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Review

Spatial and temporal analyses to investigate infectious disease transmission within healthcare settings

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SUMMARY

Background: Healthcare-associated infections (HCAIs) cause significant morbidity and mortality worldwide, and outbreaks are often only identified after they reach high levels. A wide range of data is collected within healthcare settings; however, the extent to which this information is used to understand HCAI dynamics has not been quantified.

Aim: To examine the use of spatiotemporal analyses to identify and prevent HCAI transmission in healthcare settings, and to provide recommendations for expanding the use of these techniques.

Methods: A systematic review of the literature was undertaken, focusing on spatiotemporal examination of infectious diseases in healthcare settings. Abstracts and full-text articles were reviewed independently by two authors to determine inclusion.

Findings: In total, 146 studies met the inclusion criteria. There was considerable variation in the use of data, with surprisingly few studies ($N = 22$) using spatiotemporal-specific analyses to extend knowledge of HCAI transmission dynamics. The remaining 124 studies were descriptive. A modest increase in the application of statistical analyses has occurred in recent years.

Conclusion: The incorporation of spatiotemporal analysis has been limited in healthcare settings, with only 15% of studies including any such analysis. Analytical studies provided greater data on transmission dynamics and effective control interventions than studies without spatiotemporal analyses. This indicates the need for greater integration of spatiotemporal techniques into HCAI investigations, as even simple analyses provide significant improvements in the understanding of prevention over simple descriptive summaries.

Introduction

Healthcare-associated infections (HCAIs) are problematic worldwide, with a recent report by the World Health Organization estimating hospital-wide prevalence in high-income countries at 8%.[1] In addition to causing significant, yet preventable, morbidity and mortality[2] in countries with centrally-funded and managed healthcare systems, such as the UK

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National Health Service, HCAIs increase waiting times and reduce availability of resources to provide care to the population.[3]

HCAIs present a unique challenge as active transmissions are often only identified after numerous patients have been infected. Additionally, the wide range of HCAI facilitators (e.g. procedures,[4] environment[5]) and increasingly susceptible patients[6] complicate transmission dynamics, making prospective identification and control exceedingly difficult. When multiple cases of an infection occur within a hospital, it is difficult to differentiate a true nosocomial transmission from unrelated cases, and cohorting patients by risk group may lead to assumptions of a common source but molecular analyses often demonstrate lack of transmission.[7]

Sophisticated spatiotemporal analyses can be used to confirm clustering statistically over time and/or space, which would increase confidence in assuming the relatedness of cases. These methods can also be used to control for the effects of cohorting and other patient characteristics that may give the spurious impression of clustering or transmission when it has not occurred. This, in turn, would provide better information on where interventions could be targeted most effectively, and when or where to anticipate outbreaks. These methods may also be useful in more rapid identification of a problem, as even small clusters (e.g. two or three cases) can be detected. Even the introduction of more simplified analytical methods to evaluate spatial and temporal relationships could be beneficial. One example is the Knox test, which has been used widely to detect time–space clusters since the 1960s. The null hypothesis in Knox testing would be that all HCAI cases are independent, and the test returns the number of pairs of cases that are deemed to cluster in time and/or space. The tool is simple to apply as it only requires information on cases, not controls or susceptible individuals, and can work on a minimal clinical dataset.[8]

Nowadays, researchers are using geographic information systems (GIS) to further extend understanding of spatiotemporal clustering and transmission. These are computer-based programs that combine cartography, statistical analysis and database technology to layer databases on top of a predefined map. They have been applied in a range of ecological investigations of disease,[9] and to determine whether there is a spatial association between disease risk and environmental pollution. In this study, GIS and spatial analysis were employed to investigate the risk of breast and lung cancer in a small region.[10] After identification of significant clusters, it was possible to identify local risk factors specific to each cancer type, providing evidence of potential environmental contamination. The use of similar techniques to create hospital maps, on which infection data can be displayed and analysed, could increase understanding of local transmission and risk,[11] and provide rapid dissemination of information through visualization.[12]

With healthcare systems worldwide under pressure to improve patient safety whilst cutting costs, use of the existing infrastructure of routinely collected data, which are often overlooked for HCAI investigation and research,[13] is an innovative solution. Frequently, investigations of HCAIs provide a basic epidemiological description of cases over time by providing an epidemic curve, or show how cases are distributed across wards using a diagram. However, hospital databases contain laboratory results, building management data and floor plans, and information on patient admissions and movement that could easily be incorporated into more detailed analyses to improve understanding of local HCAI epidemiology. Use of interdisciplinary tools may increase the ability to identify transmission prospectively and implement preventive measures.[14]

The aims of this review were to determine the extent of use of spatiotemporal analyses for identifying and preventing HCAI transmission, and to provide recommendations for expanding the use of GIS and spatiotemporal statistical analyses within healthcare settings.

Methods

A systematic review of the literature on spatiotemporal examination of infectious diseases in healthcare settings between January 1961 and June 2013 was conducted using the following search terms: infection (e.g. HCAI, nosocomial, etc.); healthcare settings (e.g. hospital, intensive care, etc.); and time/space (e.g. space–time, spatial epidemiology, etc.). Potential synonyms for each search term (e.g. infection, healthcare settings and time/space) were identified and combined using Boolean operators.

To ensure comprehensive capture of the literature, BIOSIS, Cochrane Review, CSA, DARE, Embase, HEED, JSTOR, PubMed, Science Direct and Web of Science were searched for all indexed publications. Additionally, Google Scholar was searched for indexed and grey literature using the above search terms. All papers, reports, abstracts and letters were included in the initial search.

Inclusion/exclusion criteria

Inclusion/exclusion was conducted in two stages: abstract/title review and full-text review. All identified titles/abstracts were reviewed independently by two authors to ensure reliability in full-text retrieval. Papers were retrieved if they mentioned time or space in the abstract, or no abstract was provided and the title did not provide enough information to assess inclusion.

Full-text papers were reviewed independently by two authors and included if they were: (a) published post-1961; (b) written in English; (c) examined potential transmission in more than three patients; (d) provided more than a simple report of cases over time periods exceeding three months (i.e. not routine national surveillance reports); and (e) discussed time/space as a specific aim or discussion point of the study, rather than a simple mention in the results. Any studies on which the reviewers did not agree were discussed and a consensus was reached.

Data extraction

The methodologies of all included studies were reviewed and categorized into either descriptive or analytical studies of time/space, and further 'subtyped' based on the data and analyses employed. Studies were classified as 'case reporting' if they only used temporal or spatial data as an overview (i.e. an epidemic curve). 'Basic descriptive epidemiology' studies examined how the cases were linked by describing their locality in time and/or space and possible exposure events, but did not use statistical methods to determine the probability that they were linked. 'Basic descriptive epidemiology with