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Studies on Nurse staffing and Healthcare Associated Infection: Methodological Challenges and Potential Solutions

Jingjing Shang, PhD, Patricia Stone, PhD, and Elaine Larson, PhD.

Columbia University, School of Nursing (Dr. Shang); Columbia University, School of Nursing (Dr. Stone); Columbia University, School of Nursing (Dr. Larson)

Abstract

Background—Researchers have been studying hospital nurse staffing in relation to healthcare associated infections (HAIs) for over two decades, and the results have been mixed. We summarized published research examining these issues, critically analyzed the commonly used approaches, identified methodologic challenges, proposed potential solutions, and suggested the possible benefits of applying an electronic health record (EHR) system.

Method—A scoping review was conducted using Medline and Cumulative Index to Nursing and Allied Health Literature since 1990. Original research studies examining relationships between nurse staffing and HAIs in the hospital setting and published in peer-reviewed English-language journals were selected.

Results—A total of 125 articles/abstracts were identified and 45 met inclusion criteria. Findings from these studies were mixed. The methodologic challenges identified included database selection, variable measurement, methods to link the nurse staffing and HAI data and addressing temporality. Administrative staffing data were often not precise or specific. The most common method to link staffing and HAI data did not assess the temporal relationship. We proposed using daily staffing information 2–4 days prior to HAI onset linked to individual patient HAI data.

Discussion—To assess the relationships between nurse staffing and HAIs, methodological decisions are necessary based on what data are available and feasible to obtain. National efforts to promote EHR may offer solutions for future studies by providing more comprehensive data on HAIs and nurse staffing.

Background

Healthcare-associated infections (HAIs), defined as infections a patient obtains while receiving medical treatment in a healthcare facility, are a serious patient safety issue. There were an estimated 722,000 HAIs in U.S. acute care hospitals in 2001, with more than half of

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Correspondence: Jingjing Shang, PhD, RN, OCN, Columbia University, School of Nursing, 630 West 168th Street, New York, NY, 10032 (js4032@columbia.edu).

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them occurring outside of the intensive care unit (ICU).¹ On any given day, approximately 1 in 25 hospital patients have at least one HAI, and every year there are approximately 75,000 hospital deaths attributed to HAI.¹ The costs associated with HAIs have been estimated at 9.8 billion dollars annually.² Despite the staggering burden, most HAIs are preventable.³ For these reasons, reducing preventable HAIs has become one of the important components of the Department of Health and Human Services (DHHS)'s Action Plan to build a safer and affordable health care system,⁴ and it is a top priority for hospital administrators in their efforts to reduce hospital costs and improve quality of care.

The nursing profession is the largest segment of the U.S. health care workforce⁵ and is essential in preventing and controlling HAIs. Nurses not only provide bedside patient care which can directly impact infection prevention, but they also play an important role in care coordination and act as patient advocates to create a safe environment for patients, both of which are related to infection control and prevention.⁶ Therefore, it is important to understand the relationship between nurse staffing and HAIs.

Researchers have been studying hospital nurse staffing in relation to patient outcomes for over two decades, with many focusing on HAIs.⁷ However, findings from these studies have varied or even conflicted.^{8,9} Mark¹⁰ critically analyzed the methodological issues in research related to nurse staffing and suggested that the dissimilar data sources, staffing allocations, and risk adjustment methods are among the reasons for inconsistent findings. However, while these issues apply to studies focusing on HAIs, there may also be other reasons for variations in findings related to temporality. Unlike falls or medication errors, which have also been identified as a "nursing sensitive indicators", HAIs are defined by the Centers for Disease Control and Prevention (CDC) as infections that occur more than 48 hours after hospital admission due to infection incubation period. The infection incubation period should be addressed in studies examining relationships between nurse staffing and HAIs. In other words, the staffing attributed to the HAI should be the staffing that occurred prior to the incubation period, not when the HAI was detected.

There is a national push to enhance electronic health record (EHR) systems and health information technology. The HiTech provisions of the American Recovery and Reinvestment Act of 2009 have included \$20 billion in spending to stimulate health care institutions to adopt electronic medical records. A national survey of physicians revealed that majority of providers reported that the EHR systems improve diagnosis and patient care.¹¹ Importantly, EHR systems offer new ways of measuring HAIs, improving infection case identification,¹² and enhancing research.

While there have been reviews of HAI and hospital staffing,⁸ to our knowledge there is no published review that addresses the methodological issues specific to HAIs including temporality and potential use of EHR. Therefore, the objectives of this scoping review¹³ were to summarize published research that has examined the relationship between nurse staffing and HAIs, critically analyze the commonly used approaches, identify methodologic challenges, proposed potential solutions, and suggested the possible benefits of applying an electronic health record (EHR) system.

Methods

Literature was searched using the Medline and the Cumulative Index to Nursing and Allied Health Literature (CINAHL) databases with key terms “nurse staffing” crossreferenced with “infection”, as well as synonyms, related phrases, and pluralized terms such as “nosocomial infection(s)”, “pneumonia”, “nurses”, and “nurse staffing level”. The reference lists of published articles were hand-searched to identify any additional studies that may have been missed. Articles eligible for review were those that: 1) were original research studies; 2) published since 1990 in peer-reviewed English-language journals; and 3) examined relationships between nurse staffing and HAIs in the hospital setting. Reviews, editorials, commentaries, or policy papers were excluded. Studies that focused on nurse staffing with patient outcomes other than HAIs were also excluded. Figure 1 illustrates the article selection process. A total of 125 titles/abstracts were identified, of which 12 were excluded as duplicates and 9 were not research (e.g., editorials). After applying inclusion/exclusion criteria, we excluded 59 more articles after reviewing the abstracts and full text due to articles not addressing the content of interest, leaving 45 articles included in the final review. The literature search and article selection process was conducted by two researchers to ensure validity. From each study, the following data elements were audited: study design, level of analysis, sample size, nurse staffing data source, nurse staffing measures, definition for nurse staffing level, outcome (HAI) measure, temporality, and findings.

Overview of Evidence between Nurse Staffing and HA

As shown in Table 1, different study designs were used including cross-sectional ($n = 18$, 40%), cohort ($n = 12$, 27%), longitudinal ($n = 7$, 16%), case-control ($n = 3$, 7%), pre-post ($n = 3$, 7%), and retrospective ($n = 2$, 5%). Two studies were related to infection outbreaks. Over half of the studies ($n = 29$, 64%) were multi-site. About two-fifths of the studies focused on multiple infections ($n = 23$, 47%). Studies included three different levels of analysis: hospital-level ($n = 13$, 29%), unit-level ($n = 8$, 18%), or patient-level ($n = 24$, 53%).

Different data sources were used for identifying nurse staffing, including administrative data ($n = 18$, 40%), data from nursing services departments ($n = 18$, 40%), nurse surveys ($n = 5$, 11%), payroll data ($n = 3$, 7%), and daily log ($n = 1$, 2%). Different aspects of nurse staffing were examined in the studies, with the most commonly examined staffing variable being the amount of nurse staffing, measured by the nursing hours per patient days (NHPPD) ($n = 24$, 53%) and nurse to patient ratio (or patient to nurse ratio) ($n = 16$, 36%). In six studies (13%) researchers compared the actual nurse to patient ratio with the required ratio by state regulations or hospital recommendations. Nursing skill mix was also studied in about a third of the studies ($n = 15$, 33%), generally calculated as the percentage of the registered nurse (RN) hours of all nursing hours. In four studies (9%) investigators assessed the type of nurse employment contract (i.e., full-time versus part-time or temporary nursing staff); others examined how nursing overtime ($n = 2$, 4%) and nurse absenteeism ($n = 1$, 2%) affected HAIs. When examining the relationship between nurse staffing and HAIs, most researchers ($n = 35$, 78%) aggregated both nurse staffing and HAI variables into hospital or unit level

over the study period. In a few ($n = 3$, 7%) studies the investigators compared the staffing levels between the periods with and without infections.

To examine the temporal relationship between nurse staffing and HAIs, one researcher team (2%) compared nurse staffing before and after outbreaks;¹⁴ two others (4%) compared between time periods (months or weeks) with and without infections.^{15,16} The most common ($n = 3$, 7%) method to address temporality was to examine nurse staffing prior to infection onset and its relation to HAIs;^{17–19} of these, only one group of researchers (2%) in a single site study actually examined the nurse staffing levels 2–4 days prior to the onset of infection, and found that suboptimal staffing in these 2–4 days had the most significant impact on HAIs.¹⁷

While the majority of the studies ($n = 37$, 82%) found that more nurse staffing was related to decreases in some types of HAIs, the findings varied across studies. For example, some reported that nurse staffing level or skill mix was significantly related to urinary tract infection (UTI),^{20,21} while others did not find this relationship.²² Or even in the same study, nurse staffing was found to be significantly related to one type of infection but not to other types.^{20–25} In addition, one study found that total licensed nurse staffing had more effect on HAIs than skill mix and suggested that if hospitals could maintain an adequate licensed nursing staff (total number of RNs and licensed practical nurses [LPNs]), the high proportion of RNs is not crucial for high quality of patient care.²¹

Challenges and Approaches

The inconsistency of findings are caused by a variety of reasons, such as dissimilar features of the study designs, variation in data sources, definitions of study variables, level of analysis, and frequent lack of consideration of staffing prior to the infection incubation period. Researchers examining nurse staffing in relation to HAIs often face methodological challenges that pose potential threats to internal validity. For example, one researcher attributed the limitations of the analysis to the reliability and validity of the measures.²¹ In Table 2 we summarize the challenges found in the existing evidence in terms of data sources, measurement of staffing, measurement of HAIs and the linkage of the two. Following the challenges, we recommend potential approaches to address each of the corresponding challenges.

Challenges related to data sources for nurse staffing and suggested solutions

Administrative data—The first challenge is that there is no comprehensive, valid and reliable database available for nurse staffing. Previous studies have primarily used two types of data sources for nurse staffing: 1) nationally available or state-level administrative data, or 2) unit/hospital based data from nursing services, the nursing departments, or payroll. The national/state level administrative datasets of nurse staffing are available from organizations such as the American Hospital Association (AHA) Annual Survey of Hospitals, or the Office of Statewide Health Planning and Development (OSHPD) in California. The advantages of these data are that they are readily available, relatively easily obtained, and allow cross-institution comparison, which increases sample sizes and power as well as enhancing generalizability of findings. However, these data are limited by a lack of

precision and not capturing the care provided by individual nurses for individual patients.²⁶ For example, the AHA data, which is the most frequently used and one of the few existing data sets available for nationwide studies, does not separate staffing by different types of facilities (acute care hospital, nursing home or long-term care unit); does not differentiate between nurse staffing in inpatient units and outpatient units;¹⁰ and does not distinguish the direct patient care from nursing administrative functions.^{26,27} The OSHPD data from California can partially address these issues by providing more details on service-level nurse staffing, but still receives criticism because of lacking unit-specific information.¹⁰

Approaches to decrease these limitations^{20,23,24,28,29} involve using information from other data sources to estimate service-level nursing hours. For example, the Centers for Medicare and Medicaid Services (CMS) Provider of Services file provides information on staffing for long-term care units. By subtracting these non-acute care staff from the total facility staff obtained from AHA, an estimate of acute care nurse staffing information may be calculated. In addition, the service-level administrative cost data from the CMS Medicare Cost Report can also be used with AHA data to estimate the staffing information for acute-care inpatient services.³⁰ Other researchers also used the model developed from the OSHPD in California State to estimate the allocation of nurse staffing in the inpatient setting for other states.^{20,31} However, none of these strategies are ideal,^{24,32} and these adjustments do not take into account the aggregation of the staffing data to an annual estimate, which does not allow for the assessment of temporality. Existing national level administrative data sets of staffing are still limited because of the imprecision and resulting measurement errors.^{10,24}

Data from nursing services, nursing departments and payroll—In comparison, nurse staffing data directly from nursing departments, nursing services, or payroll provide detailed information for working hours for each type of nursing staff on a daily basis, capturing a more accurate picture of direct patient care nursing hours. In studies using this type of data, the nurse staffing variables can be calculated for each day or even each shift in each unit. There are, however, important issues to be considered when using these data. First, the nursing service or payroll data are usually not in a format that can be directly used for research and it may be difficult to obtain permission to gain access and use these data. Intensive data mining and technologic programmatic expertise is also required for data extraction. Because of these challenges, studies that used nursing services data have generally been conducted at a single site with small sample sizes. This leads to minimal variation of nurse staffing within a single institution, therefore limiting the study's ability to detect significant effects on outcomes. In addition, the local scope of inquiry precludes crossinstitutional comparison and restricts the study's generalizability.

Challenges related to measurement of nurse staffing and suggested solutions

The second challenge is related to the measurement of nurse staffing. The two commonly used measures are NHPPD and nurse to patient ratio. NHPPD is calculated by the total number of nursing hours divided by the total hospitalization hours from all patients during the study period, reflecting the amount of time nurses spend with each patient each day. The nurse to patient ratio is often calculated as the total number of nurses divided by the total number of patients in a day. Neither measure reflects the acuity of patients. This can be

problematic in multi-site studies when different hospitals treat patients with varying acuity levels. Researchers have constructed a nursing case-mix index or nursing intensity weights^{20,24,31,33} that are based on a patient's diagnosis related group to estimate the relative nursing care need and incorporate the proportion of hospitals days spent in acute care and intensive care³³. Furthermore, for studies in which individual patient data are available, other comorbidity indices such as the Elixhauser Comorbidity Index or Charlson Comorbidity Index are available and have been used.

Another nurse staffing measurement issue is related to consolidation of nurse staffing levels from different unit types.^{34–37} Studies, especially those performing unitlevel analysis, often examined staffing from different unit types. Problems emerge, however, when different unit types have different staffing level requirements. For example, the California mandated nurse staffing ratio law stipulates the RN to patient ratio as 1:5 or 1:6 for general medical/surgical units, but 1:2 for most ICUs.³⁸ Mixing the nursing levels from different unit types, especially between ICUs and general medical/surgical units in the models,^{19,34,37} may mask the real effect of nurse staffing on outcomes.^{34,37}

A potential approach to address this issue is to use a standardized nurse staffing measure. More specifically, instead of using the actual nursing hours or nurse-to-patient ratios directly in their analyses, some researchers^{36,39–43} generated variables such as understaffing or overstaffing by comparing actual nursing hours with the required nursing hours. By doing this, a unified measure of nurse staffing levels is created, making the comparison across different unit types possible.

Challenges related to measurement of HAIs and suggested solutions

The third challenge involves the measurement of HAIs. In studies that use administrative data sources, HAIs have often been detected using the International Classification of Diseases (ICD) codes. However, the use of ICD codes in diagnosing HAIs is controversial. Some researchers have criticized ICD codes for low accuracy for measuring health care outcomes.⁴⁴ One group of researchers compared different computer algorithms for identification of surgical site infections (SSIs); they identified 235 SSIs from the ICD 9-only rule, 287 SSIs from the culture-only rule, and 426 SSIs from the combined method.⁴⁵ In some studies, the patient safety indicators (PSI) were used^{26,31} to identify infections due to medical care. The PSI, a standard algorithm developed by the Agency for Healthcare Research & Quality and applied to the administrative data sets based on ICD codes, was found to have little concordance with CDC methods in identifying infections.⁴⁴ The ICD codes alone do not match well with definitions developed by the CDC's National Healthcare Safety Network (NHSN), which require the combination of signs and symptoms with microbiologic results, and also considers the temporal aspect related to infection onset and time of admission. While such information is obtainable through patients' medical records and routinely used by infection preventionists in their surveillance, these surveillance data are not always available for researchers in a usable format and going through the medical charts and extracting this information post-hoc is time and labor-consuming. Another challenge related to administrative data is that this type of data cannot distinguish between a complication – a condition that develops during hospitalization period and comorbidity – a

co-existing diagnosis that can be identified by using the present on admission indicator. This failure prevents studies from testing a causal relationship between nurse staffing and HAIs.⁴⁶

Woeltje and colleagues⁴⁷ recently summarized electronically available data elements needed to identify HAIs based on specifications of the NHSN and underlined the long-term benefits of adopting EHR in HAI surveillance. Although still in the early stages, the EHR system clearly holds promise for future electronic HAI surveillance and research. Indeed, nationwide implementation of health information systems is gradually taking place in health care institutions. With such systems in place, HAIs as defined by NHSN can be more readily identified.

Challenges related to linkage of nurse staffing data to HAIs and suggested solutions

The final challenge for assessing the relationship between nurse staffing and HAIs is how to link the staffing and HAI data. In the studies that have used national or state level administrative data, aggregation of staffing to hospital-level was the only option. In the studies using hospital or unit level data with daily staffing measures, however, staffing variables were still often aggregated to a monthly average staffing level (or average staffing level within study period), and these aggregated staffing levels were examined in relation to the monthly HAI rate. This approach does not make it possible to assess the temporal relationship between staffing and HAI, therefore limiting the interpretation to association, not causality.

Considering the delay between nurse staffing exposure and onset of HAIs, linking each individual HAI to the staffing 2–4 days prior to the infection onset is necessary to examine the causal relationship. However, this approach is only possible when daily nurse staffing data are available. In this type of study, the 2–4 days pre-infection staffing levels for patients with infection needs to be compared with the staffing for those without infection. While the 2–4 days prior to infection onset are easily selected for patients with infection, it is critical for researchers to choose the right time point for patients without infection. Matching patients based on clinical presentation (severity of illness or nursing case mix) and length of stay prior to infection (or days between unit admission and infection onset) will be necessary.

Conclusions

This scoping review provides an overview of current evidence examining the relationship between nurse staffing and HAIs, and most importantly, identifies the major methodological challenges facing researchers. These challenges, which involve database selection, measurement of study variables, and methods to link the nurse staffing and HAI data, contribute to the inconsistent findings and quality among studies. The inconsistency of study findings across studies may make decision making difficult for health care administrators regarding management of nursing staff. Obtaining reliable and valid data is the first critical step toward methodologically rigorous study design and evidence. However, given the lack of standardized datasets to measure nurse staffing and HAIs, researchers must make decisions based on what is available and feasible. In this review, we suggest potential

solutions to improve the methodological quality of studies to examine this issue. Ultimately, however, while NHSN is a standardized, large scale database with validated HAI measures, there is limited ability to link detailed information on nurse staffing, which is necessary. The national efforts to promote EHRs and surveillance systems have great potential to address this issue. Hospital administrators may face considerable start-up and maintenance costs related to establishment of EHR systems in the early stages. However, considering the long-term benefits of improvement of patient care, researchers suggested that these costs will gradually diminish overtime.⁴⁷ In addition, the HiTech provisions provide a financial incentive for a facility to adopt an EHR system. Indeed, in responding to the national initiatives to eliminate HAIs, many hospitals have already established systems to record HAIs and related information. Linking the infection data source with already detailed time-stamped staffing data on a large scale can resolve many of the challenges such as the local scope of payroll data. This will aid in better understanding of the impact of nurse staffing on HAIs, and therefore provide validated evidence to inform hospital administrators in their decision making.

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Figure 1. Literature search flowchart (PRISMA format)*

*Reference: Moher, D., Liberati, A., Tetzlaff, J., Altman, D. G.; The PRISMA Group (2009). Preferred reporting items for systematic reviews and meta-analyses: The PRISMA Statement. *Journal of Clinical Epidemiology*, 62(10), 1606–1612. doi: 10.1016/j.jclinepi.2009.06.005.

Table 1

Summary of studies on nurse staffing and HAIs

Author (year)	Design	Level of analysis	Sample	Staffing level definition	Staffing data source	Other staffing measures	Infection(s)	Staffing parameter used
Taunton (1994) ³⁶	Cross-sectional	Unit	4 hospitals	Required nursing hours/actual nursing hours	Nursing service data	Nurse absenteeism	Multiple site infections	Calculated average staffing level
Grillo-Peck (1995) ⁴⁸	Pre-post	Patient	71 patients	Not studied	Nursing service data	Skill mix	Unspecified infections	Calculated average staffing level
Haley (1995) ⁴¹	Pre-post	Patient	10943 patients	Required nursing hours/actual nursing hours	Nursing service data	Not included	MRSA infection	Calculated average staffing level
Fridkin (1996) ⁴⁹	Case control	Patient	1760 patients	Patient/nurse ratio	Nursing service data	Not included	BSI	Comparison of monthly patient/nurse ratio between months with ≥ 1 BSI and without BSI
Archibald (1997) ⁵⁰	Cross-sectional	Patient	782 patients	NHPPD	Administrative data	Not included	Unspecified HAIs	Calculated average staffing level
Blegen (1998) ³⁴	Cross-sectional	Unit	42 units	NHPPD	Payroll data	Skill mix	Unspecified infections	Calculated average staffing level
Kovner (1998) ⁵¹	Cross-sectional	Hospital	589 hospitals	NHPPD	Administrative data	Not included	Multiple site infections	Calculated average staffing level
Harbarth (1999) ⁴³	Cohort (Outbreak)	Patient	60 patients	Nurse/patient ratio (compared with required ratio)	Nursing service data	Not included	Nosocomial <i>E. cloacae</i> infection	Information not available
Liehtig (1999) ⁵²	Cross-sectional	Hospital	791 hospitals	NHPPD	Administrative data	Skill mix	Postoperative infections	Calculated average staffing level
Vicca (1999) ⁵³	Cohort	Patient	50 patients	Nurse/patient ratio	Nursing service data	Temporary nurse	MRSA infection	Calculated average staffing level
Amaravadi (2000) ⁵⁴	Cohort	Patient	366 patients from 35 hospitals	Nurse/patient ratio	Nurse survey	Not included	Multiple site infections	Categorized to more or fewer ICU nurses

Author (year)	Design	Level of analysis	Sample	Staffing level definition	Staffing data source	Other staffing measures	Infection(s)	Staffing parameter used
Dorsey (2000) ⁵⁵	Cohort (Outbreak)	Patient	52 patients	Nurse/patient ratio	Nursing service data	Not included	Organism specific HAI	Compared staffing before and after outbreak
Robert (2000) ¹⁹	Case control	Patient	127 patients	Nurse/patient ratio	Nurse service data	Temporary nurse	BSI	Examined staffing 72 hours before infection
Dimick (2001) ⁵⁶	Cohort	Patient	569 patients from 25 hospitals	Nurse/patient ratio	Nurse survey	Not included	Multiple site infections	Categorized to more or fewer ICU nurses
Pronovost (2001) ⁵⁷	Cross-sectional	Patient	2606 patients from 52 hospitals	Nurse/patient ratio	Nurse survey	Not included	Multiple site infections	Categorized to more or fewer ICU nurses
Grundmann (2002) ⁴⁰	Cohort	Patient	331 patients	Nurse/patient ratio (compared with required ratio)	Nursing service data	Not included	MRSA infection	Defined understaffing, & Examined days of staff deficit
Kovner (2002) ²⁷	Cross-sectional	Hospital	570 hospitals	NHPPD	Administrative data	Not included	Multiple site infections	Calculated average staffing level
Needleman (2002) ⁴⁰	Cross-sectional	Hospital	799 hospitals	NHPPD	Administrative data	Skill mix	Multiple site infections	Calculated average staffing level
Stegenga (2002) ⁵⁸	Retrospective	Patient	2929 patients	NHPPD & Nurse/patient ratio	Nursing service data	Not included	nosocomial viral gastrointestinal infections	Examined staffing 72 hours before infection
Tucker (2002) ⁵⁹	Cohort	Patient	186 hospitals	Nurse/patient ratio	Nursing service data	Not included	BSI	Compared actual ratio with national recommended ratio
Whitman (2002) ³⁷	Cohort	Unit	95 patients from 10 units	NHPPD	Nursing service data	Not included	BSI	Calculated average staffing level
Alonso-Echanove (2003) ⁶⁰	Cohort	Patient		Nurse/patient ratio	Daily log	Temporary nurse	BSI	Calculated average staffing level
Cho (2003) ²²	Cross-sectional	Patient	232 hospitals	NHPPD	Administrative data	Skill mix	Multiple site infections	Calculated average staffing level
McGillis (2003) ³⁵	Cross-sectional	Unit	77 units from 19 hospitals	Not studied	Survey of nurse managers	Skill mix	Multiple site infections	Calculated average staffing level

Author (year)	Design	Level of analysis	Sample	Staffing level definition	Staffing data source	Other staffing measures	Infection(s)	Staffing parameter used
Needleman (2003) ²⁴	Case control	Hospital	799 hospitals	NHPPD	Administrative data	Skill mix	Multiple site infections	Calculated average staffing level
Unruh (2003) ²¹	Longitudinal	Hospital	Not reported	NHPPD	Administrative data	Skill mix	Multiple site infections	Calculated average staffing level
Yang (2003) ²⁵	Cross-sectional	Unit	21 units	NHPPD	Administrative data	Skill mix	Multiple site infections	Calculated average staffing level
Mark (2004) ²³	Longitudinal	Hospital	422 hospitals	NHPPD	Administrative data	Skill mix	Unspecified HAI	Calculated average staffing level
Sujjantararat (2005) ⁶¹	Cross-sectional	Unit	19 units	NHPPD	Nursing service data	Skill mix	UTI	Calculated average staffing level
Berney (2006) ²⁸	Longitudinal	Hospital	161 hospitals	NHPPD	Administrative data	Nursing overtime	Multiple site infections	Calculated average staffing level
Cimiotti (2006) ⁶²	Cohort	Patient	2675 patients	NHPPD	Unit nurse staffing data	Temporary nurse	BSI	Calculated average staffing level
								Defined understaffing by comparing with required staffing level, & Compared staffing level between weeks with and without infections
Dancer (2006) ³⁹	Outbreak study	Patient	174 patients	Nurse/patient ratio compared with required ratio	Nursing service data	Not included	MRSA infection	Calculated average staffing level
Halvani (2006) ⁴²	Longitudinal	Patient	430 patients	Nurse/patient ratio	Nursing service data	Not included	Unspecified HAI	Calculated average staffing level
Hugonnet (2007) ¹⁷	Cohort	Patient	2740 patients	Nurse/patient ratio	Nursing service data	Not included	Unspecified HAI	Calculated average staffing level
Mark (2007) ²⁹	Longitudinal	Hospital	286 hospitals	NHPPD	Administrative data	Not included	Multiple site infections	Calculated average staffing level
Hugonnet (2007) ¹⁸	Cohort	Patient	1883 patients	Nurse/patient ratio	Nursing service data	Not included	Ventilator-associated pneumonia	Calculated average staffing level
Stone (2007) ⁶³	Cross-sectional	Patient	6385 patients from 31 hospitals	NHPPD	Payroll data	Nurse overtime	Multiple site infections	Calculated average staffing level
Stratton (2008) ⁶⁴	Retrospective, correlational	Unit	7 hospitals	NHPPD	Administrative data	Skill mix	Multiple site infections	Calculated average staffing level

Author (year)	Design	Level of analysis	Sample	Staffing level definition	Staffing data source	Other staffing measures	Infection(s)	Staffing parameter used
Firth (2010) ⁶⁵	Cross-sectional	Unit	35,000 patients from 11 units in 4 hospitals	NHPPD	Administrative data	Skill mix	Multiple site infections	Calculated average staffing level
Mark (2010) ⁴⁶	Longitudinal	Hospital	283 hospital	NHPPD	Administrative data	Not included	Multiple site infections	Calculated average staffing level
Cimiotti (2012) ⁶⁶	Cross-sectional	Hospital	161 hospitals	Patient/nurse ratio	Nurse survey	Not included	Multiple site infections	Calculated average staffing level
Glance (2012) ⁶⁷	Cross-sectional	Patient	70,142 patients from 77 hospitals	NHPPD	Administrative data	Skill mix	Multiple site infections	Calculated average staffing level
Roche (2012) ⁶⁸	Cross-sectional	Patients	14 units from 2 hospital	Skill mix	Payroll data	Skill mix	Multiple site infections	Calculated average staffing level
Unruh (2012) ²⁶	Longitudinal	Hospital	1,116 patients from 124 hospitals	NHPPD	Administrative data	Not included	Infection due to medical care (AHRQ patient safety indicator)	Calculated average staffing level
Mark (2013) ³¹	Cross-sectional	Hospital	34.7 million discharges from 600 hospitals	NHPPD	Administrative data	Not included	Infection due to medical care (AHRQ patient safety indicator)	Calculated average staffing level

Notes: NHPPD: nursing hours per patient days, BSI: bloodstream infection, UTI: urinary tract infection, MRSA: Methicillin-resistant *Staphylococcus aureus*. * Understaffing is defined if the actual staffing is lower than the required staffing for the unit, AHRQ: Agency

Table 2

Summary of challenges and approaches to address the challenges

	Challenges	Approaches
Data source	Administrative data: Lack of precise measure of staffing level <ul style="list-style-type: none"> Do not separate staffing by different types of facilities Do not differentiate the nurse staffing in inpatient units from that in outpatient units 	<ul style="list-style-type: none"> Use CMS POS file and Medicare Cost Report data to estimate the nursing administration hours Use model developed from California OSHPD to improve the allocation of nurse staffing into inpatient setting; use data from nursing service data, or payroll data
Measure of staffing	<ul style="list-style-type: none"> Nursing hours per patient days and nurse to patient ratio are not adjusted for patient's acuity Consolidation of nurse staffing level from different unit types mix 	<ul style="list-style-type: none"> Use patient's diagnosis related group to create a severity of illness or nursing case-mix index. Add Elixhauser comorbidity index or Charlson score to model for patient risk adjustment. Use standardized nurse staffing index
Measure of HAIs	<ul style="list-style-type: none"> ICD codes lack precise measure of HAIs 	<ul style="list-style-type: none"> Use electronic medical record to measure infection following CDC definitions
Linkage of nurse staffing to HAIs	<ul style="list-style-type: none"> Average value of staffing cannot examine the temporal relationship between nurse staffing and HAIs 	<ul style="list-style-type: none"> Examine nurse staffing level 2–4 days before infection onset and its relation with HAIs

Note: CMS: Centers for Medicare & Medicaid Services, POS: Provider of Services, OSHPD: Office of Statewide Health Planning and Development, ICD: International Classification of Diseases, CDC: Centers for Disease Control and Prevention.