Research and Applications

Estimating the impact of deploying an electronic clinical decision support tool as part of a national practice improvement project

Ellen K. Kerns,^{1,2} Vincent S. Staggs,^{3,4} Sarah D. Fouquet,^{5,6} and Russell J. McCulloh^{1,2}

¹Department of Pediatrics, University of Nebraska Medical Center, Omaha, Nebraska, USA, ²Division of Hospital Medicine, Children's Hospital & Medical Center, Omaha, Nebraska, USA, ³Department of Pediatrics, University of Missouri-Kansas City, Kansas City, Missouri, USA, ⁴Division of Health Services and Outcomes Research, Children's Mercy, Kansas City, Missouri, USA, ⁵Department of Biomedical & Health Informatics, University of Missouri-Kansas City, Kansas City, Missouri, USA and ⁶Department of Medical Information Technology and Telemedicine, Children's Mercy, Kansas City, Missouri, USA

Corresponding Author: Ellen Kerns, MPH, Department of Pediatrics, University of Nebraska Medical Center 982165, Nebraska Medical Center Omaha, Nebraska 68198-2165, USA (ellen.kerns@unmc.edu)

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ABSTRACT

Objective: Estimate the impact on clinical practice of using a mobile device-based electronic clinical decision support (mECDS) tool within a national standardization project.

Materials and Methods: An mECDS tool (app) was released as part of a change package to provide febrile infant management guidance to clinicians. App usage was analyzed using 2 measures: metric hits per case (metric-related screen view count divided by site-reported febrile infant cases in each designated market area [DMA] monthly) and cumulative prior metric hits per site (DMA metric hits summed from study month 1 until the month preceding the index, divided by sites in the DMA). For each metric, a mixed logistic regression model was fit to model site performance as a function of app usage.

Results: An increase of 200 cumulative prior metric hits per site was associated with increased odds of adherence to 3 metrics: appropriate admission (odds ratio [OR], 1.12; 95% confidence interval [CI], 1.06-1.18), appropriate length of stay (OR, 1.20; 95% CI, 1.12-1.28), and inappropriate chest x-ray (OR, 0.82; 95% CI, 0.75-0.91). Ten additional metric hits per case were also associated: OR were 1.18 (95% CI, 1.02-1.36), 1.36 (95% CI, 1.14-1.62), and 0.74 (95% CI, 0.62-0.89).

Discussion: mECDS tools are increasingly being implemented, but their impact on clinical practice is poorly described. To our knowledge, although ecologic in nature, this report is the first to link clinical practice to mECDS use on a national scale and outside of an electronic health record.

Conclusions: mECDS use was associated with changes in adherence to targeted metrics. Future studies should seek to link mECDS usage more directly to clinical practice and assess other site-level factors.

Key words: clinical decision support, mobile applications, clinical practice guideline, guideline adherence, quality improvement

BACKGROUND AND SIGNIFICANCE

Mobile device-based electronic clinical decision support (mECDS) tools are increasingly being developed and used to disseminate evidence-based recommendations to healthcare providers, given their

ability to be deployed across a variety of clinical settings without the institutional limitations inherent to tools based on electronic health records (EHRs).^{1–3} However, the impact of mECDS tool use on clinical practice and health outcomes is poorly described. Previous studies

have primarily reported on the distribution and usage patterns for mECDS tools.^{1,2} Researchers have also studied the perceived usability and acceptability of such applications by end users as well as healthcare providers' perceptions related to the clinical care of patients based on their level of mECDS tool usage.^{3,4} Only 2 published studies have assessed the impact of mECDS on clinical practice: one assessed the effect of mECDS use at the individual physician level via test performance⁵ and the other only looked at overall system performance pre- and postimplementation with no way to account for variance in usage.⁶

Infants <60 days of age with fever pose a significant challenge to clinicians, as they are at risk (albeit low) of harboring a serious bacterial infection that, if left untreated, could lead to severe illness or death. Multiple risk stratification tools and institutional clinical practice guidelines (CPGs) exist to guide the management of these infants.^{7,8} Despite this, inconsistencies in guidelines and usage paired with an inability to identify with high accuracy infants likely to have a bacterial infection have resulted in clinical practice that varies widely across healthcare institutions.⁹ To address this variation in care on a national level, the American Academy of Pediatrics (AAP) Value in Inpatient Pediatrics (VIP) Network conducted a clinical practice standardization project focused on the care of febrile infants 7-60 days of age.¹⁰ This project, entitled Reducing Excessive Variation in Infant Sepsis Evaluation (REVISE), deployed a change package of materials to the 133 participating hospitals across the United States that was aimed to disseminate evidence-based recommendations for the appropriate use of diagnostic tests, hospitalization, and antibiotics for young infants with fever.

OBJECTIVE

Our group developed a mECDS tool (called Febrile Infant embedded within an app entitled PedsGuide) and released it as part of the REVISE change package to provide stepwise guidance to clinicians. The development, initial distribution, and usage patterns of PedsGuide have been previously described.¹¹ Releasing this application (app) as part of a national quality improvement project provided our team with a unique opportunity to assess not only the distribution and use of the app, but also to pair such data with large-scale clinical practice and health outcomes data. Thus, the objective of this study was to investigate the association between mECDS tool usage and clinical practice patterns in the course of a national quality improvement and practice standardization project.

MATERIALS AND METHODS

Setting

The REVISE project was conducted at 133 hospitals across the United States from September 2016 to January 2018. Healthcare provider teams at hospitals ranging from small, community-based institutions to free-standing university-affiliated children's hospitals participated in the project.

PedsGuide development

Our interprofessional development team (which included clinical experts, human factors practitioners, health outcomes researchers, and a member of the REVISE project leadership team) developed and deployed Febrile Infant within PedsGuide with the specific intent of aligning app content with the REVISE core compliance metrics. These compliance metrics were developed with the assistance of nationally recognized experts in febrile infant management (Table 1).

Deployment of the app was one component of the change package provided to all REVISE participants. The complete change package included paper order sets, standard educational presentations, academic detailing (eg, posters, handouts), and the PedsGuide app. The free app was available globally for download from the Apple App Store and GooglePlay on November 9, 2016, and was introduced via webinar to REVISE participants in December 2016. The app was also promoted through the REVISE project's email listserve. Feedback on content and usability postrelease was obtained both formally via survey and informally from end users.

PedsGuide user analytics

App usage data were collected from December 2016 to November 2017 using Google Analytics. Google Analytics records app usage in terms of the number of devices that the app has been opened on (users), the number of times the app has been opened or used (sessions), how long the app was used for each session (duration), and the number of times each button or screen within the app was touched (events). For our analysis, eligible users were restricted to those who had ever touched a Febrile Infant-specific app page within PedsGuide, and all session-related variables were restricted to those app uses that involved touching the Febrile Infant home screen within PedsGuide. All possible user events within the Febrile Infant portion of the PedsGuide app were classified as to whether they led to the user viewing content related to 1 of the 5 core compliance metrics (metric-related screen views). Some events involved the selection of check boxes that determine what portion of the app that the user will be sent to next. Because these events did not lead to independent screens, but rather were options within a screen, they were excluded from the event variables. Instead, these interactions were reported as their own variable (user decision selected), indicating the total number of times in which 1 of these selections was made.

Geocoding of user analytics and REVISE sites

Google Analytics captures the latitude and longitude of the cell tower or WiFi hotspot that the device is receiving data from or is registered to. This location data, while linked to a specific device, are completely de-identified and can be aggregated at various regional levels. Thus, we were able to capture a general location of where each use of the app was occurring. For the purposes of this analysis, all Google Analytics variables were aggregated by the designated marketing area (DMA) in which the device was being used, based on prior evidence of this geographic level's use in measuring behavior across regions.¹² Usage data were further stratified by month. The mapping software ArcGIS 10.1 (Esri, Redlands, CA) was used to produce a map shaded according to the number of metric-related screen views that occurred in the study period within each DMA. The DMA of each REVISE site was then determined by geocoding each site's address and performing a spatial join with a map of the DMA boundaries. All sites that fell within a DMA's boundary were assigned to that DMA.

REVISE site-reported data collection

Participating site characteristics such as the average annual number of febrile infants seen and presence of a university affiliation were collected at project initiation via survey. Clinical practice data, including adherence to the REVISE core compliance metrics, were collected via site chart reviews. Data were entered into a secure, web-based electronic database (Quality Improvement Data Aggregator) maintained by the AAP. Sites collected 12 monthly cycles of retrospective baseline

Table 1. Implementation metrics and balancing metric for the REVISE National Collaborative¹⁵

Metric	Definition	Target	Integrated into PedsGuide?
Appropriate admission	Infant had an appropriate evaluation ^a that indicated non-low risk. ^b	90% of hospitalized infants	Yes
Appropriate length of stay	<30 h for low risk ^b <42 h for non-low risk ^b	80% of hospitalized infants	Yes
Urinalysis utilization	Infant had a UA performed by any method on the first day of encounter.	95% of infant evaluations	Yes
Inappropriate chest x-ray	Infant without documented respiratory symptoms received a chest x-ray either 24 h before, or after, presentation.	≤10% of infants without respiratory symptoms	Yes
Appropriate antibiotic use	Infant received recommended empiric antibiotic regimens within 24 h of presentation.	90% of antibiotics prescribed	Yes
Missed serious bacterial infection	Infant returned to the ED or was readmitted for a new diagnosis of meningitis, bacteremia, or UTI within 7 d of discharge from the ED or inpatient setting.	<2% of evaluated infants discharged home	No

ED: emergency department; REVISE: Reducing Excessive Variation in Infant Sepsis Evaluation; UA: Urinalysis; UTI: urinary tract infection.

^aAn evaluation was deemed appropriate if it included at least a urinalysis and a marker of inflammation or infection (eg, white blood cell count, C-reactive protein, procalcitonin).

^bDefined as having had a relevant prior medical history or requiring admission for social reasons.

data from September 2015 to August 2016. They then collected 12 monthly cycles of implementation data from December 2016 to November 2017. A 3-month window from September 2016 to November 2016 where data collection was optional was created to allow time for sites to obtain appropriate approvals and allocate sufficient resources to undertake implementation of the change package. Clinical practice data collected on the 5 core compliance metrics (appropriate hospitalization, appropriate length of stay, urinalysis obtainment, inappropriate chest x-ray, and appropriate antibiotic use) were analyzed for each hospital from its monthly data (Table 1).

Statistical analyses

Two measures of app usage were derived to examine as correlates of outcome metrics. The first was metric hits per case, computed for each DMA-month combination by dividing the total number of metric-related screen views during the month by the total number of febrile infant cases reported by the sites within the DMA for the month. This measure serves as a very rough estimate of the monthly app usage “density” for the DMA. The second measure was cumulative prior metric hits per site, designed to reflect accumulated knowledge gained by use of the app over time. We computed this measure by summing metric-related screen views by users in the DMA across months, from the DMA’s first month of usage data through the month immediately preceding the index month, and then dividing by the number of sites in the DMA. For example, the value for March was computed by summing the DMA’s metric hits through February and dividing by its number of sites. The measure was set to zero for the first study month (December 2016).

To examine associations between app usage and metric change, mixed logistic regression models were fit (1 per metric) using the GLIMMIX Procedure in SAS 9.4. Given clustering of months within sites within DMAs, random site and DMA intercepts were included in each model, and a first-order autoregressive error structure was specified. Explanatory variables included the 2 app usage measures (metric hits per case and cumulative prior metric hits) and the site characteristic variables.

Ethical considerations

REVISE was sponsored by the AAP’s VIP Network and deemed exempt by the AAP institutional review board. Teams at each partici-

Table 2. REVISE site characteristics

Variable	Data
Non-ICU pediatric beds	
≤50	56 (46)
>50	67 (54)
Annual cases	
≤100	53 (43)
>100	70 (57)
University affiliation	
No	49 (40)
Yes	74 (60)
Pediatric emergency medicine physicians	
No	24 (20)
Yes	99 (80)
Census region	
Midwest	38 (31)
Northeast	27 (22)
South	40 (33)
West	18 (15)

Values are n (%).

ICU: intensive care unit; REVISE: Reducing Excessive Variation in Infant Sepsis Evaluation.

pating site obtained local institutional review board approvals as necessary. This analysis was deemed nonhuman subjects research by the Children’s Mercy Kansas City Institutional Review Board.

RESULTS

Of the 133 initially selected sites, 7 dropped out of the project or did not provide data. Three additional sites did not submit complete pre- or postintervention data and were excluded from analysis. Thus the sample comprised data from 123 sites in 64 DMAs. A total of 19 320 febrile infant evaluations were reported (11 871 in the preintervention period, 7449 postintervention). Site demographics are shown in Table 2. All but 3 sites reported at least 12 months of clinical data, 89% reported data for at least 18 months, and 45% of sites reported data for all 24 months.

Figure 1. Cumulative metric hits per site by U.S. designated market area (December 2016–November 2017). REVERSE: Reducing Excessive Variation in Infant Sepsis Evaluation.

A total of 10 883 use sessions occurred during the study period. These sessions consisted of 60 377 screen views of which 33 134 (55%) were metric-related. There were 88 543 user decisions made for an average of 6 screen views and 8 user decisions per session. Most ($n = 42$, 66%) DMAs contained a single site; 19 (30%) contained 2–4 sites and 3 (5%) contained 7 or more sites. Median DMA population was 1.9 (interquartile range, 0.9–4.2) million. The number of metric hits per site accumulated during the study varied widely by DMA, ranging from 0 to 2185 with a median of 140 (interquartile range, 61–292) (see [Figure 1](#)).

The number of accumulated metric hits in a DMA per site was a statistically significant predictor of site performance in the following month for 3 metrics ([Figure 2](#)). According to model estimates, an increase of 200 cumulative hits per site (a level achieved in 33% of DMAs) was associated with a 12% increase in odds of appropriate admission, a 20% increase in odds of appropriate length of stay, and an 18% decrease in odds of chest x-ray. In terms of change from the baseline rates for the 3 metrics, these numbers would imply respective increases of 2.0 and 2.8 percentage points in rates of appropriate admission and appropriate length of stay, and a 2.8 percentage point decrease in the rate of chest x-ray.

Number of metric hits per febrile infant case was a statistically significant predictor of these same 3 metrics. Ten additional metric hits per case was associated with 18% higher odds of appropriate admission (implying an increase of 3.0 percentage points from the baseline rate; 95% confidence interval [CI], 1.02, 1.36), 36% higher odds of appropriate length of stay (95% CI, 1.14–1.62; 5.0 percent-

age point increase from baseline), and 26% lower odds of chest x-ray (95% CI, 0.62–0.89; 4.0 percentage point reduction from baseline). These effects were scaled for visualization and are not large when considered in terms of change associated with an increase of a single metric hit per case. Associations between app use and the balancing metric of missed serious bacterial infection were not statistically significant. Of the site characteristics, only census region and the presence of pediatric emergency physicians were predictive of change in any metric.

DISCUSSION

We identified an association between geographically aggregated mECDS tool usage data and clinical practice data provided during the course of a national practice standardization and improvement project. App usage seems to act in a cumulative manner in its impact on site adherence; cumulative metric hits per site was a statistically significant predictor of 3 of 5 metrics. Hits per case, a rough measure of app “dose” per patient, was also a statistically significant predictor for 3 metrics. These findings suggest that the app facilitates learning over time, and as this learning increases, physicians would not require use of the app in every case, though its earlier use would remain an influence on future clinical decisions made. Cumulative use may also result in a ripple effect, changing the culture of practice as one clinician makes decisions using the app and others mimic the criteria used. There was insufficient evidence to conclude that either measure of app usage impacts appropriate antibiotic use

Figure 2. Logistic regression results: odds ratio estimates with 95% confidence limits. EM: Emergency medicine; LOS: length of stay; SBI: serious bacterial infection.

or urinalysis, but adherence to these metrics at baseline were already 97% and 90% on average respectively leaving little room for additional improvement.

Our results highlight several novel insights into estimating the impact of a mECDS tool on clinical practice. First, by identifying a common unit of observation (the DMA), we were able to combine 2 disparate large-scale datasets. Roughly 20 000 febrile infant evaluations were analyzed against over 10 000 user sessions to assess for association. To our knowledge this report is the first of its kind linking clinical practice to mECDS use on such a large scale and outside of an EHR. Several studies have analyzed the usage patterns of their mECDS, but did not attempt to link this usage to measures of clinical practice or outcomes.^{1,2} A few studies attempted to determine impact on clinical practice, but none compared usage data and clinical practice data directly. One study looked at healthcare providers' perceptions related to the clinical care of patients based on their self-reported level of mECDS tool usage via a post implementation survey.³ Another study compared test scores of providers using an mECDS with those using a standard reference tool or memory alone.⁵ Most closely comparable is a study that evaluated the impact of introducing a mECDS into an ongoing antimicrobial stewardship program. However, this study only evaluated impact in terms of pre- and postintervention rather than level of usage, and their intervention only involved 3 teaching hospitals in the same overall organization.^{6]}

The change in metric adherence from baseline that can be attributed to cumulative app metric hits per site may seem small, but it has the potential for a large impact given the sheer number of infants with this presentation. Even a 2- to 3-percentage-point improvement in an outcome like appropriate admission or length of stay, multiplied across tens of thousands of febrile infant visits each year, translates into substantial cost savings to the healthcare system and avoidance of potentially traumatic events experienced by patients and families.¹³ It also must be kept in mind that this analysis only includes 12 months of usage. It would be expected that the app will continue to be used, leading to even further improvement in metric adherence over time, not only for providers at participating REVISE sites but for any provider who may use the app in the future.

The presence of physicians certified in pediatric emergency medicine (PEM) had a strong association with improvement in inappro-

priate chest x-ray obtainment and, though it was not statistically significant ($P = .056$), with improvement in appropriate admission. PEM physicians were already predisposed not to admit low-risk infants when compared with those with only adult training, which may reflect a greater familiarity with this patient population based on prior training. Similarly, PEM physicians are less likely to order an unwarranted chest x-ray for a febrile infant, presumably because of greater understanding of common underlying diseases processes and likely diagnoses. An additional analysis conducted on the baseline chart review data revealed a similar increase in metric adherence among community hospitals that employed PEM physicians (data not shown). It is possible that these PEM physicians were empowered to influence other providers at their institution toward greater adherence when the VIP project was initiated at their site and they were made aware of the discrepancy in practice.

Strengths and limitations

This study had some considerable strengths. The app being paired with such a far-reaching national improvement project allowed for both evaluations of association with app usage and good representation of hospitals as seen by the site characteristics in Table 2. Usage at the DMA level varied significantly, which enhanced our ability to attribute differences in outcomes to differences in DMA app usage. We were also able to account for several site factors that are known to be associated with adherence to evidence-based practices such as institution size, patient volume, and the presence of a university affiliation.^{14,15}

Our study has several limitations. First, we could only measure app usage at the DMA level and outcomes at the site level, making this analysis purely ecological in nature. We cannot assume that differences based on app usage at this level are representative of effects on individual clinical decision making. However, in a study of decisions made on simulated cases with the app versus a standard reference tool among both attending and resident physicians, app usage was found to be associated with a large statistically significant increase in adherence and reduction in cognitive workload.¹⁶ We also cannot assume that app usage within a DMA was all occurring at one of the REVISE sites during a patient assessment. It is quite likely

that there is a contagion effect in app downloads, as evidenced by the observed usage of PedsGuide in DMAs without REVISE sites (Figure 1). However, despite the unavoidable mismatches in linking measures of DMA app usage with clinical metrics at REVISE sites, we found associations that were both statistically significant and clinically meaningful. To address the inability to identify app users who are also participants in the national project, future rollouts of mECDS tools through the app will include a survey that will allow users to indicate if they are a clinician practicing at one of the participating sites.

Next, REVISE project guidelines capped case collection from each site at 20 per month. This means that for the larger sites with higher febrile infant volumes, our app usage density measure (metric hits per case) may be inflated, as it really measures metric hits per captured case rather than all cases seen by the site. It is also possible, particularly at teaching hospitals, that the metric screens are being seen by multiple providers as they evaluate one case together, which may bias this measure in the other direction. It is unclear what effect this may have on the association between usage and metric change, but the probability of multiple viewers per 1 instance of screen display at academic institutions may at least partially be accounted for by our inclusion of site university affiliation in the model.

Interestingly, in a subanalysis of DMAs with only 1 REVISE site, effects of app use on the 3 metrics for which we observed significant findings with the full sample were in the same direction but generally weaker (data not shown). When we followed this up by rerunning the full sample analysis with models that included interaction terms to allow for app usage to have different effects for single-site and multisite DMAs, we generally observed stronger effects for multisite DMAs, including a positive effect of accumulated metric hits per site on the urinalysis metric for multisite, but not for single-site, DMAs (results not shown). DMAs with only a single site are more likely to have app use occurring at nonsite hospitals, as less of the DMA's total hospitals are participating which may have weakened the association with DMA-level use among these sites. Multisite DMAs were disproportionately represented in the Northeast region, accounting for 4 of its 6 DMAs (67% as compared with 34% in the overall sample) and 93% of its sites (as compared with 66% sites in the overall sample). Thus, it is possible that regional differences are being reflected in the apparent differences between single-site and multisite DMAs, though with region being included as a model covariate this seems like a partial explanation at best.

Finally, we cannot rule out the possibility that increased adherence co-occurring with increased app usage was due simply to increased site engagement in general. Future studies will involve a staged rollout to account for site engagement as well as an in-depth qualitative study to identify other potential institutional, cultural, or environmental factors associated with changes in clinical practice.

CONCLUSION

mECDS tools are increasingly being developed and used in practice. Therefore, it is important that their impact on such practice is evaluated. To our knowledge this report is the first of its kind to attempt to link clinical practice to mECDS use on a national scale and outside of an EHR. Despite limitations in directly linking usage and practice data, a clear association between usage of the tool in a site's DMA and an increase in that site's adherence to national standards in practice was found. Future studies should make attempts to link mECDS usage more directly to measures of clinical practice and

account for other site-level factors that may explain change in practice.

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AUTHOR CONTRIBUTIONS

EK made substantial contributions to the conception and design of the work; the acquisition, analysis, or interpretation of data for the work, drafting the work and revising it critically for important intellectual content; and final approval of the version to be published, and agrees to be accountable for all aspects of the work in ensuring that questions related to the accuracy or integrity of any part of the work are appropriately investigated and resolved. VSS made substantial contributions to the conception and design of the work; the acquisition, analysis, or interpretation of data for the work, drafting the work and revising it critically for important intellectual content; and final approval of the version to be published, and agrees to be accountable for all aspects of the work in ensuring that questions related to the accuracy or integrity of any part of the work are appropriately investigated and resolved. SF made substantial contributions to the conception and design of the work, drafting the work and revising it critically for important intellectual content, and final approval of the version to be published, and agrees to be accountable for all aspects of the work in ensuring that questions related to the accuracy or integrity of any part of the work are appropriately investigated and resolved. RM made substantial contributions to the conception and design of the work, drafting the work and revising it critically for important intellectual content, and final approval of the version to be published, and agrees to be accountable for all aspects of the work in ensuring that questions related to the accuracy or integrity of any part of the work are appropriately investigated and resolved.

CONFLICT OF INTEREST STATEMENT

None declared.

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