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Identifying and Reconciling Patients' Allergy Information Within the Electronic Health Record

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Abstract

Allergy information is often documented in diverse sections of the electronic health record (EHR). Systematically reconciling allergy information across the EHR is critical to improve the accuracy and completeness of patients' allergy lists and ensure patient safety. In this retrospective cohort study, we examined the prevalence of incompleteness, inaccuracy, and redundancy of allergy information for patients with a clinical encounter at any Mass General Brigham facility between January 1, 2018 and December 31, 2018. We identified 4 key places in the EHR containing reconcilable allergy information: 1) allergy modules (including free text comments and duplicate allergen entries), 2) medication laboratory tests results, 3) oral medication allergy challenge tests, and 4) medication orders that have been discontinued due to adverse drug reactions (ADRs). Within our cohort, 718,315 (45.2% of the total 1,588,979) patients had an active allergy entry; of which, 266,275 (37.1%) patient's records indicated a need for reconciliation.

Keywords:

Medication Reconciliation, Allergy and Immunology, Natural Language Processing

Introduction

Adverse drug reactions (ADRs) have been reported to affect 10-20% of hospitalized patients and up to 25% of outpatients. [1-3] The cost of ADRs has been estimated to be as high $30.1 billion dollars, associated with longer length of hospital stay, and up to twice the mortality. [4-6] Insufficient information about a patient's allergies by their provider before prescribing medications accounts for 12% of medication errors. [7-9] Accurate documentation of allergy information is critical for patient safety and quality of care.

Electronic health records (EHRs) are widely used in the United States and many other countries. [10] Within the EHR, the allergy module provides a central location for clinicians to document ADRs. However, allergy information can be documented as free-text comments within the allergy module or in a variety of locations in the EHR outside of the designated allergy module, such as laboratory results section, allergy diagnosis codes, problem lists, flowsheets, and clinical notes, in which allergic information often never makes it to the allergy list, resulting in incomplete patient allergy information records. Previous studies have found that as little as 0.6% of patients have fully detailed and accurate allergy lists. [11-15] Therefore, reconciling information from different parts of the EHR and maintaining a complete and accurate allergy list for each patient is warranted to reduce the risk of potentially harmful ADRs. Previous studies have found that allergy documentation tends to accumulate over time with relatively few deletions and that despite negative allergy testing, the discrepancy in documentation often continue to remain on patients' charts. [16,17]

Current EHR modules rely on underlying terminologies to encode allergy information, including allergens and reactions. Coded allergy entries are the basis of clinical decision support (CDS) systems that alert clinicians about drug allergies during the medication ordering workflow. While computerized CDS systems have been widely shown to reduce the risk of allergic reactions through the generation of real-time alerts; [18,19] current CDS systems present over alerting and alert fatigue issues. Reactions are sometimes stored in the EHR's allergy module as free-text comments without coded reaction(s); uncoded entries cannot be processed by CDS systems. Prior studies have also found that 50% of allergy alerts were triggered by medications the patients were not truly allergic to and that 90% of drug allergy alerts were overridden. [20,21] Inaccurate and outdated documentation of allergies can result in inappropriate or unnecessary alerts when ordering medications in the future. This can lead to alert fatigue due to the cognitive overload caused by the volume of alerts and effort needed to distinguish between informative and uninformative alerts. [22] However, only one study, to our knowledge, has investigated comprehensive allergy reconciliation methods, [23] and none have examined the design or implementation of a more expansive automated allergy reconciliation tool.

The aim of this study was to examine allergy documentation within various EHR sections to better understand the prevalence of incomplete, inaccurate, and redundant allergy information documentation and identify approaches for extracting and reconciling allergy information in the EHR.

[*] Sachin Vallamkonda and Carlos A. Ortega contributed equally.

Methods

Clinical Setting and Data Collection

We conducted a retrospective cohort study at Mass General Brigham (MGB, formerly Partners HealthCare), a non-profit integrated health care delivery network in Boston, MA, which includes two founding hospitals, Brigham and Women's Hospital and Massachusetts General Hospital, and a group of community hospitals and health centers which provide inpatient and outpatient primary and specialty care. In this study, we included patients who visited an MGB site between January 1, 2018 and December 31, 2018. This study was approved by the MGB's Institutional Review Board (IRB).

While allergy information can be documented in different places across the EHR, we selected four sections (i.e., allergy module, laboratory results, flowsheets, and orders) where allergy information often resides and identified them as major potential sources of discrepancies.

We extracted patients' demographics, allergens (culprit drug), allergy status (active, inactive, or deleted), date/time of allergy entry/update, coded reaction(s), free-text comments, laboratory data, allergy challenge tests, and corresponding drug-allergy alerts from the enterprise data warehouse. For information on allergen synonyms, interaction allergens, allergen groups, and ingredients, we referred to a commercial drug knowledgebase (the First DataBank [FDB]®).

Data Analysis and Statistics

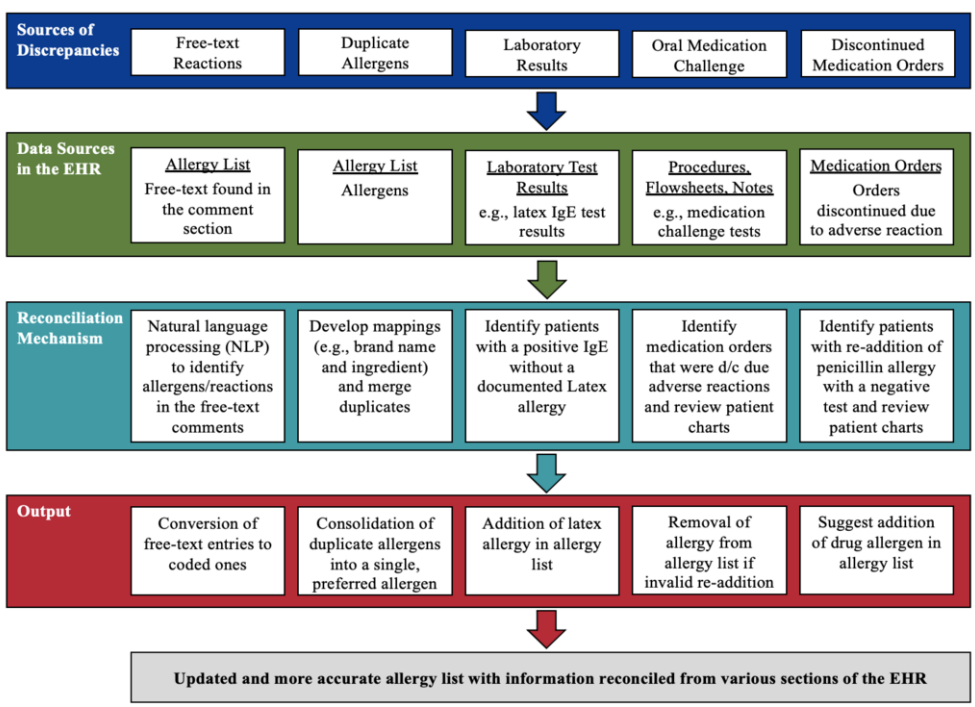
We proposed a systematic mechanism to identify, compare, and examine allergy documentation in four EHR sections and their discrepancies, which may facilitate the development of a reconciliation method that improves patients' allergy list accuracy and completeness (Figure 1).

Reaction Entries as Free-Text Comments in the Allergy Module: We calculated the percentage of allergies that had reactions mentioned in the free-text comment field. We further investigated whether the reactions extracted from the free-text were available as coded options in the EHR or as reaction concepts in our value set. In this step, the Medical Text Extraction, Reasoning, and Mapping System (MTERMS), a multipurpose natural language processing (NLP) tool, was used to identify reactions in the free-text comments. [24] We pre-processed the comments for misspellings; [26] then we used the MTERMS lexicon-based search module to identify reaction mentions in the free-text comments. [27] Each reaction extracted from free-text was mapped to a SNOMED-CT concept, which was subsequently mapped, if possible, to the corresponding reaction name in the EHR's reaction list. The MTERMS negation module was further applied to exclude negated reactions (e.g., "no cough").

Duplicate Allergens Entries in the Allergy Module: The reference allergen table in the EHR contained over 42,000 allergens among which many are synonyms, duplicates, brand names, or other variations. Duplicated allergens might have been entered in patients' allergy list. In a prior study, we systematically identified duplicate allergens from the reference allergen table by checking whether they were different versions of the same allergen, have the same names, or have the same ingredients and allergen groups. [28] We reconciled those duplicated allergens by mapping the allergens to the preferred allergens. With that, in the present study, we measured the breadth of reconciliation needed for "duplicate" allergen entries in our study cohort. Specifically, we determined the number of patients with duplicate allergens in their allergy list, total number of duplicate allergen entries, and number of drug-allergy interaction (DAI) alerts that could have been eliminated given reconciliation of the duplicate allergens.

Medication Allergy Laboratory Tests Results – Latex IgE: Among our study cohort, we identified patients who have had a

Figure 1. Methods for Allergy Reconciliation



Latex IgE test during the study period, pulled their latest result value, and compared their results with the allergy list to determine patients who required reconciliation. If the result was abnormal, we checked whether a Latex-related allergy entry was in patients' allergy list.

Oral Medication Allergy Challenge Tests – Penicillin: To identify patients who needed their allergies reconciled based on the results of their challenge test – a procedure performed by allergy specialists with free-text documentation – we first found the date that an allergy challenge test was ordered. Then, we identified patients who had an allergy to a penicillin removed and, at a later date, had an allergy to a penicillin re-added. We then reviewed patients' charts to determine if the re-addition of a penicillin was valid based on if delayed reactions were reported or if the patient had reactions to a subsequent penicillin medication after passing the challenge test.

Medication Orders Discontinued due to ADRs: To identify patients who needed their allergies reconciled based on a medication previously discontinued due to allergic response, we first found the date that the order was discontinued. We then reviewed patients' charts, focusing on ACE inhibitor and sulfa antibiotic orders, to determine if there was documentation in their chart of the allergic response and if a reaction was mentioned.

Table 2. Coded reactions and value set reaction concepts frequently entered in free-text comments

Rankings	Allergies with Coded Reactions in the Free-Text Comments (n = 208,395)		Allergies with Value Set Reaction Concepts in the Free-Text Comments (n = 251,458)	
	Reaction	n (%)	Reaction	n (%)
1	Rash	46,009 (22.1)	Fatigue	6,770 (2.7)
2	Vomiting	30,568 (14.7)	Hallucinations	6,209 (2.5)
3	Hives	23,866 (11.5)	Erythema	5,542 (2.2)
4	GI Upset	14,196 (6.8)	Syncope	4,896 (1.9)
5	Dizziness	13,167 (6.3)	Facial swelling	4,612 (1.8)
6	Cough	12,463 (6.0)	Red color	4,278 (1.7)
7	Itching	11,452 (5.5)	Lip swelling	4,165 (1.7)
8	Swelling	11,001 (5.3)	Edema	4,127 (1.6)
9	Palpitations	8,731 (4.2)	Pharyngeal swelling	4,056 (1.6)
10	Headaches	8,168 (3.9)	Tongue swelling	3,966 (1.6)

Results

The study cohort included 1,588,979 patients, of which 718,315 (45.2%) patients had at least one active allergy entry, resulting a total of 1,751,179 active allergy entries. Demographics for the entire patient cohort and the patient cohort with allergies can be found in Table 1. Approximately 50% of allergy entries (942,576) had missing reaction information in the allergy module. Of all active allergies, we found that 19.6% (343,867) do not have a coded reaction, and 26.3% of all allergies (459,853) contain additional free-text reaction information that can either be coded using our existing reaction lexicon or could potentially be coded with an enhanced reaction lexicon. For the study cohort, our commercial EHR contained 42,027 allergen concepts, but only 24.4% (10,254) had active allergy entries in the database.

***Free-Text Comment Entries*:** Overall, 43.0% of allergy entries (753,170) had a free-text comment and 24.5% of all allergies (428,770) had at least one reaction mentioned in the free-text; 11.9% (208,395) had a coded reaction and 14.4% (251,458) had a reaction from our value set. Table 2 shows the most frequent reactions found in the free text, including rash, vomiting, hives, Gastrointestinal (GI) upset.

Duplicate Allergen Entries: Among the patients with allergy entries, we found 21,051 (2.9%) patients with a total of 52,914 duplicate allergens on their allergen list. Among these patients, 2,168 (10%) patients had 9,041 orders with a medication that triggered a DAI alert for their duplicate allergens, and this resulted in additional 10,092 drug-allergy alerts. Reconciliation of allergens would remove 26,804 allergens from patients' allergy lists and would have prevented 10,092 duplicate drug-allergy alerts during the study period. The top 10 most frequently occurring duplicate allergens can be found in Table 3.

***Medication Allergy Laboratory Tests Results – Latex IgE*:** We identified 16 patients without a documented latex allergy who had a k/uL greater than 0.35 (positive test result), of which 12 had a k/uL greater than 0.64 (positive test result with high severity).

***Oral Medication Allergy Challenge Tests – Penicillin*:** In our cohort, 737 patients had a documented penicillin challenge order. After reviewing the results, a total of 55 (7.5%) patients had a penicillin allergy removed, and subsequently re-added, following the challenge test. After thorough review, we found that 36 (65.5%) patients had the allergy inappropriately re-added. 11 of these patients received a penicillin medication since testing, with only 2 patients reporting gastrointestinal intolerance related reactions. Of the 19 patients who had a valid reason for the allergy to be re-added, 16 had delayed reactions to the penicillin challenge test, and 3 had reactions to a subsequent penicillin medication after passing the challenge test.

Medication Orders Discontinued due to ADRs: There were a total of 1,366 ACE inhibitor and 969 sulfa antibiotic orders that were discontinued with the discontinuation reason "Allergic Response". We manually reviewed charts for 137 ACE inhibitor and 174 sulfa antibiotic randomly selected orders from unique patients and found that 47 (34.2%) of the reviewed ACE

Table 1. Cohort Characteristics of Patients with Allergies

Age, *median (IQR), years*	57 (39, 70)					
	No. (%)					
	Total	**White**	**Black**	**Asian**	**Hispanic**	**Other Unknown**
Female	472724 (65.81)	383045 (53.33)	19350 (2.69)	14694 (2.05)	28373 (3.95)	27262 (3.80)
Male	241936 (33.68)	197863 (27.55)	9003 (1.25)	7360 (1.02)	12686 (1.77)	15024 (2.09)
Unknown	3655 (0.51)	13 (0.00)	0 (0.00)	1 (0.00)	1 (0.00)	3640 (0.51)
Total	718315 (45.21)	580921 (80.87)	28353 (3.95)	22055 (3.07)	41060 (5.72)	45926 (6.39)

**Asian Includes Hawaiian/Pacific Islanders; * Other includes Unknown, Native American, More than one race*

inhibitor orders and 31 (17.2%) of the reviewed sulfa antibiotic orders needed reconciliation, as the allergens had not been added to the patients' EHR allergy list.

Discussion

Our main finding was that 266,275 (37.1%) patient's allergy records indicated the need for reconciliation based on our methods. We found that clinicians often fail to delete medications that patients can tolerate or are not truly allergic to (e.g., after a negative allergy challenge test), which leads to allergy entries accumulating over time as well as inappropriate alerts firing. Reconciling reaction information from the allergy module's comments section into coded fields is important for downstream CDS.

Based on the discrepancies identified, we propose several solutions that, when combined with the allergy reconciliation tool, may improve the quality of allergy documentation in the EHR.

One potential solution involves enhancement of the predefined list of coded allergens and reactions. The duplicate allergen reconciliation process revealed problems in the EHR system such as how it is was possible to add multiple allergens that referred to the same substance in patients' charts. Through reconciling these allergens and improving the back-end mapping, duplicate allergen entries can be prevented. It also has the added benefit of preventing health care members with less experience with brand and generic names from cluttering up the allergy list. In terms of reactions, our current EHR has a limited and static set of reactions that can be entered into the coded allergy field. Synonyms of reactions, such as 'Edema' for the coded reaction 'Swelling', or more specific reactions such as 'Lip Swelling', 'Facial Swelling' and 'Pharyngeal Swelling' are not searchable terms and this may lead to clinicians entering these more granular reactions as free-text. Expanding our coded reaction list and synonym lexicon is a potential solution for this issue, but consistent reconciliation is needed to ensure that CDS systems can maintain patient safety and provide clinically relevant information. [24, 25]

In regard to laboratory tests, a reconciliation module embedded in the EHR would be able to automatically locate and highlight needed test result information for clinician users. For instance, for latex, the combination of latex IgE >0.64 k/uL and history of a latex allergy places a patient at risk of potential anaphylaxis, and a k/uL > 0.35 without documentation a latex allergy warrants further investigation. [28,29] A reconciliation module can bring the latex IgE test results to the attention of providers, such that users can reconcile.

Likewise, an additional area for allergy list reconciliation pertains to drug-allergy alerts and associated clinician alert fatigue. Unreconciled and duplicated allergy entries lead to accumulation of entries over time; this results in unnecessary alerts when ordering those drugs in the future, which leads to clinician alert fatigue. Since inaccurate or outdated allergy entries are rarely edited or removed by clinicians, alerts are repeatedly fired and overridden. During the study period, we conducted analysis on the extent to allergy alert override orders and found that these unnecessary overrides, and the subsequent alert fatigue, can be addressed through various mechanisms, such as consolidating allergy entries and implementing alert tiering strategies.

One knowledge base modification involves tiering alerts into importance levels based on the reaction severity (high, medium, low) and type (immune-mediated or not), whether the alert is based on an exact match or a cross-sensitivity between the allergen and prescribed medication, and whether the alert was repeatedly overridden or tolerated in the past. Topaz et al. previously identified high allergy-alert overrides, with many of the triggering DAI alerts being non-clinically relevant (e.g., oxycodone triggering an alert to the allergy Morphine with the reaction Gastrointestinal [GI] Upset). [20,21] To reduce the alert-burden on physicians, the EHR knowledge base can be updated to exclude combinations of medications and allergens/reactions that can be silenced. This would require reconciliation of free-text reactions, so that an allergen with a coded reaction of 'GI Upset' and a free-text of 'Hives' is not silenced.

In addition, modifications to the EHR design could potentially make updating the allergy module more compatible with efficient workflow practices. As we demonstrated for penicillin allergy, the addition of allergies for which patients tested negative highlights issues inherent to maintaining up-to-date allergy information. The results of allergy challenge tests are found in two uncoded, free-text fields: allergy comment in the allergy list and clinical notes for the allergy test. Currently, there is no notification system when a provider re-enters an allergy that was tested for as negative. To improve the accuracy of algorithms for allergy test reconciliation, a coded field that contains information on the medication that was tested and the results in a uniform, structured manner is needed. It is important to have negative lab results and challenge tests documented in coded fields such that downstream systems can prevent duplicate testing and ADRs. Another modification to the EHR design involves presenting a pop-up after a provider discontinues a medication due to an ADR asking the provider if they want to add the medication to the patient's allergy list. The reconciliation of medications discontinued due to allergic response is useful to identify allergies that may need to be added to patients' charts, and facilitating allergy entry in the EHR's order screen is a potential solution to prevent discrepancies between the allergy module and medication order history. Manually returning to the

Table 3. Top 10 Allergens with Duplicate Allergens Entered in Patients Allergy Module

Ranking	Allergens with Duplicate Allergens Entered in Patient Allergy Module	Number of Patients with Duplicate Allergens				
		Total	2 Duplicates	3 Duplicates	4 Duplicates	5 Duplicates
1	SULFAMETHOXAZOLE-TRIMETHOPRIM	1119	1116	3	0	0
2	PROCHLORPERAZINE	1058	919	129	9	1
3	MEPERIDINE	993	953	40	0	0
4	OXYCODONE-ACETAMINOPHEN	791	790	1	0	0
5	NITROFURANTOIN	753	713	40	0	0
6	CEPHALEXIN	740	720	20	0	0
7	CIPROFLOXACIN	728	717	11	0	0
8	ERYTHROMYCIN	685	672	12	0	0
9	OXYCODONE	605	577	28	0	0
10	AMOXICILLIN-POT CLAVULANATE	583	582	1	0	0

allergy module to enter the allergen and reaction to patients' allergy list is incompatible with efficient workflow practices. Thus, this automated pop-up could ultimately improve the quality of documentation in the allergy module.

There were several relevant limitations to our approach. Firstly, these algorithms were developed at one large healthcare system located in the northeastern United States operating a commercial EHR that included allergens and reactions carried over from previous EHR systems. Likewise, although our study included a large cohort size, we only examined one year's worth of data. Furthermore, when examining medication allergy laboratory test results we only focussed on Latex IgE test results, and for the investigation of oral medication allergy challenge tests, we only focussed on penicillin challenge test orders. A more extensive examination of different test result types and various challenge test types may be further valuable.

Conclusions

Our study found that over 37% of patient's active allergy records indicated a need for reconciliation. Automated allergy reconciliation algorithms and tools embedded within the EHR are needed to help clinicians identify potential allergy information discrepancies from different EHR sections in order to improve the accuracy and completeness of patient allergy lists. Such efforts are likely to reduce the number of inappropriate and duplicate drug-allergy alerts and mitigate clinician alert fatigue

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