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Evaluating the Impact of Health IT on Medication Safety

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Abstract. Health IT is becoming an increasingly powerful tool for improving medication safety. While errors may happen at all stages of the medication process, different tools have been developed to support the prescribing process (e.g. computerized prescribing with decision support), the dispensing process (e.g. barcoding or automated dispensing and unit-dose systems), or the administration process (e.g. electronic medication administration records and smart pumps). Health IT can reduce medication error and preventable adverse drug event rates by increasing documentation quality and transparency, enhancing accuracy and correctness of the medication process, and supporting information exchange and interlinking different stages of the medication process. Typical evaluated endpoints comprise process-related outcomes such as number of medication errors, harm-related outcomes such as adverse drug events, or cost-related outcomes. Typical study design to measure effectiveness of health IT in medication safety comprises before-after studies and randomized controlled trials. However, implementation is challenging; it often has a major impact on the overall workflow and such technologies must be carefully introduced and their effects must be closely monitored in order to achieve the desired reductions, as in addition to preventing errors they nearly always introduce new ones. As complex interventions, their impact depends crucially on the real world setting and the implementation details and thus, transferability of study results is variable.

Keywords. Medication safety, medication error, computerized physician order entry, clinical decision support, complex intervention.

1. What is medication safety?

Medication safety can be defined as the attempt to safeguard the medication process ensuring that the risk for medication errors is minimized [1]. One definition of a medication error which has been widely used in research is that they are errors "in the process of ordering, dispensing, or administering a medication, regardless of whether an injury occurred or whether the potential for injury was present." [2].

Every sub-step of the medication process is error-prone and errors may happen at all stages, though they are much more common at some stages than others. Most errors do not result in patient harm because errors especially during early stages of the medication process can be caught and corrected (i.e. near misses) and even errors that reach the patient may not necessarily result in actual patient harm. While the risk of

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whether an error reaching a patient results in harm depends predominantly on the (dose-dependent) toxicity of a drug, evidence regarding which errors are likely to harm the patient is scarce.

Thus, medication safety describes a safety net of routine drug prescription and treatment, ideally in which well-trained personnel or responsible patients handle medical products which were designed to prevent faulty administration. To safeguard their actions, processes are optimized to minimize human errors, reduce information loss and anticipate future challenges in an intended treatment course.

However, today's routine drug treatment does not always meet these expectations, and therefore, errors arise and some of them result in harm. The risk of error at each sub-step depends on the complexity of the respective process and is therefore particularly high during the prescription process when the provider must consider the patient's history, his current clinical situation and the risk-benefit ratio of the intended treatment [3].

2. In what ways can health IT influence medication safety?

Health IT in the context of medication safety may support an individual sub-step of the medication process as well as their interlinkage (Figure 1).

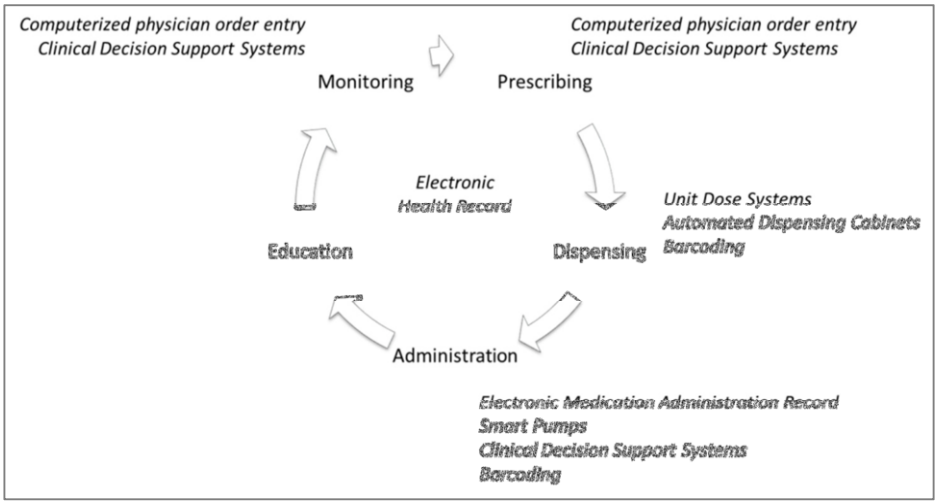

Figure 1. Display of health IT solutions along the medication process.

In general, health IT has the potential to (1) increase documentation quality and transparency including structure, standardization, readability and retrievability of information, (2) increase accuracy and correctness of clinical decisions or single tasks, and (3) improve information exchange and interlinkage of single sub-steps of the medication process.

2.1. Increase documentation quality and transparency

Compared to handwritten documentation, health IT can increase the process safety and documentation quality throughout the entire medication process. The most prominent examples of such health IT solutions are electronic prescribing systems (computerized physician order entry, CPOE). These systems offer the possibility to chart prescriptions and indicate dosage schemes. Thus, their benefit strongly depends on their design and usability. If the CPOE is basically a typing machine allowing free-text entries only, readability of orders will be increased in comparison to handwritten prescriptions, but prescriptions will not necessarily be more accurate. On the other hand, if the CPOE provides a catalogue referencing the prescribable drugs including their characteristics such as dosage forms and strengths etc., prescriptions can be more easily structured and prepared for basic plausibility checks, and if a default dose is suggested based on the patient's characteristics such as age and level of renal function that adds substantial additional benefit.

CPOE systems typically offer the possibility to pre-enter order templates or order sets, enabling standardization of prescriptions. There are a number of (national) recommendations for which functionalities CPOE systems should have [4-6]. Often CPOE systems are linked to a medication administration record (eMAR) which translates the provider's order into a request for administration. Thus, in the eMAR, nurses can seamlessly document whenever a drug was actually administered and thereby eliminate transcription errors [7].

2.2. Increase accuracy and correctness of the medication process

Health IT can increase accuracy and correctness of the medication process by redefining processes prone to human errors. For instance, during the drug distribution process in hospitals, drugs are typically ordered in the hospital pharmacy, packaged, sent to the ward, stocked on the ward and the dispensed to the patient. During each of those steps, confusions or look-alike errors may happen. The introduction of consequent barcoding [8] or automated dispensing [9] as well as unit-dose dispensing [10] can reduce these errors by automatizing the single steps and reducing interfaces.

In addition, many errors particularly during drug prescribing result from a lack of knowledge or information at the time of decision making. These errors are harder to address than for instance dispensing errors, because prescribing is typically the first step in the treatment process and not referring to executing a planned action. To reduce such errors, clinical decision support systems (CDSS) have been developed. Typically, CDSS are linked with CPOE and include a knowledge-base including the respective prescription-related information, an algorithm that links the prescription-related information with the actual information on the clinical context and the clinical case and a graphical user interface to display the resulting advice [11].

Depending on their scope, CDSS may support the selection (considering contraindications), the dosage (considering indication and patient characteristics) or the combination (considering drug-drug interactions) of drugs. CDSS can either lead providers in the correct direction, or redirect them using warnings. In contrast to health IT supporting the dispensing process, CDSS will only be effective if the provider considers the displayed information and changes his behavior. In many systems, as many as 95% of displayed warnings are neglected [12]. Thereby, the major challenges include the specificity of warnings and the integration in the workflow. Hence, we

know today that it is possible to refine the generation and display of warnings so that fewer are shown [13] and most are accepted [14]. Thus, while CDSS are clearly beneficial in certain systems and improve prescribing performance [15], they are insufficiently integrated in other systems and hence ignored, which leaves their actual impact on the overall healthcare marketplace unclear.

2.3. Increase information exchange and interlinkage of the medication process

A major challenge of medication safety is discontinuities in the medication process with changes of responsibilities, involved persons, and media. Thus, any health IT platform that enables seamless care might support medication safety. However, exchange of medication-related information is complex and can result in errors in dosage or route, for example. Many vendor applications do not routinely support reconciliation of medication lists from different electronic health records. Thus, a personal electronic health record supporting drug treatment throughout different health care sectors might be a way forward to seamless care.

A crucial prerequisite enhancing or limiting the effect of health IT is the fact how it is implemented into existing practice. Often, health IT influences existing workflows and forces the staff to potentially alter their routines. If the impact of health IT on existing workflows is not closely monitored and encountered difficulties solved this can both lead to workarounds (i.e. sometimes the health IT is not even used and hence cannot positively influence processes of care) or – which is even worse – can cause new iatrogenic errors, i.e. new errors that are actually caused by the health IT solution [17]. It is thus essential to prepare the implementation of health IT by depicting the existing workflows, assessing the potential influence of the planned health IT intervention and potentially adopting both existing workflows or the health IT solution before putting them together. It is also critical to monitor after the introduction of health IT for new errors, and to make changes that reduce their likelihood.

3. What are typical outcomes to measure effectiveness of health IT in medication safety?

Medication safety can be measured using several approaches, depending on the stakeholder's perspective. Typically, the most frequent approach is to assess process-related outcomes including the number of medication errors that occur. However, process-related outcomes are only a proxy for actual quality in care and indeed, not every medication error translate into actual patient harm. Hence, the rate of preventable adverse drug events or a number of higher level outcomes also assessing patient harm including (re)hospitalization and mortality can be used as measure for medication safety. Further approaches include impact on patient-related endpoints such as quality of life and patient satisfaction with care as well as cost-related endpoints that combine both savings resulting from prevented adverse events and spending on measures to improve medication safety.

Typically, the most preliminary endpoints applied for the assessment of health IT are those directly related to the purpose of the respective solution. For instance, if a clinical decision support system is designed to support the choice of a specific antibiotic treatment in the emergency department, the ratio of correctly chosen antibiotics before and after implementation could be assessed. However, these highly

specific outcome measures are of limited usefulness for comparison and to overall judge the benefit of any health IT solution. Hence, general outcome measures are applied and discussed in more detail:

3.1 Process-related outcomes

Medication errors are the most commonly used outcomes used to assess the effectiveness of health IT. The number of overall medication errors as well as of predefined subgroups (e.g. drug prescribing errors, or drug dosing errors) is generally assessed, typically as a ratio that gives some sense of overall potential for errors, i.e. for example patient-days or the overall number of drug prescriptions. The definitions used for medication errors in different studies vary [16], making it difficult to compare study results when studies use different definitions. Nevertheless, the impact on the medication error rate has been assessed for the majority of health IT solutions for medication safety [18].

3.2. Harm-related outcomes

Harm-related outcomes are frequently applied to estimate the potential benefit of medication safety strategies. Adverse drug events have been defined as "an injury resulting from medical intervention related to a drug" [19]. Thereby, a fraction of adverse drug events results from medication errors and is thus classified as preventable whereas inherited risks with a certain drug are classified as non-preventable adverse drug events Only a minority of medication errors actually cause adverse drug events, with one estimate being one in 10 medication errors. [20]

More distal harm-related outcomes include (re)hospitalization and mortality, however, only a few studies have actually evaluated impact of health IT on these higher level outcomes and results are inconsistent [21]. Moreover, when assessing these higher level outcomes, it becomes more and more difficult to assess the influence of health IT, probably both because the events are infrequent and the health IT solution is just one intervention amongst many other influencing factors in a complex setting.

3.3. Cost-related outcomes

Cost-related outcomes include assessing the costs of adverse drug events, cost-minimization, cost-utility, cost-benefit and cost-effectiveness analysis.[2] Such assessments have been done for a minority of health IT solutions. However, for example, bar-coding in the pharmacy appears highly cost-effective [22]. Cost-effectiveness of CPOE potentially is modulated by the fact whether it is linked to a CDSS or not [23], and moreover, even if CPOE and CDSS might prevent adverse drug events and medication errors, hospitals might need to invest for this improvement of medication safety [24]. Since many health IT solutions are complex interventions that are implemented over a longer period of time and that might affect the medication process in several ways cost-related assessments remain challenging.

[2] See also: D. Luzi et al., Economic evaluation of health IT, in: E. Ammenwerth, M. Rigby (eds.), Evidence-Based Health Informatics, Stud Health Technol Inform 222, IOS Press, Amsterdam, 2016.

4. What are typical study designs to measure effectiveness of health IT in medication safety?

The assessment of effectiveness of health IT on medication safety generally falls into the category of quality improvement studies, so that study planning and reporting should consider the SQUIRE guidelines [25]. Typically quality improvement studies comprise complex interventions and therefore, meticulous descriptions of the setting, the intervention and the implementation are required to ensure a high study quality.[3] This approach takes into account the fact that the medication process often is highly tailored in a specific setting which affects the generalizability of the results. Indeed, the success of a distinct quality improvement strategy is difficult to predict [26] and a quality improvement strategy proven successful in one setting might fail in another. The following section presents two typical study designs to measure effectiveness of health IT in medication safety.

4.1. Before-after designs

Given the uniqueness of a specific care setting and because many health IT interventions affect the medication process of an entire care setting, many studies are performed with a before-after design in the respective setting. This has the advantage of allowing the setting to serve as a control for itself, and the disadvantage that it is hard to assess the impact of other temporal considerations.

In a before-after study, baseline assessment is followed by an implementation period and a follow-up phase. Typically, data from the baseline assessment are then compared with the follow-up phase, however, there is no standardized rule on what the time span should be between baseline assessment and follow-up phase. Since the majority of health IT interventions also affect the processes and process changes are typically not easily implemented, the full benefit of the health IT intervention often becomes obvious only after a certain period of time. Indeed, immediately after implementation the risk of errors might even be higher, so that it is common to exclude that period, and only to conduct the "post" evaluation after stabilization in order to assess a net effect. However, particularly the phase during or immediately after implementation is crucial to assess the potential risk of health IT and its potency to introduce iatrogenic errors into the care process (on the risks of health IT, compare.[4]

While before-after designs allow for a very detailed look at a specific health IT intervention in a specific setting, the transferability of study results may be limited. Part of this restriction can be mitigated by the thorough description of the implementation and the intervention, however, the quality of healthcare over time might always be affected by other factors of influence than the implemented intervention.

4.2. (Randomized) controlled designs

To account for time effects and overall changes in a respective setting, (randomized) controlled designs can also be applied.[3] Typically, the level on which the study is

[3] See also: C.R. Weir, Ensuring the quality of evidence: Using the best design to answer health IT questions, in: E. Ammenwerth, M. Rigby (eds.), Evidence-Based Health Informatics, Stud Health Technol Inform 222, IOS Press, Amsterdam, 2016.

[4] See also: F. Magrabi et al., Health IT for patient safety and improving the safety of health IT, in: ibid.

controlled depends on the level of the intervention. For instance, if a CPOE is introduced in an intensive care unit, a suitable control would be another similar intensive care unit. However, whether this control unit is an appropriate control depends on whether the two wards are indeed comparable with regard to baseline error rate, case mix and other factors. Hence, even in a controlled design, typically a baseline assessment is performed. In case of randomization, this baseline assessment can be used for a stratified randomization.

If the health IT intervention does not affect the overall medication process but rather supports a distinct sub-step (e.g. smart pumps or CDSS), randomization can also be performed on the individual patient level, however, in these cases, carry over effects are frequent, and typically cluster randomization is preferred.

5. What are pitfalls of today's methods to evaluate the impact of health IT on medication safety and how can they be overcome?

5.1. Real world settings

A major pitfall of today's methods to evaluate the impact of health IT on medication safety is the fact that most studies are typically performed in routine care, and hence processes are often not standardized. Indeed, the implementation of health IT often provokes the standardization and redesign of routine medication processes and hence it is not possible to separate the benefit of the health IT intervention from the additional benefits from the redesign of the medication process.

Moreover, health IT interventions are designed to support or improve a specific medication process and hence interventions might be deliberately adapted to a specific setting. While this approach might limit the comparability of several implementations of a distinct intervention [27], it will likely increase the success for a specific setting – which is, after all, the first and most urgent aim of the implementing institution. Indeed, the adaption rather than the unmodified adoption of interventions is a core element of quality improvement strategies. To account for resulting differences, the SQUIRE guidelines recommend describing in detail which adaptions were performed and for what reason.

5.2. Limited implementation details

In the past, most studies on health IT interventions often lacked implementation details, and for instance report on a "CDSS" that was introduced in an "intensive care unit" warning against potential "drug interactions". Any result reported on the potential benefit of such system depends on how the CDSS is designed, what alerts it contained, how it was integrated into the routine care, when and how the alerts were displayed, how the provider was encouraged to interact with the system, etc. The simple description that such a system reduced the number of drug-drug interactions by half is hard to interpret, because it remains unclear how these results might apply to a different CDSS, a different drug-drug interaction database or a different setting and how reproducable they might be.

5.3. Limited comparability of studies

Indeed, the most common sentence in today's reviews trying to gather information on health IT intervention is probably the limited comparability of studies making meta-analysis difficult.[5] However, to assess the impact of health IT on major endpoints such as hospitalization and mortality it will be essential to have larger datasets. One positive is that it is becoming increasingly easy to extract large quantities of data from electronic health records, and also to organize and share clinical decision support enabling very large implementations, so that it is likely to be possible to assess the impact of certain rule sets, for example, at scales that have not previously been possible.

One development which could be helpful would be to develop an adaptation of SQUIRE guidelines for specific health IT interventions, including some suggestions about which details on the health IT intervention or their implementation should be reported in order to allow for accounting for these details in meta-analysis. It will also be helpful to perform large-scale analyses across populations to get better assessment of the net impact of medication safety-related interventions on populations.

6. Case study

One early study which was a landmark in medication safety was a study that evaluated the impact of computerized physician order entry linked with clinical decision support on the serious medication error rate in two academic hospitals [15]. Units were divided into intervention and control and matched by patient type.

Key results were that the serious medication error rate fell by 55% in the intervention units, and that the decline occurred for all stages of the medication process. The preventable adverse drug event rate also fell 17%, but that decrease was not statistically significant. A team intervention was also evaluated, but that conferred no additional benefit over CPOE.

The generalizability of these results was uncertain, because the study was conducted in only two hospitals using an internally developed system, but many other studies have subsequently confirmed that the medication error rate falls with computerization of prescribing in the inpatient setting [28]. These results helped justify implementation of the HITECH Act in the U.S., which provided approximately $30 billion in financial incentives to providers and hospitals which adopt health information technology and has resulted in broad adoption of electronic health records in both the inpatient and outpatient settings in the U.S. [29].

7. Conclusions

Health IT has now been shown to improve medication safety in a number of ways. It can have an impact at all major stages of the medication process in the hospital setting

[5] See also: C. Urquhart et al., Systematic reviews and meta-analysis of health IT, in: E. Ammenwerth, M. Rigby (eds.), Evidence-Based Health Informatics, Stud Health Technol Inform 222, IOS Press, Amsterdam, 2016.

that are known to be error prone: prescribing – by structuring prescriptions and checking them for errors, dispensing – through bar-coding and automation of dispensing, and administration – through electronic medication administration records and smart pumps. The evidence for benefit is stronger for some of these stages than for others. Most studies have used process-related outcomes such as medication error rates, but some use harm-related outcomes such as adverse drug events, and a few studies have evaluated costs. The most frequent types of study design are before-after studies and randomized controlled trials. Implementation has a major effect on whether or not any particular intervention will be successful or not, and transferability has been variable. Any intervention can introduce or create new problems, and organizations as well as evaluators health IT should track these and attempt to minimize them.

Recommended further readings

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3. *SQUIRE Guidelines*, http://www.squire-statement.org. Last access: 11.2.2016.
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Food for thought

1. What health IT interventions do you think would most improve medication safety in your setting?
2. If you were designing a study to assess this health IT intervention, what design would you use?
3. What are the biggest risks related to medication safety in the main setting that you work in?

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