Journal of Biomedical Informatics 73 (2017) 62–75

Contents lists available at ScienceDirect

Journal of Biomedical Informatics

journal homepage: www.elsevier.com/locate/yjbin

Special Communication

Development and classification of a robust inventory of near real-time outcome measurements for assessing information technology interventions in health care

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ARTICLE INFO

Article history:
Received 28 January 2017
Revised 8 July 2017
Accepted 23 July 2017
Available online 25 July 2017

Keywords:
Electronic health records
Medical informatics applications
Outcome assessment

ABSTRACT

Objective: To develop and classify an inventory of near real-time outcome measures for assessing information technology (IT) interventions in health care and assess their relevance as perceived by experts in the field.

Materials and methods: To verify the robustness and coverage of a previously published inventory of measures and taxonomy, we conducted semi-structured interviews with clinical and administrative leaders from a large care delivery system to collect suggestions of outcome measures that can be calculated with data available in electronic format for near real-time monitoring of EHR implementations. We combined these measures with the most commonly reported in the literature. We then conducted two online surveys with subject-matter experts to collect their perceptions of the relevance of the measures, and identify other potentially relevant measures.

Results: With input from experienced health care leaders and informaticists, we developed an inventory of 102 outcome measures. These measures were classified into a taxonomy of commonly used measures around the categories of quality, productivity, and safety. Safety measures were rated as most relevant by subject-matter experts, especially those measuring medication processes. Clinician satisfaction and measures assessing mean time to complete tasks and time spent on electronic documentation were also rated as highly relevant.

Discussion: By expanding the coverage of our previously published inventory and taxonomy, we expect to help providers, health IT vendors and researchers to more effectively and consistently monitor the impact of EHR implementations in near real-time, and report more standardized outcomes in future studies. We identified several measures not commonly assessed by previous studies of IT implementations, especially those of safety and productivity, which deserve more attention from the broader informatics community.

Conclusion: Our inventory of measures and taxonomy will help researchers identify gaps in their measurement approaches and report more standardized measurements of IT interventions that could be shared among researchers, hopefully facilitating comparison across future studies and increasing our understanding of the impact of IT interventions in health care.

1. Background and significance

Positive outcomes associated with Electronic Health Record (EHR) systems adoption in both ambulatory and non-ambulatory settings [1–8], and financial incentives provided by the Centers for Medicare and Medicaid (CMS) Meaningful Use program, contributed to unprecedented EHR adoption in the U.S. [9]. In 2009, EHR adoption among office-based physicians was estimated to be 48% [10]; after implementation of Meaningful Use Stage 1, studies of the same population demonstrated that adoption had increased to 72% [11]. The observed changes in adoption and use of EHR systems have also contributed to an increasing number of studies assessing the impact on clinical practice of health information technology (health IT) adoption. Several studies evaluating the

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http://dx.doi.org/10.1016/j.jbi.2017.07.014

impact of such interventions have been published in the last decades, and were discussed by a sequence of recent systematic reviews [12–15]. In one of the reviews, Buntin et al. [14] identified that studies at settings that implemented EHRs containing more functionality required by the Meaningful Use criteria, observed more positive findings as compared to those with less functionality. In another recent study commissioned by the Office of the National Coordinator for Health IT (ONC), Jones et al. [15] concluded that most studies evaluating health IT adoption projects report positive outcomes. However, despite the increasing number of positive findings, Jones et al. concluded that the results of current research are still mixed, failing to increase our understanding of the effectiveness of IT interventions in health care settings. According to their analysis, more information and evidence are necessary to understand why some organizations thrive, while others struggle when adopting health IT tools. Possible contributing factors to these gaps include insufficient information describing the implementation settings, implementation strategy and EHR capabilities, and inconsistent sets of outcome measurements [15]. In a first attempt to fill these gaps, we identified the outcome measures most commonly reported in the studies reviewed by Jones et al. and developed a taxonomy of measurements. We also identified characteristics of implementation settings and IT interventions reported in those studies [16].

In the present study, we assess if the measures identified in our previous study provide a comprehensive coverage of clinical and administrative processes by interviewing leadership from a large care delivery system implementing a commercial EHR. We identify other measures not commonly reported in the literature. We then combine the new suggested measures with those identified in our previous study, collect subject-matter experts' perceptions of the relevance of these measures, and obtain suggestions for additional measures. We also update our previously published taxonomy with the resulting measures to create an enhanced inventory. Finally, we compare the measures in our inventory to those included in reporting systems commonly required by policy makers and government agencies to assess the potential availability of data required to calculate these measures. We expect that the resulting inventory and taxonomy will help researchers select measures in future studies and identify gaps in their measurement approaches, hopefully facilitating comparison of health IT outcomes across future studies and enabling improved understanding of the impact of IT interventions in health care.

2. Materials and methods

In our previous study [16] we identified the 79 most common measures, reported in the literature, to assess the impact of health IT interventions. Since frequency of use does not necessarily assure usefulness of measure, we followed a multi-method and iterative approach to determine whether those measures provide a comprehensive coverage of clinical and administrative processes that can be impacted by the implementation of a new EHR system. The components of the method include: (1) conduct interviews with clinical and administrative leaders from a large care delivery system implementing a commercial EHR; (2) combine the newly suggested measures with those reported earlier [16] in the literature, to produce an enhanced inventory of measures; (3) collect subject-matter experts' perceptions of the relevance of the combined inventory of measures and identify additional measures suggested by these experts; (4) update our previously published taxonomy with the larger measure inventory; and (5) compare the measures in our inventory to those included in reporting systems commonly required by policy makers and government. These steps are described in detail in the subsequent sections. Fig. 1 illustrates the multi-method approach.

2.1. Step 1 – semi-structured interviews with Intermountain Healthcare leadership

We conducted semi-structured interviews with clinical and administrative leaders at Intermountain Healthcare, a not-for-profit integrated care delivery system of 22 hospitals and over 185 ambulatory care clinics covering the entire state of Utah and southern Idaho. Intermountain is conducting a large commercial EHR implementation, replacing a group of legacy systems developed and operated by Intermountain for several decades [17,18]. The aim of our interviews was to identify measures used to evaluate the impact of this transition to Intermountain's clinical and administrative processes supported by electronic data collected or impacted by their EHR systems. We first selected a convenience sample of interviewees from the Medical Informatics Department, representing eight clinical areas: Behavioral Health, Cardiovascular, Intensive Medicine, Oncology, Pediatrics, Primary Care, Surgical Services, and Women and Newborn. Given the size and complexity of the Intermountain care delivery system, we used snowball sampling [19] to obtain referrals to other potential interviewees. We asked each informant representing the clinical areas above for referrals to other personnel from the same clinical areas, or areas that work in conjunction with them. Interviews were conducted until we had interviewed at least two representatives of each clinical area and/or had no more referrals. In addition to the initial eight clinical areas, we also asked for referrals to employees from other departments such as human resources, risk management, pharmacy, implementation teams, or other departments considered relevant by the interviewees. Interviews were conducted in person or by phone according to the convenience of participants. Interviewees were asked to suggest outcome measures they consider relevant and would recommend to be tracked for monitoring the impact of the EHR implementation over time, and to classify their suggestions into the categories *quality of care*, *productivity* and *patient safety*, according to their use at Intermountain or interviewee's expertise. We considered only measures that can be calculated with data available in electronic format in order to detect the impact of the implementation in near real-time. The complete list of questions can be found in the online supplement.

2.2. Step 2 – development of a compiled inventory of outcome measures

We compared and combined the measures suggested by Intermountain interviewees with the measures reported before [16] as the most commonly used in the literature. This comparison resulted in an expanded inventory of outcome measures.

2.3. Step 3 – online surveys with subject-matter experts

Since the measures in our list include suggestions from leaders of a single care delivery system, we designed two online surveys to collect perceptions of subject-matter experts from around the country. One survey contained measures used in ambulatory settings, and the other included measures used in non-ambulatory settings. The surveys have three parts: Section 1: Respondent information (required); Section 2: Questions about the relevance of proposed outcome measures (required); and Section 3: Open-ended question for suggestions of additional measures (optional). In the questionnaire, a short description of each measure was provided. The measures were grouped by the categories *quality of care*, *productivity*, and *patient safety* according to their classification in our previous study [16] or as suggested by Intermountain interviewees. Respondents were asked to provide their perceptions about the relevance of each proposed measure when used for assessing the impact of EHR implementations in the target setting

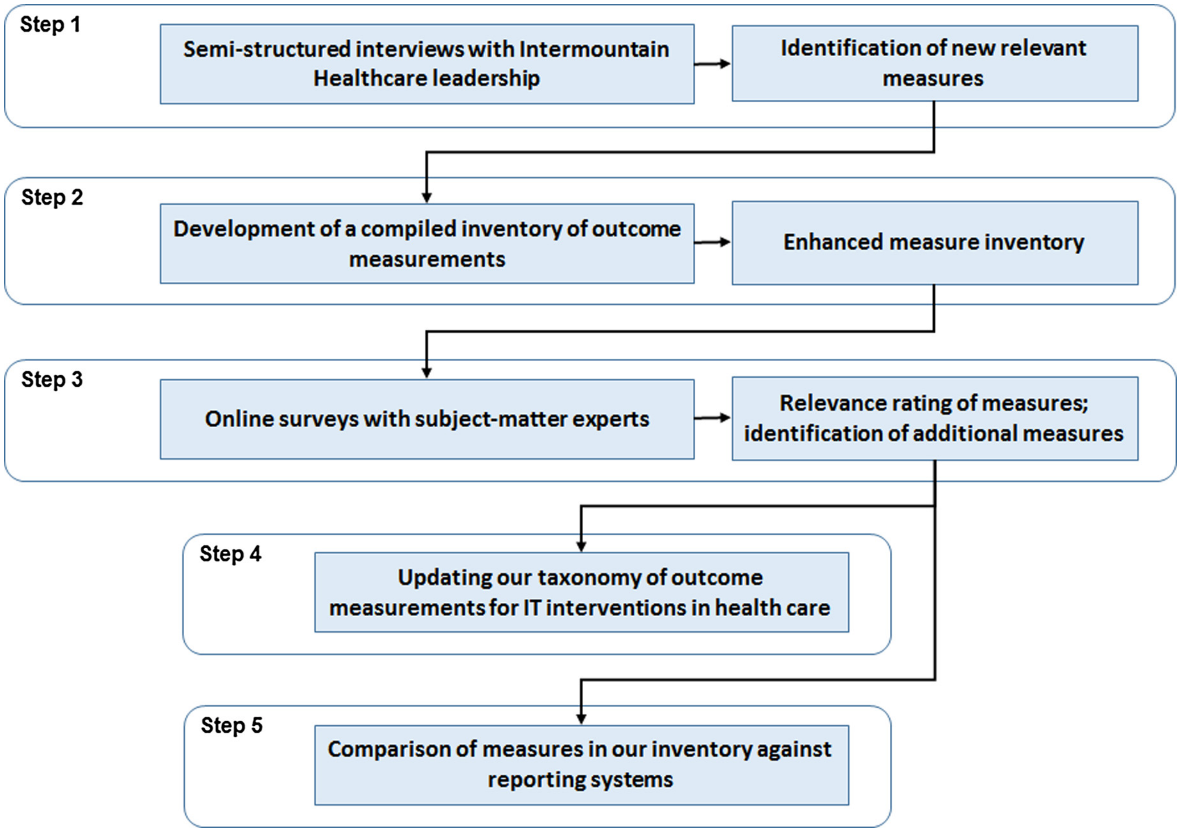

Fig. 1. Flowchart illustrating the multi-method approach.

(ambulatory vs. non-ambulatory) using a 7-point Likert scale, with options ranging from "very low relevance" (1) to "very high relevance" (7). To further clarify the concept of relevance, we provided the following example to respondents: "*The implementation of a new EHR system may introduce changes to the workflow of computerized provider order entry, therefore, it may be relevant to measure the 'volume of medical orders entered electronically' for tracking the impact of the new EHR in such a process*". Note: an option "I do not know" was provided in case interviewees were not familiar with specific outcomes. The questions of each survey can be found in the online supplement.

One of the authors (TKC) reviewed the answers to the open-ended question to identify suggestions for new measures; measures suggested by two or more respondents were selected for inclusion in our inventory. We collected survey data using REDCap electronic data capture tools hosted at Intermountain Healthcare [20]. We invited four independent researchers from the University of Utah Department of Biomedical Informatics and the Salt Lake City Veterans Affairs (VA) Medical Center to pilot the surveys. We iteratively gathered suggestions and updated the instruments before inviting the subject-matter experts to complete the surveys.

Respondents were eligible to participate if they had any prior experience conducting EHR implementations in health care settings or evaluating EHR implementations from a research standpoint. We used several methods to recruit study participants: (1) we sent invitations to the members of the American Medical Informatics Association (AMIA) Implementation Forum, and to the Healthcare Information and Management Systems Society (HIMSS) Nursing Informatics Alliance; (2) we invited authors of four systematic reviews assessing health IT adoption studies: Chaudhry et al. [12], Goldzweig et al. [13], Buntin et al. [14] and Jones et al. [15]; and (3) we invited primary faculty from several U.S. biomedical informatics programs listed on the AMIA website [21]. For the faculty invitations, we screened biographical information to identify potential participants with research interest in health IT adoption or Electronic Health Record systems, and contacted those whose contact information was available online.

Each invitee who demonstrated interest in participating was asked to indicate his/her preference of type of setting (ambulatory vs. non-ambulatory); if no preference was stated, the participant was included in the survey with fewer respondents at the time of invitation. We also asked all participants to suggest other experts to increase sample size.

2.4. Step 4 – updating our taxonomy of outcome measurements for IT interventions in health care

We have previously developed a taxonomy of outcome measurements for assessing IT interventions in health care. Our methodology was described in detail in our previous study [16]. One of the authors (TKC) first classified the new measures identified through the semi-structured interviews and online surveys into the previously published taxonomy, and identified the new taxa that had to be developed to accommodate measures not detected by our previous study [16]. As in our previous study, we used a modified Delphi process in which the first version of the classification of measures and the updated taxonomy were shared with the study co-authors, who then provided suggestions iteratively until consensus about measures' classification and nomenclature was reached.

2.5. Step 5 – comparison of measures in our inventory against reporting systems

In our previous study [16], we compared measures classified as quality of care or patient safety against performance measures included in widely used reporting systems. In the present study, we conduct the same examination for all measures in our inventory classified as quality of care or patient safety. For ambulatory settings, we used the 2016 version of the Healthcare Effectiveness Data and Information Set (HEDIS) [22]; for non-ambulatory settings, we used the CMS Hospital Compare measures data archive dated May 4, 2016 [23].

2.6. Data analysis

Each category (quality of care, productivity, patient safety) was composed of multiple individual items, each with an identical 7-point Likert scale. The items within each category were evaluated for internal consistency using Cronbach's alpha [24]. Having determined their internal consistency, the items composing each category were then combined into a composite score by taking their arithmetic average. This resulted in a composite score that remained in the 7-point scoring scheme, making the three categories comparable. Furthermore, since data were to be analyzed in a paired sample fashion, with respondents being compared to themselves across the three categories, such an approach insured that the composite scores of the three categories had a greater common underlying metric. Thus, differences of means among the three categories can be reliably interpreted as differences in relevance to the survey respondents. Two categories were compared at a time using a paired sample *t*-test. The reported p-values are adjusted for three multiple comparisons using Hommel's multiple comparison procedure [25]. All steps above were performed separately for ambulatory and non-ambulatory settings. Data analysis was performed using Stata version 13 statistical software [College Station, TX: StataCorp LP].

3. Results

Thirty clinical and administrative leaders from Intermountain Healthcare were interviewed (Step 1) and suggested additional measures that were combined with those extracted from our previous study [16], producing an enhanced inventory of outcome measures (Step 2). One-hundred twelve experts participated in the online surveys (Step 3), rating the relevance of the measures in our inventory and providing suggestions of additional measures. By assessing the measures suggested by interviewees and subject-matter experts, we identified seven new taxa that were added to our taxonomy (Step 4), and compared the measures in our final inventory against those required by HEDIS and Hospital Compare (Step 5).

3.1. Step 1 – semi-structured interviews with intermountain healthcare leadership

From the original sample of eight Intermountain Healthcare Informatics professionals, we collected referrals to other leaders within Intermountain's care delivery system and conducted 30 semi-structured interviews. Interviewees included leaders with an average of 16.3 years of experience with EHR systems and an average of 19.5 years of experience in their current field. They represent a wide range of clinical and administrative departments, and have mostly high-level positions at Intermountain Healthcare. Table 1 of the online supplement summarizes interviewees' characteristics.

Overall, we identified 63 outcome measures in the categories of quality of care, productivity and patient safety, measuring outcomes of ambulatory (15 measures) and non-ambulatory settings (48 measures). From the 15 measures suggested for ambulatory settings, 5 (33%) were among the most commonly reported measures in the literature [16]; from the 48 measures for non-ambulatory settings, only 7 (15%) were among the measures identified in our previous study.

3.2. Step 2 – development of a compiled inventory of outcome measures

The resulting inventory combining interviewees' suggested measures and measures from the literature contained a total of 91 measures; out of these 37 were quality of care measures (Appendices A and B), 34 were productivity measures (Appendices C and D), and 20 were safety measures (Appendices E and F).

3.3. Step 3 – online surveys with subject-matter experts

The online surveys included the 91 measures from Step 2. Surveys were open from July 7, 2016, to November 1, 2016. Forty-five experts participated in the ambulatory survey and 67 in the non-ambulatory. Since invitations were sent to membership-based lists such as the AMIA Implementation Forum and HIMSS Nursing Informatics Alliance, we were not able to identify the exact number of people who received/read the invitations; therefore, we were not able to calculate the exact response rate. Respondents of the ambulatory survey had on average 15.8 years of experience with EHR systems, and respondents of the non-ambulatory survey had 14.1 years of experience. Table 2 of the online supplement summarizes survey participants' characteristics.

3.3.1. Step 3 – internal consistency and comparison of ratings among measure categories

Internal consistency coefficients ranged from 0.86 to 0.96 for different measure categories. For the ambulatory survey, internal consistency was 0.93 for quality of care measures, 0.87 for productivity measures, and 0.86 for safety measures. For the non-ambulatory survey, internal consistency was 0.96 for quality of care measures, 0.95 for productivity measures and 0.95 for safety measures.

Safety was the most relevant category of measurements, with average scores significantly higher than quality of care in both ambulatory (safety = 5.94 vs. quality = 5.16; p = 0.001) and non-ambulatory (safety = 5.63 vs. quality = 5.17; p = 0.001) settings, and productivity in both ambulatory (safety = 5.94 vs. productivity = 4.59; p = 0.001) and non-ambulatory (safety = 5.63 vs. productivity = 4.85; p = 0.001) settings. Quality of care was the second most relevant category of measurements with higher average scores than productivity in both ambulatory (quality = 5.16 vs. productivity = 4.59; *p* = 0.004) and non-ambulatory (quality = 5.17 vs. productivity = 4.85; p = 0.003) settings.

3.3.2. Step 3 – relevance of quality of care measures

The ambulatory survey included 15 measures of quality of care with relevance ratings ranging from 4.24 to 5.73, and the non-ambulatory survey included 22 measures with relevance ratings ranging from 4.13 to 6.07. The measures rated as most relevant for ambulatory settings were "pneumococcal immunization documented" (mean = 5.73, SD [1.38]); followed by "breast cancer screening" (mean = 5.55, SD [1.32]); "colorectal cancer screening" (mean = 5.53, SD [1.45]); "hemoglobin A1c control" (mean = 5.40, SD [1.54]); and "diabetes bundle" (mean = 5.38, SD [1.48]). All top five relevant measures are among the most commonly reported in the literature.

The measures rated as most relevant for non-ambulatory settings were "clinician satisfaction" (mean = 6.07, SD [1.14]); followed by "venous thromboembolism (VTE) prophylaxis compliance" (mean = 5.88, SD [1.30]); "appropriate use of antibiotics" (mean = 5.88, SD [0.92]); "sepsis bundle" (mean = 5.81, SD [1.48]); and "sepsis mortality" (mean = 5.68, SD [1.71]). Three of

Table 1
Top relevant measures of quality of care.

Source	Taxa	Measure	Description	HEDIS/HC Equivalent	Relevance M (SD)	Do not know, (%)
Ambulatory – quality of care measures						
Literature	2	Pneumococcal immunization documented	Evidence of pneumococcal immunization documented in patient's electronic health records	Childhood Immunization Status Pneumococcal Vaccination Status for older adults	5.73 (1.38)	–
Literature	1	Breast cancer screening	Breast cancer screening ordered as preventive care in target patients	Breast Cancer Screening	5.55 (1.32)	–
Literature	1	Colorectal cancer screening	Colorectal cancer screening ordered as preventive care in target patients	Colorectal Cancer Screening	5.53 (1.45)	–
Literature	5	Hemoglobin A1c control	Rate of diabetes patients with hemoglobin A1c under control	Comprehensive Diabetes Care	5.40 (1.54)	–
Literature/IH	7	Diabetes Bundle	Composite measure for diabetes control	Comprehensive Diabetes Care	5.38 (1.48)	2%
Non-ambulatory – quality of care measures						
Literature	10	Clinician Satisfaction	Clinicians' satisfaction as end-user of a new or updated Health IT system	Not included	6.07 (1.14)	–
Literature/IH	3	VTE prophylaxis compliance	Rate of orders of prophylaxis for venous thromboembolism in compliance with guidelines	SCIP-VTE-2; VTE-1; VTE-2; PSI-12	5.88 (1.30)	–
Literature	3	Appropriate use of antibiotics	Orders of antibiotic drugs in compliance with guidelines	PN-6; SCIP-Inf-1; SCIP-Inf-2; SCIP-Inf-3	5.88 (0.92)	–
IH	7	Sepsis bundle	Composite measure for sepsis care measured as compliance to all composite items	Not included	5.81 (1.48)	1%
IH	4	Sepsis mortality rate	Rate of patients who died during hospitalization due to severe sepsis or septic shock	Not included	5.68 (1.71)	–

Abbreviations: IH: Intermountain Healthcare; HC: Hospital Compare.
Note: Measures are sorted by descending order of relevance.

the top 5 relevant measures are among the most commonly reported in the literature and two were suggested by Intermountain leaders. Table 1 presents the top 5 relevant quality of care measures from each survey. Appendices A and B summarize the complete list of quality of care measures.

3.3.3. Step 3 – relevance of productivity measures

The ambulatory survey included 11 productivity measures with relevance ratings ranging from 3.14 to 5.51, and the non-ambulatory survey included 23 measures with relevance ratings ranging from 3.17 to 5.92. The measures rated as most relevant for ambulatory settings were "time to provider" (mean = 5.51, SD [1.57]); followed by "patient visits" (mean = 5.04, SD [1.95]); "laboratory orders" (mean = 4.95, SD [1.82]); "net collection ratio" (mean = 4.95, SD [1.81]); and "medication orders" (mean = 4.75, SD [1.84]).

The measures rated as most relevant for non-ambulatory settings were "time spent by nurse documenting" (mean = 5.92, SD [1.47]); followed by "radiology orders" (mean = 5.40, SD [1.16]); "antibiotic turnaround time" (mean = 5.34, SD [1.29]); "ED wait time" (mean = 5.34, SD [1.61]); and "ED length of stay" (mean = 5.29, SD [1.74]). Table 2 presents the top five relevant measures from each survey. Appendices C and D summarize the complete list of productivity measures.

3.3.4. Step 3 – relevance of patient safety measures

Only two measures of patient safety were rated by the expert panel in the ambulatory survey. The two safety measures were "medication errors" (mean = 5.95, SD [1.29]) and "adverse drug events (ADEs) rate" (mean = 5.93, SD [1.35]). Both measures are among the most commonly reported in the literature.

The non-ambulatory survey included 18 measures of patient safety with relevance ratings ranging from 4.39 to 6.22. The measures rated as most relevant for non-ambulatory settings were "ADEs rate" (mean = 6.22, SD [1.11]); followed by "medication errors" (mean = 6.19, SD [1.04]); "bar-code medication

Table 2
Top relevant measures of productivity.

Source	Taxa	Measure	Description	Relevance, M (SD)	Do not Know, (%)
Ambulatory – productivity measures					
IH	18	Time to provider	Mean time between patient check-in and patient visit initiated	5.51 (1.57)	–
Literature/IH	14	Patient visits	Number of patient visits to ambulatory settings	5.04 (1.95)	–
Literature	15	Laboratory orders	Number of orders of laboratory tests	4.95 (1.82)	–
IH	16	Net collection ratio	Proportion of the amount of money received from payers in relation to the amount planned	4.95 (1.81)	4%
Literature	15	Medication orders	Number of medication orders	4.75 (1.84)	–
Non-ambulatory – productivity measures					
IH	18	Time spent by nurse documenting	Mean time spent by nurse documenting on electronic health records in the ICU	5.92 (1.47)	1%
IH	15	Radiology orders	Number of orders of imaging tests	5.40 (1.16)	–
IH	18	Antibiotic turnaround time	Mean time between antibiotic order and administration in newborn patients	5.34 (1.29)	6%
IH	18	ED wait time	Mean time between patient arrival and seen by provider in emergency departments	5.34 (1.61)	1%
Literature/IH	14	ED LOS	Length of stay of patients in emergency departments	5.29 (1.74)	–

Abbreviations: IH: Intermountain Healthcare.
Note: Measures are sorted by descending order of relevance.

Table 3
Top relevant measures of safety.

Source	Taxa	Measure	Description	HEDIS/HC Equivalent	Relevance, M (SD)	Do not know, (%)
Ambulatory – patient safety measures						
Literature	20	Medication errors	Medication errors of any source	Not included	5.95 (1.29)	–
Literature/ IH	20	ADEs rate	Rate of adverse drug events	Not included	5.93 (1.35)	–
Non-ambulatory – patient safety measures						
Literature	20	ADEs rate	Rate of adverse drug events	Not included	6.22 (1.11)	–
Literature	20	Medication errors	Medication errors of any source	Not included	6.19 (1.04)	–
IH	20	BCMA override rate	Rate of bar-coded medication administration override	Not included	6.19 (1.23)	–
Literature	20	Medication orders changed	Rate of medication orders changed following clinical decision support recommendation	Not included	6.13 (1.17)	–
IH	20	Missed home medication	Rate of medication errors caused by missing a medication during medication reconciliation	Not included	6.10 (1.10)	–

Abbreviations: IH: Intermountain Healthcare; HC: Hospital Compare.
Note: Measures are sorted by descending order of relevance.

administration (BCMA) override rate" (mean = 6.19, SD [1.23]); "medication orders changed" (mean = 6.13, SD [1.17]); and "missed home medication" (mean = 6.10, SD [1.10]). Three of the top 5 relevant measures are among the most commonly reported in the literature and two were suggested by Intermountain leaders. Table 3 presents the most relevant safety measures. Appendices E and F summarize the complete list of safety measures.

3.3.5. Step 3 – additional measures suggested by subject-matter experts

For the ambulatory survey, 25 (56%) participants answered the open-ended question. Two of the responses included general comments without suggestions of specific measures, e.g. "*I think you should be looking to measures that are much more closely linked or associated with EHR use. Many of these measures depend in large part on patient behavior, which has little to do with EHR use*...". Three participants suggested measures that require non-automated data collection methods (e.g. "*time spent by clinicians on patient care activities*"). Since our goal is to develop an inventory of measures with the ability to detect in near real-time the effect of an EHR implementation on the care delivery organization, measures that require non-automated data collection methods were not included in our inventory. We identified 24 unique outcome measures, 6 of which were suggested by 2 or more participants and were selected for inclusion in our inventory.

For the non-ambulatory survey, 35 (52%) participants answered the open-ended question. Four of the responses included general comments without suggestions of specific outcomes, e.g. "*Very comprehensive survey*...", and "*I dislike process measures. Measure the outcomes, not the process*...." Six participants suggested measures that require non-automated data collection methods, e.g. "*Clinicians' perception of verbal communication about patient post implementation*". We identified 25 unique measures, 5 of which were suggested by two or more participants and were included in our inventory. The 11 total additional measures were added to our original list, producing a final inventory of 102 outcome measures. Table 4 summarizes the additional measures included in our inventory. Table 3 of the online supplement provides the complete list of suggested measures.

Table 4
Additional measures suggested by two or more survey participants.

# Suggestions	Taxa	Measure	Description
Ambulatory measures			
9	10	Clinician Satisfaction	Clinicians' satisfaction as end-user of a new or updated Health IT system
3	18	Time to complete visits	Mean time between patient seen by provider and visit completed
3	18	Time spent by provider documenting after hours	Mean time spent by provider documenting on electronic health records after work hours
2	18	Time to sign notes	Mean time between visit completed and note signed
2	14	Patient phone calls	Number of patient phone calls during work hours
2	18	Time spent by provider documenting	Mean time spent by provider documenting on electronic health records
Non-ambulatory measures			
3	18	Time spent by provider documenting	Mean time spent by provider documenting on electronic health records
2	19	Electronic orders rate	Rate of orders entered electronically
2	20	Medication reconciliation rate	Rate of patients with medication reconciliation documented in patient electronic health records
2	18	Medication turnaround time	Mean time between medication ordered and administered
2	20	Overdue medication rate	Rate of overdue medications administered

Note: Measures are sorted by descending number of suggestions.

3.4. Step 4 – updating our taxonomy of outcome measurements for IT interventions in health care

From the 63 measures suggested by Intermountain Healthcare interviewees, we identified 6 new taxa that were added to our taxonomy: "time efficiency as a proxy for productivity" (16 measures); "hospital-acquired infection" (8 measures); "health care cost" (7 measures); "staff management" (5 measures); "appropriate use of diagnostic test" (3 measures); and "risk management" (2 measures). From the 11 additional measures suggested by the expert panel we identified an additional taxon that was added to our taxonomy: "health IT usage" (1 measure). With the added measures and taxa, the taxonomy was expanded from 15 [16] to 22 types of measurements (Fig. 2).

3.5. Step 5 – comparison of measures against reporting systems

Overall, data required for 13 (81%) measures of quality of care in ambulatory settings can be relatively easily found in the data needed to calculate HEDIS measures, including the top five relevant measures. Table 1 presents HEDIS equivalent measures for the top five relevant measures. The complete list of HEDIS equivalent measures can be found in Appendix A. HEDIS measures

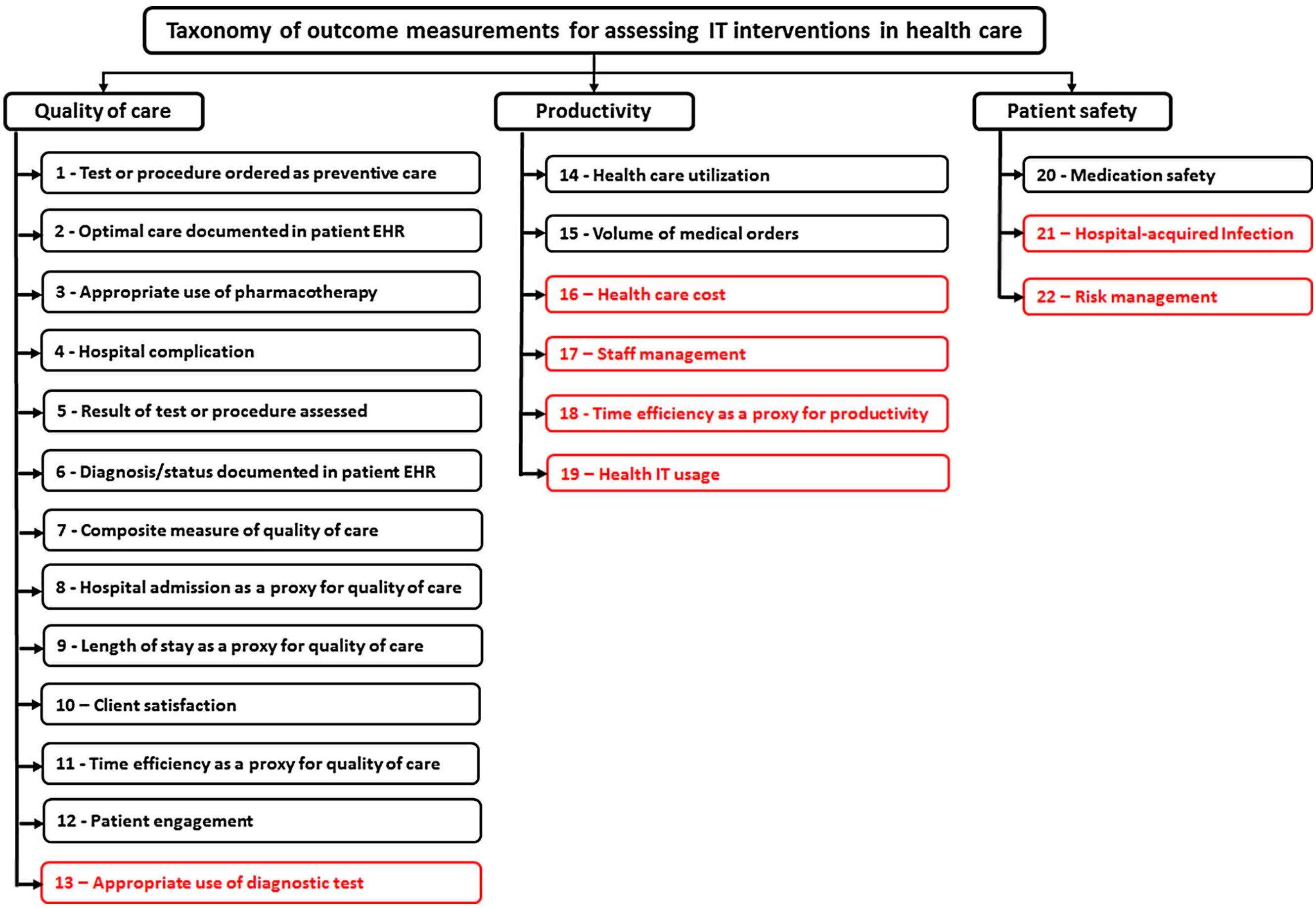

Fig. 2. Updated taxonomy of outcome measurements for assessing IT interventions in health care. Taxa in black originated from our previous study based on secondary analysis of a systematic review. Taxa in red were added from the present study based on interviews and survey responses. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

do not provide data for the safety measures included in our inventory.

Data required for 6 (27%) measures of quality of care in non-ambulatory settings can be relatively easily found in the data needed to calculate the measures included in Hospital Compare. Among the top five relevant measures, only 2 have an equivalent in Hospital Compare. Table 1 presents Hospital Compare equivalent measures for the top five relevant measures. The complete list of Hospital Compare equivalent measures can be found in Appendix B. As opposed to our previous study, where none of the safety measures had an equivalent in Hospital Compare [16], 7 (35%) of the measures suggested by Intermountain leaders have an equivalent in Hospital Compare; however, none of those are among the top five relevant measures. The complete list of Hospital Compare equivalent measures can be found in Appendix F.

None of the additional measures suggested by the expert panel has an equivalent in the reporting systems consulted.

4. Discussion

Our study provides a robust inventory of outcome measures for assessing the impact of IT interventions in health care settings and a taxonomy to classify these measures. Although measures of health IT outcomes have been reported in previous research [26,27], to our knowledge, this is the first systematic inventory of measures specifically developed to assess the impact of health IT interventions through a multi-method approach that combined measures commonly reported in the literature with those suggested by experienced health care leaders and health IT adoption experts. Further, this is the first time an inventory has been rated by experts nationwide. The broader informatics community can benefit from our inventory and taxonomy in several ways. Our inventory provides a list of measures covering several relevant care processes including quality, productivity, and safety, for both ambulatory and non-ambulatory care settings. Our taxonomy will help researchers identify gaps in their measurement approaches and report more standardized measures that could facilitate comparison of health IT outcomes in future studies.

Previous studies indicate that quality of care is the most commonly used type of measurement in health IT adoption studies [15,16]. Several measures in our inventory were considered to have "moderate" or "high relevance" and were among the most commonly reported in current research, including the top five most relevant measures for ambulatory and the top three for non-ambulatory. However, we were still able to identify 14 measures suggested by Intermountain leaders and survey participants that have not been frequently used in previous literature reports, indicating that potentially relevant care processes are not being reported by researchers. In our previous study [16], we have also identified that researchers tend to use quality measures that are required by widely used reporting systems. In the present study, we confirmed this tendency for the ambulatory setting, where 81% of the measures in our list can be calculated with data provided by HEDIS and 27% of non-ambulatory measures have an equivalent in Hospital Compare.

Productivity measures received lower relevance ratings compared to quality and safety, and had the option "I don't know" more frequently selected by survey respondents. Our previous study [16] identified only 11 productivity measures commonly reported in the literature. This likely contributed to having 32 measures of productivity suggested by Intermountain leaders and survey respondents that have not been frequently used in previous research. The measures of productivity rated as most relevant often assess time efficiency processes. Six measures suggested by survey participants were measures that assess mean time to complete specific care processes or time spent on electronic documentation.

Overall, safety measures were rated as more relevant than quality and productivity, and were more frequently rated as "high relevance" or "very high relevance". Findings from our previous study [16] indicate that medication safety measures are the most commonly reported in current research, and the present study attests to their relevance, with the top eight measures rated as most relevant assessing medication safety processes. However, we identified measures of other care processes such as infectious disease management that were also considered highly relevant. Safety measures suggested by Intermountain leaders tend to be those required by reporting systems: 35% of safety measures have an equivalent in Hospital Compare; however, none of those are among the top eight relevant measures.

Although patient safety outcomes are less frequently assessed in health IT adoption studies [16], they seem to be a common concern among different stakeholders [28,29]. The subject-matter experts who answered our surveys confirmed the importance of monitoring safety outcomes by rating safety measures as the most relevant. The importance of monitoring safety processes during EHR implementations is also confirmed by several studies eliciting unintended consequences of health IT adoption, especially those introduced by computerized provider order entry (CPOE) [30], as stated in a recent study by the Food and Drug Administration (FDA) [31]. Safety concerns [30,31], usability problems [32], and EHR vendor's "legal invulnerability" [33], may also have contributed to clinician satisfaction as being rated as the most relevant measure for quality in non-ambulatory setting, and as an additional measure suggested by several respondents of the ambulatory survey. EHR impact on mean time to complete tasks and time required for documentation also seem to be common concerns among experts, and are also perceived as a common unintended adverse consequence and a barrier to health IT adoption among clinicians [34]. We did not include in our inventory suggestions of measures that require alternative, non-automated data collection methods; however, the expert panel frequently suggested outcomes that assess impact of EHR implementation on workflow, communication, and satisfaction; therefore, we recommend future research focused on alternative methods that can efficiently capture different aspects of clinician satisfaction with EHRs for continuous monitoring.

Given the complexity and high cost involved in implementing commercial EHR systems, EHRs recently adopted by care delivery systems will likely be maintained by these institutions for many years. However, similar to complex changes common in other industries [35], EHR implementations warrant ongoing monitoring, not only during the transition phase, but also to assess deployment of new versions, ongoing customization, and especially ongoing monitoring to detect failures and unintended/unexpected effects. Our proposed inventory and taxonomy can help providers, health IT vendors, and the broader informatics community to monitor such complex projects, both during the transition phase and after the system has been stabilized and ongoing monitoring and maintenance start. In addition, since target population and outcome criteria may vary across institutions, our proposed measures and taxonomy will help investigators to properly classify and report measures that assess similar outcomes with different inclusion and exclusion criteria. For example, diabetes bundles with different components could always be reported as "diabetes bundle" and classified as "composite measure of quality of care". As a result, the scientific community will be able to report more standardized measurements of health IT evaluations that can be shared among researchers, hopefully facilitating comparison among future studies, leading us to a better understating of the impact of IT interventions in health care.

4.1. Limitations

Our study has several limitations. A single author first evaluated and classified the measures suggested by interviewees and survey respondents. However, several iterations of measure classification and nomenclature were performed to minimize data misclassification. Intermountain Healthcare is a care delivery system well known for its extensive experience with informatics applications, and the perception of its leaders could differ from leaders in other organizations. We believe that the high ratings of relevance provided by the expert panel mitigate this threat to the generalizability of our findings. We were not able to calculate the exact response rate of the surveys; however, given the number of participants, and their diversity and years of experience with EHR systems, we believe that we formed a strong expert panel. Lastly, we included only HEDIS and Hospital Compare reporting systems in our analysis; nevertheless, they are widely adopted and well known to providers and researchers. The data necessary to calculate all the proposed measures may not be readily available at every care delivery system. However, data availability is likely to increase with increasing EHR adoption and the introduction of value-based reimbursement models.

5. Conclusions

We developed a robust inventory of 102 outcome measures relevant to assessing the impact of EHR implementations in health care settings according to experienced health care leaders and health IT adoption experts. We also expanded the coverage of our previously reported taxonomy that will help researchers identify gaps in their measurement approaches and report more standardized measures that could be shared among researchers in future studies. Patient safety was rated as the most relevant type of measurement for assessing the impact of EHR implementations and deserves more attention from the broader informatics community. Measures assessing clinician satisfaction, time to complete tasks and time spent on electronic documentation are also highly relevant according to the experts. We expect that our inventory of measures and taxonomy will help providers, EHR vendors, and researchers to more effectively monitor the impact of EHR implementations, and report their results with more standardized measures, hopefully facilitating comparison among future studies and leading us to a better understating of the impact of IT interventions in health care.

Acknowledgements

Authors would like to acknowledge professors Damian Borbolla, MD, MS and Charlene Weir, PhD, RN, and members of the Socio-Technical Committee at the University of Utah, Department of Biomedical Informatics for their support on the development of our surveys. We would also like to acknowledge Damian Borbolla, MD, MS, Polina Kukhareva, MS, MPH, Makoto Jones, MD, MS, and David Shields for their participation piloting the surveys, and Greg Stoddard for his contribution to the statistical analysis. We thank the leaders from Intermountain Healthcare who participated in the interviews and the respondents to our online surveys. This research was supported by Intermountain Healthcare, Salt Lake City, UT, USA. JCF has been partially supported by the National Center for Advancing Translational Sciences of the National Institutes of Health under Award Number 5UL1TR001067-03.

Conflict of interest

Authors declare that there is no conflict of interest.

Appendix A. Quality of care measures for ambulatory settings

Source	Taxa	Measure	Description	HEDIS Equivalent	Relevance M (SD)	Do not know, (%)
Ambulatory - Quality of Care Measures						
Literature	2	Pneumococcal immunization documented	Evidence of pneumococcal immunization documented in patient's electronic health records	Childhood Immunization Status Pneumococcal Vaccination Status for older adults	5.73 (1.38)	–
Literature	1	Breast cancer screening	Breast cancer screening ordered as preventive care in target patients	Breast Cancer Screening	5.55 (1.32)	–
Literature	1	Colorectal cancer screening	Colorectal cancer screening ordered as preventive care in target patients	Colorectal Cancer Screening	5.53 (1.45)	–
Literature	5	Hemoglobin A1c control	Rate of diabetes patients with hemoglobin A1c under control	Comprehensive Diabetes Care	5.40 (1.54)	–
Literature/IH	7	Diabetes Bundle	Composite measure for diabetes control	Comprehensive Diabetes Care	5.38 (1.48)	2%
IH	3	Medication Management for People with Asthma	Rate of asthma patients using appropriate medication	Medication Management for People With Asthma	5.32 (1.30)	4%
Literature	1	Osteoporosis screening	Osteoporosis screening ordered as preventive care in target patients	Comprehensive Diabetes Care	5.30 (1.31)	4%
Literature	1	Chlamydia screening	Chlamydia screening ordered as preventive care in target patients	Chlamydia Screening in Women	5.18 (1.41)	2%
IH	13	Appropriate use of DEXA scan	Rate of bone density scan ordered in compliance with guidelines	Osteoporosis Management in Women Who Had a Fracture	5.18 (1.38)	2%
Literature/IH	5	Blood pressure control	Rate of hypertensive patients with blood pressure under control	Controlling High Blood Pressure	5.04 (1.62)	–
Literature	5	LDL cholesterol control	Rate of diabetes patients with low-density lipoprotein cholesterol under control	Not Included	4.93 (1.73)	4%
IH	13	Inappropriate use of pap smear test	Pap smear test ordered not in compliance with guidelines	Not Included	4.93 (1.62)	–
IH	13	Inappropriate use of imaging tests for low back pain	Imaging test for patients with low back pain ordered not in compliance with guidelines	Use of Imaging Studies for Low Back Pain	4.86 (1.59)	4%
Literature	2	Dietary counseling documented	Evidence of dietary counseling documented in patient's electronic health records	Weight Assessment and Counseling for Nutrition and Physical Activity for Children/ Adolescents	4.71 (1.39)	–
Literature/IH	10	Patient overall experience with care provided	Patients' satisfaction with care provided	CAHPS Health Plan Survey 5.0H	4.24 (1.94)	–

Abbreviations: IH: Intermountain Healthcare.
Note: Measures are sorted by descending order of relevance.

Appendix B. Quality of care measures for non-ambulatory settings

Source	Taxa	Measure	Description	Hospital Compare Equivalent	Relevance, M (SD)	Do not now, (%)
Non-ambulatory - Quality of Care Measures						
Literature	10	Clinician Satisfaction	Clinicians' satisfaction as end-user of a new or updated Health IT system	Not included	6.07 (1.14)	–
Literature/IH	3	VTE prophylaxis compliance	Rate of orders of prophylaxis for venous thromboembolism in compliance with guidelines	SCIP-VTE-2; VTE-1; VTE-2; PSI-12	5.88 (1.30)	–
Literature	3	Appropriate use of antibiotics	Orders of antibiotic drugs in compliance with guidelines	PN-6; SCIP-Inf-1; SCIP-Inf-2; SCIP-Inf-3	5.88 (0.92)	–
IH	7	Sepsis bundle	Composite measure for sepsis care measured as compliance to all composite items	Not included	5.81 (1.48)	1%
IH	4	Sepsis mortality rate	Rate of patients who died during hospitalization due to severe sepsis or septic shock	Not included	5.68 (1.71)	–
Literature/IH	8	Readmission rate	Rate of heart failure patients readmitted within 30 days	READM-30-AMI; READM-30-CABG; READM-30-COPD; READM-30-HF; READM-30-HIP-KNEE; READM-30-HOSP_WIDE; READM-30-PN; READM-30-STK	5.60 (1.58)	1%
Literature	7	Hospital Quality Alliance Scores	Composite score of quality of care for patients with acute myocardial infarction, heart failure, pneumonia, and surgical care using CMS Hospital Compare measures	Not included	5.51 (1.42)	1%
Literature/IH	4	Pressure ulcer rate	Rate of patients who developed pressure ulcer during hospitalization	Not included	5.49 (1.64)	–
Literature	4	Venous thromboembolism rate	Rate of patients who developed venous thromboembolism during hospitalization	VTE-6; PSI-12	5.44 (1.48)	–
Literature	5	Blood glucose control	Blood glucose control in ICU inpatients	Not included	5.41 (1.42)	–
Literature/IH	4	Ventilator-associated pneumonia rate	Rate of patients with diagnosis of ventilator-associated pneumonia	Not included	5.23 (1.75)	–
Literature/IH	4	Mortality rate	Rate of patients who died during hospitalization	MORT-30-AMI; MORT-30-HF; MORT-30-PN; MORT-30-COPD; MORT-30-STK; MORT-30-CAGB	5.17 (1.67)	–
Literature/IH	10	Patient satisfaction	Rate of patients who gave their hospital a rating of 9 or 10 on a scale from 0 (lowest) to 10 (highest)	Hospital Consumer Assessment of Healthcare Providers and Systems Survey	5.04 (1.74)	1%
IH	11	Time in ventilator	Mean time of ventilator therapy	Not included	4.98 (1.64)	–
Literature	9	Hospital LOS	Length of stay of hospitalized patients	Not included	4.85 (1.61)	–
Literature	4	In-hospital bleeding rate	Rate of bleeding events during hospitalization	Not included	4.61 (1.54)	3%
IH	9	NICU LOS	Length of stay of Newborn Intensive Care Unit patients	Not included	4.60 (1.85)	9%
IH	9	Maternity LOS for unplanned c-section deliveries	Length of stay of maternity patients after unplanned c-section delivery	Not included	4.50 (1.58)	10%
IH	11	Length of unplanned c-section	Mean time of labor and delivery of unplanned c-section	Not included	4.36 (1.72)	13%

(*continued on next page*)

Appendix B. (*continued*)

Source	Taxa	Measure	Description	Hospital Compare Equivalent	Relevance, M (SD)	Do not now, (%)
IH	8	NICU admission rate	Rate of patients admitted to Newborn Intensive Care Unit	Not included	4.36 (1.88)	10%
IH	9	Maternity LOS for vaginal deliveries	Length of stay of maternity patients after vaginal delivery	Not included	4.31 (1.62)	10%
IH	11	Length of vaginal delivery	Mean time of labor and delivery of vaginal delivery	Not included	4.13 (1.63)	12%

Abbreviations: IH: Intermountain Healthcare.
Note: Measures are sorted by descending order of relevance.

Appendix C. Productivity measures for ambulatory settings

Source	Taxa	Measure	Description	Relevance, M (SD)	Do not Know, (%)
Ambulatory - Productivity Measures					
IH	18	Time to provider	Mean time between patient check-in and patient visit initiated	5.51 (1.57)	–
Literature/ IH	14	Patient visits	Number of patient visits to ambulatory settings	5.04 (1.95)	–
Literature	15	Laboratory orders	Number of orders of laboratory tests	4.95 (1.82)	–
IH	16	Net collection ratio	Proportion of the amount of money received from payers in relation to the amount planned	4.95 (1.81)	4%
Literature	15	Medication orders	Number of medication orders	4.75 (1.84)	–
Literature	15	Radiology orders	Number of orders of imaging tests	4.75 (1.96)	–
IH	14	New patients visits	Rate of new patient visits to ambulatory settings	4.57 (1.98)	–
IH	16	Net operating income	Operational income before taxes	4.46 (2.00)	9%
Literature	14	After-hours patient calls	Number of patient phone calls after work hours	4.25 (1.81)	4%
IH	17	Employee movement	Rate of employees moved permanently to a different facility or department	3.34 (1.81)	13%
IH	17	Employee turnover	Rate of employee contracts terminated	3.14 (1.69)	9%

Abbreviations: IH: Intermountain Healthcare.
Note: Measures are sorted by descending order of relevance.

Appendix D. Productivity measures for non-ambulatory settings

Source	Taxa	Measure	Description	Relevance, M (SD)	Do not know, (%)
Non-ambulatory - Productivity Measures					
IH	18	Time spent by nurse documenting	Mean time spent by nurse documenting on electronic health records in the ICU	5.92 (1.47)	1%
IH	15	Radiology orders	Number of orders of imaging tests	5.40 (1.16)	–
IH	18	Antibiotic turnaround time	Mean time between antibiotic order and administration in newborn patients	5.34 (1.29)	6%
IH	18	ED wait time	Mean time between patient arrival and seen by provider in emergency departments	5.34 (1.61)	1%
Literature/ IH	14	ED LOS	Length of stay of patients in emergency departments	5.29 (1.74)	–
IH	18	Proportion of ED door to doctor (in <30 min)	Proportion of emergency department patients seen by provider in less than 30 min	5.20 (1.55)	–
Literature	15	Medication orders	Number of orders of medications	5.19 (1.44)	–

Appendix D. (*continued*)

Source	Taxa	Measure	Description	Relevance, M (SD)	Do not know, (%)
Literature	15	Laboratory orders	Number of orders of laboratory tests	5.18 (1.40)	1%
IH	18	Time to respiratory therapy	Mean time between respiratory therapy ordered and initiation of therapy	5.16 (1.49)	3%
IH	18	Time between radiology test completed and report issued	Mean time between radiology test completed and report issued by radiologist	5.03 (1.61)	1%
IH	16	Hospital cost per ICU patient	Average total hospital cost per ICU patient	5.00 (1.65)	6%
IH	18	Time between radiology test started and completed	Mean time between radiology test started and completed	4.93 (1.63)	3%
IH	16	ICU cost per patient	Average ICU cost per patient	4.92 (1.64)	3%
IH	16	ICU cost vs. Hospital cost	Proportion of ICU cost per patient compared to hospital total cost per ICU patient	4.85 (1.67)	7%
IH	18	Time between check-in and initiation of procedure	Mean time between patient check-in and initiation of procedure in the Cath-lab	4.77 (1.88)	–
IH	18	Time between procedure finished and patient discharge	Mean time between procedure finished and patient discharge in the Cath-lab	4.56 (1.81)	–
IH	16	Variable cost per delivery case	Percentage of variation between planned cost and actual cost per delivery (maternity) case	4.54 (1.77)	9%
Literature	14	Hospitalizations	Number of patients hospitalized	4.54 (2.00)	1%
Literature	14	ED visits	Number of patient visits to emergency departments	4.53 (2.09)	–
IH	17	ICU Nurse patient ratio	Ratio of nurse per patient in the ICU	4.39 (1.80)	1%
IH	16	RVU per respiratory therapist per shift	Relative value unit of respiratory therapist per shift	4.31 (1.72)	9%
IH	17	Employee movement	Rate of employees moved permanently to a different facility or department	3.44 (1.90)	12%
IH	17	Employee turnover	Rate of employee contracts terminated	3.17 (1.75)	13%

Abbreviations: IH: Intermountain Healthcare.
Note: Measures are sorted by descending order of relevance.

Appendix E. Safety measures for ambulatory settings

Source	Taxa	Measure	Description	HEDIS Equivalent	Relevance, M (SD)	Do not know, (%)
Ambulatory - Patient Safety Measures						
Literature	20	Medication errors	Medication errors of any source	Not included	5.95 (1.29)	–
Literature/ IH	20	ADEs rate	Rate of adverse drug events	Not included	5.93 (1.35)	–

Abbreviations: IH: Intermountain Healthcare.
Note: Measures are sorted by descending order of relevance.

Appendix F. Safety measures for non-ambulatory settings

Source	Taxa	Measure	Description	Hospital Compare Equivalent	Relevance, M (SD)	Do not know, (%)
Non-ambulatory - Patient Safety Measures						
Literature	20	ADEs rate	Rate of adverse drug events	Not included	6.22 (1.11)	–
Literature	20	Medication errors	Medication errors of any source	Not included	6.19 (1.04)	–
IH	20	BCMA override rate	Rate of bar-coded medication administration override	Not included	6.19 (1.23)	–
Literature	20	Medication orders changed	Rate of medication orders changed following clinical decision support recommendation	Not included	6.13 (1.17)	–
IH	20	Missed home medication	Rate of medication errors caused by missing a medication during medication reconciliation	Not included	6.10 (1.10)	–
IH	20	Drug-allergy interaction override rate	Rate of drug-allergy interaction alerts overridden during ordering process	Not included	6.05 (1.28)	–

(*continued on next page*)

Appendix F. (*continued*)

Source	Taxa	Measure	Description	Hospital Compare Equivalent	Relevance, M (SD)	Do not know, (%)
IH	20	Drug-drug interaction override rate	Rate of drug-drug interaction alerts overridden during ordering process	Not included	6.04 (1.26)	–
Literature	20	Non-recommended medications ordered	Rate of medications orders not in compliance with guidelines	Not included	5.86 (1.34)	–
IH	21	Bloodstream infection rate	Rate of hospital-acquired central line associated bloodstream infections	HAI-1; HAI-1a	5.61 (1.64)	–
IH	21	Urinary tract infection rate	Rate of hospital-acquired Foley catheter-associated urinary tract infections	HAI-2; HAI-2a	5.46 (1.76)	–
IH	21	Colon surgery infection rate	Rate of hospital-acquired surgical site infections for colon surgeries	HAI-3	5.42 (1.79)	1%
IH	21	Hospital-acquired CDiff rate	Rate of hospital-acquired infections caused by Clostridium Difficile	HAI-6	5.34 (1.76)	1%
IH	21	Hospital-acquired MRSA rate	Rate of hospital-acquired infections caused by Methicillin-resistant Staphylococcus Aureus	HAI-5	5.28 (1.64)	1%
IH	21	Hospital-acquired VRE rate	Rate of hospital-acquired infections caused by Vancomycin-resistant Enterococci	Not included	5.27 (1.63)	1%
IH	21	Hospital-acquired CRA rate	Rate of hospital-acquired infections caused by Carbapenem-resistant Acinetobacter	Not included	5.23 (1.63)	6%
IH	21	Abdominal hysterectomy infection rate	Rate of hospital-acquired surgical site infections for abdominal hysterectomy surgeries	HAI-4	5.19 (1.68)	1%
IH	22	Fall rate	Rate of patient falls during hospitalization	ASC-2	5.11 (1.88)	–
IH	22	Ventilator disconnection rate	Rate of ventilator disconnection in the ICU	Not included	4.39 (1.93)	4%

Abbreviations: IH: Intermountain Healthcare.
Note: Measures are sorted by descending order of relevance.

Appendix G. Supplementary material

Supplementary data associated with this article can be found, in the online version, at http://dx.doi.org/10.1016/j.jbi.2017.07.014.

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