Original Article

Near field communications technology and the potential to reduce medication errors through multidisciplinary application

Emer O'Connell[1], Joe Pegler[2], Elaine Lehane[3], Vicki Livingstone[1], Nora McCarthy[4], Laura J. Sahm[5,6], Sabin Tabirca[2], Aoife O'Driscoll[1], Mark Corrigan[1,7]

[1]Cork Breast Research Centre, Cork University, Hospital, Wilton, Cork, Ireland; [2]Department of Computer Science, [3]School of Nursing, [4]School of Medicine, [5]School of Pharmacy, University College Cork, Cork, Ireland; [6]Department of Pharmacy, Mercy University Hospital, Grenville Place, Cork, Ireland; [7]Royal College of Surgeons Ireland, 121 St Stephen's Green, Dublin 2, Ireland

Contributions: (I) Conception and design: M Corrigan, S Tabirca, E O'Connell, J Pegler, V Livingstone, L Sahm, E Lehane; (II) Administrative support: M Corrigan, S Tabirca, E Lehane, L Sahm, N McCarthy, A O'Driscoll; (III) Provision of study material or patients: S Tabirca, E Lehane, L Sahm, N McCarthy, J Pegler; (IV) Collection and assembly of data: E O'Connell, A O'Driscoll, E Lehane, J Pegler; (V) Data analysis and interpretation: E O'Connell, V Livingstone, E Lehane, N McCarthy, L Sahm, M Corrigan; (VI) Manuscript writing: All authors; (VII) Final approval of manuscript: All authors.

Correspondence to: Emer O'Connell, MB. Department of Surgery, Cork University Hospital, Cork, Ireland. Email: emer.oconnell@umail.ucc.ie.

Background: Patient safety requires optimal management of medications. Electronic systems are encouraged to reduce medication errors. Near field communications (NFC) is an emerging technology that may be used to develop novel medication management systems.

Methods: An NFC-based system was designed to facilitate prescribing, administration and review of medications commonly used on surgical wards. Final year medical, nursing, and pharmacy students were recruited to test the electronic system in a cross-over observational setting on a simulated ward. Medication errors were compared against errors recorded using a paper-based system.

Results: A significant difference in the commission of medication errors was seen when NFC and paper-based medication systems were compared. Paper use resulted in a mean of 4.09 errors per prescribing round while NFC prescribing resulted in a mean of 0.22 errors per simulated prescribing round (P=0.000). Likewise, medication administration errors were reduced from a mean of 2.30 per drug round with a Paper system to a mean of 0.80 errors per round using NFC (P<0.015). A mean satisfaction score of 2.30 was reported by users, (rated on seven-point scale with 1 denoting total satisfaction with system use and 7 denoting total dissatisfaction).

Conclusions: An NFC based medication system may be used to effectively reduce medication errors in a simulated ward environment.

Keywords: Near field communication (NFC); medication errors; safety; multidisciplinary healthcare

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Introduction

Medication errors are responsible for a significant number of adverse outcomes in clinical practice. A 2007 report by the Institute of Medicine (IOM) estimated that between 380,000 and 450,000 preventable adverse drug events occur annually in the United States (1). As patients become older and polypharmacy increases, safer methods for medication management must be developed to promote patient safety. Given the complexity of medication use and the potential for errors, there is widespread encouragement for the use of technology to assist healthcare professionals (1).

Near field communication (NFC) is a technology which allows contactless data transfer. This technology

has been commercially developed to allow for electronic applications such as "Google wallet" and electronic ticketing system (2,3). "Bluetooth" and "Wi-Fi" are technologies that could be likened to NFC, but there are a number of important differences between these popular technologies, which are applicable in several ways. All three are methods of transferring information wirelessly, facilitating communication between smartphones. While "Bluetooth" and "Wi-Fi" focus on radio transmissions, NFC uses electromagnetic radio fields to operate. They are based on the similar Radio-Frequency Identification (RFID) standards, but operate over a shorter range than its predecessor. NFC extends functionality of RFID systems by facilitating bi-directional communication between endpoints, using magnetic field induction to enable communication between electronic devices.

NFC technology has the potential for use within healthcare systems to allow secure transfer of data and provides a sophisticated alternative to single-direction data transfer in RFID bar code medication systems (4,5). Landman *et al.* compared the efficiency and usability of a NFC medication system with a traditional barcode medication system for nursing medication administration. Authors found that the NFC system performed with a similar efficacy to barcode systems and was described as easy to use by nursing staff (6).

Electronic medication management such as barcode systems are used infrequently in Irish hospitals, with paperbased medication systems the predominate mechanism for facilitating medication prescription and administration We aimed to develop and then determine if a prototype NFC system could be used by doctors, nurses and pharmacists through each stages of medication use in hospital. In addition, we aimed to evaluate if use of an NFC system could reduce medication errors when compared with the currently used paper-based system.

Methods

Study design

For this study we implemented a "Proof of Concept" design to evaluate the use of NFC. A proof of concept study is a feasibility assessment of the capabilities of a new technology. It provides a valid and safe approach to assess a relatively new technology in healthcare (7).

NFC medication system

We designed a NFC-based system entitled "eRemedy" using the "PhoneGap" framework for Android tablet computers and NFC-tagged identification bracelets. PhoneGap is a mobile development framework which facilitates application development by software developers for mobile devices using JavaScript, HyperText Markup Language (HTML), and Cascading Style Sheets (CSS), instead of device-specific languages such as Java (for Android) or Objective-C (for iOs) (8). The system allows simulated patient records to be stored electronically within a patient identification bracelet with back up storage in the system database. To view a patient's medication record, a user swipes over the NFC ID bracelet with the NFC tablet. The tablet then displays the patient's demographics, medical history, allergies and medication record to date (*Figure 1*). A medication task can then be performed using the tablet. A prescription may be written, a drug may be administered or a medication record may be reviewed. All updates are saved by swiping over the patient's ID bracelet. This process updates the patient's record immediately and saves updates to the support database.

Clinical decision support (CDS)

Capabilities of the system included the incorporation of CDS. Comprehensive support was provided for use with prescribing functions. The NFC system was designed to cross-check each prescription written against the known correct drug spelling, dosage ranges, routes of administration and frequencies for administration. Likewise, the system was designed to cross-check each medication prescribed against existing prescriptions and items in the patient's medical history for potential interaction. A prescription that passed the cross-checking process would be added to the patient's medication list as a valid prescription. Failure of the prescribed medication to pass the cross-checking steps triggered a warning alert (*Figure 2*).

The British National Formulary (BNF) is a widely used medication formulary for use and provided CDS for those providing medication management using paper based systems. Drug information used in the prototype NFC system was sourced from the BNF and the BNF was provided as CDS for testing the Paper system control limb of this study, replicating current standard ward procedure.

NFC system security

NFC communication is usually executed through an insecure channel which is not always satisfactory from a

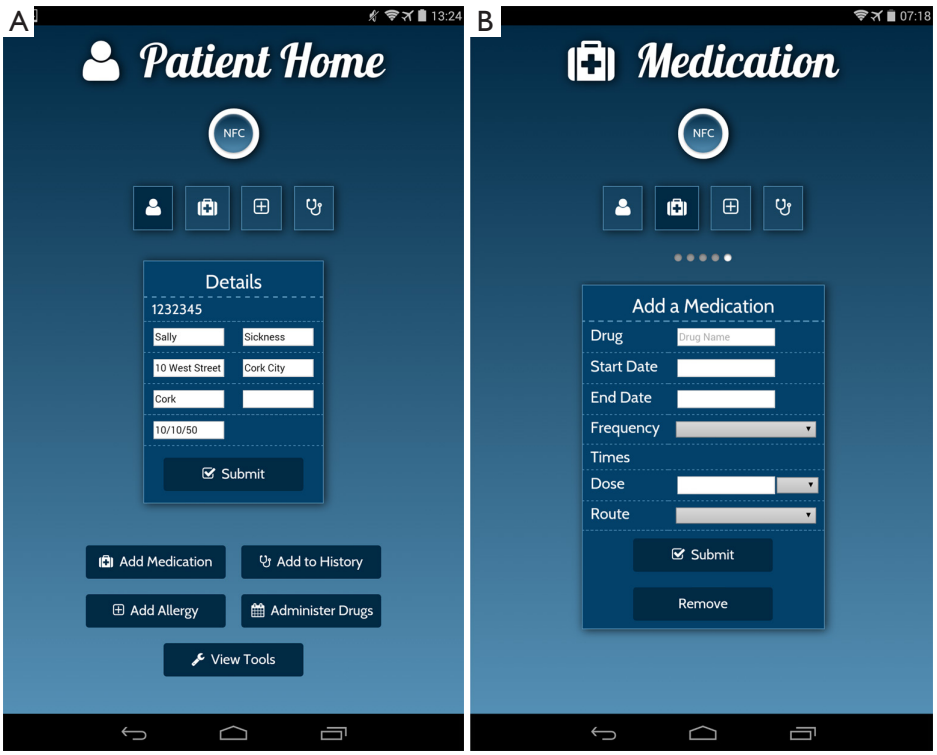

Figure 1 NFC system user interface. (A) Patient demographics; (B) Medication prescription.

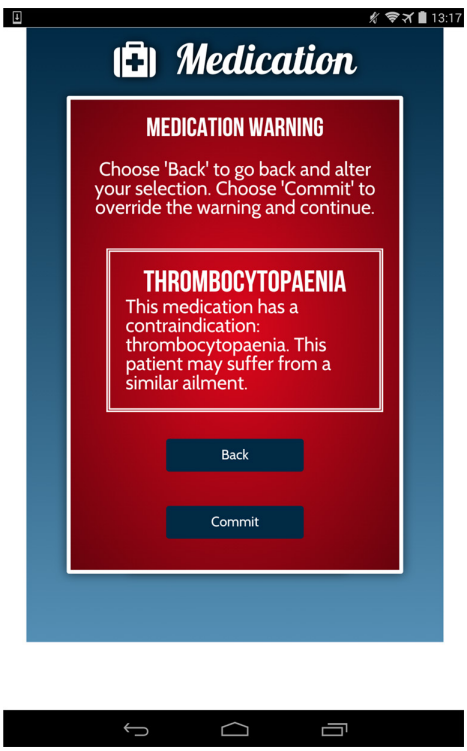

Figure 2 NFC system medication error warning.

security standpoint. The small range over which it operates helps to keep important data secure, but Mulliner (9), revealed several flaws of the system, where several possible attacks on applications were highlighted. To overcome these security issues a number of technological contributions had to be devised. An encryption algorithm, "AES", was selected to ensure that the patient data remained accessible only to those with system-user privileges. AES is a block cipher algorithm used as an encryption standard by the U.S. government. The PhoneGap AES-NFC design was developed to secure information being written and read from NFC tags deployed within the eRemedy system. The new methods provided by the developed system ensure that a non-authorised user looking to attack the insecure line of communication exhibited by NFC would receive only indecipherable information, useful only when the key used for encryption is known.

Prospective cross-over testing of NFC and paper medication systems

Medicine, Nursing and Pharmacy students were recruited to participate in three separate testing sessions. Groups of

Figure 3 NFC system testing. (A) Scanning NFC tagged patient bracelet; (B) medication administration using NFC system.

medical students, nursing and pharmacy students attended a testing session on three different dates in September 2014. A second group of medical students attended a testing session in December 2014. Testing was conducted in the simulated ward of a University Medical School (*Figure 3*). Inclusion criteria for the study included final year medical students, final year pharmacy students and final year nursing students in University College Cork. Excluded were students with previous qualifications or employment in areas of Pharmacy, Clinical Pharmacology, Health technology and Computer Science as they were expected to possess expert knowledge of medication use and advanced computer skills.

Sampling

Representatives of the Schools of Medicine, Nursing and Pharmacy identified a final year class who had a number of hours unfilled in their teaching schedule during the testing months of September and December. This class was scheduled to attend the session for four hours. The Schools selected the class at random. This method of recruitment avoided selection bias on the part of the investigator while minimising volunteer bias on the part of the students. Following attendance at the scheduled session the role of the NFC system and the purpose of the testing session was explained to students. Those students who wished to participate in the testing session were invited to complete a written consent form to participate in research.

Pre-test measurement

Pre-test measurements were taken before commencing the testing session consisting of a Technology Familiarity Questionnaire (10). The Technology Familiarity Questionnaire quantifies the frequency of use of computer and mobile bases technologies by the participant.

Intervention

The simulated ward was divided into two separate sections for the purpose of the session. The first section of the ward operated the NFC system for medication management. Here all patient mannequins wore an NFC tag on their patient identification bracelet. The second ward section used a paper medication record called a "Kardex" for medication management. Patient mannequins wore a simple paper identification bracelet and a paper Kardex was affixed to the patient's end of bed clipboard. A simulated name, medical record number, date of birth and address was provided for each patient.

Medical students were invited to perform four prescribing tasks using the NFC system and four prescribing tasks using the Paper system. Nursing students were invited to perform three medication administration tasks using the NFC system and three administration tasks

using the Paper system. Pharmacy students were invited to perform four medication review tasks using the NFC system and four review tasks using the Paper system. Testing of medical students was conducted over two sessions. The first session compared student performance while using both the NFC system with CDS *vs.* performance using the Paper system alone. The second testing session compared student performance using both the NFC system with CDS *vs.* performance using the Paper system with BNF support (current standard).

Post-test measurement

Having completed all required tasks using both systems students were invited to complete post-test measurements and provide feedback. Post-intervention measurement consisted of a Technology Satisfaction Questionnaire (11). Students provided qualitative feedback through open answer questions.

Data analysis

Data were analysed using the IBM SPSS Statistics Package Version 20. The total number of medication errors committed by each participant per prescribing, administration or review round was recorded. A total of 27 prescribing errors could potentially have been committed during each prescribing round. A total of 19 administration errors could potentially have been committed during each nursing administration round. Pharmacy students were asked to recognize the errors present within prescriptions. A total of 12 errors were present in prescriptions reviewed in each round.

The number of errors pertaining to error subtypes including patient identification, drug name, dosage, frequency, timing, route, allergy, erroneous withholding, contraindications and documentation were recorded for each student during each NFC and Paper round.

It was ensured that students faced tasks of equivalent difficulty when using both systems. This was achieved by preliminary testing and revision of the session tasks prior to the planned student sessions. Between three and four students from each of the Schools of Medicine, Nursing and Pharmacy were recruited to evaluate the content of the scenarios. Session task were also reviewed by subject matter experts to ensure tasks were appropriate for the current expertise level of students.

Descriptive statistical analyses were performed and mean errors were compared between groups using the t test.

Ethical considerations

Permission for the conduction of this study was sought from the Clinical Research Ethical Committee of the local teaching hospitals as well as from the Schools of Medicine, Nursing and Pharmacy in the University.

Results

A total of 89 students were recruited between September and December 2014 for participation including 36 medical students, 10 nursing students, and 43 pharmacy students. Students possessed high levels of familiarity with technology with all students registering that they used either a smartphone or computer daily.

Medication errors

Medical students

Twenty-two medical students were recruited to test performance of the NFC system in contrast with the Paper system. A statistically significant difference was seen between the mean errors committed during the test session when the NFC and Paper systems were compared (mean errors per group using Paper =4.09; 95% CI, 3.30–4.87 *vs.* mean errors per group using NFC =0.22; 95% CI, 0.03–0.41; P=0.000, *Table 1*).

The NFC application was re-tested by a second group of 14 medical students. On this occasion, the role of CDS was evaluated by comparing the NFC system and CDS with the Paper system and CDS provided by the BNF. Again a significant difference was seen between the mean errors per group when both systems were compared (mean errors per group =2.71; 95% CI, 2.18–3.24 *vs.* mean errors per group =0.42; 95% CI, 0.008–0.86; P=0.000, *Table 1*).

Errors related to drug contra-indications and drug dosage were the most frequent error sub-types committed by paper users (42.2% and 44.4% of Papers respectively). Frequency errors were the most common error subtype seen with NFC prescribing (60% of NFC errors).

Nursing students

Ten nursing students were recruited to perform drug administration tasks using both NFC and Paper systems in a cross-over test session. A significant difference was seen between the mean errors committed using the NFC and Paper systems (Paper =2.30; 95% CI, 1.23–3.37 *vs.* NFC =0.80; 95% CI, 0.35–1.25; P=0.015, *Table 1*).

Table 1 Summary of medication errors per round

Medication system	Prescribing errors		Administration errors		Pharmacy error recognition	
	Median (IQR)	P value	Mean (SD)	P value	Mean (SD)	P value
Without CDS		<0.001		0.01		0.11
Paper system	4.5 (2.25–5)		2.3 (1.49)		4.14 (2.25)	
NFC system	0 (0)		0.8 (0.63)		4.56 (2.03)	
With CDS		<0.001		–		–
Paper system	3 (3.25–3)		–		–	
NFC system	0 (0–0.75)		–		–	

Table 2 Satisfaction with NFC components

System usage	Mean (SD)
Simplicity of use	2.03 (1.51)
Efficiency of use	2.12 (1.50)
Ease of learning	1.70 (1.32)
Error messages	3.15 (2.06)
Organisation of information	1.86 (1.62)
System interface	1.96 (1.53)
Range of function	2.93 (1.81)
Use by medical students	2.45 (1.49)
Use by nursing students	2.14 (0.72)
Use by pharmacy students	2.22 (1.14)

Satisfaction reported on scale (1, total satisfaction; 7, total dissatisfaction).

Incorrect documentation practice was the most common error observed in users of the Paper system (58% of all errors committed with Paper system). The documentation process was performed correctly throughout use of the NFC system. Similarly, the use of incorrect patient records for drug administration represented 12.5% of all Paper errors but such errors did not occur with use of the NFC system. The most frequent error committed with use of the NFC system was the withholding of patient medication for an incorrect indication (50% of all NFC errors).

Pharmacy students

Forty-three pharmacy students were recruited to review prescriptions using both the NFC and Paper systems in a cross-over test session. They were tasked with identifying medication errors. Prescriptions provided for review contained eight errors within the NFC prescriptions and eight errors within the Paper prescriptions. A mean of 4.14 errors per review round (95% CI, 3.45–4.83) were identified using the paper-based system. A higher number of errors per round (mean =4.53; 95% CI, 3.90–5.17) were identified using the NFC system although this difference was not statistically significant (P=0.145).

Satisfaction with system use

The NFC system was assessed by each student using a validated tool. Overall satisfaction scores recorded by student groups are displayed in *Table 2*. Satisfaction was measured on a Likert scale with range 1–7 where 1 denotes total satisfaction and 7 denotes total dissatisfaction. Users reported high satisfaction with system components resulting in an overall score corresponding with good satisfaction levels. Overall satisfaction scores of 2.45 (95% CI, 1.77–3.13), 2.14 (95% CI, 1.66–2.61) and 2.22 (95% CI, 1.84–2.60) were reported by medical, nursing and pharmacy groups respectively.

In addition, students were asked if they wished to use NFC technology in educational sessions and in clinical practice. Students were enthusiastic about the use of NFC technology with 90% of students stating they would like to use NFC systems on the hospital ward.

Qualitative feedback

Students were invited to give feedback regarding the NFC system through open questions. Responses were collated, from which common themes and relevant statements were extracted. The speed of NFC use and provision of

CDS were frequently liked aspects of the system. Medical students advised development of the technology to remove system "glitches" while pharmacy and nursing students requested access to CDS and drug information.

Discussion

We have demonstrated with a "proof of concept" study that a NFC medication system may be employed by multiple health disciplines to provide electronic medication management with demonstrable reduction in drug related errors when compared to a currently used paper system.

Electronic medication management has frequently demonstrated the ability to reduce error. A large audit of over 3,000 patient admissions to Australian hospitals found that use of electronic prescribing systems reduced serious clinical errors by 44% (10). Similarly, this study demonstrated a dramatic reduction in prescribing errors in a simulated ward when NFC was compared with paper prescribing. The difference was statistically significant, even in the setting of a small sample size.

The incorporation of bar code technology into medication management is demonstrated to be effective in reducing administration and dispensing errors (12). However, bar code systems have several important limitations. NFC technology offers distinct advantages over barcode technology. Barcode systems involve a unidirectional flow of information, namely from barcode to reader. Therefore, it cannot be used for prescribing; a major step of the medication management process. While NFC readers can read the information stored in NFC tags they can also be used to update that stored information. Therefore, the information in tags may be constantly revised as patient progresses through the hospital visit. In contrast, the static nature of barcode information requires a barcode to be replaced to update the information. This bi-directional flow of information offers a significant advantage over barcode systems. From a practical viewpoint, NFC data tags are less prone to physical damage than barcodes. Unlike barcodes, NFC tags can be read without a direct line of vision (5). While barcodes may be torn, folded or water-damaged; plastic NFC tags offer a durable alternative. Further advantages are the small size of tags allowing incorporation into wearable identification wristbands and the low cost of NFC tags with prices varying from E0.50 to E2.00 per tag.

NFC provides technology which may be used for prescription, administration and review of medications due to its inherent bi-directional data flow. We would encourage evaluating the effectiveness of an NFC system in reducing errors across all stages of medication use when compared to existing barcode systems.

Electronic prescribing may be supplemented with CDS technology. CDS systems are technology applications in-built with the electronic prescribing process (13). Clinical decision making is a complex process that depends on human ability to provide undivided attention and to memorize, recall, and synthesize huge amounts of data. Clinicians often 'know' the information but forget to consider it at the time of prescribing (14). CDS systems are effective in bridging this 'knowing–doing' gap, by presenting the relevant information to the clinician at the time of decision making (14). A striking difference was noted between the performances of students using NFC with CDS versus using Paper without CDS (mean errors per round of 0.22 using NFC with CDS *vs.* 4.09 using Paper without CDS). When the performance of NFC with CDS was compared with Paper with CDS there remained a significantly lower number of errors in the NFC group. It would appear that immediate access to drug formulary information and automatic cross-checking for errors contributed to the difference between error rates in the groups.

For a technology to be effective it must be user-friendly. User dissatisfaction is a major barrier to the implementation of novel technologies (15). We objectively measured satisfaction with use of NFC technology in order to determine what modifications may be necessary before introduction into further educational and clinical practice. High levels of satisfaction were recorded with system use. However, on open feedback participants commented that system "glitches" may impair user satisfaction. Participants experienced difficulty with unplanned log outs and tag scanning failures. Further development of the system to prevent such problems is necessary before the technology may be fully implemented.

Landman *et al.* have previously tested the performance of a NFC system for medication administration in a simulated environment (6). Twenty nurses performed medication administration using a barcode system and a prototype NFC system. It was found that administration was performed in a similar length of time and using a similar number of scanning attempts. In addition, the users declared that the system easy to use (6). This study demonstrates that NFC is a viable technology for use in healthcare.

Our study continues to expand the role for NFC in

medication management by demonstrating that a single NFC system may be used by multiple healthcare disciplines for several stages of medication management, rather than for medication administration alone. Providing a common system for doctors, nurses and pharmacists is anticipated to facilitate easier transition to electronic medication management as only a single system is required. In addition, we have demonstrated that NFC technology may be adapted for developing custom-designed systems for use in a different healthcare environment from that tested by Landman *et al.*

NFC technology has been shown to be both efficient and easy to use for medication administration. However, further research is required to determine if NFC technology may reduce medication errors and improve patient safety when compared with currently used medication systems. Our study adds further to this work by demonstrating that NFC can reduce medication errors within a simulated hospital environment compared to the current standard practice within Irish hospitals.

There are a number of limitations associated with this study. The system was tested by final year university students rather than practicing clinicians. We selected final year healthcare students as participants as this study was designed as a "proof of concept" rather than a full-scale clinical evaluation. This approach allowed testing of a novel technology in a safe and controlled environment. Likewise, it facilitated the evaluation of NFC for use in simulated learning. To evaluate the effects of such a system in clinical practice it will be necessary to recruit practicing clinicians. In addition, the role of CDS technology was not evaluated by nursing and pharmacy students. It will be necessary to reassess the effect of CDS when the system is further developed for use by all healthcare disciplines.

Conclusions

This study has demonstrated the effective use of an NFC medication management system in a multidisciplinary setting. The system may be used universally for the prescription, administration and review of medications. It is an innovative teaching and learning tool which facilitates both health education and IT skill acquisition. In addition, it has demonstrated the ability to reduce errors related to the many stages of medication use.

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Footnote

Conflicts of Interest: Presented orally at the Society of Academic and Research Surgery annual meeting, January 7th, Durham University, UK.

Ethical Statement: Permission for the conduction of this study was sought from the Clinical Research Ethical Committee of the local teaching hospitals as well as from the Schools of Medicine, Nursing and Pharmacy in the University. Those students who wished to participate in the testing session were invited to complete a written consent form to participate in research.

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