DOI: 10.32481/djph.2020.08.007

A Social Network Analysis Approach for Contact Tracing in the Hospital Setting

Mina Ostovari, PhD; Claudine Jurkovitz MD, MPH; Lee Pachter, D.O.; David Chen MD, MPH

Value Institute, Christiana Care

Abstract

Since the beginning of the COVID-19 pandemic, the State of Delaware has implemented various strategies including a stay-at-home order, mask-wearing requirements in public places, and community-based testing to control the spread of the disease. Health systems across the U.S. have taken actions including symptom monitoring and screening for visitors and healthcare workers, providing personal protection equipment (PPE), and contact tracing of confirmed infected individuals to provide maximum possible protection for healthcare workers. Despite such efforts, there remains a significant risk of intra-hospital transmission of COVID-19. Healthcare workers who contact patients with COVID-19 or were exposed to the disease in the community may transmit the infection to coworkers in the inpatient setting. In addition to universal and case-based precautions to prevent exposure and disease transmission, contact tracing is essential to minimizing the impact of outbreaks among healthcare workers and the community. A rapid increase in cases can quickly diminish hospital infection control and prevention program capacity to perform high-quality contact tracing. This article will describe an approach using the application of social network analysis (SNA) and Electronic Medical Records (EMR) to enhance the current efforts in COVID-19 contact tracings.

COVID-19 Pandemic

On January 30, 2019, the World Health Organization (WHO) declared the novel coronavirus outbreak (2019-nCoV) as a Public Health Emergency of International Concern.[1] COVID-19 is caused by the severe acute respiratory syndrome coronavirus 2 (SARS-CoV-2) virus, which is highly infectious and can be transmitted from person-to-person in close contacts and through droplets.[2] The spread of the virus may also occur through aerosolization by healthcare-related activities and possibly via contaminated surfaces.[3] Compared to similar conditions such as SARS and MERS, COVID-19 may have a lower mortality rate[4]; however, it has a longer incubation period (2 to 14 days) and some patients may never develop symptoms.[5] Asymptomatic individuals are those infected by the virus but without symptoms, and though their contribution to the transmission of SARS-CoV-2 is not clear,[6] some reports have shown that isolating confirmed asymptomatic infected individuals can help eliminate the spread of the virus.[7]

At this time, the number of confirmed cases in the United States with COVID-19 has surpassed two million with more than 100,000 deaths.[8] As of June 12, 2020, in the State of Delaware, more than 9,000 confirmed cases were identified with more than 300 deaths.[9] According to the Center for Disease Control and Prevention (CDC), since the beginning of the pandemic, there have been more than 70,000 cases among healthcare workers with more than 300 deaths.[10] Early reports of COVID-19 infection among healthcare workers showed wide variability in the rate of confirmed transmission.[11] Successful control of the infection in hospital settings depends on several factors including symptom monitoring, appropriate use of PPE for close contacts with patients, identification of healthcare workers with high-risk exposure through contact tracing, and subsequent quarantine of the exposed staff.[12] While the number of new cases has been declining in Delaware and some other states, some researchers have warned about a potential second wave of COVID-19 in the fall.[13] Therefore, it is essential to learn from the current situation and prepare for future potential outbreaks.

Contact Tracing during the Pandemic

Individuals who have had close contacts with someone infected with SARS-CoV-2 are at a higher risk of becoming infected and potentially infecting others. Prompt monitoring of these individuals is essential to both appropriately quarantine them before they may transmit the virus to secondary contacts as well as to ensure they receive appropriate supportive care.[14] This process of high-quality contact tracing, whether in the community or in health systems, is a complicated procedure with high consumption of resources. During the traditional contact tracing procedure, public health officials interview each case and help them recall everyone with whom they have had close contact. Once identified, public health officials will get in touch with the contacts to inform them about their exposure and of precautions to limit the spread.[15] An exponentially increasing number of cases can severely impact the ability of public health officials and hospital infection control management to perform effective contact tracing.[16]

The CDC has provided general guidelines for monitoring and prioritization of individuals for contact tracing.[17] Every state across the U.S. has planned accordingly to control the spread of the disease in their community[18] including mask requirements in public places, planned phases for reopening, and enhancing contact tracing procedures. Tech companies like Apple and Google have provided a contact tracing system to public health officials to augment traditional contact tracing methods.[19] Despite the potential benefits, this technology might not be implemented effectively and on a large scale.[20] While many actions have been taken by public health officials and tech companies, health systems still need to take the lead in controlling the infection in their hospital settings. Contact tracing in the hospital system is managed by the infection control and prevention team and follows a similar approach to contact tracing in the community. There have already been rapid and widespread outbreaks within skilled nursing facilities of COVID-19, partly attributed to the risk of asymptomatic infectivity causing nosocomial transmission within healthcare settings.[21] Such incidents can severely strain infection control management and diminish their capacity to control the disease spread when most needed.[16]

Application of Social Network Analysis in Contact Tracing

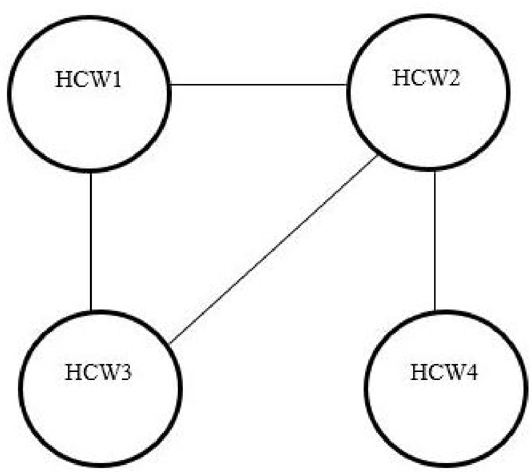
To augment the contact tracing efficiency in the inpatient setting, we present a methodology using social network analysis (SNA) to develop a contact network of healthcare workers and to detect the intra-system interactions and their frequencies. SNA is a technique that uses graph theory and network analysis to model and quantify the relations among a set of actors (individuals/organizations).[22] The analysis methodology includes three main stages: 1) identifying set of actors (nodes), 2) describing the nature of relationships (edges) between the actors, and 3) analyzing the structure of the system.[23] Previously, studies had used social network analysis to assess collaboration and communication among healthcare providers using data collected from surveys and interviews.[24,25]

In recent years, the application of social network analysis has been expanded to be applicable to large-scale data.[26] Instead of using surveys and interviews, studies use large-scale health data including administrative claims or electronic medical records (ERM) to identify the actors (nodes) and their relations (edges). Researchers have used the SNA technique in various topics including understanding communication among healthcare workers,[24] modeling of the referral patterns among healthcare providers,[27,28] and modeling of the collaboration among healthcare providers and the impact on patient outcomes.[29,30] When applied in the context of epidemiology, SNA can be referred to as a contact network which represents cases and their contacts linkages during a specific time period.[31]

Contact networks allow visualization of the potential scenarios or risk factors that can impact an outbreak and provide perspectives about how to address such situations. Previously, SNA has been used to model the spread of nosocomial infections between different hospitals[32,33] These studies define a network of hospitals as nodes that are connected through edges defined as patient transfer among the hospitals. A similar approach can be applied to model potential transmission of COVID-19 among healthcare workers in the inpatient setting.

An SNA approach can be applied to health data extracted from Electronic Medical Records (EMR) to develop a contact network of healthcare workers who provided care to patients with COVID-19 in the inpatient setting. This intra-hospital healthcare worker contact network may increase the speed of contact tracing through the automated identification of contacts with no additional hardware investment.[34] Such networks may estimate the exposure and susceptibility among healthcare workers and may inform resource allocation in potential future epidemics. Figure 1 presents a simple example of a contact network, which is undirected and unweighted. Nodes represent healthcare workers, and edges represent patients. If two healthcare workers share patients, they are connected. From this network, we can identify some network characteristics, for example, HCW2 is connected to three other providers (SNA degree centrality=3) that can be interpreted as the highest number of connections with other healthcare providers; therefore, if HCW2 is identified as a case, there is a high risk that all three other healthcare workers might have to be quarantined. On the other hand, if HCW1 is identified as a case, only HCW3 and HCW2 are the potential contacts who might need to go under quarantine.

Figure 1. An example of a contact network of healthcare workers in the inpatient setting. The nodes represent the healthcare workers (HCW) and the edges show that healthcare workers provide care to shared patients.



DOI: 10.32481/djph.2020.08.007

Further details can be added to the network, for example, giving weights to the edges based on the number of shared patients/hospital units between the healthcare workers. A similar approach can be taken to model disease outbreaks in different units based on patient locations. Physical unit locations that patients stay in during their in-patient visits can be tracked from the EMR. Based on the transfer of patients to different units, a small-world network of patient transfers between hospital units can be generated. The network characteristics can be utilized to develop probabilistic models to predict disease outbreaks in different hospital units. The SNA approach on EMR data is particularly useful to identify outbreaks caused by healthcare workers providing care to patients who are asymptomatic but are transmitting the virus prior to diagnosis and isolation. Such patients without symptoms might have been admitted for health reasons other than COVID-19; exposing healthcare providers who were therefore not utilizing the same level of PPE used for patients with confirmed or even suspected COVID-19.

Implementation of the SNA Approach for Contact Tracing

EMR collects patient data including diagnosis, admission/discharge date, testing results, procedures performed on the patient, healthcare provider types, and hospital units that patients visit. A de-identified dataset of patients with COVID-19 and their healthcare providers can be developed from the EMR. One method of tracking healthcare worker interaction is through explicit paper logs of patient contact; however tracking a large number of patients and providers requires a cumbersome amount of work for data entering, cleaning, and processing. Another method that can be automated would be tracking healthcare provider location in the hospital through the Radio-Frequency Identification (RFID) devices that connect with providers or other special badges[35]; however, this requires significant hardware investment and maintenance including RFID badges, RFID readers, and adherence to badge-wearing. Moreover, tracking the location through RFID does not provide information about the type of interaction that the providers had with each other or the patient and is a more invasive method of data collection that may raise privacy concerns.

The social network analysis provides tools to apply on large-scale data from the EMR to reasonably approximate contacts among healthcare workers that are at risk for infection transmission. Measures generated from the network analysis, such as describing healthcare workers with the highest number of interactions (high degree centrality in the network), can be used to identify those with a higher possibility of transmitting the disease to others. Further opportunities based on this work include modeling and classification of healthcare workers by risk and simulation of disease transmission across the network based on different scenarios. The findings can inform resource allocation and staffing assignments to reduce the risk of infection. In addition, this approach using de-identified electronic health data protects the privacy of healthcare workers.

Public Health Significance

To control the spread of the COVID-19, strategies including mask requirements in public places and stay-at-home orders have been issued in states across the U.S. With the decreasing number of cases and deaths, many states are moving toward reopening their economy. Having contact tracing protocols and resources in place is essential to reduce the potential of another surge in the number of cases. Providing solutions to accelerate contact tracing efforts will reduce the cumbersomeness of the process and liberate public health resources for other challenges in the community.

References

1. World Health Organization. (2020). COVID-19 Timeline. Retrieved from: https://www.who.int/news-room/detail/27-04-2020-who-timeline---covid-19
2. Chan, J. F., Yuan, S., Kok, K. H., To, K. K., Chu, H., Yang, J., . . . Yuen, K. Y. (2020, February 15). A familial cluster of pneumonia associated with the 2019 novel coronavirus indicating person-to-person transmission: A study of a family cluster. *Lancet*, *395*(10223), 514–523. PubMed https://doi.org/10.1016/S0140-6736(20)30154-9
3. van Doremalen, N., Bushmaker, T., Morris, D. H., Holbrook, M. G., Gamble, A., Williamson, B. N., . . . Munster, V. J. (2020, April 16). Aerosol and surface stability of SARS-CoV-2 as compared with SARS-CoV-1. *The New England Journal of Medicine*, *382*(16), 1564–1567. PubMed https://doi.org/10.1056/NEJMc2004973
4. Chen, J. (2020, March). Pathogenicity and transmissibility of 2019-nCoV-A quick overview and comparison with other emerging viruses. *Microbes and Infection*, *22*(2), 69–71. PubMed https://doi.org/10.1016/j.micinf.2020.01.004
5. Zou, L., Ruan, F., Huang, M., Liang, L., Huang, H., Hong, Z., . . . Wu, J. (2020, March 19). SARS-CoV-2 viral load in upper respiratory specimens of infected patients. *The New England Journal of Medicine*, *382*(12), 1177–1179. PubMed https://doi.org/10.1056/NEJMc2001737
6. Al-Tawfiq, J. A. (2020, May - June). Asymptomatic coronavirus infection: MERS-CoV and SARS-CoV-2 (COVID-19). *Travel Medicine and Infectious Disease*, *35*, 101608. PubMed https://doi.org/10.1016/j.tmaid.2020.101608
7. Day, M. (2020, March 23). Covid-19: Identifying and isolating asymptomatic people helped eliminate virus in Italian village. *BMJ (Clinical Research Ed.)*, *368*, m1165. PubMed https://doi.org/10.1136/bmj.m1165
8. Johns Hopkins Coronavirus Resource Center. (2020). COVID-19 United States cases by county. Retrieved from: https://coronavirus.jhu.edu/us-map
9. Delaware.gov. (2020). Coronavirus. Delaware's Coronavirus Official Website. Retrieved from: https://coronavirus.delaware.gov/
10. Centers for Disease Control and Prevention. (2020, Mar). Coronavirus Disease 2019 (COVID-19) in the U.S. Retrieved from: https://www.cdc.gov/coronavirus/2019-ncov/cases-updates/cases-in-us.html
11. Guan, W., Ni, Z., Hu, Y., Liang, W., Ou, C., He, J., . . . Zhong, N. (2020). Clinical characteristics of 2019 novel coronavirus infection in China. *MedRxiv*. https://doi.org/10.1101/2020.02.06.20020974
12. Wong, S. C. Y., Kwong, R. T., Wu, T. C., Chan, J. W. M., Chu, M. Y., Lee, S. Y., . . . Lung, D. C. (2020, June). Risk of nosocomial transmission of coronavirus disease 2019: An experience in a general ward setting in Hong Kong. *The Journal of Hospital Infection*, *105*(2), 119–127. PubMed https://doi.org/10.1016/j.jhin.2020.03.036

13. Strazewski, L. (2020). Harvard epidemiologist: Beware COVID-19's second wave this fall. American Medical Association. Retrieved from: https://www.ama-assn.org/delivering-care/public-health/harvard-epidemiologist-beware-covid-19-s-second-wave-fall
14. World Health Organization. (2017). Contact tracing. Retrieved from: https://www.who.int/news-room/q-a-detail/contact-tracing
15. Center for Disease Control and Prevention. (2020). Case investigation and contact tracing : Part of a multipronged approach to fight the COVID-19 pandemic. Retrieved from: https://www.cdc.gov/coronavirus/2019-ncov/php/principles-contact-tracing.html
16. Daskalaki, I., Hennessey, P., Hubler, R., & Long, S. S. (2007, April). Resource consumption in the infection control management of pertussis exposure among healthcare workers in pediatrics. *Infection Control and Hospital Epidemiology*, *28*(4), 412–417. PubMed https://doi.org/10.1086/513121
17. Centers for Disease Control and Prevention. (2020). Contact Tracing. Retrieved from: https://www.cdc.gov/coronavirus/2019-ncov/php/contact-tracing/contact-tracing-plan/contact-tracing.html
18. Delaware.gov. (2020). Contact Tracing. Retrieved from: https://coronavirus.delaware.gov/contact-tracing/
19. Schumaker, E. (2020). Apple and Google launch digital contact tracing system. ABC News. Retrieved from: https://abcnews.go.com/Technology/apple-google-launch-digital-contact-tracing-system/story?id=70789376
20. Servick, K. (2020). COVID-19 contact tracing apps are coming to a phone near you. How will we know whether they work? Science Retrieved from: https://www.sciencemag.org/news/2020/05/countries-around-world-are-rolling-out-contact-tracing-apps-contain-coronavirus-how
21. Arons, M. M., Hatfield, K. M., Reddy, S. C., Kimball, A., James, A., Jacobs, J. R., ... Jernigan, J. A., & the Public Health–Seattle and King County and CDC COVID-19 Investigation Team. (2020, May 28). Presymptomatic SARS-CoV-2 infections and transmission in a skilled nursing facility. *The New England Journal of Medicine, 382*(22), 2081–2090. PubMed
22. Scott, J. (1988). Social network analysis. *Sociology*, *22*(1), 109–127. https://doi.org/10.1177/0038038588022001007
23. Blanchet, K., & James, P. (2012, August). How to do (or not to do) ... a social network analysis in health systems research. *Health Policy and Planning*, *27*(5), 438–446. PubMed https://doi.org/10.1093/heapol/czr055
24. Creswick, N., Westbrook, J. I., & Braithwaite, J. (2009, December 31). Understanding communication networks in the emergency department. *BMC Health Services Research*, *9*(1), 247. PubMed https://doi.org/10.1186/1472-6963-9-247
25. Mascia, D., Cicchetti, A., Fantini, M. P., Damiani, G., & Ricciardi, W. (2011, July 25). Physicians' propensity to collaborate and their attitude towards EBM: A cross-sectional study. *BMC Health Services Research*, *11*(1), 172. PubMed https://doi.org/10.1186/1472-6963-11-172

26. Barnett, M. L., Landon, B. E., O'Malley, A. J., Keating, N. L., & Christakis, N. A. (2011, October). Mapping physician networks with self-reported and administrative data. *Health Services Research*, *46*(5), 1592–1609. PubMed https://doi.org/10.1111/j.1475-6773.2011.01262.x

27. An, C., O'Malley, A. J., Rockmore, D. N., & Stock, C. D. (2018, February 28). Analysis of the U.S. patient referral network. *Statistics in Medicine*, *37*(5), 847–866. PubMed https://doi.org/10.1002/sim.7565

28. An, C., O'Malley, A. J., & Rockmore, D. N. (2018). Referral paths in the U.S. physician network. *Applied Network Science*, *3*(1), 20. PubMed https://doi.org/10.1007/s41109-018-0081-4

29. Ostovari, M., & Yu, D. (2019, September 9). Impact of care provider network characteristics on patient outcomes: Usage of social network analysis and a multi-scale community detection. *PLoS One*, *14*(9), e0222016. PubMed https://doi.org/10.1371/journal.pone.0222016

30. Barnett, M. L., Christakis, N. A., O'Malley, J., Onnela, J. P., Keating, N. L., & Landon, B. E. (2012, February). Physician patient-sharing networks and the cost and intensity of care in US hospitals. *Medical Care*, *50*(2), 152–160. PubMed https://doi.org/10.1097/MLR.0b013e31822dcef7

31. Chen, Y., Chen, H., & King, C. (2010). Social network analysis for contact tracing. Castillo-Chavez, C., Chen, H., Lober, W.B., Thurmond, M., Zeng, D., eds. *Infectious Disease Informatics and Biosurveillance*, 27, 339-358. doi:https://doi.org/10.1007/978-1-4419-6892-0_15

32. Ray, M. J., Lin, M. Y., Weinstein, R. A., & Trick, W. E. (2016, October 1). Spread of carbapenem-resistant enterobacteriaceae among Illinois healthcare facilities: The role of patient sharing. *Clin Infect Dis*, *63*(7), 889–893. PubMed https://doi.org/10.1093/cid/ciw461

33. Fernández-Gracia, J., Onnela, J. P., Barnett, M. L., Eguíluz, V. M., & Christakis, N. A. (2017, June 7). Influence of a patient transfer network of US inpatient facilities on the incidence of nosocomial infections. *Scientific Reports*, *7*(1), 2930. PubMed https://doi.org/10.1038/s41598-017-02245-7

34. Cusumano-Towner, M., Li, D. Y., Tuo, S., Krishnan, G., & Maslove, D. M. (2013, May 1). A social network of hospital acquired infection built from electronic medical record data. *Journal of the American Medical Informatics Association : JAMIA*, *20*(3), 427–434. PubMed https://doi.org/10.1136/amiajnl-2012-001401

35. Hellmich, T. R., Clements, C. M., El-Sherif, N., Pasupathy, K. S., Nestler, D. M., Boggust, A., . . . Hallbeck, M. S. (2017, December 1). Contact tracing with a real-time location system: A case study of increasing relative effectiveness in an emergency department. *American Journal of Infection Control*, *45*(12), 1308–1311. PubMed https://doi.org/10.1016/j.ajic.2017.08.014

DOI: 10.32481/djph.2020.08.007