any disease with a long median time to first appearance of symptoms, although the asymptomatic rate complicates this problem further. In effect, these analyses further demonstrate the need for wider public health mitigation and suppression strategies above and beyond contact tracing or self-isolation for any disease with a high rate of asymptomatic cases.

3.3. Reduced Transmission in Asymptomatic Cases

There is a critical assumption to test with asymptomatic cases. Namely, these patients could transmit the virus to others, albeit at some reduced rate. This possibility would differentiate reproduction rates
among presymptomatic and asymptomatic cases, where the presymptomatic transmission rate retains the full viability of the virus and asymptomatic cases have some fraction of the effective reproduction rate. Several factors could explain the difference, although especially for a disease spread by respiratory droplets, the lack of common respiratory issues (e.g., cough, shortness of breath) would reduce the likelihood of transmitting the disease to others solely through exhalation and not sputum or other effusion.

This analysis presumes the effective quarantine procedures to address, in part, whether a pandemic can be sustained by a reduced transmission rate from asymptomatic cases. See Figure 3. Four rates of asymptomatic transmission were used (100%, 75%, 50%, and 25%) with a presumed rate of 50% asymptomatic transmission in the population ($R_0 = 2.5$, 50% asymptomatic, 10 days to resolution). At only a 50% reduction in asymptomatic transmission rates relative to symptomatic transmission, the outbreak would never exceed 2.56% peak percentage of population infected compared to the 15.00% of the population infected with a transmission rate equivalent to symptomatic cases. A 25% asymptomatic transmission rate would never lead to an actual outbreak as the pandemic would lose steam before reaching pandemic levels. For a disease like COVID-19, if there is some reduced transmission rate for asymptomatic cases, the reduction is quite small or else the outbreak would never have reached pandemic levels.

### 3.4. Relationship to Social Obedience of Public Health Measures

The analyses thus far demonstrated the need for public health suppression and mitigation strategies for a disease with a high rate of asymptomatic cases, such as COVID-19. Perfect isolation procedures would not prevent an outbreak, nor would the hope of reduced transmission rates from asymptomatic cases. These circumstances make public health strategies critical to control an outbreak, although a critical question becomes social obedience to these measures. Specifically, if wearing a mask would prevent an outbreak by reducing the effective reproduction rate, what would the effect be if some asymptomatic cases were also socially disobedient and did not adhere to public health guidance?

For this analysis, mobility reduction due to public health measures (e.g., lockdowns, social distancing) was used as a model for how reduced mobility might impact peak number of cases (Zhou, Xu et al., 2020). A 40% mobility reduction produced a reduction in peak cases of 66%, which was used here as a factor to model the impact of social obedience. The
presumption here is that the socially obedient subpopulation who adhere to public health guidance reduce their viral transmissibility by 50%. This approach creates a socially obedient group with reduced effective reproduction rates, and a socially disobedient group with full viral reproduction rates. The question is what percentage of the population would need to follow public health guidance to avoid continued viral spread through asymptomatic, socially disobedient cases.

Using these base metrics of a 50% potency versus a 10% potency (50% and 90% reduction in effective reproduction rate, respectively) for the socially obedient subgroup ($R_0 = 2.5, 50\%$ asymptomatic, 10 days to resolution), the rates were modeled for the full continuum of different percentages for social obedience (see Fig. 4). The different reduced reproduction due to reduced mobility dramatically impact peak infection rates, even accounting for perfect quarantine procedures and asymptomatic carriers who are socially disobedient. The 50% potency rate hit a peak case load of 1% with 78% social obedience, and the 10% potency rate hit a peak case load of 1% with 43% social obedience. These data indicate that adherence to social distancing, reduced mobility, and other public health strategies could overcome asymptomatic carriers who did not adhere to public health guidance so long as the majority of the population followed the measures.

4. DISCUSSION

Based on these considerations, the conclusion should be that a high asymptomatic case rate represents substantial challenges for containing a viral pandemic. Not even perfect quarantine procedures would be effective if the virus has characteristics similar to the novel coronavirus, SARS-CoV-2. Likewise, core suppression strategies such as contact tracing would be difficult because asymptomatic cases are likely to escape all forms of surveillance except positive identification in a diagnostic laboratory test or prophylactic restriction of movement for all contacts. This point is especially salient due to the logistical burden of providing blanket surveillance testing for a population during a pandemic and is further complicated by the imperfect characteristics of tests to identify an emerging virus. From a more practical perspective, high rates of asymptomatic cases would only be problematic if those cases could transmit the virus with a high degree of viability. The estimations here suggest that even a 50% reduction in transmissibility for asymptomatic cases would be sufficient to flatten an outbreak. For COVID-19, this outcome would suggest that asymptomatic cases retain a high level of potency in transmitting live virus to others.

For public health guidance, the concern is what approach should be taken to mitigate an outbreak with a high ratio of asymptomatic cases. Modeling
procedures demonstrate that core suppression strategies alone would be insufficient under these circumstances. In addition to the core suppression strategies such as quarantine or contact tracing, another manipulation identified how mitigation strategies such as social distancing would affect the spread. This procedure modified the $\beta$ weight to account for the efficacy of social distancing with a variable rate of obedience among the population, yielding for the presymptomatic infection rates a modified characteristic of $\beta_{\psi,\eta} \ast i_{\psi}(t)$, using $\eta$ to depict the obedient group, and $\beta_{\psi,\theta} \ast i_{\psi}(t)$, using $\theta$ to depict the disobedient group. The obedient group is presumed to reduce their $\beta$ weight to 10% of its original value as a representation of reduced number of contacts in the most beneficial condition, whereas the disobedient group assumes the normal $\beta$ weight (100%) as they maintain regular social contacts. So long as half the population follows the public health guidelines, the procedures would be effective despite the potential for asymptomatic carriers to be socially disobedient to public health guidance.

The concern for future applications then becomes how to combat a pandemic with a high ratio of asymptomatic cases. Each approach tends to require some large-scale intervention to prevent spread of the virus given that quarantine procedures are most effective when combined with other public health safety protocols (Eikenberry et al., 2020; Feng et al., 2020; Greenhalgh, Schmid, Czyzynka, Bassler, & Gruer, 2020; Islam et al., 2020; Nussbaumer-Streit et al., 2020). For example, travel restrictions and other national-level actions could dramatically reduce the median daily reproduction number of COVID-19 (Kucharski et al., 2020). These interventions require similarly large-scale logistical efforts. As such, pandemics in the modern age stress the importance of emerging public health tools, such as digital contact tracing (Ferretti et al., 2020) and big data analytics (Chen et al., 2020; Ienca & Vayena, 2020; Ting, Carin, Dzau, & Wong, 2020; Wang, NG, & Brook, 2020). Asymptomatic transmission merely highlights the importance of these tools and emphasizes the need for suppression and mitigation strategies as the outbreak will be extremely difficult to contain without them.

A final issue should be addressed here regarding terminology, specifically the differences between asymptomatic, presymptomatic, and mildly symptomatic. The dispute arises when differentiating between someone who is truly asymptomatic versus someone who will go on to develop symptoms or someone who has an extremely mild case. The latter individual may subjectively report a lack of symptoms despite another person willingly reporting positive symptomology consistent with COVID-19, making the issue one of reporting and subjective differences as much as actual transmission rates. A similar outcome could be a Hawthorne-like effect (cf. McCarney, 2007; Parsons, 1974), where knowledge of being observed is going to alter behavior. Individuals highly attentive to pandemic conditions may develop an observer bias that produces psychosomatic symptoms consistent with COVID-19. Any variant of these behaviors could alter perception of asymptomatic transmission and particularly affect the interpretation about the viability of viral transfer from an asymptomatic case. The modeling effort here makes no explicit differentiation between asymptomatic and extremely mild symptoms.

5. LIMITATIONS AND FUTURE DIRECTIONS

Several limitations should be noted regarding this effort, especially as it produces lessons learned from the COVID-19 pandemic for future pandemic-related public health strategies. Foremost, the reproduction rate is clearly a critical factor, and the reproduction rates are modeled here based upon a range similar to SARS-CoV-2. Further extremes were not incorporated which might have additional implications. Specifically, reduced asymptomatic transmission compared to symptomatic transmission could have significant impact on the effective reproduction rate. The practical public health interpretation might be whether less imposing restrictions might be sufficient to control viral spread (e.g., mask wearing) rather than implementing full social distancing, restricted indoor gatherings, or full lockdowns. The data limitation here is that more complex modeling techniques could do a more thorough evaluation of the numerous ways reduced asymptomatic transmission could interact with the basic reproduction rate.

Another limitation involves the use of an SIR model for the data. Within the SIR model, there could be greater emphasis on factors such as threshold characteristics in a stochastic model (Ji & Jiang, 2014), the behavior of random partners in the population instead of a random individual (Miller & Volz, 2013), or more mathematically intensive calculations due to asymptomatic behavior (Jiang, Yu, Ji, & Shi, 2011). The larger issues would be incorporating additional factors common to compartmentalized
infection models beyond the basic SIR dynamic (Tolles, & Luong, 2020). For example, the SIR model does not address issues such as existing immunity within the population, the likelihood of an exposed person becoming infected, or the role of vaccines. This simple approach functions well for a novel virus where there is neither a vaccine available nor existing immunity in the population. Additional modeling efforts could build upon the exposed component (e.g., SEIR model) to provide more complexity to the interpretation of asymptomatic transmission, especially as vaccines are produced and the global situation changes significantly.

A final concern involves the use of real data versus modeling data to reach a conclusion. Early in a pandemic, modeling efforts are essential to extrapolate from limited data. This point is best demonstrated in how early pandemic efforts that led to substantial government action (cf. Ferguson et al., 2020) would be evaluated after more data is accumulated (cf. Biggs & Littlejohn, 2021). Real data and modeling data are reinforcing efforts, not contrary efforts. Modeling data helps confirm real-world observations and interpretations, whereas real-world data reinforces or establishes model parameters. They are inherently a check-and-balance that enhance one another. Modeling efforts will always be essential pieces of public health strategic planning, and especially early in a pandemic, they can help guide decisions much more so than emerging data that might be unduly influenced by a sampling bias. The COVID-19 pandemic effectively demonstrated this challenge as the early infection fatality ratio estimates were influenced by a lack of testing capabilities and lack of understanding about asymptomatic cases. More than most factors, asymptomatic cases and asymptomatic transmission illustrate the challenges in containing a novel virus and the importance of modeling to influence public health mitigation and suppression strategies.

CONFLICT OF INTERESTS

The views expressed in this article are those of the authors and do not necessarily reflect the official policy or position of the Department of the Navy, Department of Defense, nor the U.S. Government. The authors are military service members or employees of the U.S. government. This work was prepared as part of their official duties. Title 17 U.S.C. §105 provides that “Copyright protection under this title is not available for any work of the United States Government.” Title 17 U.S.C. §101 defines a U.S. Government work as a work prepared by a military service member or employee of the U.S. Government as part of that person’s official duties. The authors have no financial or nonfinancial competing interests in this manuscript.

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