

Title of Project:

Improving Allergy Documentation and Clinical Decision Support in the Electronic Health Record (EHR)

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Abstract

Purpose: Improve allergy documentation by developing a comprehensive value set, implement an innovative allergy reconciliation module within the electronic health record (EHR), redesign drug allergy alerting mechanisms, and distribute our outputs to healthcare institutions and the research community.

Scope: Allergies affect over 50 million people in the United States and impact all age groups, including 30 percent of adults and 40 percent of children. Many EHRs have limitations in allergy documentation and alerting. Strategic interventions will enhance allergy documentation quality and related care. This study spanned two healthcare systems, Mass General Brigham (MGB; Boston, MA) and UCHealth (Aurora, CO), and involved both clinician participants and historical data analysis.

Methods: This multi-step study conducted both quantitative and qualitative analyses and implemented a real-time EHR clinical decision support tool to improve allergy documentation.

Results: Variability in picklists across sites may cause differences in documentation practices. 89 percent of participating clinicians preferred an enhanced dynamic picklist over the currently used static picklist. The real-time allergy reconciliation tool piloted within the MGB EHR achieved a suggested action acceptance rate exceeding 97 percent. New drug-allergy alerting mechanisms have been developed to improve the appropriateness of the alerts.

Key Words: allergy, electronic health records, clinical decision support

Purpose

Many allergies and adverse reactions warrant documentation in the electronic health record (EHR) allergy section to inform future medical care and prescribing. Obtaining a complete and reliable allergy history for each patient is critical to support safe patient care and provide clinicians with an efficient allergy alerting and management clinical decision support (CDS) tool. However, the allergy modules in most existing EHRs have serious limitations in how allergies and reactions are documented and drug allergy alerts are fired. *First*, while EHRs allow structured/coded entries, reactions are frequently entered as free text, perhaps due to insufficiently comprehensive terminologies for encoding diverse reactions. *Second*, patients' allergy lists are often inaccurate and/or incomplete and are infrequently reviewed and/or updated by clinicians. More than 50 percent of drug allergy alerts are triggered for medications that patients are not allergic to or have previously tolerated. Accurate and complete drug allergy information leads to more effective prescribing and improved quality and safety. To date, there are no established processes for reconciling diverse allergy information. *Third*, while drug allergy alerts can safeguard against prescribing medications that could result in an adverse reaction, over 90 percent of these alerts are overridden, which compromises patient safety through "alert fatigue".

To tackle these shortcomings, we proposed a system redesign that employs a suite of innovative health information technology (IT) solutions, including an enhanced reaction value set, dynamic pick lists, natural language processing (NLP), and increased knowledge generated by domain experts and big data analytics, with an *overall goal* of improving healthcare quality and safety using health IT.

Aim 1: Improve reaction documentation by developing a comprehensive and interactive value set. Most current EHR allergy modules rely on commercial or local dictionaries whose adverse reaction lists are often incomplete, ambiguous, and static (i.e., one list for all allergens). These limitations result in half of reaction fields being left blank and one sixth being entered as free text. In this aim, we developed a comprehensive reaction value set, which was implemented as an enhanced reaction pick list in Mass General Brigham (MGB)'s Epic EHR system. We also designed and evaluated a dynamic reaction pick list in a simulated allergy module with historic patient data.

Aim 2: Develop an innovative allergy reconciliation module within EHR. Patient allergy information exists in different parts of the EHR (e.g., flowsheets, specialist notes). We developed an allergy reconciliation module within our EHR system to assist clinicians in reconciling discrepancies by comparing different data sources to identify missing or outdated allergy information and update patient allergy lists. A user-centered approach was applied to design, implement, and evaluate this module in MGB primary care practices.

Aim 3: Redesign drug allergy alerting mechanisms. The current drug allergy alerting strategy is ineffective, and substantial changes are needed. Untargeted alerting produces inappropriate warnings, which not only costs physicians' time, but also impacts patient safety as warnings that require attention may be missed. We developed informatics algorithms based on analyzing large amounts of EHR data to tier alerts by importance level. The tiers are based on reaction severity (high, medium, or low) and type (immune-mediated or not), whether the alert is based on an exact match or a cross-sensitivity between the allergen and the prescribed medication, whether the alert was repeatedly overridden or tolerated in the past, and salient patient characteristics. Tiering informs the alerting mechanism (e.g., interruptive versus informative) to reduce alert fatigue.

Aim 4: Distribute our methods and tools, so they are widely available to other researchers and healthcare institutions for non-commercial use.

Background

Allergies are among the leading causes of chronic disease, affecting over 50 million people in the United States. Allergic diseases, such as asthma, allergic rhinitis, and food allergies, impact all age groups, including 30 percent of adults and 40 percent of children. Drug allergies known to cause adverse drug reactions (ADRs) account for 6 percent of hospitalizations and result in longer hospital stays with greater healthcare costs. A significant inpatient and outpatient health burden, allergies must be thoroughly and effectively documented. Allergy documentation is one of the most fundamental steps to upholding patient safety and minimizing preventable ADRs. Information recorded in the electronic health record (EHR) allergy section can directly impact prescribing practices, clinical decision support (CDS) functionality, and alert mechanisms. As such, optimizing information technology and EHR functionality to improve allergy documentation and clinical practice is critical. Limitations including incomplete allergy documentation, inconsistent or outdated allergy information, and excessive alerting must be addressed.

It is highly recommended to define the allergen, reaction(s), reaction type, and reaction severity when entering an allergy entry in the EHR. Nonetheless, there is no official standard for complete documentation, and allergy module design varies across EHR vendors. Additionally, there is no agreed upon value set for documenting adverse reactions across healthcare institutions. Rather, systems use their local dictionary to describe reactions in varying levels of granularity (e.g., “pain” versus “abdominal pain”). Furthermore, non-allergists often lack the training needed for appropriate documentation. Based on a survey of Mass General Hospital clinicians, over 40 percent of physicians reported not having allergy training. Most individuals entering allergies are not allergists and are less likely to know how to classify reaction severity and type.

Clinicians may enter allergy information in the form of structured (e.g., checkboxes or dropdown menus) and unstructured (free text) data fields. Despite having structured fields to facilitate documentation and support CDS, including computerized physician order entry (CPOE) systems and alerts, many clinicians leave allergy fields blank or primarily describe the reaction as free text only. Approximately 29 percent of reactions are entered as free text, and a third of allergy entries lack reaction descriptions entirely. These statistics are particularly concerning because the lack of information often alters physician prescribing practices, for physicians must decide what to prescribe without knowing the reaction, the severity, or the reaction type (intolerance versus allergy). As a result, they are less likely to prescribe medicines that patients are likely able to tolerate, including more effective antibiotics, because of the nondescriptive allergy entry.

In addition to incomplete allergy records, information regarding allergies is often stored across various sections of the EHR. Because there is no internal infrastructure to reconcile the allergy information across the EHR, the information in the allergy module is not regularly updated with the information found in clinical notes, medication laboratory test results, and medication orders. About 3 percent of allergy entries are duplicates, and nearly 17 percent of allergy entries must be reconciled with information found in other EHR sections, including the results of challenge tests. Furthermore, allergy entries are rarely deleted, resulting in an accumulation of inaccurate or outdated allergy entries. Taken together, allergy reconciliation is essential to alleviate the burden on specialists, ensure accurate allergy information, and uphold safe prescribing practices.

The allergy section is also an integral part of the CDS systems that inform drug allergy alerts to further support safe prescribing. The structured information encoded in the allergy module informs CDS alerts, but with nearly 30 percent of reactions entered as unstructured free text, these alerting tools are often operating with incomplete information. Further, despite their purpose as a point of care intervention, clinicians override 80 to 90 percent of alerts in both inpatient and

outpatient settings. These exorbitantly high override rates in conjunction with clinician feedback indicate that these alerts are untargeted, excessive, and likely to contribute to alert fatigue.

Context

Despite the shortcomings of allergy documentation in the EHR, EHR systems have the potential to advance allergy documentation through intelligent CDS tools and alerting mechanisms that truly maintain patient safety. If optimized and redesigned, EHR functionalities paired with CDS can facilitate complete allergy documentation for clinicians that are not specialists and may not have the requisite training. With automated features, including built-in internal and external reconciliation tools, allergy records are more likely to be updated regularly, even with shortages of specialists, time, and resources. Moreover, changing alerting mechanisms can harness and leverage the true potential of alerts and possibly prevent ADRs without contributing to alert fatigue. Altogether, strategically developing interventions within the EHR to support the clinical workflow will enhance the quality of allergy documentation and clinical care provided.

Settings

This research was conducted across two healthcare systems, Mass General Brigham (MGB) and UCHealth. MGB is a prominent healthcare system in the Boston, Massachusetts area that includes Mass General Hospital, Brigham and Women's Hospital, several community hospitals, a physician network, and other affiliated sites. Headquartered in Aurora, Colorado, UCHealth includes fourteen hospitals throughout Colorado (including University of Colorado Hospital), along with affiliated hospitals in Wyoming and Nebraska, making it the region's largest care provider. Both MGB and UCHealth have dedicated resources, including a team of specialists and a dedicated center, to develop new digital health technologies and improve the EHR system. Thus, our multi-site investigation across these two sites has aligned with their individual institutional goals and helped confirm the generalizability of the findings. Furthermore, we are able to assess how the proposed interventions will apply in diverse settings.

Incidence/Prevalence: Not applicable

Methods

Study Design

This study was designed as a 4-year project to complete all four aims.

Aim 1

Aim 1 examined how to advance the design of the reaction pick list such that it supports efficient clinical use and improves the quality of allergy documentation and comprised three main steps: 1) developing a comprehensive reaction value set, 2) implementing a comprehensive reaction picklist, and 3) designing, implementing, and evaluating a dynamic reaction picklist.

To develop a comprehensive reaction value set, we studied drug hypersensitivity and contrast agent allergic reactions documented in the EHR (Wong 2019, Deng 2019). For drug hypersensitivities, we obtained all active allergy entries in the Partners Enterprise Allergy Repository (PEAR) from January 1, 2000 through October 31, 2013, from which we identified those with potentially immune-mediated reactions (i.e., hypersensitivity reactions; HSRs) from coded and free text reaction data. With input from domain experts, we manually excluded drug-reaction combinations that are less likely to be HSRs (e.g., hypotension from beta blockers). We further classified HSRs by their typical onset latency as either immediate (e.g., hives, anaphylaxis)

or delayed (e.g., maculopapular rash, pneumonitis). We also created a hierarchy of causative drugs based on a commercial knowledge base (i.e., First DataBank, South San Francisco, CA) including parent (e.g., anti-infective agents), intermediary (e.g., penicillins), and drug (e.g., penicillin). We identified patients with any, immediate, delayed, and both immediate and delayed HSRs.

For contrast agent allergic reactions (Deng 2019), we determined the frequency of contrast agent allergens, which we calculated and stratified by sex and race/ethnicity. We evaluated the quality of each record based on its level of specificity, where high quality records listed a specific contrast agent (e.g., iopamidol), intermediate quality records indicated an unspecified agent of a specific imaging modality (e.g., CT contrast), and low quality records listed an ambiguous concept that could apply to more than one imaging modality (e.g., intravenous dye). Reaction quality was categorized by whether a reaction was specified or unknown.

We also examined the heterogeneity of drug allergies and reaction picklists in the EHRs of two U.S. healthcare systems (Yerneni 2022). We obtained data from patients who visited the emergency department and/or outpatient clinics at BWH and UCHealth's University of Colorado Hospital from January 1, 2013 through December 31, 2018. We extracted patients' demographics and ADR information, including allergen, allergy status (active, inactive, or deleted), date and time of entry or update, coded reaction(s), and role of the documenting healthcare team member (e.g., physician, nurse, medical assistant) from the EHR data warehouses at each site.

Aim 2

Because allergy information is recorded in various disparate sections of the EHR, the objective of Aim 2 was to develop an allergy reconciliation module using a user-centered approach that could then be implemented for pilot testing at MGB primary care clinics. Aim 2 involved the following steps: 1) developing the allergy reconciliation algorithms, 2) developing the reconciliation module in our Epic EHR using a user-centered approach, and 3) evaluating the allergy reconciliation module.

We first conducted a retrospective cohort study to examine allergy documentation across different EHR sections to assess the prevalence of incomplete, inaccurate, and redundant allergy documentation and identify approaches for extracting and reconciling this information in the EHR. After establishing five reconciliation mechanisms (i.e., consolidating duplicate allergies, reconciling allergy lists with laboratory test results, reconciling allergy lists with oral challenge test results, adding medications that were discontinued due to an allergic response, and adding and updating coded allergy entries with reaction and allergen information entered in the free text comment section), we iteratively developed, implemented, tested, and refined a combination of database queries and natural language processing (NLP) algorithms to obtain the relevant allergy information and identify potential reconciliatory actions. We worked closely with MGB's Epic extension team to implement our reconciliation algorithms in our EHR as a real-time application launched from within Epic.

Aim 3

Due to the ineffectiveness of drug allergy alerts and the excessive overrides, Aim 3 worked to introduce strategic changes that tier alerts on importance level. The steps for Aim 3 included: 1) knowledge base development and refinement, 2) developing a new alerting algorithm, and 3) implementing and evaluating the drug allergy alerting mechanisms in a simulation environment.

For knowledge base development, we processed MGB's EHR data to identify alert override reasons. We also further examined the triggered alerts by the exact medication and cross-sensitivity to see whether these alerts were appropriately triggered and effective. Through this

analysis and literature review, we outlined areas for improvement that could be addressed including alerts triggered by a medication that is actually tolerated, alerts that are inappropriately interruptive, and alerts that trigger indiscriminately for both immune-mediated and non-immune reactions. Because opioid alerts constitute the significant majority of overridden alerts, we examined the possibility of tiering alerts based on the coded reaction such that non-immune mediated reactions would be silenced or non-interruptive. For cephalosporin and penicillin alerts, the clinical pathway used to decide whether a patient can receive either drug despite a documented allergy has been converted to apply for drug allergy alerts. We used data from previous alerts to improve the logic for penicillin and cephalosporin alerting.

Data Sources and Collection

For Aims 1-3, data from 1980-2020, including patient demographics, allergy history, and other relevant items, were collected from PEAR and MGB's EHR data warehouse. Comparable UCHealth data from 2013-2018 were also collected, along with their reference allergen and medication tables. Drug allergy alert information from September 1, 2017 through August 31, 2018 was also obtained from UCHealth.

Aim 1

We compared drug allergy entries and reactions across MGB and UCHealth using historical allergy entry data of 2,160,116 patients, with 1,530,641 (71%) from MGB and 629,475 (29%) from UCHealth, between 2013 and 2018 (Yerneni, 2022). To examine the effect of the enhanced reaction picklist, we analyzed allergy entries before (Phase 1; June 1, 2019 through December 31, 2019) and after (Phase 2; June 1, 2020 through December 31, 2020) the implementation of the expanded picklist.¹ In total, we analyzed allergy entries of 194,264 patients with 360,520 allergy entries and 149,416 patients with 273,049 entries in Phase 1 and Phase 2, respectively. To assess the usability of a dynamic reaction picklist, we recruited 36 clinicians from MGB to complete allergy entries using one of two prototype dynamic reaction picklists as well as a reproduction of MGB's current allergy entry interface and static picklist. Participants also completed a post-test interview.

Aim 2

We manually identified 111 primary care providers at MGB's Brigham and Women's Hospital to participate in the pilot study of our allergy reconciliation module. As of June 30, 2022, our module has processed the allergy information of 58,061 patients who visited BWH outpatient clinics between October 1, 2021 and June 30, 2022. To assess the accuracy of the algorithms upon which the module was built, we randomly selected a total of 1,339 patients across all reconciliation mechanisms. To assess the module's usability and impact on workflow, we solicited qualitative feedback from 10 clinicians through 3 individual interviews and one 7-person focus group. Prospective participants were manually identified based on their usage level and/or their informatics expertise.

Aim 3

We compared the patterns of alert override behavior among penicillin, cephalosporine, and opioid orders at MGB and UCHealth. Between January 1, 2019 and December 31, 2019, we identified 18,739 MGB patients and 17,314 UCHealth patient. There were 15,554 patients at MGB and 14,857 at UCHealth with penicillin alert overrides, 4,272 patients at MGB and 3,100 at UCHealth with cephalosporine alert overrides, and 25,330 patients at MGB and 25,197 at UCHealth with opioid alert overrides. Patients' demographic information (including age group, gender, race, and ethnicity), allergy information (including allergen name, reaction category,

reaction type, and reaction severity), medication orders, and comorbidity information were collected and used in our statistical analysis.

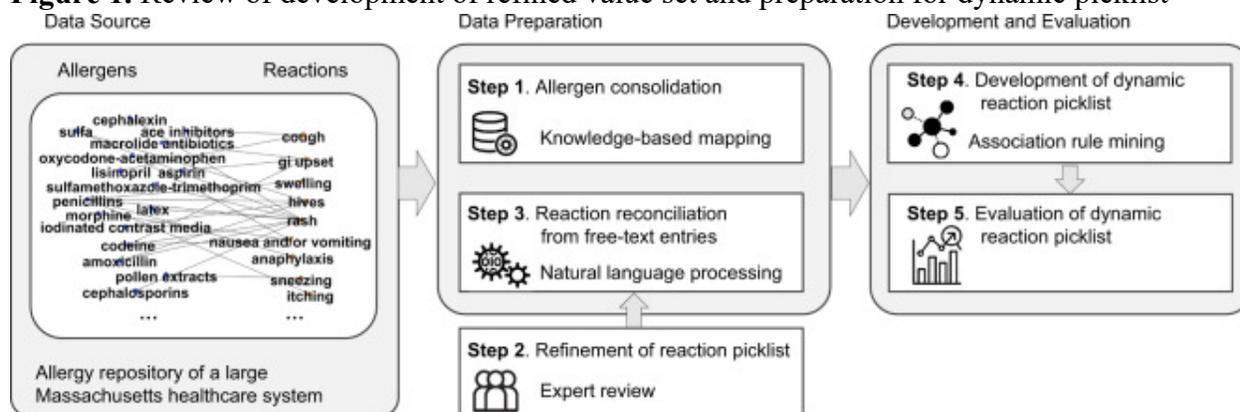
Interventions

Aim 1

With the oversight of the MGB eCare Allergy Clinical Consensus Group, 51 new reactions were added to enhance the picklist. We also defined reaction type and severity for the reactions using the Delphi Method. These 51 new reactions were added to the reaction picklist in MGB's Epic allergy module for all providers across all MGB sites (Varghese 2022).

A lexicon of 490 reactions was used to create a dynamic pick list. Three dynamic picklists were validated using a validation set based on previous allergy entries. After testing four approaches, a dynamic reaction list ranked by derived term frequency-inverse document frequency (tf-idf) was found to be the most clinically appropriate (Wang 2020).

Figure 1. Review of development of refined value set and preparation for dynamic picklist



The EHR allergy module relies on underlying terminologies to represent and encode allergy and reaction information. However, different hospitals use EHRs from different vendors with different features and clinical terminologies. Allergy reaction picklists are often provided by third-party content vendors and/or are customized to institution-specific dictionaries; even healthcare institutions that use the same EHR system can have different reaction picklists, ranging from a fewer than 20 to more than a hundred reactions. This lack of standardization and interoperability has downstream consequences for data exchange between different healthcare sites, as well as for research that relies on the accuracy and consistency of coded data. However, at the time of our study, whether the lack of a standardized reaction picklists impacts healthcare provider data entry remained an open question. We therefore investigated the differences in drug allergy reactions documented at both MGB and UHealth between 2013 and 2018.

We first classified drugs into corresponding drug classes using the American Hospital Formulary Service Pharmacologic-Therapeutic Classification, then further classified some drug classes into broader classes (e.g., “cephalosporin antibiotics – 1st generation” and “cephalosporin antibiotics – 2nd generation” were combined into “cephalosporins”). We included only drug class allergens that comprised at least 0.5 percent of all reported drug allergies.

Allergy entries from 1980-2018 with free text comments were processed to determine if the original 46 reactions in MGB's pick list were sufficient. We also received 5 years of allergy data from UHealth to assist with this analysis. Using a reaction value set of 783 reactions derived from PEAR, our NLP tool, MTERMS was used to recognize reactions in the free text comments.

Aim 2

To develop the allergy reconciliation algorithms, we collected, cleaned, and analyzed one year of allergy data from BWH's outpatient clinics study the type of discrepancies involved. The data included patients' notes, medications, test results, and diagnoses. From this data, discrepancies related to latex allergies, penicillin oral challenges, duplicate allergens, free-text reaction entries, and medication orders discontinued due to allergic response were identified. This data informed the development of the reconciliation algorithms that were then integrated into the custom reconciliation module. While validating the queries used for the module, workflows and logic sequences were developed such that the custom reconciliation module worked effectively with real-time data in the EHR environment (Ortega 2020, Vallamakonda 2022).

To integrate the allergy reconciliation module with Epic, we collaborated with MGB's Epic Extension Team to identify the best way to integrate the module with Epic and outlined the ideal workflow. The module's functions, design, and placement were discussed, and the Extension Team's input was taken into consideration while designing the module. With the Extension Team, we created a prototype of the Allergy Reconciliation within the Epic Development environment. Using this prototype, we collected feedback internally regarding the user interface and used this feedback to improve the design. The module was then implemented and tested with real patient data in the Epic Support environment, which mirrors (but does not interact with) the production environment and is refreshed on a daily basis. We piloted our module with a group of 111 primary care providers at BWH and assessed whether the recommendations proposed were well-received and accurate. We regularly reviewed usage data and user feedback to identify exceptions to our logic and other issues.

To optimize workflow and minimize the burden of manual allergy reconciliation, we implemented a version of the free text reaction update mechanism that automatically performs a subset of these updates on the backend. The set of reactions for which automated updates can be applied were identified and approved by members of our multi-disciplinary team, including an allergist, a pharmacist, and an emergency medicine clinician, and included exact or near-exact matches. Update suggestions that could be considered ambiguous or involved a degree of uncertainty, such as broad matches or reactions that are similar but not identical (e.g., "racing heartbeat" and "palpitations") remain in the reconciliation module for PCPs to review manually.

Aim 3

To develop the alert tiering algorithm, we developed new rules based on historical data analysis. We first analyzed the severity of the reactions involved in penicillin and cephalosporin alerts. By comparing the override rate along with the severity, we identified what alerts should and should not trigger interruptive alerts. Using historical data, we estimated the reduction in alerts. Furthermore, alerting for allergens that trigger more than one alert with several reactions was redesigned to only trigger one alert for the most severe reaction. The new rules were created after factoring in allergy group, cross-sensitivity groups, severity, and alert history.

We also designed a simulation user interface implementing our proposed alert tiering mechanism. We built a prototype web application using Flask, a Python framework for building web applications, and created use cases with which to test the novel interruptive and informational alerting mechanisms. The layout of the application and the wording and timing of the alerts were developed, reviewed, and revised iteratively by an interdisciplinary team of clinicians, informaticians, developers, and usability experts.

Measures

Aim 1

For drug hypersensitivities, descriptive statistics were used to summarize patient characteristics and HSRs. We compared the prevalence of HSRs by sex and race using a Chi-square test or Fisher's exact test, as appropriate. A negative binomial regression was used to compare the number of HSRs per patient by sex. For contrast agent allergic reactions, descriptive statistics were used to summarize patient characteristics and the number of contrast agent allergens of each quality level. Dichotomous variables were compared using a Chi-square test.

For our comparison of drug allergy reaction documentation between MGB and UCHealth, we compared patient demographics of the overall population and those with allergies between the two sites. We also determined the number of allergies entered by provider role. Because MGB transitioned to a new EHR system during the study period, some allergy records were updated automatically via a conversion process; we therefore used a subset of the records post-conversion from August 1, 2018 to December 31, 2018 to estimate the proportions of reactions entered by different types of providers. Reported allergy reaction prevalences were calculated as the number of patients with an active allergy to a drug class divided by the total study population. We compared the proportions of the 40 most frequently reported reactions at both sites by dividing the count of each reaction by the total number of reported reactions at each site. We further examined and compared the top ten reported coded reactions for each drug class at each site. Frequencies were compared using a Chi-square test. The enhanced picklist was evaluated using a pre-post retrospective analysis of allergy entries 6 months before and 6 after the implementation of the enhanced picklist.

Dynamic picklists created using data-mining association rules were compared with the static picklist by measuring the recall of the top-k suggested reactions. Additionally, a web-based user interface that resembles the EPIC environment was developed for clinicians to compare the effects of the dynamic and static reaction picklists. 36 clinicians were recruited to compare the dynamic and static picklists and provide their input in a post-user testing interview. This interview paired with the user testing asked about: 1) the user's role, 2) the current Epic reaction pick list, 3) free text entries, 4) mockups of the static and new dynamic reaction picklists, 5) usability metrics to assess user experience (for both the static and new dynamic picklists), 6) free text comments and the new picklist tool, and 7) overall remarks. While testing, the participants would be asked to complete a few questions following specific steps. These responses were analyzed for quantitative and qualitative findings.

Aim 2

We analyzed the demographic information for patients with outpatient clinical visits with clinicians in our pilot group between October 1, 2021 and June 30, 2022. Within this patient cohort, we determined the count of various allergy discrepancies. The discrepancy mechanism (i.e., consolidating duplicate allergies, reconciling allergy lists with laboratory test results, reconciling allergy lists with oral challenge test results, adding medications that were discontinued due to an allergic response, and adding and updating coded allergy entries with reaction and allergen information entered in the free text comment section) and suggested action type (i.e., "add", "update", "delete", and "remove duplicates") were determined for each recommendation. Precision, recall, and F1 score were used to measure the performance of the reconciliation algorithms. We also collected usage statistics and monitored user feedback to understand users' acceptance of the reconciliation tool and identify any potential areas for further improvement.

Aim 3

We compared and analyzed patterns in the alert override histories of the MGB and UCHealth patient cohorts. Descriptive statistics were used to summarize patient and cohort characteristics, with mean and standard deviation used for continuous variables and count and proportion for categorical variables. For statistical inferences across the two sites, numerical variables were compared using independent t-tests and categorical variables using a Chi-square test. A p -value of < 0.05 was considered to be statistically significant.

Limitations

Aim 1

The expanded picklist was implemented in Epic in March 2020, at the beginning of the first wave of the COVID-19 pandemic in the U.S. Thus, Phase 1 and Phase 2 took place before and after the start of the pandemic, respectively. As such, there may be confounding variables related to COVID-related changes in practice that we did not control for at the time. The assessment of dynamic versus static picklists involved a comparatively small study cohort ($n=36$), which does not sufficiently power the study. A sample size of approximately 120 clinicians would allow for more generalizable results and reveal whether there are substantial significant differences.

Aim 2

The NLP-based reconciliation algorithms were developed based on and applied to outpatient clinical notes only and thus may not be directly applicable to other clinical settings. Although the module's suggestions were judged to be accurate in at least 97 percent of cases, and despite biweekly reminder emails, usage remained relatively low throughout the study period. This is likely a result of the immense documentation burden already facing clinicians, which underscores the importance of efficient EHR integration. However, there are considerable challenges to fully integrating the module within Epic, as clients are limited in the types of customization and extensions they can implement. For our study, the module was instead opened externally by clicking a hyperlink in the Epic Storyboard, location chosen for its accessibility and visibility.

Aim 3

Our proposed alert tiering mechanism was built, tested, and evaluated using historical data; thus, we were unable to assess the performance and user acceptance of our tiered alerts in a real-time EHR setting. Additionally, our alert tiering logic is designed to decrease the number of overridden alerts with a goal of decreasing alert fatigue; however, this does not directly address the underlying problem of adverse drug reactions themselves, and further study is needed to investigate whether our approach can significantly improve drug safety. Finally, our cross-reactivity logic was based on drug classes, not individual drugs. Although data exist regarding cross-reactivity of individual drugs, it remains an area of uncertainty.

Results

Principal Findings

Aim 1

Reaction Pick List Lexicon Expansion

Expanding the reaction picklist at MGB by 46 reactions has resulted in more complete allergy documentation with greater detail. Between Phase 1 without the enhanced picklist and Phase 2 with the expanded picklist, the proportion of coded entries increased from 45 percent to 49 percent. In Phase 2, the percentage of uncoded reactions decreased from 33 percent to 30 percent.

Furthermore, there was a 10 percent reduction in allergy entries with minimal or blank reaction descriptions with the implementation of the comprehensive picklist.

Table 1. Comparison of Allergy Entries Before and After Implementing Comprehensive Picklist

	Phase 1, N = 194,264	Phase 2, N = 149,416	<i>p</i> -value
Allergy Entry Characteristics			
Entries with Coded Reactions	163,045 (45.22%)	134,004 (49.08%)	
Allergy Entries without Reactions	102,220 (28.35%)	69,622 (25.50%)	
Entries with Free Text Comments	123,875 (34.36%)	95,837 (35.10%)	
Entries with Free Text Comments Containing Uncoded Reactions	73,949 (20.51%)	52,838 (19.35%)	
Total Allergy Entries	360,520	273,049	
Reaction Characteristics			
No. of Coded Reactions	184,718 (67.03%)	152,929 (70.30%)	<0.001
No. of Reactions Entered Only as Free Text	90,841 (32.97%)	64,618 (29.70%)	<0.001
Total Reactions	275,559	217,547	
Expanded Reaction Term Usage			
Total No. of Reactions Containing Newly Added Terms	16,826	18,790	
No. of Coded Entries Containing Newly Added Terms	-- (0.00%)	8,606 (45.80%)	
No. of Expanded Reactions Entered Only as Free Text	16,826 (100.00%)	10,184 (54.19%)	<0.001

Comparison of Drug Allergy Reaction Entries

A total of 2,160,116 patients were included in this comparison, with 1,530,641 (71%) from MGB and 629,475 (29%) from UCHealth. 454,011 patients (30%) at BWH (30%, n = 454,011) and 186,433 (30%) at UCHealth had at least one documented drug allergy. In total, there were 705,413 active drug allergy records with 1,230,165 reactions at MGB and 223,560 active drug allergy records with 586,750 reactions at UCHealth.

Across both sites, the most commonly reported drug class allergens were penicillins (14%), opioids (10%), sulfonamide antibiotics (9%) and non-steroidal anti-inflammatory drugs (NSAIDs) (5%). MGB’s reaction picklist had 48 reactions, while UCHealth’s had 160, with a total of 179 unique reactions across the two sites. Of these, 29 (16%) were common to both picklists, 19 (11%) were only on MGB’s picklist, and 131 (74%) were only on UCHealth’s picklist. The most commonly reported reactions were similar across sites and included “rash”, “GI upset”, “hives”, “itching”, and “anaphylaxis.” Providers more frequently entered “Other (See comments)” at MGB than at UCHealth (18% versus 3%, respectively). On the other hand, UCHealth had considerably more reactions that were left blank than MGB (29% versus 12%, respectively).

Overall, the majority of reported reactions to antibiotic drug classes were potential hypersensitivity reactions (e.g., rash and hives) which appear on the picklist at both sites. Penicillins, sulfonamides, cephalosporins, and lincosamides displayed similar reaction distribution across sites; however, rash was reported more at MGB than at UCHealth across all antibiotic drug classes. Musculoskeletal pain to fluoroquinolones at MGB was comparable in prevalence to myalgia to fluoroquinolones at UCHealth.

Reported reactions to non-antibiotics exhibited greater variability. Rash to opioids, NSAIDs, and thiazide diuretics was reported considerably more at MGB than at UCHealth. While mental

status change to opioids was reported at MGB, this term is not included in UCHealth's picklist. Instead, hallucinations to opioids were reported at UCHealth. The sum of "swelling" and "angioedema" reported reactions to ACE inhibitors at MGB is comparable to "swelling" at UCHealth, whose picklist does not include angioedema. For NSAIDs, bronchospasm and renal toxicity were among the top 10 reactions MGB, but not at UCHealth as they do not appear on UCHealth's picklist, while bleeding was only reported at UCHealth as it is absent from MGB's picklist. For statins, both myalgia and musculoskeletal pain comprised the top 10 reactions at MGB, which were comparable in prevalence to myalgia at UCHealth, whose picklist does not include musculoskeletal pain.

Dynamic Pick List Analysis

The reaction value set was refined using the input of diverse experts in the field in combination with a data-driven approach. Most terms selected reflected terms frequently entered in the database, although some terms were selected based on experts' feedback. The reaction value set was refined to reduce highly granular terms and mainly capture frequently used, clinically relevant terms. Future research must be done to define the ideal reaction value set.

For the development of the dynamic reaction picklist, the development dataset consisted of 3,743,628 allergy entries for 1,683,678 unique patients. Among these entries, 3,280,743 were considered active allergy entries, 1,535,657 had free text reactions included in the comments, and 2,171,548 had at least one 1 reaction from the previously defined reaction set. The validation dataset contained 490,774 allergy entries for 272,108 unique patients, 96.9 percent of which were considered active allergy entries, 31.8 percent of which had free text reactions included in the comments, and 56.3 percent of which had at least one reaction from the pre-defined reaction set.

Using the development dataset, three dynamic reaction picklists were validated along with the static reaction picklist by calculating the recall of the top-k reactions. The static reaction picklist had the lowest recall for the top 5, 10, and 15 suggested reactions, and all picklists had significantly different recall from one another ($p < 0.001$).

27 physicians and 9 nurses participated in the survey and pilot testing. Clinicians tested 3 different reaction picklists (2 dynamic picklists with different ranking algorithms and 1 static picklist that resembles the current reaction picklist). Compared with the static picklists, the pilot clinicians were less likely to enter reactions as free text using the dynamic reaction picklists and spent at least 15 percent less time completing an allergy entry. The differences in number of free-text entries and time to complete the entries were statistically different. Furthermore, over half of the coded entries corresponded to the 10 reactions suggested by the dynamic picklists.

According to the clinician surveys, there was general dissatisfaction with the EHR's current reaction picklist and its functionality. Only 42 percent of the clinicians found the current picklist satisfactory, and nearly a fifth indicated that the picklist lacked sufficient granularity and comprehensiveness. In the same vein, 30 percent of clinicians recommended expanding the picklist. Participants also suggested that reactions lacked a standard level of specificity and broadness, leading to variability when documenting reactions that may not accurately embody the true reaction. At least a third of clinicians supported the use of intelligent reaction picklists that would present frequent reactions at the top and improve the search function. Clinicians also expressed that they entered reactions as free text for several reasons including 1) to enter more specific information, 2) to describe reactions they could not find in the picklist, 3) to communicate cross-reactivity, and 4) to describe/enter reactions faster.

The vast majority of the clinicians interviewed (n=32, 89%) preferred the dynamic pick list over the current static picklist. After using the different picklists, 72 to 94 percent of participants rated the two dynamic picklists as easy to use, while only 33 to 39 percent stated that the static picklist was efficient to use. In the first comparison group with one dynamic picklist (UI-1D) and the static picklist (UI-1S), all users preferred the dynamic picklist, and only 11 percent of clinicians stated the dynamic reaction picklist was a frustrating experience relative to the 44 percent who found the static picklist frustrating. Comparing the second dynamic picklist (UI-2D) and UI-1S, 77.8 percent preferred the dynamic list, and about 3 percent found the dynamic picklist frustrating relative to 50 percent for the static picklist.

Clinicians themselves indicated that because of the 1) comprehensive picklist, 2) ranked reaction picklist by allergen, 3) ability to select multiple reactions from the dropdown list, and 4) better search functionality, they were less likely to input free text. Still, a little over a fifth of the participants did not believe the dynamic pick list would affect the number of free-text entries. Their reasoning was that typing directly in the free-text section may be faster than searching the picklist and that the enhanced picklist may not be sufficiently comprehensive.

Table 2. Performance of the dynamic picklists versus the static picklist for reaction entry

	Comparison Group 1				Comparison Group 2			
	UI-1D	UI-3S	Difference	p-value	UI-2D	UI-3S	Difference	p-value
Free-text entries per user per 10 cases, mean (SD)	2 (2)	4 (2)	2 (2)	.003	2 (2)	4 (2)	2 (2)	.002
Time to complete allergy entry for 10 cases, mean (SD) seconds	280 (86)	331 (164)	51 (154)	.102	256 (120)	306 (146)	50 (127)	.067

Abbreviations: SD, standard deviation

*p-value calculated using Wilcoxon signed-rank test.

Aim 2

Allergy Reconciliation Algorithm Development

We identified five mechanisms for allergy reconciliation: 1) consolidating duplicate allergies, 2) reconciling allergy lists with laboratory test results, 3) reconciling allergy lists with oral challenge test results, 4) adding medications that were discontinued due to an allergic response to the allergy list, and 5) adding and updating coded allergy entries with reaction and allergen information entered in the free text comment section.

We reviewed the accuracy of the back end free text reaction updates seven times between April 25, 2022 and June 30, 2022. During this time, 3,894 allergy records with free text reaction discrepancies were updated automatically.

Evaluation of Allergy Reconciliation Module

We designed and developed an allergy reconciliation module as an extension within MGB's Epic EHR. The tool runs in real-time to reconcile allergy information across a patient EHR and identify and present discrepancies to clinicians for reconciliation.

Out of 58,061 total patients with outpatient clinical visits with clinicians in our pilot group between October 1, 2021 and June 30, 2022, 20.5% had at least one discrepancy identified by our reconciliation algorithms resulting in a total of 20,763 recommendations (Table 3). The performance of our free text allergen/reaction detection, challenge test result interpretation, and duplicate allergen identification NLP algorithms are shown in Table 4.

Table 3. Number of recommendations for each mechanism

Mechanism	Add	Remove	Update	Total
Free Text Allergen/Reaction	*	*	19487	19487
Duplicated Allergen	*	1146	*	1146
Latex IgE	*	*	44	44
Medication Discontinuation	43	*	*	43
Medication Challenge Test	1	42	*	43
Total	44	1188	19531	20763

*Not applicable

Table 4. Performance of NLP-Based Reconciliation Mechanisms

Mechanism	No. Reviewed	Precision	Recall	F1 Score*
Free Text Allergen/Reaction	1755	0.97	0.99	0.98
Medication Challenge Test**	200	0.99	0.76	0.86
NLP alone		0.96	0.62	0.75
Structured data alone		1.00	0.42	0.59
Duplicated Allergen	200	1.00	1.00	1.00

*F1 score = $2(\text{Precision} \times \text{Recall}) / (\text{Precision} + \text{Recall})$

**Combined NLP and structured data

User-Centered Reconciliation Module Development

In our analysis of user behavior, we observed 662 active sessions between October 1, 2021 and June 30, 2022. Users took at least one action (to “accept”, “edit”, or “reject” a recommendation) in 625 (94.4%) sessions, with “accept” rates ranging from 97 to 100 percent depending on the mechanism.

Table 5. User behavior statistics for each mechanism

Mechanism	No. of Accepted Recommendations	No. of Rejected Recommendations	Acceptance Rate (%)
Free Text Allergen/Reaction	933	18	98.1
Free Text Reaction (Severe)	163	5	97.0
Duplicated Allergen	67	1	98.5
Latex Allergy	3	0	100.0
Medication Discontinuation	3	0	100.0
Medication Challenge Test	2	0	100.0
Total	1008	19	98.1

The focus group provided feedback pertaining to the functionality, usability, and overall perception of the allergy reconciliation tool. Recurring themes from the discussion included 1) integration with Epic, 2) internal and external data reconciliation, and 3) ideal versus burdensome workflow. In general, providers agreed that allergy reconciliation across diverse data sources is critical but felt that it was unclear how this application differed from the existing reconciliation tab in Epic, which identifies and displays allergy from external data sources.

Aim 3

MGB and UCHealth Drug Allergy Alert Analysis

For both MGB and UCHealth data, over half of all alerts for penicillins and cephalosporins are overridden (54.5% and 55.1%). The cross-sensitivity rate was 79.9 percent and 52.2 percent for penicillins and cephalosporins, respectively. Across MGB and UCHealth, override rates ranged

from 89.8 to 93.9 percent for penicillin allergy alerts triggered by cross-sensitive class match. We found that drug matches are less likely to be overridden.

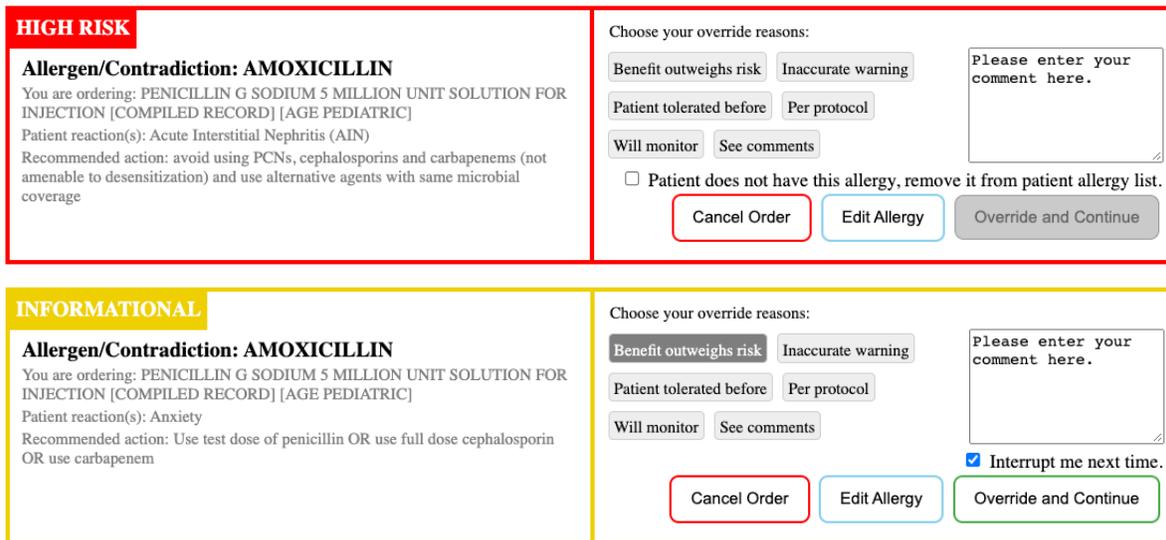
About two thirds of opioid alerts are overridden at both MGB and UCHealth, and there are more than 700,000 interruptive alerts for 50,527 patients for morphine analogue opioids specifically. Alerts concerning codeine and morphine are the most frequently overridden at both MGB and UCHealth. The most common reactions for the allergy entries that triggered an alert primarily concerned non-immune mediated reactions. Approximately one fifth of reactions were immune mediated (e.g., hives, rash).

Based on this data analysis and literature review, we recognize the importance of factoring reaction severity for alerting. According to 2019 MGB data, the override rate for allergy entries with a low severity was 36.7 percent for penicillins and 39.1 percent for cephalosporins. This percentage decreased to 6 percent and 6.8 percent, respectively, for penicillin and cephalosporin reactions of greater severity. Medium severity reactions had variable override rates that depended on allergen, alert history, and patient comorbidity. Thus, alert rules should introduce interruptive alerts for high severity reactions, but perhaps only informational alerts for reactions of lower severity. Other factors that should be considered include override rates (4 or more overrides per patient), history of tolerance, and disease states.

Allergy Alert Simulation

We designed prototype user interface for both informational and interruptive alerts to gather override reason feedback for interruptive alerts. The designs can be found in Figure 2. The most important difference between informational and interruptive alerts is that an informational alert does not force users to provide any feedback. Even with no override reason selected, the user can proceed and override this alert. Secondly, the checkbox above the buttons provides the user an option to display this as an interruptive alert in the future.

Figure 2. Screenshot of the prototype interruptive and informational alert user interfaces



We created several scenarios (Table 6) to test our alert tiering mechanism in a web-based simulation environment. The scenarios were reviewed by a multidisciplinary team of clinicians and informaticians to confirm that our proposed tiering logic was reasonable and practical from a clinical standpoint.

Table 6. Example testing scenarios

Patient	Medication	Allergy	Reaction(s)	Alert type	Recommended action(s)
1	PENICILLIN G SODIUM 5 MILLION UNIT SOLUTION FOR INJECTION	AMOXICILLIN	Acute Interstitial Nephritis (AIN)	Interruptive	Avoid using penicillins, cephalosporins, and carbapenems (not amenable to desensitization) and use alternative agent with the same microbial coverage OR continue order when override reason is selected
		PENICILLIN	Anxiety	Informational	N/A
2	AMPICILLIN 250 MG/5 ML ORAL SUSPENSION	AMPICILLIN	Cough, Headaches, Hives	Interruptive	Use a test dose of 3rd/4th/5th generation cephalosporin or carbapenem OR use alternative agent with the same microbial coverage OR use aztreonam or carbapenem OR continue order when override reason is selected
3	CEFOXITIN 1 GRAM IV SOLUTION	CEFTIN	Seizures, Shortness of Breath	Interruptive	Continue order when override reason is selected

Discussion

Our findings suggest that drug allergy reaction documentation is indeed influenced by the number and level of detail of the available coded reactions. While the top reported drug allergens, including antibiotics, opiates, and sulfonamides, were similar at MGB and UHealth, we found greater variability in the commonly reported adverse drug reactions across the two sites, which may be a product of each institution having its own reaction picklist. In addition to their effects on documentation, picklist size and granularity may also have consequences for downstream clinical decision making as well as for drug surveillance and research. For studies involving secondary use of EHR data, researchers should consider potential biases in clinical documentation due to EHR design. Overall, the rates of all reported drug class allergens were comparable between both sites. This similarity could potentially be attributed to the fact that both MGB and UHealth use the same commercial medication data dictionary (i.e., First Databank Inc.) for drug allergens, which may facilitate more accurate and feasible comparisons across sites.

Further evidence of the role picklists can play in allergy reaction documentation is found in the changes in reaction documentation behavior following the implementation of an enhanced reaction picklist in MGB's EHR system. The 6-month period following the introduction of the enhanced picklist saw an increase in coded reactions alongside a decrease in both incomplete allergy entries and allergy reactions entered as free text. However, while the prevalence of free text reactions did decrease, they still remained relatively common. Possible reasons for the persistence of free text reaction entries include the enhanced picklist being too inefficient or cumbersome to navigate, a continued lack of appropriately granular reaction options, or providers simply preferring the level of specificity and detail that free text allows.

In an effort to address the possible drivers of entering reactions as free text, we developed and implemented a prototype of two variants of a dynamic reaction picklist that presents users with the most relevant reactions based on the allergen entered. Fewer than half of participants in our dynamic reaction picklist usability study expressed satisfaction with the static reaction picklist currently in Epic with both physicians and nurses/physician assistants describing the current picklist as inefficient and unintuitive, supporting the idea that the enhanced picklist may still be too cumbersome to use regardless of its comprehensiveness. As predicted, most participants reported using free text entries to provide specific details about a reaction (e.g., the circumstances under which it occurred or information about cross-sensitivity) or document a reaction not on the

picklist, although a handful did report using free-text because it was easier or faster. Some participants expressed concerns that the recommended reactions might bias users toward entering a reaction that is slightly different from what they truly intended, such as entering “GI upset” instead of “nausea” or “abdominal pain”. However, because suggested reactions are identified based on the co-occurrence of allergens and reactions in a large database, we anticipate that they will be appropriate in the majority of cases.

We developed an allergy reconciliation module as another means of increasing the accuracy and reducing the burden of allergy documentation. We also developed a system of tiering drug allergy alerts by severity to address the problem of inaccurate or redundant alerts contributing to clinician alert fatigue. Across all of the interventions proposed in this study’s aims, we faced the challenge of being unable to fully integrate our tools within MGB’s Epic EHR system due to limitations placed by Epic on the extent to which customization and integration of externally developed algorithms are supported. For the allergy reconciliation module, this meant that we were required to have our tool launch “externally” via a link on the navigation panel, which focus group participants said limited its ability to be adopted into existing workflows. However, pilot users of the reconciliation module agreed on the importance of reconciling disparate allergy information from across the EHR and the value of a dedicated tool for internal allergy reconciliation to supplement Epic’s existing module for reconciling allergy information imported from other sites.

There were a number of interesting findings identified during the course of the allergy reconciliation module’s development. For example, we identified 16 patients without a documented latex allergy whose latex IgE test results exceeded the threshold at which they would be considered allergic. Due to the seriousness of this discrepancy, we worked directly with MGB’s safety leadership to correct these patients’ records, but a robust allergy reconciliation module could prevent such documentation errors from happening in the first place. Additionally, while evaluating the mechanism for removing duplicate allergens, we found that 55 of the 200 sampled patients had both a drug class (e.g., ACE inhibitor) and at least one specific drug within that class (e.g., Captopril) on their allergy list, a scenario that cannot currently be processed by our algorithm without incurring information loss but that warrants further attention due to its prevalence.

We found that the number of drug allergy alerts can decrease dramatically if the alerting mechanism can take into consideration the reaction type, reaction severity, and cross-sensitivity. Currently, the majority of medication alerts in our EHR system are interruptive alerts, which contribute significantly to alert fatigue. Evidence shows that inaccurate allergy records and suboptimal alerting systems lead to unnecessary and inappropriate alerts and that more advanced mechanisms leveraging advanced informatics methods are needed to reduce the cognitive burden associated with EHR documentation. Based on our analysis of historical data, our proposed tiering system has the potential to improve patient safety by decreasing the number of unnecessary alerts. In the future, allergy alerts associated with low severity and non-allergy reactions could also be made informational to avoid additional interruptions to clinical workflow.

Conclusions

The size and granularity of reaction picklists likely influence drug allergy and reaction documentation behavior, which may vary even among sites using the same commercial EHR system. After implementing an expanded reaction picklist within MGB’s EHR system, the number of reactions entered as free text and the number of incomplete reaction entries both demonstrated a noticeable decrease. A picklist’s user interface also plays an important role; in a usability study, a comprehensive, dynamic reaction picklist displaying reactions in order of relevance based on the

entered allergen reduced both documentation time and the number of free text reaction entries compared to a static picklist ordered alphabetically. The majority of study participants preferred the dynamic picklist with regard to efficiency, usability, and utility.

Discrepancies in allergy information documented in different locations in the EHR can affect the quality and safety of patient care and often result in accurate alerts contributing to alert fatigue among clinicians. We implemented and conducted a pilot analysis of an allergy reconciliation module to automatically identify discrepant allergy information from multiple sources in the EHR and prompt providers to review and update inaccurate, incomplete, or contradictory allergy entries with the goal of enhancing patient safety and improving the appropriateness and usefulness of drug allergy alerts.

The clinical significance of drug allergy alerts is highly variable, but many are likely not be serious enough to affect clinicians' prescribing decisions. Our novel tiering mechanism classifies alerts as informational or interruptive according to their clinical importance and relevance. This proposed alerting mechanism has the potential to dramatically decrease the frequency of interruptive alerts and in turn improve drug safety and combat alert fatigue.

Significance

We expect that expanding the reaction picklist to include more frequently mentioned reactions will result in improved documentation and reduce free-text reaction entries. To truly improve allergy documentation, however, greater efforts must be made to consider how clinicians interface with the allergy module. The reaction list should not only provide comprehensive coverage of frequent and important reactions, but it should also be designed in a way that is both user-friendly and intuitive while integrating seamlessly with clinicians' existing workflows and supporting point of care CDS. Exploring the concept of a dynamic picklist has helped us understand clinicians' current points of dissatisfaction and moved us toward better integrating clinical practice priorities with EHR use. Our findings demonstrate that a dynamic reaction picklist has significant potential to outperform the static picklists currently used in Epic with respect to accuracy, completeness, and usability. Citing these advantages, study participants exhibited a strong preference for dynamic picklists over static picklists. Furthermore, our analysis of drug allergy reaction entries across two hospital systems suggests that picklists' comprehensiveness and ease of use may impact documentation behavior, underscoring the importance of promoting standardization and interoperability in future picklist enhancement efforts.

The real-time implementation of our allergy reconciliation module within MGB's Epic EHR system further demonstrates the value of comprehensive allergy CDS tools. During the 9-month pilot period, our module processed and analyzed the allergy information of nearly 60,000 patients of 111 providers, identifying more than 20,000 discrepancies. Despite the high level of accuracy of the module's suggestions, and despite biweekly reminder emails, usage remained relatively low throughout the study period. However, we did observe that among users who did open and use the module, most of the suggestions were accepted. Furthermore, we found that once users accessed the module a few times, they typically continued to use the module regularly. This, combined with the focus group's agreement that allergy reconciliation across diverse data sources is critical, demonstrates the vast potential of a well-integrated allergy reconciliation CDS tool to improve patient safety and care while simultaneously facilitating allergy documentation that is both more accurate and less burdensome for providers.

Clinically irrelevant allergy alerts contribute to alert fatigue and may pose drug safety risks. We built an alert tiering mechanism to differentiate between drug allergy alerts that should be

interruptive versus those that can be informational only. Our proposed mechanism greatly reduced the number of inaccurate or inappropriate alerts when implemented in a proof-of-concept web application. Taken together, an allergy documentation framework that leverages enhanced picklists prioritizing the most likely reactions for a given allergen, comprehensive tools to support real-time allergy reconciliation, and alerting systems that reduce rather than increase the cognitive burden currently associated with EHR use can radically transform existing EHR allergy modules into more accurate, efficient, clinically useful documentation tools while simultaneously supporting drug safety.

Implications

Collectively, our findings provide several key takeaways regarding the current state and potential enhancement of allergy documentation and decision support infrastructure within the EHR. First, the lack of standardization of allergy reaction picklists has real consequences for both patient care and downstream surveillance and research tasks, and efforts to promote interoperable allergy and reaction documentation standards are needed. Second, our dynamic reaction picklist algorithm and proposed interface allowed clinicians to document drug allergy reactions faster while using fewer free text reactions in a usability study setting, suggesting that future work to investigate whether these advantages carry over into real-time allergy documentation is warranted. However, based on feedback from the study participants, there are still a number of ways in which our proposed dynamic picklist can be improved, including allowing for different reaction list ordering mechanisms (e.g., alphabetical), auto-populating reaction type and severity, and supporting ontological term search.

Similarly, despite the accuracy of our allergy reconciliation module, usage was relatively low throughout the study period even as participants agreed that reconciling allergy information from across the EHR is vital. Based on feedback from pilot users, more research is needed to identify the optimal allergy reconciliation workflow, and seamless integration with the existing EHR is likely essential for achieving that workflow and encouraging user adoption. While this is complicated by the limitations on local customization imposed by many EHR vendors, future efforts to work collaboratively with these vendors may provide a route to achieving better integration of independently developed decision support tools. Implementing our novel alert tiering mechanism, or any number of other data-driven EHR enhancements, will pose similar challenges and require similar collaborative solutions.

List of Publications

Aim 1

1. Wong A, Seger DL, Lai KH, Goss FR, Blumenthal KG*, Zhou L*. Drug Hypersensitivity Reactions Documented in Electronic Health Records within a Large Health System. *J Allergy Clin Immunol Pract*. 2019;7(4):1253-1260.e3. PMID: 30513361.
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12. Bassir F, Zhou L. Drug Reaction With Eosinophilia and Systemic Symptoms (DRESS): Clinical Characteristics and Outcomes in Patients With Skin of Color. 18TH ANNUAL Skin of Color Society SCIENTIFIC SYMPOSIUM, Boston, MA.

Aim 2

13. Ortega C, Lo Y, Blackley SV, Vallamkonda S, Chang F, James OD, Yerneni S, Wang, L, Seger D, Blumenthal KG, Goss FR, Wickner PG, Zhou L. Methods for Identifying and Reconciling Allergy Information in the Electronic Health Record. Presented at the 2020 AAAAI Annual Meeting. Journal of Allergy and Clinical Immunology. 2021 Feb 1;147(2):AB168. <https://doi.org/10.1016/j.jaci.2020.12.597>.
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16. Lo Y, Varghese S, Blackely S, Chang FY, James OD, Seger DL, Blumenthal KG, Goss FR, Zhou L. An allergy reconciliation module to improve allergy information documentation in the electronic health record (in preparation).
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18. Lo Y, et al. Evaluation of an allergy reconciliation tool in the EHR (in preparation).

Aim 3

19. Goss F, et al. Analysis of opioid allergy alerts (in preparation)
20. Edrees H, et al. Analysis of penicillin allergy alerts (in preparation)