Electronic prescribing systems in hospitals to improve medication safety: a multimethods research programme

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Declared competing interests of authors: David Bates is a co-inventor on patent number 6029138, which is held by Brigham and Women's Hospital (Boston, MA, USA), on the use of decision support software for medical management, held by Medicalis Corporation (Kitchener, ON, Canada). He also holds a minority equity position in the privately held company Medicalis Corporation, which develops web-based decision support for radiology test ordering, and served on the board for SEA Medical Systems (Emerald Hills, CA, USA), which makes intravenous pump technology (2012–20). David Bates is on the clinical advisory board for Zynx Health Inc. (Los Angeles, CA, USA), which develops evidence-based algorithms, consults for EarlySense (Ramat Gan, Israel), which makes patient safety monitoring systems, and received cash and equity from QPID Inc. (Boston, MA, USA), a company focused on intelligence systems for electronic health records. He also receives cash compensation from CDI Ltd (Negev, Israel), which is a non-for-profit incubator for health IT start-ups, receives equity from Enelgy (Northbridge, CA, USA), which makes software to support clinical decision-making in intensive care, and receives equity from MDClone (Tel Aviv-Yafo, Israel), which takes clinical data and produces deidentified version of them. David Bates receives equity from ValeraHealth (Brooklyn, NY, USA), which makes software to help patients with chronic diseases, and equity from Intensix (Los Angeles, CA, USA), which makes software to support clinical decision-making in intensive care.

David Bates' financial interests have been reviewed by Brigham and Women's Hospital and Partners HealthCare (now Mass General Brigham) (Boston, MA, USA) in accordance with their institutional policies. Lisa Slee reports personal fees from NHS England and PCS Health Ltd (Chester, UK) outside the submitted work. Sarah Slight is a member of the Health Technology Assessment Primary Care, Community and Preventive Interventions Panel.

Published September 2022
DOI: 10.3310/KSRS2009

Scientific summary

ePrescribing in hospitals for medication safety

Programme Grants for Applied Research 2022; Vol. 10: No. 7
DOI: 10.3310/KSRS2009

NIHR Journals Library www.journalslibrary.nihr.ac.uk

Scientific summary

Background

A number of international benchmark studies have now demonstrated that prescribing errors are common and are responsible for considerable, potentially avoidable, morbidity and mortality. Given the increasing number and complexity of prescribing decisions, the risk of prescribing-related iatrogenic harm is likely to increase further. There is, then, a pressing need to identify effective approaches to improving the safety of prescribing and medication administration. Interest has in particular converged on the potential offered by electronic prescribing (ePrescribing) systems incorporating computerised provider order entry and, in the more advanced systems, related clinical decision support. These systems, however, vary considerably in functionality, interoperability and costs. Building on our substantial body of completed and ongoing work investigating the potential of health information technology to enhance the quality of care, we undertook a multifaceted programme of work to inform important national deliberations on the safe, effective and efficient procurement and implementation of ePrescribing systems into hospitals in NHS England.

Aims

We sought to:

- describe the procurement, implementation, adoption and maintenance of the basic and more advanced ePrescribing systems
- estimate their effectiveness and cost-effectiveness
- develop a toolkit for system integration into hospitals incorporating implications for practice from our research.

Methods

We undertook a theoretically informed, mixed-methods, context-rich, naturalistic evaluation. Our research was organised into four complementary work packages:

- work package 1 – procurement, implementation, adoption and connectivity
- work package 2 – assessing impact on prescribing safety
- work package 3 – health economic evaluation and a value of investment analysis
- work package 4 – integration across work packages to develop implications for practice and a toolkit for the NHS.

We undertook six longitudinal case studies that comprised four hospitals (sites C, E, J and K) that did not have ePrescribing systems at the start of the programme (three of which went live during the programme and one that experienced repeated delays and never went live during the course of our research) and two hospitals with embedded ePrescribing systems (sites A and D). In the three hospitals that implemented the system during our research programme, we conducted one set of interviews prior to implementation, one set shortly after the roll out and one set approximately 1 year post implementation; three sets of pre-implementation interviews were undertaken in the hospital with delayed implementation. In the two hospitals with embedded systems, we conducted two rounds of interviews separated by approximately 18 months. To complement this hospital and health-care professional-focused data

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collection, we introduced two additional substudies that involved collection of interview and observational data from suppliers of ePrescribing systems and from patients/patient groups. This work was informed by insights into the challenges of developing and implementing information infrastructures: long-lived systems of computer systems that support increasingly wide arrays of users and uses. We applied analytical templates and frameworks from the Biography of Artefacts and Practices perspective to study their longitudinal emergence and evolution. Data were inductively and deductively analysed, initially within cases and then across case study sites.

We undertook a three-round eDelphi exercise that involved 20 national experts from medical and pharmacy backgrounds to identify clinically important prescribing errors that could potentially be prevented through the use of ePrescribing systems. We then developed a data capture tool [Investigate Medication Prescribing Accuracy for Critical error Types (IMPACT)] to electronically identify and record these 80 errors, which were assessed before and approximately 6 months after 'go-live' of the ePrescribing systems in three adopting hospitals: two with more basic ePrescribing systems and one with a more advanced integrated ePrescribing system. The before–after design represented a change from our original plan to undertake a stepped-wedge trial, which was necessitated by changes to hospital implementation plans and delays with implementation. Error rates were calculated, with changes over time represented using ratios of error rates with confidence intervals from Poisson regression analyses and two-sided *p*-values from Fisher's exact test of proportions.

We used a Bayesian framework to estimate outcomes for the health economic analysis, which involved the convening of an expert group to generate priors, which were then considered together with the findings from the above-described evaluation to generate posteriors. This was supplemented by a systematic review to estimate the incremental effects of an adverse event on patient length of stay, costs or health outcomes. Our participating hospitals were very reluctant to share their cost data (largely on the grounds of these being considered commercially sensitive), but we were able to obtain cost data from one trust. We then used the 'headroom' approach (also referred to as 'threshold analysis'), which elicits the maximum price a decision-maker would be willing to pay for a technology on the basis of overall expected benefits.

Finally, we organised four national conferences and five expert round-table discussions that were used to integrate and contextualise the above findings and inform deliberations on implications for policy, practice and research.

Results

Across the six longitudinal qualitative case studies we conducted 242 interviews and 32.5 hours of observations, and collected 55 documents. This substantial body of qualitative work found that there was no shared understanding across the NHS as to what ePrescribing systems are, that the supplier market was relatively immature and dominated by systems that had their origins outside the UK, and that hospitals found it very challenging to develop business cases and procure these systems. The implementation process was far more prolonged than had originally been envisaged by the implementation teams, particularly in relation to ensuring adequate integration and interfacing between systems, and delays were commonly observed. The limited range of processes currently available through configuration of existing packaged solutions resulted in mismatches with existing hospital procedures. As a result, many customisation requests and frequent workarounds (that occasionally became sanctioned to ensure usability) arose following implementation. Our work in the embedded sites found that much of the decision-support functionality remained switched off because of concerns about over alerting already busy health-care professionals. The struggle to get these systems operational meant that little attention had yet been devoted to system optimisation or secondary use of data, although this was becoming a focus in the later post-implementation phases.

The eDelphi exercise enabled us to identify 80 clinically important prescribing safety indicators. Drug charts from a total of 2422 patients were reviewed at the three sites: 1244 before and 1178 after the implementation of system A at sites J and K, and system B at site S. These drug charts contained a total of 28,526 medication orders: 14,371 before and 14,155 after implementation. Following implementation, the proportion of medication orders that were technically incomplete or that showed inappropriate dose units or route of delivery was reduced to zero at all three sites (from 61.80%, 5.06% and 4.94% at sites J, K and S, respectively). After implementation of ePrescribing, the overall proportion of errors (per opportunity) fell from 5.79% (95% confidence interval 5.40% to 6.20%) to 4.56% (95% confidence interval 4.18% to 4.94%). Subgroup analyses showed that this reflected an improvement at sites J and S only. At site K, the error rate rose from 4.81% (95% confidence interval 4.26% to 5.41%) to 5.36% (95% confidence interval 4.80% to 5.97%).

For the three sites that went live during our research (i.e. sites J, K and S), the annual expected headroom per patient was £83.38, –£4.86 and £57.51 per admission, respectively. The two positive headroom levels were large such that it was considered most unlikely that an ePrescribing system would cost that much per patient.

We produced an ePrescribing toolkit that spans the entire ePrescribing life cycle from conception and development of the business case to systems optimisation. The toolkit is supported by NHS England and has over 2000 views per month from users internationally. Our national survey found that the majority of trusts were aware of it and had used it to support their ePrescribing implementation, use and benefits realisation efforts.

Conclusions

The implementation and adoption of ePrescribing was extremely challenging and time-consuming. This was, in large part, reflected by the relative immaturity of currently available ePrescribing system offerings, the lack of local expertise and experience within individual hospitals in their implementation and exploitation, and the unrealistic user expectations. Despite this, and the inherent challenges in interpreting observational data, we found that the implementation of ePrescribing systems was associated with overall reductions in the risk of clinically important prescribing errors, which were likely to be achieved in a more cost-effective manner. These data suggest that system configuration and optimisation are important in achieving these benefits. The ePrescribing toolkit and the associated frameworks and tools that we have produced appear to be widely used by hospitals across NHS England (and beyond). Google Analytics (Google Inc., Mountain View, CA, USA) snapshot for January 2015 indicated 400 visits per month from over 300 users from the USA and the UK. The toolkit may help overcome some of the above-described challenges, maximise the benefits of ePrescribing systems, and minimise potential harms and associated costs. Our programme of work suggests that hospitals may need support in procuring, implementing and optimising ePrescribing systems (Mozaffar H, Williams R, Cresswell K, Morrison Z, Bates DW, Sheikh A. The evolution of the market for commercial computerized physician order entry and computerized decision support systems for prescribing. *J Am Med Inform Assoc* 2016;**23**:349–55; Lee L, Williams R, Sheikh A. How does joint procurement affect the design, customisation and usability of a hospital ePrescribing system? *Health Inform J* 2016;**22**:828–38; Cresswell K, Coleman J, Slee A, Williams R, Sheikh A, ePrescribing Programme Team. Investigating and learning lessons from early experiences of implementing ePrescribing systems into NHS hospitals: a questionnaire study. *PLOS ONE* 2013;**8**:e53369; Cresswell K, Mozaffar H, Lee L, Williams R, Sheikh A. Workarounds to hospital electronic prescribing systems: a qualitative study in English hospitals. *BMJ Qual Saf* 2017;**26**:542–51; Mozaffar H, Williams R, Cresswell K, Sheikh A. Anglicization of hospital information systems: Managing diversity alongside particularity. *Int J Med Inform* 2018;**119**:88–93; Mozaffar H, Cresswell KM, Lee L, Williams R, Sheikh A, NIHR ePrescribing Programme Team. Taxonomy of delays in the implementation of hospital computerized physician order entry and clinical decision support systems for prescribing: a longitudinal qualitative study. *BMC Med*

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Inform Decis Mak 2016;**16**:25; Cresswell K, Coleman J, Slee A, Morrison Z, Sheikh A. A toolkit to support the implementation of electronic prescribing systems into UK hospitals: preliminary recommendations. *J R Soc Med* 2014;**107**:8–13; Cresswell K, Mozaffar H, Lee L, Williams R, Sheikh A. Safety risks associated with the lack of integration and interfacing of hospital health information technologies: a qualitative study of hospital electronic prescribing systems in England. *BMJ Qual Saf* 2017;**26**:530–41; and Wiegel V, King A, Mozaffar H, Cresswell K, Williams R, Sheik A. A systematic analysis of the optimization of computerized physician order entry and clinical decision support systems: a qualitative study in English hospitals. *J Health Inform* 2019;**26**:1118–32).

Key deliverables

- Typology of ePrescribing systems.
- System life-cycle model for ePrescribing systems.
- Typology of implementation strategies.
- Taxonomy of delays for ePrescribing systems.
- Taxonomy of factors underlying unintended safety threats.
- National agreement on 80 key clinically important prescribing errors.
- IMPACT tool enabling electronic capture of these errors.
- Taxonomy of approaches to and a roadmap for ePrescribing system optimisation.
- The UK's first evaluation of the effectiveness of commercial off-the-shelf ePrescribing system on clinically important prescribing errors.
- An ePrescribing toolkit for use in NHS hospitals covering the entire ePrescribing life-cycle.
- A series of national and local events disseminating this work.
- Supporting colleagues in the Department of Health and Social Care and NHS England through the Technology Fund, Wachter Review and the creation of the NHS Global Digital Exemplars.
- Leadership position on the World Health Organization's Third Global Safety Challenge: 'Medication Without Harm' (Donaldson LJ, Kelley ET, Dhingra-Kumar N, Kieny MP, Sheikh A. Medication without harm: WHO's third global patient safety challenge. *Lancet* 2017;**389**:1680–1).

Funding

This project was funded by the National Institute for Health and Care Research (NIHR) Programme Grants for Applied Research programme and will be published in full in *Programme Grants for Applied Research*; Vol. 10, No. 7. See the NIHR Journals Library website for further project information.

Programme Grants for Applied Research

ISSN 2050-4322 (Print)

ISSN 2050-4330 (Online)

Programme Grants for Applied Research (PGfAR) was launched in 2013 and is indexed by Europe PMC, NCBI Bookshelf, DOAJ, Ulrichsweb™ (ProQuest LLC, Ann Arbor, MI, USA) and Scopus® (Elsevier, Amsterdam, Netherlands).

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This report

The research reported in this issue of the journal was funded by PGfAR as project number RP-PG-1209-10099. The contractual start date was in November 2011. The final report began editorial review in February 2018 and was accepted for publication in September 2020. As the funder, the PGfAR programme agreed the research questions and study designs in advance with the investigators. The authors have been wholly responsible for all data collection, analysis and interpretation, and for writing up their work. The PGfAR editors and production house have tried to ensure the accuracy of the authors' report and would like to thank the reviewers for their constructive comments on the final report document. However, they do not accept liability for damages or losses arising from material published in this report.

This report presents independent research funded by the National Institute for Health and Care Research (NIHR). The views and opinions expressed by authors in this publication are those of the authors and do not necessarily reflect those of the NHS, the NIHR, CCF, PGfAR or the Department of Health and Social Care. If there are verbatim quotations included in this publication the views and opinions expressed by the interviewees are those of the interviewees and do not necessarily reflect those of the authors, those of the NHS, the NIHR, the PGfAR programme or the Department of Health and Social Care.

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