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REVIEW

Technological innovations and hospital performance: a systematic review of the literature

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Abstract: Given the ongoing concerns about health care quality and costs during the 21st century, significant attention has been focused on the clinical and financial performance of US hospitals. On one hand, hospitals have been adopting various clinical technologies to improve their clinical quality and financial performance. On the other hand, there is no comprehensive study that has examined the research evidence on the relationship between clinical high technology and hospital performance (clinical and financial). This systematic literature review attempts to account for the technology–performance link in US hospitals by focusing on clinical technologies and services. The review confirms the paucity of research on this topic and reveals that there are mixed findings across research studies. It also provides directions and recommendations for future research by identifying major gaps in the existing literature.

Keywords: clinical performance, financial performance, hospital technology, quality

Introduction

US hospitals have been facing increasing challenges to improve their clinical and financial performance. Some of these challenges arise from efforts to control increasing hospital costs. As a result of legislative pressures, pay-for-performance initiatives, quality-enhancement measures, and various other external pressures, hospitals are searching for ways to improve their performance. Since technology represents a high proportion of hospital capital investments, it has long been identified as a major contributor to both clinical and financial performance.

Hospital technology, for the purposes of this paper, is defined as high-technology clinical equipment and services that are designed to solve certain human health problems, to improve human health conditions, or to improve the precision of diagnosis (eg, high-tech medical/surgical intensive care, electron beam computed tomography, etc).[1] About 50% of hospital capital investment is spent on technology-improvement initiatives.[2] Importantly, the adoption of new technologies, including both big- and small-ticket items, and the increased use of existing technologies are responsible for 30%–75% of the health care costs in the United States.[2–7] Technological advancements also are a major contributor to better clinical performance in hospitals. For example, hospital technologies such as minimally invasive surgeries and cardiac catheterization have improved quality of care by reducing recovery time and mortality rates.[8,9]

There are significant challenges for researchers who want to investigate the causal links between hospital technology and clinical and financial performance. Exploring this relationship is not a trivial exercise. It requires, among other factors, accounting for the socioeconomic and demographic variance among patients, the variances in

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payers' reimbursement and regulatory policies, as well as the various diseases diagnosed and treated by hospitals. Given the complexity of the health care context and the complexity of the relationship between hospital technology and performance, we believe it is critical to evaluate the state of existing research to determine the knowledge gaps and inform future research agendas.

This study addresses this need by systematically reviewing the literature on the relationship between hospital technology and performance. In this study, hospital performance refers to both clinical and financial performance. This review focuses only on clinical technologies and services; health information technology, with its own substantial body of research, is outside the scope of this study. When adopting new clinical technologies, hospital decision makers focus on two rationales: the expected improvement in clinical performance, and the expected positive impact on financial performance. Therefore, the intent of this literature review is to provide systematically aggregated information on the clinical and financial performance implications of clinical technologies for hospital decision makers.

To better inform hospital executives, we focus on organizational-level performance, rather than departmental- or unit-level performance, for two reasons. First, although there are a large number of studies that focus on individual clinical technologies and departmental-level performances (eg, cost–benefit analyses of individual technologies), these studies typically do not look at the organizational implications of high-tech services. Second, organizational performance does not only depend upon unit/departmental performance, but also on other factors (eg, external competition, regulatory costs, unfunded legislative mandates, etc). In other words, organizational performance cannot be defined as the aggregate of various departments' performances; rather, organizational performance is achieved through the interaction of technologies with individuals, departments, other organizations, and various other external forces, including both governmental and other regulatory bodies.

New contribution

This review examines the empirical studies that have investigated the impact of hospital technologies on organizational performance, both clinical and financial. There are four ways in which this review differs from previous reviews on this topic. First, it particularly focuses on high-tech clinical services and attempts to account for the relationship between these services and hospital performance. In this review, hospital performance is considered a dependent variable and technology an independent variable. Most other studies (eg, diffusion of innovation or technology adoption studies)[10–19] have focused on technology as the dependent variable. By focusing on technology as an independent variable, this review attempts to bring attention to this less explored area of study while also viewing technology as a strategic asset. Second, it addresses a need to evaluate the strategic implications of high-tech services, accomplished by focusing on organizational-level performance rather than unit- or departmental-level performance. Third, this review draws upon Spetz and Maiuro's[1] typology (focused on hospital technology measurement) and extends it by focusing on the relationship between hospital technology and performance. Finally, this review integrates traditional literature review processes (eg, manual searches of bibliographies) with a systematic review process to improve its comprehensiveness.

Analytical framework

As seen in Figure 1, the main objective of this review is to examine the relationship between hospital technology and organizational performance (clinical/financial). Especially for the clinical performance dimension of our analytical framework, this review is informed by Donabedian's structure–process–outcome framework.[20–22] We emphasized the technology–clinical performance (quality) link in our framework since the impact of technology is considered within the structure dimension of Donabedian's structure–process–outcome framework. The rest of the details of this analytical framework are based on the following four main research questions:

1. What are the major findings in regards to the relationship between hospital technology and financial/clinical quality performance?
2. What types of research designs were used in these studies?
3. What types of hospital technology measures were used in these studies?
4. What types of hospital financial/quality performance measures were used?

Methods

The search process included several steps. First, we identified relevant papers as those that were US-based empirical peer-reviewed studies that investigated the relationship between high-tech clinical services (equipment) and hospital performance, particularly clinical quality and financial performance. Non-US publications were excluded because

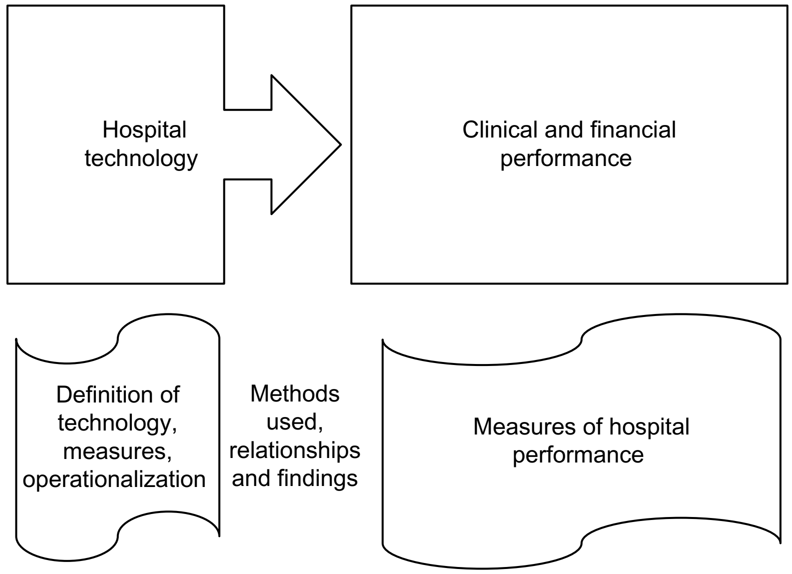

Figure 1 Analytical framework for the relationship between hospital technology and performance.

of differing regulatory and market environments in other countries. Single-hospital studies were also excluded due to the limited generalizability of their findings.

Second, search terms were identified based on the authors' own expertise, two books on medical technology,[2,23] several seminal articles on health care technology,[1,24–26] and several seminal articles on quality and financial performance.[21,27,28] After conducting a pilot search in PubMed and searching the PubMed MeSH terms, the following keywords and phrases were used in this review: 1) for the technology dimension – "hospital", "technology", "high-tech", "equipment", "service line", "service mix", "service offering", "full service", and "hospital service"; and 2) for the performance dimension – "quality", "mortality", "readmission", "outcome", "hospital performance", "performance", "cost", "financial performance", and "financial".

Third, multiple searches were performed by using the keyword combinations in four data search engines (see Figure S1 for keyword combinations). To improve the manageability and relevancy of the results, several filters were used to limit publications to those that: 1) were published in English between 1980 and July 2012; and 2) had key words in the abstract and/or title. A total of 21,682 articles were retrieved from these searches including 12,361 from PubMed; 6,527 from the Web of Science; 994 from Business Source Premier; and 1,800 from the Cumulative Index to Nursing and Allied Health (CINAHL). Thomson Reuters' EndNote was used to aggregate the search results and to screen for duplicates. After eliminating the 7,046 duplicate articles, initial results returned 14,636 articles.

Fourth, to improve the search/selection/retention process and achieve the ultimate focus of this review, a priori-determined exclusion/inclusion criteria were applied at three stages: 1) criteria stage one removed publications that were not relevant to hospital performance (ie, financial or clinical); 2) criteria stage two screened features of publications according to a priori criteria (ie, paper type, unit of analysis, location, and relevancy); and 3) criteria stage three confirmed the presence of clinical technology, hospital performance measures, and the relationship between these two variables.

Figure 2 summarizes the selection process for identifying published studies that investigated the relationship between hospital technology and performance. After applying the three-staged inclusion/exclusion criteria and adding manually searched articles, the number of articles for full-text review was reduced from 14,636 to 288. Following a full text review, 24 publications were abstracted. To strengthen the review search process, the reference section of each abstracted publication was also screened for the inclusion of any potentially relevant publication that might have been missed during earlier steps. Two additional articles were included among the abstracted ones, resulting in 26 empirical articles for this review study.

Results

The results of this literature review of hospital technology and performance are summarized in Table 1 (financial performance) and Table 2 (clinical performance). Overall, the studies showed mixed results. This is not surprising since the reviewed

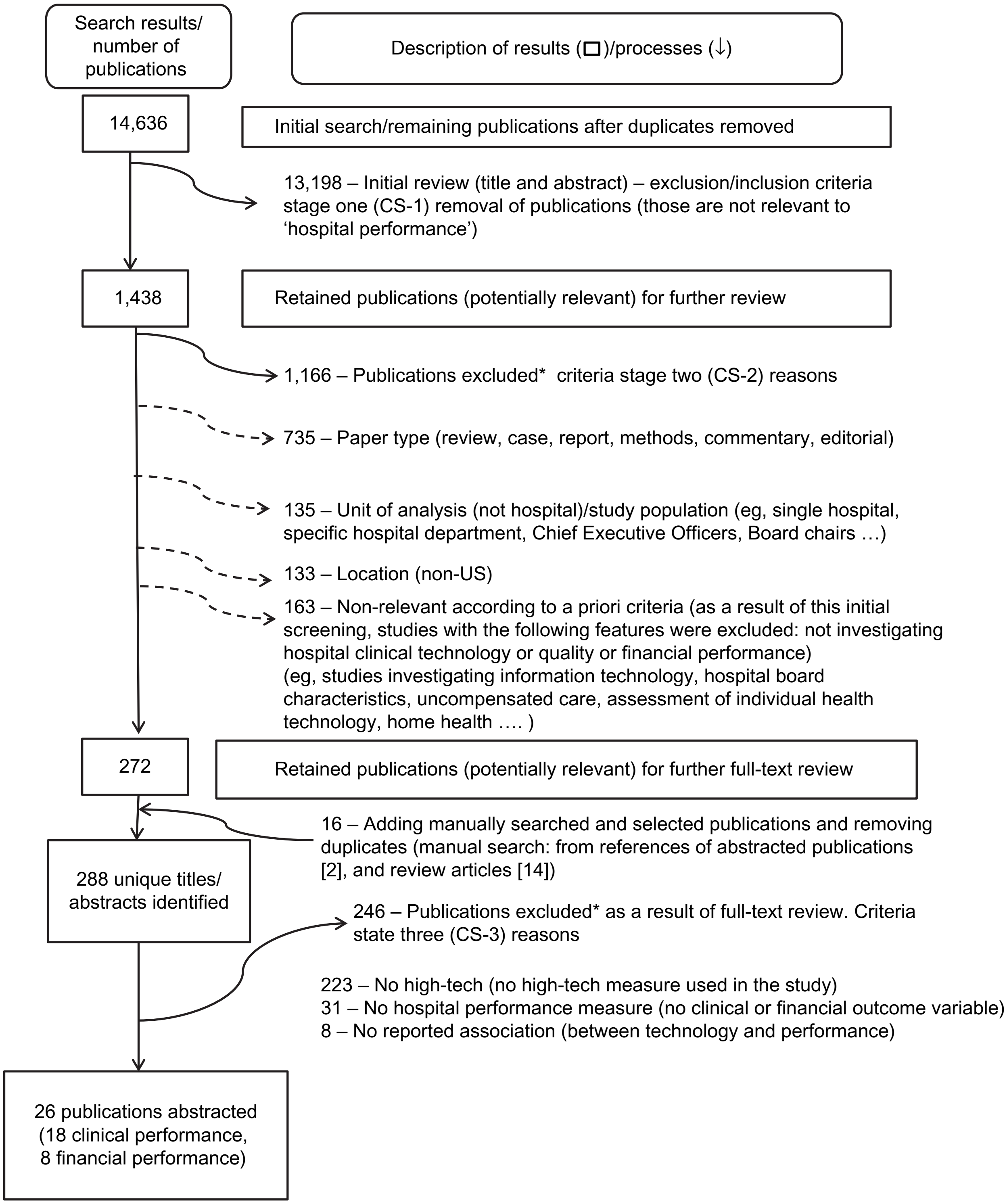

Figure 2 Selection of publications investigating the relationship between hospital technology and performance.
Note: *Exclusions are not mutually exclusive.

studies use a variety of technology and performance measures, as well as different analytical methods. Moreover, technology was not the main focus in most of these studies; instead, technology measures were typically included as a control variable within a study investigating another research topic.

There were also differences across the research studies in terms of their measures of hospital technology (Tables 1 and 2). Out of the 26 publications, seven used one or two technological services as a marker of hospital technology;[29–35] 14 publications used an index of three or

Table 1 Studies examining the relationship between hospital technology and financial performance

Authors	Study period	Sample	Design	Outcome variables (OV)	Hospital technology (HT)	Other independent variables	Analysis	HT relationship with OV
Chen et al[29]	2006	3,146 hospitals for CHF, 3,152 hospitals for pneumonia	CS	1: Cost of care for pneumonia and CHF	No-direct definition, however, among independent variables' presence of CICU and MICU were included	Process quality measures, mortality, readmission, and hospital structural characteristics	Linear regression and multivariate models	Hospitals classified in higher-cost quartile for CHF were more likely to have CICU Hospitals in low-cost quartile for pneumonia had slightly less presence of MICU
Irwin et al[36]	1990, 1991	222 general, short-term hospitals in FL	CS	1: ROA 2: TM	A high-tech index developed by using the AHA data and the ratings of health professionals by using Likert-type surveys on value, inimitability, rareness, and non-substitutability	Hospital size (only control variable)	OLS, hierachical, multiple regressions	Positive significant relationship (both for ROA and TM) especially for those hospitals with technologies that are valuable, rare, and inimitable
Li and Collier[37]	1994	157 community hospitals with 33% return rate	CS	1: Operating profit 2: ROA 3: Return on investments	Clinical technology measure based upon survey questions on 1) lab equipment, 2) radiology equipment, and 3) drug dispensing	1: Clinical outcome 2: Physician participation	Chi-square to see responder/nonresponder difference. SEM	Positive association between clinical technology and financial performance (ROA, operating profit, ROI)
Jha, et al[30]	FY 2002	Out of 4,648 AHA hospitals, 3,794 were used due to missing data on hospital costs	CS	1: Risk-adjusted costs for AMI, CHF	No direct definition, however, structural characteristics include presence of ICU or MICU	Risk-adjusted quality and mortality measures for AMI, CHF, and pneumonia	chi-square tests, Student's *t*-tests, multivariable logistic regressions	Hospitals at the lowest quartile of risk-adjusted costs were less likely to have ICU
Jiang et al[38]	1997 and 2001	Final sample: 934 nonfederal, general acute hospitals in 10 states	CS	1: CMS cost-to-discharge ratios 2: Operating margin 3: TM	Presence of 9 high-tech services including CABG, angioplasty, cardiac catheterization, extracorporeal shock-wave lithotripsy, CT, and diagnostic radioisotope, MRI, PET, and single photon	Market characteristics, hospital, characteristics, human-resource characteristics	Stratification of C/MQ, and logistic regression.	Hospitals' likelihood of moving from worst to best quadrant was positively associated with number of high-tech services. NS association was found between presence of high-tech and persistenly being in the low C/MQ overtime.
McCue et al[48]	1990–1995	422 acute-care hospitals	LG	1: Operating margin 2: Operating expense	Saidin index	RN, LPN, non-nurse staffing (separate); mortality;	Dynamic model regression with lagged dependent variable	Used as a control variable/ NS
Trinh et al[39]	1998, 2000, 2002	2,204 acute-care hospitals in US	LG	1: Average cost per patient day 2: Average cost per discharge 3: Operating margin 4: ROA	Count of 15 high-tech services such as angioplasty, cardiac catheterization lab service, certified trauma service, extracorporeal shock wave lithotripter service, HIV/AIDS service,	Duplication of services for inpatient and ancillary services	SEM with maximum likelihood estimator	High-tech duplication was associated with higher cost and lower operating margin

(*Continued*)

Table 1 (*Continued*)

Authors	Study period	Sample	Design	Outcome variables (OV)	Hospital technology (HT)	Other independent variables	Analysis	HT relationship with OV
Trinh et al[40]	1997, 2000, 2003	1,227 urban acute-care hospitals belong to multihospital system	LG/SEM	1: Average cost per patient day 2: Average cost per discharge 3: Operating margin 4: ROA	Number of 15 high-tech services such as MRI, PET, single photon emission computerized tomography, ultrasound, and reproductive health	Duplication of services for inpatient and ancillary services	SEM with maximum likelihood estimator	Receiving high-tech services is financially more beneficial than service sharing for individual hospitals

Abbreviations: AHA, American Heart Association; AIDS, acquired immunodeficiency syndrome; AMI, acute myocardial infarction; CABG, coronary artery bypass grafting; CHF, congestive heart failure; CICU, cardiac ICU; C/MQ, cost/mortality quadrants; CMS, Centers for Medicare & Medicaid Services; CS, cross-sectional; CT, computed tomography; FY, fiscal year; HIV, human immunodeficiency virus; HT, hospital technology; ICU, intensive care unit; lab, laboratory; LG, longitudinal; LPN, licensed practical nurse; MICU, medical ICU; MRI, magnetic resonance imaging; NS, not-significant; OLS, ordinary least squares; PET, positron emission tomography; RN, registered nurse; ROA, return on assests; ROI, return on investment; SEM, structural equation modeling; TM, total margin.

more technological services;[36–47] and five publications, all with a nursing focus, used the Saidin index, a special high-tech index that takes into account both the breadth and rareness of high-tech services.[48–52]

Eight studies investigated the technology–financial performance link, again with differing research designs, sample sizes, and study periods (Table 1), and mixed results. Four of the eight studies analyzed longitudinal data.[25,28–30] On one hand, a cross-sectional study found a positive relationship between a technology index and financial performance (return on assets [ROA] and total margin);[36] on the other hand, a longitudinal study found a nonsignificant relationship for ROA and operating expenses as financial performance measures.[48] Both studies developed their technology indices by using the American Hospital Association's annual survey. Both studies also used similar profitability measures as dependent variables such as total margin, operating margin, and ROA.

Some of the results indicate an association between the availability of technologies and higher costs at hospitals. For example, a cross-sectional study that used a cardiac intensive care unit and a medical intensive care unit as markers of technological sophistication found that hospitals with a cardiac intensive care unit/medical intensive care unit were in the highest cost quartile for congestive heart failure/pneumonia.[29] Similarly, a cross-sectional study found that hospitals classified at the lowest risk-adjusted cost quartile for acute myocardial infarction, congestive heart failure, and pneumonia were less likely to have an intensive care unit.[30]

There were 18 studies analyzing the association between hospital technology and clinical performance, also with mixed results (Table 2). The majority (70%) of studies in Table 2 used cross-sectional designs, with sample sizes ranging from 54 to 4,401 hospitals. Mortality rate was one of the most frequently used outcome measures. Overall, of the nine studies that used mortality as an outcome, four studies found no significant relationship; four studies found significant and negative relationships; and one study found a significant and positive association between high-tech medical services and mortality rates. Two cross-sectional studies[41,49] and one longitudinal study[44] found nonsignificant relationships for mortality rates. Two cross-sectional studies found significant and negative associations between hospital technology and mortality rates,[42,47] while a longitudinal study found significant and positive association by using ordinary least squares.[52] For the technology–mortality link in high-managed-care-penetrated markets, a longitudinal study found significant and positive association by using ordinary least squares, and a significant and negative association by using

Table 2 Studies examining the relationship between hospital technology and clinical performance

Authors	Study period	Sample	Design	Outcome variables (OV)	Hospital technology (HT)	Other independent variables	Analysis	HT relationship with OV
Bazzoli et al[41]	1995–2000	1,544 nonfederal, general acute-care hospitals from 11 states	CS	1: In-hospital mortality in low death DRGs, 2: Nursing and Surgical PSIs	High-tech services defined as a count of up to 33 services reported in AHA survey including NICU, trauma centers, open-heart surgery, etc	Financial performance (operating margin, cashflow to total revenues)	GMM	Significantly positively associated with surgical-related PSI ($P<0.01$). No significant relationship with other outcome measures
Blegen et al[49]	2005	54 hospitals member of University Health System Consortium	CS	1: CHF mortality, 2: Decubitus ulcer, 3: FTR 4: Infection due to medical care, 5: Postoperative sepsis.	Saidin index	Safety-net status, RN skill mix, total hours of nursing care, size, ownership, location, case mix index	Robust regression	NS
Ghaferi et al[31]	2000–2006	8,862 patients in 672 nationwide hospitals	LG	FTR	Dichotomous (yes/no) variable of presence of organ transplantation or open-heart surgery	Nurse-to-patient ratio, teaching status, hospitals size, and average daily census	Multivariate logistic regression models	Significant association with lower FTR (OR 0.65, 95% CI 0.52 to 0.82)
Hartz, et al[42]	1986	3,100 hospitals	CS	Predicted mortality rates	Count of 5 high-tech services available: cardiac catheterization lab, extracorporeal lithotripter, MRI, open-heart surgery, and organ transplantation	Financial status (payroll expenses and occupancy rate), ownership, % board-certified specialists, % of RN)	Weighted least squares regression	Higher technology sophistication significantly associated with lower mortality
Jha et al[32]	2007	2,222 hospitals that reported discharge instructions on HQA and HCAHPS	CS	1: Readmission rate for CHF and pneumonia	Presence of coronary care-unit presented as an indicator of technology	Two discharge measures (chart-based, patient reported) ratio of nurses to 1,000 patient days,	Chi-square tests, Student's *t*-tests to compare hospital characteristics on discharge planning, multivariable linear regression models	There is a positive significant ($P<0.05$) association between hospitals with coronary care unit and HQA performance on discharge instructions
Jha et al[33]	2007	2,429 hospitals with patients' experience data	CS	Patient Reported quality of care based upon HCAHPS survey	Presence of medical ICU was presented as a marker of technological capability	Nurse-to-1000 patient days ratio, HQA process measures for AMI, CHF, pneumonia, and surgical care	Chi-square tests, Student's *t*-tests and multivariable linear regression models	Very modest difference found between hospitals with and without medical ICU in % of patients' global ranking (62.33% and 63.9%, respectively; $P=0.001$)

(*Continued*)

Table 2 (*Continued*)

Authors	Study period	Sample	Design	Outcome variables (OV)	Hospital technology (HT)	Other independent variables	Analysis	HT relationship with OV
Jha et al[43]	Fiscal years 1996–2002	42 more minority-serving versus 108 disproportionately nonminority serving VA hospitals	LG	30-day mortality on AMI, CHF, gastrointestinal hemorrage and pneumonia	Presence of cardiac ICU and availability of key technologies (angioplasty, CABG, and MRI)	Concentration of black veterans, hospital characteristics	Ordinary logistic regression for mortality outcome.	Adjusted mortality rates for pneumonia and AMI were significantly higher at minority-serving hospitals, which were more likely to have cardiac ICU, angioplasty, CABG
Jiang et al[38]	1997 and 2001	Final sample: 934 nonfederal, general acute hospitals in 10 states	CS	AHRQ inpatient mortality quality indicators	Presence of 9 high-tech services such as angioplasty, cardiac catheterization, extracorporeal shock-wave lithotripsy, CT, and diagnostic radioisotope	Market characteristics, hospital characteristics, human-resource characteristics	Stratification of C/MQ Logistic regression	Positive association with the likelihood of moving from worst to best quadrant. NS association was found for persistenly being in the low C/MQ overtime.
Krakauer et al[47]	1986	84 hospitals throughout US (42,773 patients)	CS	30-day mortality rates	Index including: cardiac catheterization lab, extracorporeal lithotripter, MRI, open-heart surgery facility, or organ transplantation capability	% of RN, % board-certified specialist physicians, other structural characteristics	Logistic regression	Statistically significant negative relationship both for claims and clinical models
Li and Collier[37]	1994	157 community hospitals	CS	1: Survey question on clinical quality	Clinical technology measure based upon survey questions on 1) lab equipment, 2) radiology equipment, 3) drug dispensing.	SEM based upon three stage links: 1) technology measures 2) two quality measures, 3) hospital financial performance	Chi-square to see responder/ nonresponder difference. SEM	Positive association between clinical technology and clinical quality
Mark, and Harless[50]	1996–2001	283 acute-care hospitals in CA	LG	Postoperative ratios for: 1) pneumonia, 2) septicemia, 3) urinary tract infection	Saidin index	RN, LVN, and aide hours per patient (separate measures), CMI, payer mix, HMO penetration	Dynamic panel regression model with GMM	NS
Mark et al[51]	1990–1995	422 acute-care hospitals	LG	Mortality	Saidin index	RN, LPN, non- nurse staffing (separate); market characteristics, hospital characteristics	OLS, within-group, and dynamic panel model regressions	Only in high HMO penetration markets high-tech was significantly (positive in OLS, negative in fixed effects) associated with mortality rates (except the dynamic panel model).

Mark et al[52]	1990–1995	422 acute-care hospitals	LG	Risk Adjusted complication ratios: mortality, pneumonia, Decubitius Ulcer, and urinary tract infection	Saidin index	RN, LPN, non-nurse staffing (separate); market characteristics, hospital characteristics	OLS Within Group, and dynamic panel model regressions	HT was significantly (positively) associated with mortality (only in OLS model). HT was significantly (negatively) associated with pneumonia complications ratio (dynamic panel model)
Mukamel et al[46]	1990	1,927 hospitals in 134 MSA	CS	Risk Adjusted mortality rates	Index including: cardiac catheterization lab, extracorporeal lithotripter, MRI, open-heart surgery, and organ transplantation	% of Medicaid days, % of ICU days, ratio of ER visits to total inpatient days	Regression models with MSA random effects	Hospitals in top technology quartile (having at least 2 high-tech services) had a lower mortality rate compared to hospitals with no high-tech services
Schultz et al[34]	1992	373 medical surgical hospitals in CA	CS	AMI mortality ratio	Availability of: CABG, PCI, or both	Teaching status, board-certified physician %, RN hours/inpatient days, profit status, total expenses/patient days	Bivariate corrolations. Then, linear regression and hierarchical order of entry	NS in bivariate corelations. Significant and inverse in regression results.
Person et al[45]	1994–1995	4,401 of 6,668 hospitals from Cooperative Cardiovascul ar Project (CCP)	CS	In-hospital mortality ratio	Four categories of technology availability based on 3 procedures: 1) Coronary angiogram, 2) Percutaneous coronary intervention 3) CABG	Nurse-to-patient ratio for RN and LPN (categorized into quartiles)	Comparison of RN/LPN staffing quartiles with chi-square and Student's *t*-test. Then, multivariable logistic models.	High RN staffed hospitals are more likely to have more techologies and more likely to be teaching hospital. Higher RN staffing associated with lower mortality
Tomal[44]	1991	398 general acute care hospitals in CA with at least 50 Medicare cases	LG	Adjusted mortality rate	Number of high-tech services (0–3): coronary intensive care, organ/tissue transplant, burn unit	Market characteristics, hospital characteristics	Ordered probit (compared with OLS)	NS
Werner and Bradlow[35]	2004	3,657 acute care hospitals Reported quality measures to Hospital Compare	CS	Risk Adjusted mortality rate	Presence of open-heart surgery	Process measures form AMI, CHF, and pneumonia	Regression – Bayesian approach	Significantly higher number of hospitals with open-heart surgery (67%) were categorized under low, and average mortality groups.

Abbreviations: AHA, American Heart Association; AHRQ, Agency for Healthcare Research and Quality; AMI, acute myocardial infarction; CABG, coronary artery bypass grafting; CHF, congestive heart failure; CI, confidence interval; C/MQ, cost/mortality quadrants; CMI, Case Mix Index; CS, cross-sectional; CT, computed tomography; DRGs, Diagnosis Related Groups; ER, emergency room; FTR, failure to rescue; GMM, generalized method of moments; HCAHPS, HCAHPS, Hospital-Consumer Assessments of Healthcare Providers and Systems; HQA, Hospital Quality Alliance; HMO, Health Maintenance Organization; ICU, intensive care unit; Ind, ; IV, independent variable; lab, laboratory; LG, longitudinal; LPN, licensed practical nurse; LVN, licensed vocational nurse; MRI, magnetic resonance imaging; MSA, metropolitan statistical areas; NICU, neonatal ICU; NS, not-significant; OLS, ordinary least squares; OR, odds ratio; PCI, percutaneous coronary intervention; PSI, patient safety indicator; RN, registered nurse; SEM, structural equation modeling; VA, Veterans Administration.

a within-group fixed effects model.[51] For the relationship between technology and mortality from acute myocardial infarction, a cross-sectional study found a significant and negative association.[34]

Results were also mixed for the link between technology and failure to rescue. For example, a cross-sectional study employing the Saidin index found a nonsignificant association;[49] in contrast, a longitudinal study using technology measures based upon organ transplantation and open-heart surgery found a significant and negative association.[31]

Discussion and future directions

In this systematic review, we summarized the findings from 26 empirical studies on the relationship between hospital technology and performance in the US. Several findings were revealed. First, the studies exhibited mixed and, in some cases, contradictory results regarding the relationship between hospital technology and performance (clinical and financial). In particular, this was observed for mortality (clinical measure) and ROA (financial performance measure). However, the variation in technology measures and study designs limits the comparability across studies. Therefore, based upon this review, there is no clear evidence for either positive or negative relationships between high-tech services and hospital performance.

Second, the number of empirical studies investigating the relationship between hospital technology and performance is very limited. Of the 26 abstracted publications, technology was the focus in only two of these studies[36,37] and only eight studies included financial performance measures. Given the increasing adoption of technological innovations, further research is needed to understand the implications of technology adoption on hospitals' clinical and financial performance.

Third, the generalizability and comparability of these 26 studies are constrained due to some methodological limitations. For example, the generalizability of the findings of two technology-focused publications were limited since one study[37] relied solely on cross-sectional survey data, while the other study[36] relied on cross-sectional data from only one state (Florida).

In summary, more evidence is needed to clarify the technology–performance link, especially when hospitals may be moving into another medical arms-race era.[53] In the medical arms-race era prior to the prospective payment system in 1983, hospitals exhibited uncontrolled and unplanned competitive behaviors by adopting various services and technologies to attract patients and physicians.[39] Such competitive behavior may not only increase health care costs, but may also substantially reduce the financial performance of hospitals. Trinh et al[39] found that high-tech service duplication in a hospital market was associated with higher costs and lower operating margins. However, they also found that high-tech service duplication was associated with higher occupancy rates, indicating the legitimacy of strategically using technology to attract patients. Therefore, future research should not only examine the relationship between hospital technology and performance, but should also provide managers with insights into achieving a balance between the costs and benefits of hospital technologies. Besides the aforementioned future direction, we also have several recommendations for future studies.

The first recommendation pertains to the recognition of the intricate relationship between hospital technology and performance, and the development of strategies to effectively measure these independent and dependent variables. One of the difficulties in evaluating the influence of technology on hospital performance is accounting for the many confounding organizational, operational, and market characteristics. Moreover, as a structural component, the outcomes of hospital technologies are moderated/mediated by the processes of care. Processes of care and operations are provided by the human capital of the organization. Therefore, future studies should consider more robust research designs that acknowledge both human and operational characteristics of organizations, in addition to market and organizational characteristics.

The second recommendation is with respect to the development of hospital technology measures. Our review confirmed Spetz and Maiuro's[1] conclusion about the lack of standardized methods for defining, conceptualizing, and measuring hospital technology (Tables 1 and 2). Hospital technologies have been defined and conceptualized in various ways that span from one technology as a marker to sophisticated technology indices, such as the Saidin index. Not having reliable and consistent technology measures makes it very difficult to draw inferences, generalize findings, and perform comparisons across studies. Therefore, future studies should test the reliability and strengths/weaknesses of existing technology measures in different settings and study periods, and adapt existing technology measures as new technologies arise.

The third recommendation calls for examining the organizational and societal implications of hospital technologies. Societal implications of hospital technologies, such as welfare benefit or loss, build upon organizational and individual impacts of those technological services. However, these societal implications may not be the simple cumulative forms of organizational/individual impacts. For example, in order to understand the societal cost implications of technologies, one should consider also the market forces. Newhouse, in his seminal 1992 article, identifies medical technologies as the largest contributor of rising health care cost in the United States after discussing several other plausible options. He supports his claim by pointing out the fact that the largest portion of rising health care cost is attributed to hospital expenditures, and technological change seems to represent the bulk of these hospital expenditures.[3] Others argue that the societal benefits of hospital clinical technologies exceed their costs.[4,54,55] Regardless of the position one may take, further research is needed to understand both the organizational and societal cost–benefit implications of hospital-based clinical technologies.

The fourth recommendation relates to the availability and dissemination of the hospital technology–performance research. Currently, the United States lacks a coordinated technology planning and assessment process.[56] The efficient use of the nation's limited resources may be impeded by the uncoordinated adoption of high-cost medical technologies. A hospital's adoption decision for a technology independent of another hospital might cause service duplication in the market, which may translate into underutilization, excess capacity, and operational and financial inefficiencies. The Affordable Care Act provides increased funding for training and research on the comparative effectiveness of different technologies. Increased availability and dissemination about the pros and cons of medical technologies has the potential to improve the market efficiency.

The fifth recommendation focuses on improving hospital-based clinical technology data collection and methods. The development of high-quality information requires the availability of high-quality data for analysis. Hospital performance researchers build their research according to their research objectives and the availability of data. However, the increasing number of sophisticated clinical technologies and the problems with cross-sectional data collection methods make it difficult to find reliable data, especially on hospital-based clinical technologies.[1] Thus, future policies should also address the generation of reliable data sources to improve knowledge about the relationship between hospital-based clinical technology and performance.

This review has several limitations. First, since clinical technology was not the main predictor of interest for most of the abstracted publications, we may have missed articles in which technology was not recognized in either the title or the abstract. Second, limitations might have arisen as a result of the keyword selection, search engines, or the search process itself. However, we attempted to diminish this bias by adding the review of manually selected publications from the bibliographies of two related books, including several review articles, and subjecting the abstracted articles to the snowball technique in an attempt to identify studies. Third, because this review article focused only on hospitals' clinical quality and financial performance, it does not address the consumer's perceptions about quality. Given the importance of consumer perceptions about high-technology clinical services, future reviews may consider focusing on consumer's perceptions of quality and investigate the relationships between high-technology clinical services and hospital performance.

Despite these limitations, this is the first review that attempts to summarize the literature on the relationship between hospitals' clinical technology and performance at the organizational level. Although there are many studies that investigate the cost–benefit implications of individual technologies, organizational-level research on the net benefits of high-tech services vis-à-vis their costs is limited. Given the strategic importance of hospital-based clinical technology, further research is needed to inform policymakers about their impact on organizational costs and quality.

Disclosure

The authors report no conflicts of interest in this work.

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Supplementary material

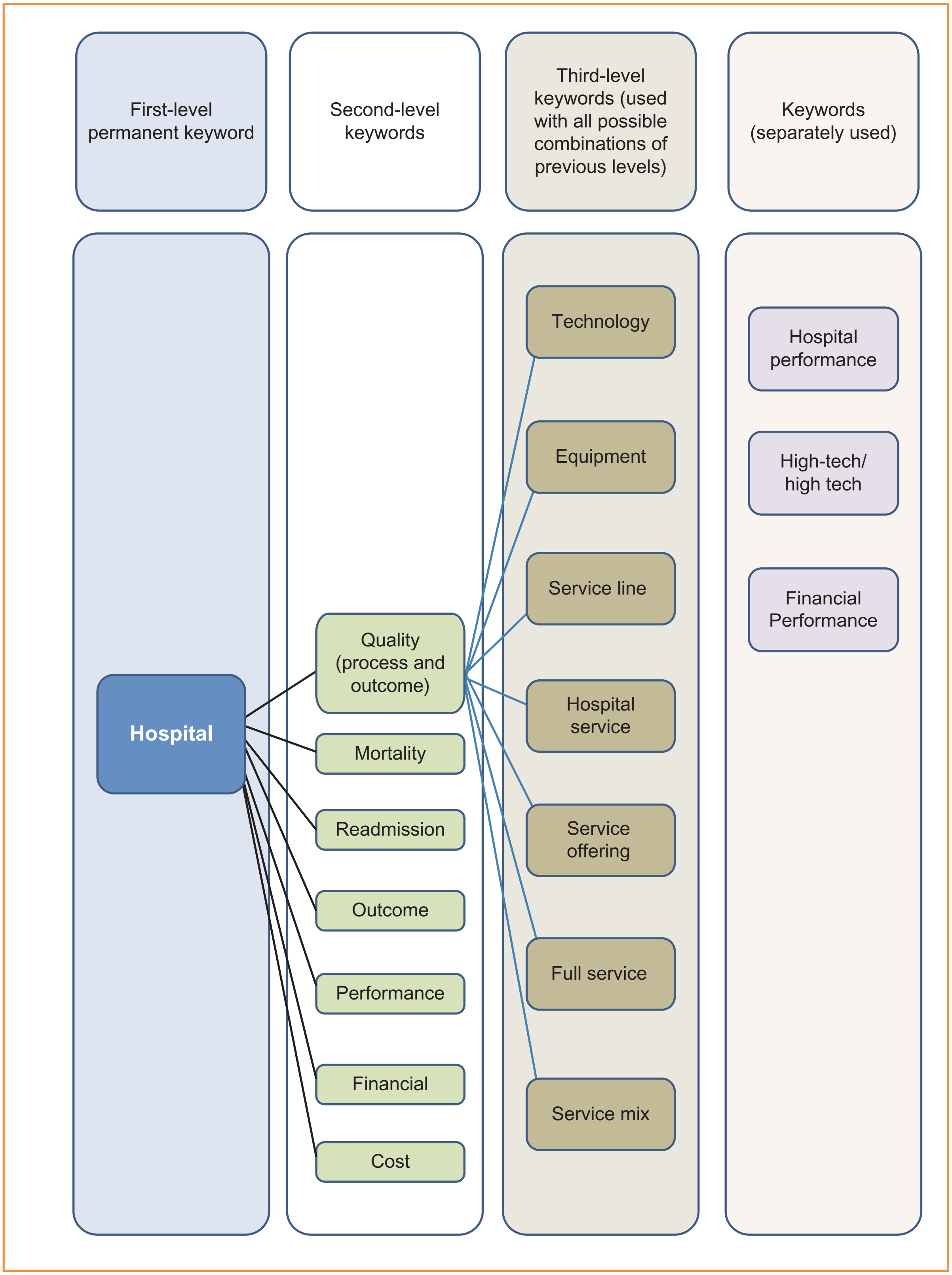

Figure S1 Keyword combinations.