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Association of a clinical knowledge support system with improved patient safety, reduced complications and shorter length of stay among Medicare beneficiaries in acute care hospitals in the United States

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ABSTRACT

Background: Electronic clinical knowledge support systems have decreased barriers to answering clinical questions but there is little evidence as to whether they have an impact on health outcomes.

Methods: We compared hospitals with online access to UpToDate® with other acute care hospitals included in the Thomson 100 Top Hospitals® Database (Thomson database). Metrics used in the Thomson database differentiate hospitals on a variety of performance dimensions such as quality and efficiency. Prespecified outcomes were risk-adjusted mortality, complications, the Agency of Healthcare Research and Quality Patient Safety Indicators, and hospital length of stay among Medicare beneficiaries. Linear regression models were developed that included adjustment for hospital region, teaching status, and discharge volume.

Results: Hospitals with access to UpToDate® ($n = 424$) were associated with significantly better performance than other hospitals in the Thomson database ($n = 3091$) on risk-adjusted measures of patient safety ($P = 0.0163$) and complications ($P = 0.0012$) and had significantly shorter length of stay (by on average 0.167 days per discharge, 95% confidence interval 0.081–0.252 days, $P < 0.0001$). All of these associations correlated significantly with how much UpToDate® was used at each hospital. Mortality was not significantly different between UpToDate® and non-UpToDate® hospitals.

Limitations: The study was retrospective and observational and could not fully account for additional features at the included hospitals that may also have been associated with better health outcomes.

Conclusions: An electronic clinical knowledge support system (UpToDate®) was associated with improved health outcomes and shorter length of stay among Medicare beneficiaries in acute care hospitals in the United States. Additional studies are needed to clarify whether use of UpToDate® is a marker for the better performance, an independent cause of it, or a synergistic part of other quality improvement characteristics at better-performing hospitals.

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1. Introduction

Multiple studies have demonstrated that a large proportion of questions regarding patient care go unanswered and that the answers to such questions can influence management decisions [1–24]. Regularly updated databases and textbooks that contain clinical knowledge (electronic knowledge resources) have decreased barriers to answering these questions but there is little evidence as to whether they have an impact on health outcomes. We set out to evaluate whether one such system (UpToDate®) was associated with the safety and efficiency of inpatient care delivered in acute care hospitals in the United States.

Previous studies involving UpToDate® have suggested that it improves acquisition of medical knowledge [25], and allows clinical questions to be answered, leading to changes in management [11,26,27]. The ability to answer questions at the point-of-care has the potential to improve patient safety and the efficiency of care. We hypothesized that benefits of improved decision-making might be reflected in patient safety and efficiency measures in hospitalized patients.

2. Methods

The study was designed to determine whether acute care hospitals in the United States with access to UpToDate® performed differently than hospitals without access and whether performance correlated with how much UpToDate® was used.

The primary outcomes were risk-adjusted mortality, complications, the Agency of Healthcare Research and Quality (AHRQ) patient safety indicators (PSI) (Table 1), [28] and length of stay [29]. These outcomes were pre-specified and were the only outcomes evaluated. They were chosen because they reflected the types of benefits that might be expected from an electronic knowledge resource, and because the measurement tools had been extensively validated in a Medicare population and used in many previous studies evaluating patient safety and efficiency of care.

Table 1 – Agency of healthcare research and quality patient safety indicator (PSI) measures

PSI description	PSI number
Death in low mortality DRGs	PSI 2
Decubitus ulcer	PSI 3
Failure to rescue	PSI 4
Iatrogenic pneumothorax	PSI 6
Selected infections due to medical care	PSI 7
Postoperative hemorrhage or hematoma	PSI 9
Postoperative physiologic and metabolic derangements	PSI 10
Postoperative respiratory failure	PSI 11
Postoperative pulmonary embolism or deep vein thrombosis	PSI 12
Postoperative sepsis	PSI 13
Postop wound dehiscence in abdominopelvic surgical	PSI 14

The PSI Measure is the unweighted mean of a hospital's normalized.
z-Scores for the following PSI measures.
See http://www.qualityindicators.ahrq.gov/psi_overview.htm for further information on PSIs.

The analysis was performed by matching hospitals with online access to UpToDate® to the Thomson 100 Top Hospitals® Study Database version 2005 (Thomson database, formerly known as the Solucient Top 100 Hospitals® study database). The Thomson database contains information regarding inpatient admissions from 3091 short-term general, non-Federal hospitals in the United States (i.e. approximately 75 percent of the 4200 acute, non-Federal hospitals in the United States). Metrics used in the 100 Top Hospitals differentiate hospitals on a variety of performance dimensions such as quality and efficiency and have been used in many previous studies evaluating healthcare quality [29–38].

2.1. *UpToDate®*

UpToDate® provides a compendium of regularly revised, evidence-based monographs on topics in adult internal medicine (and its subspecialties), pediatrics, and obstetrics and gynecology [39]. The topics (referred to as "topic reviews") are accessed by searching the database using keywords. Individual topic reviews are referenced extensively within one another using hyperlinks. The topic reviews and use of hyperlinks have been designed to avoid duplication and provided synthesized answers.

UpToDate® is delivered through the internet, on CD-ROM, and on a variety of handheld devices. Providers at hospitals that subscribe to UpToDate® access it through an internet connection at any terminal within the facility. Usage data reported in the study does not include use on CD-ROM or handheld devices.

2.2. *Patient safety indicators*

The patient safety indicator scores represent a set of measures on potential complications and adverse events on hospitalized patients. They were developed with a comprehensive literature synthesis, analysis of ICD-9 codes, and review by expert clinicians and implementation of risk adjustment and empirical studies [28]. The Agency for Healthcare Research and Quality provides free, publicly available tools necessary to determine PSI scores and they are a widely used measure of patient safety. The AHRQ Patient Safety Indicators are used in at least 9 states for public reporting on hospital performance. The rationale is that hospitals that show good performance on these measures are likely to be providing good quality of care.

There are 23 AHRQ PSIs that are relevant for provider-level (hospital-level) analysis. Seven, which are birth-related, are not relevant to a Medicare population and were thus excluded. Five require "Cause of Injury" or E-codes, which are not coded consistently across acute care hospitals in the United States, and were therefore not included in the study.

2.3. *Complications*

Thomson has constructed a database containing normative, case-level data on a national level; it contains more than 21 million annual patient discharge levels. The case-

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level data include age, sex, race, payer, length of stay, clinical grouping (Diagnosis Related Groups or Refined Diagnosis Related Groups), comorbid conditions, and hospital identification information. The database permits analysis of hospital-level data for two general types of complications: (1) "Conditions of concern" in which there are outcomes that should not occur and thus represent substandard care (e.g. air embolism); (2) "Expected complications" (e.g. venous thrombosis) that (when occurring in higher than expected frequencies) may indicate opportunities for improving patient safety.

Complication rates can be compared across hospitals after adjusting for differences in the severity of illness, geographic location, hospital size and teaching status, and community setting (urban versus rural). Thus, facilities are compared to other facilities with similar characteristics. The complications methodology has been extensively validated and used in many studies evaluating patient safety [40–42].

2.4. Mortality

Risk-adjusted mortality is determined based upon normative comparisons using patient-level data to control for case mix and severity of illness [43,44]. Thus, patients are compared to other patients with similar characteristics and comorbid conditions. The risk-adjusted mortality index has been extensively validated [43,44].

2.5. Length of stay

Determination of average length of stay was based upon severity-adjusted diagnostic related groups (DRGs) [45,46]. Severity-adjusted DRGs are intended to distinguish discharges that are clinically similar and require comparable resources (e.g. diagnostic, therapeutic, and nursing services). Severity of illness is based upon the patient's medical condition or evidence of physiologic decompensation. The DRG system is used to determine reimbursement by the Centers for Medicare and Medicaid Services (CMS) and most private insurers.

2.6. Eligibility

Hospitals included in the Thomson database were required to have a CMS Medicare Provider Analysis and Review (MEDPAR) dataset for 2003–2004, CMS standard analytic files outpatient dataset for 2002 and 2003, and a CMS cost report for 2004. Hospitals were excluded from the Thomson database if a current Medicare cost report was unavailable, if they were specialty hospitals (e.g. children's, women's, psychiatric, substance abuse, rehabilitation, cardiac, orthopedic, long-term acute care), had fewer than 25 acute care beds, 500 total facility admissions, or 100 Medicare patient discharges in fiscal year 2004, or had Medicare average lengths of stay longer than 30 days. All UpToDate® hospitals fulfilling these criteria were included in the analysis. An internet version of UpToDate® has been available since 2000. Thus, usage data were provided from all hospitals with online subscriptions since 2000 (and ending in February 2006, when the database was constructed).

2.7. Weighting strategy

Hospitals that subscribed to UpToDate® were compared to the Thomson database on bed size, teaching status, and geographic region. These are variables known to be associated with the primary outcome measures. Two weighting strategies were used to allow the model coefficients to be generalizable to a national distribution of acute care hospitals.

Because all the outcome variables were based on discharge-level observations, weighting for hospital volume was done to account for differences across hospital inpatient volume. Weighting by hospital class was done to derive model coefficients that would better reflect the national distribution of hospitals on bed size category, teaching status, and region. Thus, the analysis was performed without weighting, by weighting for discharge volume only, and by weighting for discharge volume and hospital class.

Hospital class was categorized as small community (bed size 25–99), medium community (bed size 100–249), or large community (bed size $\geq$250). Teaching hospitals were classified as standard teaching (bed size $\geq$250 and resident-to-bed ratio of $\geq$0.03 or total residency programs $\geq$3), or major teaching (bed size $\geq$400 and residents-to-beds ratio $\geq$0.25 and $\geq$10 residency programs, or resident-to-bed ratio $\geq$0.60 if fewer residency programs).

2.8. Statistical analysis

Hospital-specific performance on mortality, complications, and patient safety were represented by a z-score for each measure, while severity-adjusted length of stay (LOS) was based upon the Yale Refined Diagnosis-Related Group methodology [29,47]. Severity-adjusted LOS was represented in the models in units of days. Hospital-level, risk-adjusted mortality, complications, and PSI were based on 2 years of data (2003 and 2004) to increase the precision of hospital-level measures through larger sample sizes; LOS was based on 2004 data only.

The PSI composite measure was created by calculating the average of the normalized z-scores for 11 individual AHRQ PSI indicators that were appropriate for a Medicare population aged 65 years and older, and did not depend on E-codes. As noted above, use of cause of injury codes, or E-codes, varies extensively from hospital to hospital, thus PSI measures that used E-codes were omitted.

The measure-specific z-scores were calculated by subtracting the expected number from the observed number and dividing by the standard error [48,49]. The mortality, complications, and PSI z-scores, as well as the severity-adjusted LOS, were used as outcome variables in the analyses.

Separate linear regression models were developed for each combination of outcome and weighting strategy. All models included adjustment variables described above to control for hospital bed size category, teaching status, and geographic region (i.e. Northeast, Midwest, South, and West). The primary predictor variables of interest were: (1) the UpToDate® status of the hospital and, (2) in separate models, the average number of topic reviews per week (hits per week, or HPW). HPW refers to the average number of topic reviews that were viewed at each institution each week. All comparisons were between

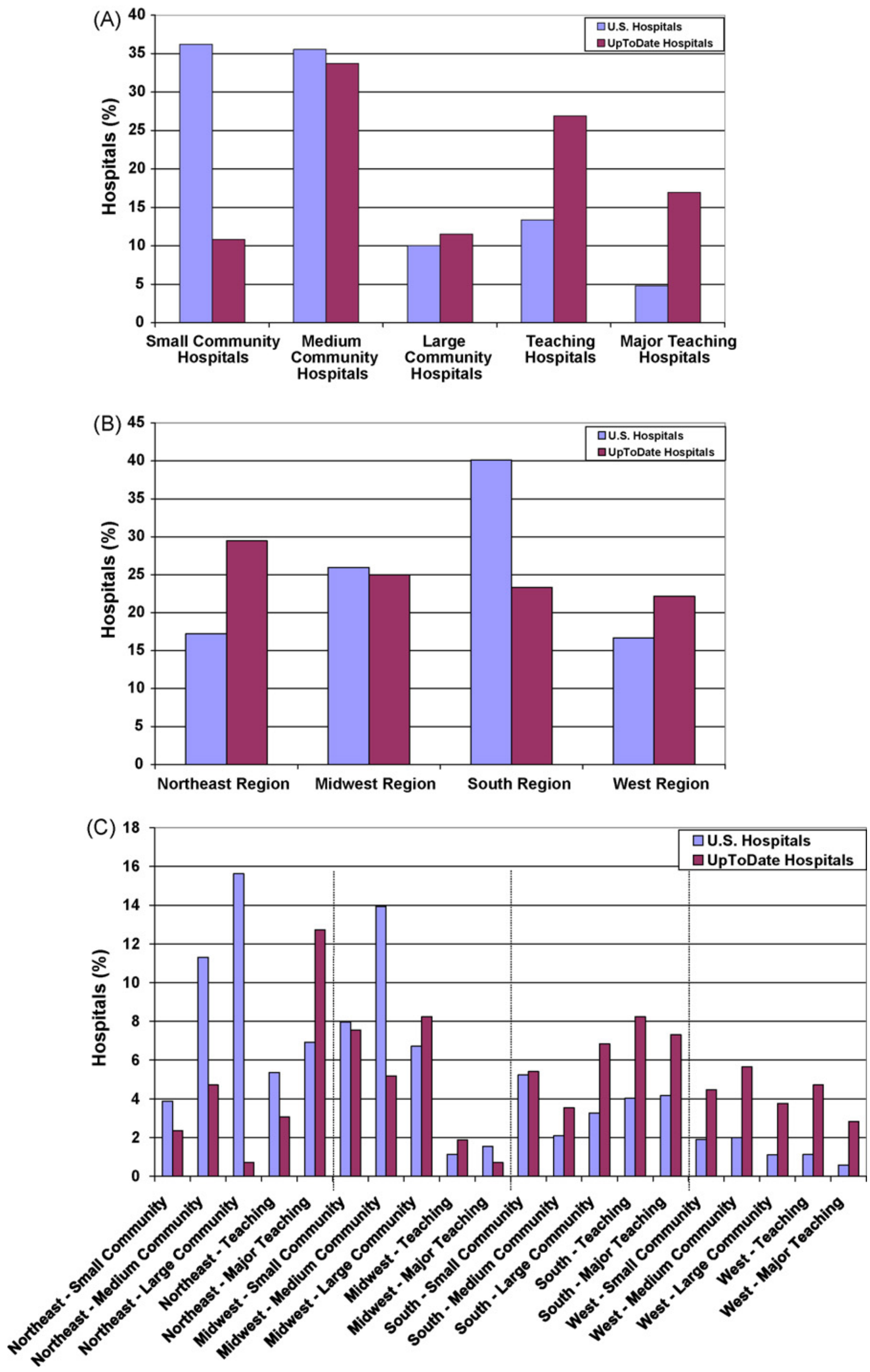

Fig. 1 – (A) Hospital distribution by class. (B) Hospital distribution by region. (C) Hospital distribution by class and region.

UpToDate® hospitals versus all non-UpToDate® hospitals in the Thomson database.

Data regarding the average hits per week were also matched to the Thomson database to determine whether associations with the primary outcomes correlated with the amount that UpToDate® was used at each facility. Thus, UpToDate® status was evaluated in two ways: (1) as a binary variable indicating whether a given hospital was using UpToDate®, and (2) as a continuous variable representing HPW. Hospitals that were not UpToDate® users were assigned a zero HPW. The relationship between the primary outcome measures and HPW was presented graphically by converting changes in z-scores associated with UpToDate® HPW to risk-adjusted rates.

3. Results

A total of 424 UpToDate® hospitals matched to the Thomson database of 3091 hospitals and formed the basis for the analysis. The class and distribution of UpToDate® hospitals differed from the universe of acute care hospitals included in

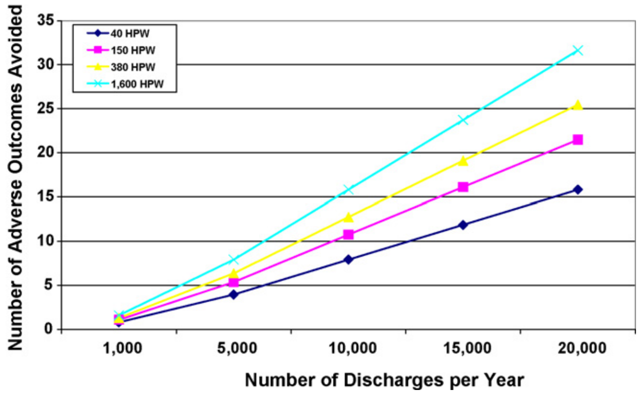

Fig. 2 – Estimated complications avoided given differing numbers of hits per week (HPW) for varying numbers of inpatient discharges.

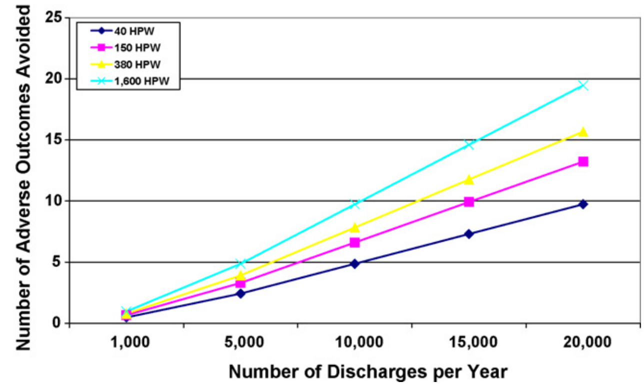

Fig. 3 – Estimated patient safety adverse outcomes avoided given differing numbers of hits per week (HPW) for varying numbers of inpatient discharges.

the Thomson database (Fig. 1A–C). In particular, UpToDate® hospitals tended to be larger, and were more likely to be teaching institutions, and located in the Northeast. There was a mean of 4423 (S.D. 3071) annual discharges per hospital for the UpToDate® hospitals compared with a mean of 2889 (S.D. 2724) annual discharges for all hospitals in the Thomson database.

Table 2 shows the model coefficients for the unweighted and weighted models. Mortality was not significantly different between UpToDate® and non-UpToDate® hospitals. By contrast, UpToDate® hospitals were associated with significantly lower risk-adjusted complication rates and patient safety adverse outcome rates. On average, severity-adjusted LOS was 0.167 days shorter in UpToDate® hospitals (95% confidence interval 0.081–0.252 days, $P < 0.0001$). As noted, the two weighted models did not produce substantially different results than the unweighted model.

Analysis based upon the average hits per week suggested that these associations correlated with the amount that UpToDate® was used (Table 3). Risk-adjusted complications rates were lower with higher numbers of hits per week. Similarly, increasing numbers of hits per week were significantly associated with a shortened severity-adjusted length of stay and lower risk-adjusted patient safety adverse outcome rates.

The relationships among hits per week, discharge volume, and the expected outcomes on an annual basis are depicted graphically in Figs. 2–4. Cut points of HPW represent quartiles of the distribution of the observed data. The figures illustrate the relationships among the number of complications, adverse safety outcomes (based on the AHRQ PSI index), and hospital days saved according to the amount that UpToDate® was used and the discharge volume of the hospital.

4. Discussion

The study showed an association between amount of use of a clinical knowledge resource, patient safety measures and hospital length of stay among Medicare beneficiaries in acute care hospitals in the United States. These associations were stable after adjustment for hospital characteristics known to be associated with the outcomes including discharge volume, teaching status, and geographic location.

However, there are many factors that influence hospital quality and length of stay that could not be fully considered in the analysis. Thus, whether UpToDate® use was a marker of quality, an independent cause of it, or one of several features of hospital quality that synergistically lead to better performance remains unclear. For example, a study of 79 academic medical centers that had been ranked on relative performance on patient safety, timely, efficient, equitable and patient-centered care demonstrated several features at top-performing hospitals [50]. These hospitals tended to have a shared sense of purpose, passionate leaders, centralized and decentralized quality control efforts, a culture of measurement and collaboration. We could not account for these factors in our analysis.

In addition, the introduction of UpToDate® might have correlated with the introduction of other quality and patient safety initiatives or use of other clinical knowledge or decision support systems. It is also possible that higher use in better performing institutions reflected the presence of a medical staff that was already predisposed to delivering higher quality care. Our analysis could not directly associate the outcomes examined with use among individual providers, to

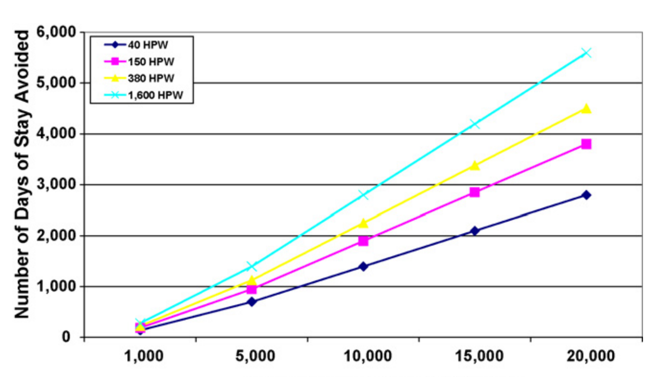

Fig. 4 – Estimated days of stay avoided given differing numbers of hits per week (HPW) for varying numbers of inpatient discharges.

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Table 2 – Model coefficients for the unweighted and weighted models comparing performance of hospitals with access to UpToDate® to all hospitals in the Thomson Database

	Complications	LOS	Mortality	Patient safety
Linear regression model coefficients (P value)				
Unweighted	−0.378 (P = 0.048)	−0.187 (P < 0.0001)	0.179 (P = 0.343)	−0.080 (P < 0.0001)
Weighted by discharge count	−0.761 (P < 0.0001)	−0.1469 (P < 0.0001)	0.1553 (P = 0.4205)	−0.067 (P < 0.0001)
Weighted by discharge count, class, and region	−0.582 (P = 0.006)	−0.182 (P < 0.0001)	−0.003 (P = 0.9890)	−0.062 (P = 0.003)

LOS: length of stay.

know whether improved outcomes were related to providers who used UpToDate®, or adjust for baseline performance of these providers.

The measurement tools used in this study were based upon hospital administrative data. A great deal of empirical research has demonstrated the limitations and merits of using administrative data for describing health outcomes [51–57]. The measures used in this study have been extensively validated but nevertheless still provide only an indirect view of the actual care that was delivered.

Some of the measures included in the AHRQ PSI index have a focus on postoperative care. UpToDate® tends to be used more frequently for medical care, although it contains content related to postoperative care, including the issues pertaining to the AHRQ PSI postoperative measures. We did not directly test whether the associations with UpToDate® were present only for specific PSI or other complication measures because of the likelihood of detecting spurious associations from making multiple comparisons.

Future studies are needed to clarify the relationships between hospital and provider characteristics that lead to better performance and the role of clinical knowledge systems and clinical decision support tools. Several studies have demonstrated that clinical decision support tools (such as those that provide alerts and reminders) can improve certain care processes, enhance patient safety, and possibly improve clinical outcomes as well [58]. Studies with favorable results have primarily demonstrated increased adherence to guidelines, a decrease in medication errors, and improvement in preventive health [58]. These tools are being incorporated increasingly in the electronic medical record and computerized physician order entry systems, and have been included in many quality improvement programs. Some payers are providing financial incentives to hospitals that use them [59]. How these systems are designed may have an important impact on whether they improve clinical outcomes (or cause harm) [60].

However, clinical decision support tools (and pay-for-performance programs that include them) cannot hope to address the spectrum of decisions required to deliver current, evidence-based care. The interventions (and quality measures) have been selected mainly based upon the scientific evidence supporting them, the healthcare burden associated with conditions that they address, the ability to measure an effect, and the likelihood that they will withstand changes in practice due to new technologies and an evolving knowledge base [61]. By contrast, electronic clinical knowledge resources allow providers to answer a broad range of clinical questions at the point-of-care leading to improved decision-making [11,26].

Whether the observed associations with hospital quality and efficiency can be generalized to all electronic knowledge resources is unclear. We could not test this directly since we did not have access to data from other electronic knowledge resources used in the hospitals that were included. It is likely benefits from an electronic clinical knowledge resource would be related to the degree to which they are adopted and used. Studies evaluating UpToDate® have found that it has been adopted widely and is used extensively [22,27,62–67]. It is also an important factor in medical knowledge acquisition among medical residents [25]. Additional studies are needed to clarify characteristics of clinical knowledge systems that contribute to improving quality and efficiency of care.

In summary, to the best of our knowledge this is the first study to show an association between use of an electronic knowledge resource and improved health outcomes among

Table 3 – Model coefficients for the unweighted and weighted models comparing performance of hospitals with access to UpToDate® to all hospitals in the Thomson Database based upon the number of hits per week (HPW)[a]

	Complications	LOS	Mortality	Patient safety
Linear regression model coefficients (P value)				
Unweighted	−0.058 (P = 0.093)	−0.039 (P < 0.0001)	0.020 (P = 0.559)	−0.015 (P < 0.0001)
Weighted by discharge count	−0.095 (P = 0.007)	−0.026 (P < 0.0001)	0.007 (P = 0.8219)	−0.011 (P = 0.001)
Weighted by discharge count, class, and region	−0.094 (P = 0.016)	−0.038 (P < 0.0001)	−0.015 (P = 0.687)	−0.012 (P = 0.001)

[a] HPW were log transformed, LOS: length of stay.

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Medicare beneficiaries in acute care hospitals in the United States. Hospitals that used UpToDate® were associated with lower risk-adjusted complication rates and had significantly shorter length of stay compared with other acute care hospitals. All of these effects correlated with the amount that UpToDate® was used. Whether use of UpToDate® is a marker for better performing hospitals, an independent cause of better performance, or acts synergistically with other factors associated with of hospital quality requires further study.

Summary table

What was already known about this topic

- Questions regarding patient care are common but answers are often not pursued.
- Electronic clinical knowledge resources are available that can help answer clinical questions but their impact on patient care has not been studied extensively.

What this study added to our knowledge

- An electronic clinical knowledge system was associated with fewer complications and shorter length of stay among Medicare beneficiaries in acute care hospitals in the United States.
- Additional studies are needed to determine whether the presence of a clinical knowledge system is a cause or a marker of better performance.

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