Grant Final Report

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Implementation and Evaluation of an Automated Email Notification System for Results of Tests Pending at Discharge

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Abstract

Purpose: We developed an automated email notification system to prompt physicians of results of tests pending at discharge (TPADs) and evaluated its impact on physician awareness.

Scope: Physician awareness of the results of TPADs is generally poor. We designed and implemented an automated email notification system to prompt responsible providers of these results during a patient's transition from the inpatient to ambulatory setting. We activated this system for patients discharged from the inpatient general medicine and cardiology services at Brigham and Women's Hospital in order to evaluate its impact on physician awareness of TPAD results of any type (chemistry, hematology, radiology, pathology, or microbiology).

Methods: We conducted a cluster-randomized controlled trial in which both the inpatient attending and primary care provider (PCP) were randomized to the automated email notification system (intervention) or usual care for any patient discharged with TPADs during an 8 month study period. We surveyed these physicians with regard to awareness of any TPAD result, awareness of actionable TPAD results, and satisfaction.

Results: We enrolled a total of 441 patients. Inpatient attendings and PCPs caring for these patients were significantly more aware of any TPAD result (chemistry, hematology, radiology, pathology, or microbiology) in the automated e-mail notification compared to usual care arm (Inpatient Attending Awareness 76% vs. 38%, $p < .0001$, PCP Awareness 57% vs. 33%, $p=0.003$). Inpatient attendings were significantly more aware of actionable TPAD results in the intervention compared to usual care arms (59% vs. 29%, $p=0.02$). Eighty-nine percent and 70% of intervention inpatient attendings and PCPs were satisfied with automated email notification of TPAD results, respectively.

Key Words: tests pending at discharge; automated email notification; care transitions

Final Report

Purpose

The specific aims of this project were as follows:

1. To develop an automated email notification system to prompt physicians of results of tests pending at discharge (supported by BWH internal funding).

2. To evaluate the impact of this system on physician awareness of results of tests pending at discharge (supported by AHRQ).

Scope

Physician awareness of the finalized results of tests pending at discharge (TPADs) is poor and this represents an important patient safety concern. Roy et al. determined that 41% of patients left the hospital before all test results were finalized, with an average of 0.77 TPADs per patient.[1] Approximately 31% of TPADs are hematology, chemistry, and pathology tests; 27% are radiology tests; and 42% are microbiology tests. Forty-three percent of these test results were abnormal. Approximately 9.4% of TPAD results were considered potentially actionable by independent physician review and could have altered the post-discharge plan; physicians were aware of only 38% of these results. Failure to follow-up on these test results can lead to delays in diagnosis, missed treatment opportunities, redundant ordering of tests, and subsequent patient harm.[2, 3]

Brigham and Women's Hospital (BWH) has approximately 44,000 admissions annually, and therefore, physicians would be unaware of almost 2000 potentially actionable TPAD results per year. Based on previous work we learned that to successfully implement HIT to address this issue, the technology must be compatible with both inpatient and ambulatory workflow (e.g., network email at our institution), and the system must clearly delineate responsibility.[4]

Using internal BWH funding, we developed an automated notification system to prompt responsible physicians of TPAD results for chemistry, hematology, radiology, pathology, and microbiology test types. The system was designed to facilitate communication and subsequent transfer of responsibility for these test results between the responsible inpatient attending and primary care physician (PCP). We used funding from AHRQ to conduct a physician-clustered randomized controlled trial for patients discharged from the inpatient general medicine and cardiology services at BWH over a 8 month study period in which the automated email notification system was activated for independently randomized inpatient attendings and PCPs.

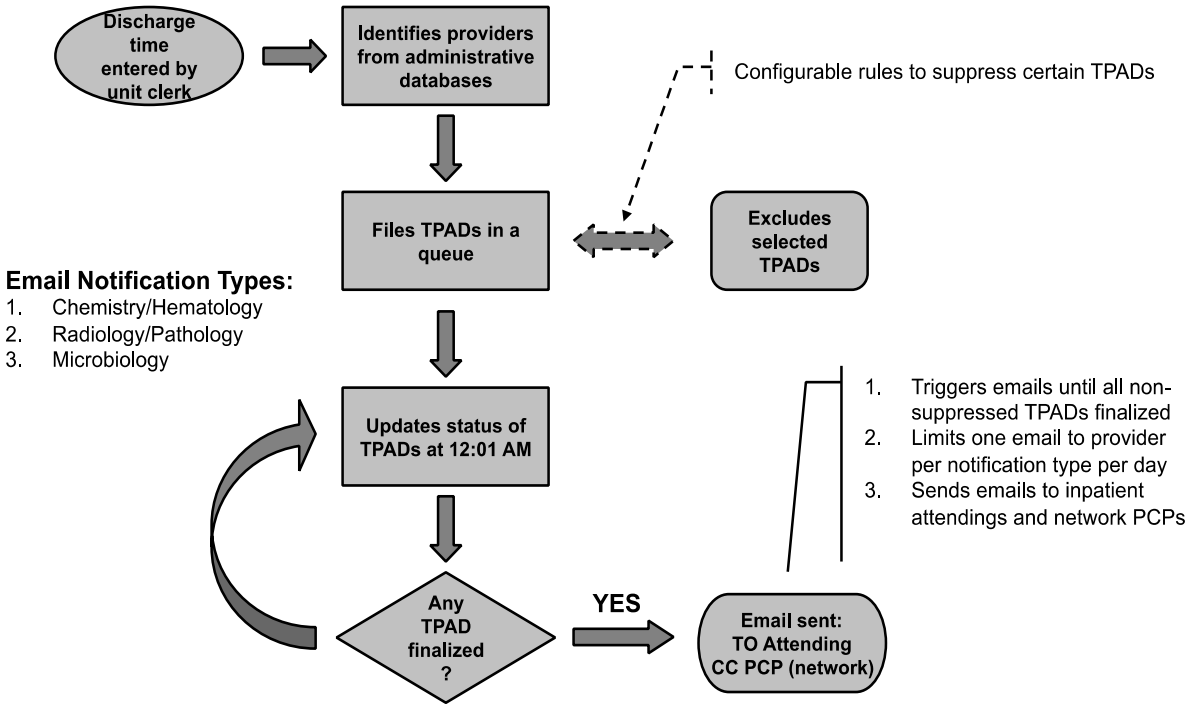
Methods

Overview of HIT Intervention

Several policy, usability, and workflow considerations (described in detail below) were paramount to the design of the automated email notification system. These considerations included 1) a method for assigning responsibility, 2) integration within clinical information systems commonly used by responsible providers in order to conform to their workflow (e.g., an understanding of electronic communication methods used both by inpatient attendings and PCPs), and 3) alert fatigue. Using BWH internal funding, we designed and implemented an automated system to notify the responsible inpatient attending of finalized TPAD results using secure, network email. This system was designed to leverage functionalities available or enhanced from existing, internally developed inpatient information systems at BWH. These included the Brigham Integrated Clinical Information System (BICS), BWH inpatient bed-management system, and BWH admitting databases. We defined TPADs to include a test ordered by any provider or service from the time the patient presented to the emergency room (or admitted directly) until the time of discharge. We included tests ordered during the entire episode of acute care within our institution (e.g., ordered in the emergency room, intensive care unit, etc) with a status of pending, received, processing, or preliminary.

The system (1) is triggered by a patient's electronic discharge time stamp (entered by the unit clerk into the BWH inpatient bed management system as part of routine care), (2) identifies the discharging inpatient-attending physician and PCP from BWH administrative databases, (3) files all non-finalized tests in a queue, (4) updates the status of non-finalized tests at 12:01 AM each day, and (5) sends an email of the patient's result(s) to the inpatient-attending physician. An electronic carbon copy of the email is sent to the PCP if within the network when newly finalized results are available; if the patient has an out-of-network PCP, or if no PCP is listed, only the inpatient-attending physician receives the notification email (but telephone contact information for the non-network PCP is included in the content of the email if available). The system continues to update the status of TPADs for each discharged patient until all are finalized. At the time TPADs are filed, an interim step suppresses selected TPADs based on configurable rules. See Figure 1 for an overview of the system.

Figure 1. Overview of the system



The system sends separate notifications for (1) chemistry and hematology, (2) radiology and pathology, and (3) microbiology test results. We chose this grouping for technical and logistical reasons. First, it largely coincides with the classification system used by our institution's clinical data repository. Second, we wished to optimize the length of the email transcript to improve readability (particularly beneficial for patients discharged with multiple TPADs of different types). Third, this allowed us to modify the frequency of email notifications to providers based on volume of TPADs by test type (e.g., we could minimize the volume of microbiology notification emails (compared with other test type emails) given the relatively high volume of pending microbiology culture results). See Figure 2 for an example of a notification email.

Design considerations of HIT intervention

We incorporated lessons learned from a previous, unsuccessful attempt at implementing a computerized results manager application at our institution.[4] We learned that to successfully implement a HIT strategy to improve physician awareness of TPAD results, responsibility for these results must be clearly delineated a priori. Ideally, the responsibility for these test results must be established by institutional or network policies (e.g., preferably a patient safety officer); the technological strategy must identify the responsible providers involved in the patient's transition from the hospital to ambulatory care setting post-discharge based on these policies.

Next, it must leverage clinical information systems commonly used by these physicians in order to accommodate clinician workflow (e.g., BICS, Partners network email). If notifications of TPAD results are not sent to information systems used by these responsible providers, the

system will be rendered useless. For inpatient attendings (e.g., hospitalists), the notifications should be sent to inpatient clinical information systems, and for ambulatory physicians (e.g., PCPs), notifications should be sent to the ambulatory electronic medical record (EMR). When possible, the notification method should target electronic communication preferences used ubiquitously by both inpatient attendings and PCPs (e.g., secure, network email). Third, it should make an attempt to maximize appropriateness of alerting and minimize alert fatigue. This may include a mechanism to suppress certain inpatient test results (e.g., routinely ordered tests with a fast turn-around-time that are typically available and reviewed by the inpatient team on the day of discharge).

Figure 2: Example of an automated email notification received by intervention physicians
SUBJECT: Important Post-Discharge Test Results
FROM: BWH Post DC Test Results
TO: [Inpatient Attending]
CC: [Network PCP] *(blank if non-network PCP or no PCP)*

March 29, 2011
Dear Dr. HOSPITALIST, M.D.:

DISCHARGED PATIENT (BWH# 12345678), for whom you were the attending of record, was discharged from Brigham and Women's Hospital on 03/27/2011. Some tests from this hospitalization were still pending at the time of discharge. We have listed below 1) tests whose results have been finalized after discharge, and 2) tests whose results are still pending. Chemistry and Hematology test types are included in this service. Radiology, Pathology, and Microbiology test types are available in separate notifications

The patient's PCP, NON-NETWORK PROVIDER, did not receive this notification because s/he does not have a Partners email address listed.

This is a new service we are piloting that we hope you will find to be helpful. Note: Any corrections or changes made after tests are finalized are not captured by this service but are reported per current lab protocol.

Inpatient Attending: HOSPITALIST, M.D. Work Phone: 111-111-1111
Primary Care Physician: NON-NETWORK PROVIDER, M.D. Work Phone: 222-222-2222

Status: Results **FINALIZED**
Hematology

Test Name	Results	Normal Range	Date Resulted
ANTITHROMBIN III FUNCTIONAL	76	(69-127 %)	03/28/2011 11:29:00
APCR (FACTOR 5 LEIDEN)	4.17;NEW REFERENCE RANGE EFFECTIVE 3/19/08; PREVIOUS REFERENCE RANGE 0.8-2.50	(2.3-15.0)	03/28/2011 11:21:00

Status: Results **PENDING**
Chemistry

Test Name	Specimen Login Time
ANTI-PROTHROMBIN	03/25/2011 17:04:00
CARDIOLIPIN IGG	03/25/2011 17:04:00
CARDIOLIPIN IGM	03/25/2011 17:04:00

Please email the BWH Post-Discharge Results Notification Service for any questions, comments, and concerns related to this alert.

The discharge time stamp was identified as the most appropriate and practical electronic trigger for our system. Typically, to alert the admissions office of bed availability, unit clerks

enter the time when a patient physically leaves an inpatient bed into the inpatient bed management system. We contemplated using the electronic discharge order entered by physicians, but because it could be entered at variable times (e.g., early in the morning) and often more than once (e.g., as discharge instructions are modified) we felt that it was neither the most reliable nor accurate trigger. We used central, BWH administrative databases to identify responsible providers. The BWH admissions office routinely updates the identity of the inpatient-attending physician and the PCP (network and non-network) in these databases (e.g., name, address, phone numbers, etc.) and both inpatient attendings and network PCPs typically verify that patients are correctly assigned when caring for patients. Each provider is assigned a unique internal provider identification (ID) number in this database such that when administrative or clinical staff enters a provider's name into any information system linked to this database, it automatically matches to this ID and identifies the provider. Notably, free-text entries bypassing this mechanism will not always match to the provider's name reliably (this may inadvertently occur when clinical staff updates PCP information at discharge).

An example of a typical email notification for TPAD results is provided in Figure 2. Consistent with our institutional policies, we designated the discharging inpatient attending as responsible for TPAD results. We decided against using the ordering provider (typically a trainee or mid-level provider) as a surrogate because of issues of multiple hand-offs, transient and weekend coverage, variable supervision, and transfers between services or different levels of care. Finally, to improve post-discharge communication, we sent a carbon copy of the notification email to the network PCP's inbox. We crafted wording with the intent of facilitating a dialog between the inpatient attending physician and the PCP in order to acknowledge the result, consider subsequent actions, and facilitate the transfer of responsibility from inpatient to outpatient provider. Because non-network PCPs (approximately 40% of patients admitted to BWH have non-network PCPs) do not have secure, Partners email addresses, they were excluded from receiving email notifications. But because to the admissions staff generally updates the contact information of non-network PCPs in the administrative databases, we were able to include the name and telephone number of non-network PCPs in the content of our email notifications (when available) so that the responsible discharging inpatient attending could still contact non-network PCPs.

Alert Fatigue

To minimize alert fatigue, we incorporated configurable rules to suppress selected tests from being filed in the system's queue and incorporated in notification emails for each test type. We assumed that both normal and abnormal results could be actionable depending on the perspective and practices of individual physicians (e.g., receipt of a negative culture result may prompt a physician to discontinue antibiotics sooner if the indications were not compelling and the risk of adverse drug events or medication interactions were high). With regard to which results to include (or exclude) from notification emails, we explored several possibilities: (a) we could include abnormal only, or both normal and abnormal results; (b) we could exclude inpatient-specific results (e.g., arterial blood gas), commonly ordered inpatient tests (e.g., complete blood counts, basic metabolic panels), or inpatient tests with a fast turn-around time likely seen by inpatient providers on the day of discharge (e.g., prothrombin time). During our pilot we suppressed a small number of tests, as we were uncertain about which types of results individual providers would find actionable (Table 1). Additionally, the system was configured to send no

more than one email per patient per day per notification type. This was achieved by a routine job that updates the status of TPADs at 12:01 AM each day. Given the high volume and variability in post-discharge finalization times for microbiology results, after the initial email was sent (for either normal or abnormal results), subsequent notifications were only sent on abnormal results and after all results were finalized.

Table 1: Test results suppressed in system

Test Type	Test Results Suppressed
Chemistry	Arterial blood gas (ABG), venous blood gas (VBG)
Hematology	Red blood cell (RBC) count, mean corpuscular volume (MCV), mean corpuscular hemoglobin (MCH), mean corpuscular hemoglobin concentration (MCHC), differential count
Radiology	Fluoroscopy use; uploaded outside hospital images (no reports generated).
Pathology & Microbiology	None

Study Design, Subjects, and Setting

See Figure 3 for an overview of the study design. We performed a cluster-randomized controlled trial in which the inpatient attending and PCP were independently randomized and patients were assigned to the HIT intervention or usual care only if these physicians were in the same arm of the study (see Table 2, Cluster Randomization Scheme). We enrolled patients discharged from the inpatient general medicine and cardiology services at BWH over an 8 month period from October 2010 through May 2011 whose inpatient attending and PCP were in concordant study arms, and excluded patients whose inpatient attending and PCP were in discordant arms. Nearly all inpatient attendings and most in-network PCPs were randomized prior to study initiation. However, because it was not possible to determine a priori the identities of physicians (particularly non-network PCPs) caring for patients during the study period, we assigned any un-randomized inpatient attendings, in-network PCPs, and all non-network PCPs at the time of discharge based on the parity of their internal provider ID. Research staff manually assigned as many un-randomized physicians as possible using this method during the first half of study period. The method was automated during the second half of the study period to enhance enrollment (e.g., for patients with non-network PCPs).

Figure 3. Study Design

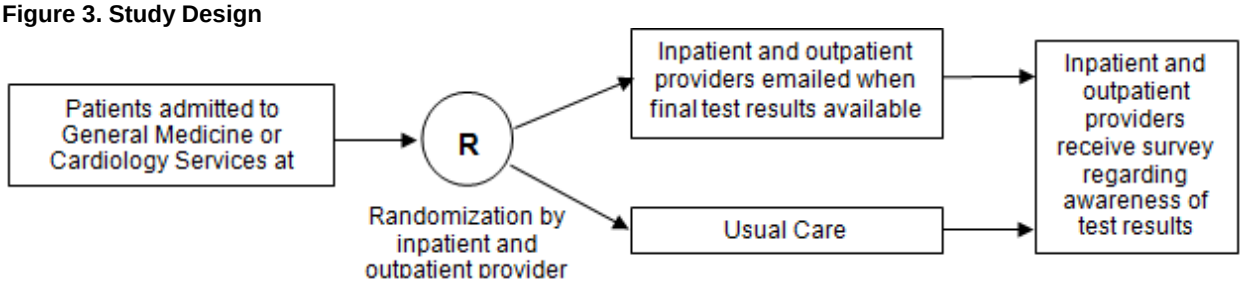


Table 2. Cluster Randomization Scheme

Physician of Discharged Patient	Att_I	Att_C
PCP_I	PCP_IAtt_I Patient Included	PCP_IAtt_C Patient Excluded
PCP_C	PCP_CAtt_I Patient Excluded	PCP_CAtt_C Patient Included

Intervention Attending = Att_I; Control Attending = Att_C; Intervention PCP = PCP_I; Control PCP = PCP_C

The TPADs of all patients discharged from these services during the study period were tracked by our system until finalized, but automated email notifications of TPAD results were only sent to concordant intervention physicians. Because many patients typically have microbiology TPADs (i.e., cultures) at discharge, we partially sampled these patients. Specifically, every third patient discharged with microbiology TPAD(s) was excluded in both arms (i.e., email notifications were suppressed and/or surveys to physicians were not generated). This was necessary to reduce the volume of surveys sent to inpatient attendings over a short period of time in an attempt to minimize survey fatigue. We also excluded patients whose PCP was their inpatient attending (a small number at BWH). We estimated that we would need to enroll 450 patients to improve awareness of any TPAD result by the inpatient attending from 40% to 60%. Eligible patients included any adults (> 18 yrs) admitted to the BWH inpatient general medicine or cardiology services regardless of age, gender, or race.

Data Sources & Collection

For each eligible study patient identified at discharge, research staff generated and emailed a web-based survey to the inpatient attending and network PCP approximately 72 hours after the last TPAD result was finalized. This procedure was performed manually during the first half of the study but was automated during the second half of the study. Research staff faxed a paper copy of surveys to non-network PCPs during the entire study because these PCPs did not have a network email address. We provided a $20 gift-card incentive for each completed survey. Physicians could opt out at anytime by responding to study staff. The survey assessed awareness of any TPAD result(s), awareness of actionable TPAD result(s), and satisfaction. Up to two reminder surveys were emailed or faxed. We collected physician demographic information, including age, gender, post-graduate year, specialty, and number of years employed from hospital administrative databases, and publicly available information (e.g., Massachusetts Board of Registration in Medicine website). To characterize our study population, we collected typical patient demographic information, including age, gender, frequency of hospitalization, and billing-based Charlson co-morbidity scores from electronic administrative systems. See Table 3 for these physician and patient demographic data.

Outcome Measures

We measured awareness of any TPAD result by the inpatient attending as our primary outcome using the survey instrument described above. As secondary outcomes, we measured awareness of any TPAD result by PCP (network and non-network), awareness of actionable TPAD results by the inpatient attending and PCP (where actionability was determined by the

surveyed provider), and satisfaction with either automated email notification of TPAD results or usual care (depending on arm of the study).

Table 3. Baseline characteristics of randomized inpatient attendings and discharged patients

	Intervention N (%)	Usual Care N (%)	p-value
Inpatient Attendings	**N=56**	**N=55**	
Age – yr	45.4 (9.4)	44.7 (11.1)	0.26
Male sex – no. (%)	35 (64)	36 (65)	0.84
Attending Experience (years)			
<5	23 (41)	33 (62)	0.09
5-10	17 (30)	10 (19)	
10+	16 (29)	10 (19)	
Specialty			
Hospitalist	21(38)	14 (25)	0.48
Traditional Internist	6 (11)	5 (9)	
Cardiologist	22 (40)	28 (51)	
Other Subspecialist	6 (11)	8 (15)	
Years Employed (BWH) (mean)	10.62 (8.42)	10.87 (9.04)	0.89

	Intervention N (%)	Usual Care N (%)	p-value
Discharged Patients[†]	**N=241**	**N=200**	
Age – yr			
Median	61.0	59.5	0.83
Inter-quartile range	44.0-75.0	45.5-73.0	
Male sex – no. (%)	114 (47)	97 (49)	0.80
Race			
White	149 (62)	120 (60)	0.71
Black	52(22)	42 (21)	
American Indian	1 (<1)	-	
Hispanic	32 (13)	27 (14)	
Other	7 (3)	10 (5)	
Socioeconomic status (Median Income by Zip Code)			
<=39,000	80 (34)	60 (31)	0.88
39,001 – 47,000	51 (22)	47 (24)	
47,001 – 63,000	52 (22)	43 (22)	
>63,000	53 (22)	46 (23)	

Insurance Status			
Private	70 (29)	66 (33)	0.85
Medicaid	34 (14)	26 (13)	
Medicare	125 (52)	96 (48)	
Self Pay	3 (1)	4 (2)	
Other	9 (4)	8 (4)	
Case-Severity Mix			
DRG weight median (IQR)	1.10 (0.80-1.75)	1.03 (0.80-1.62)	0.37
No. of pending tests per patient-discharge			
1	80 (33)	71 (36)	0.01
2	68 (28)	34 (17)	
3-5	65 (27)	54 (27)	
6-20	23 (10)	36 (18)	
21+	3 (1)	5 (3)	
No. with network PCPs	123 (72)	107 (69)	0.63
No. with non-network PCPs	48 (28)	48 (31)	
30-day readmission	56 (23)	34 (17)	0.10
30-day mortality	2 (<1)	2 (1)	1.00
Average co-morbidity score per discharge	2.06 (2.18)	2.06 (2.38)	0.76

[†]Of the 441 patient-discharges, there were 422 distinct patients; 17 patients were admitted two times, and 2 patients were admitted three times during the study period.

Limitations

This study has a few limitations. With regard to the intervention, although the notification system is fully automated, it still can be affected by human error. For example, an incorrectly entered discharge time stamp would trigger the system and potentially send out email notifications on patients still physically admitted to the hospital. Additionally, because the system relies on accurate identification of the patient's inpatient attending and PCP from electronic administrative databases, email notifications will be sent to incorrect providers if these are not kept up-to-date (i.e., if the provider's information is inaccurate or incomplete), or will not be sent at all if these are not queried appropriately (i.e., as may occur when free-text entry of a PCP's name fails to match to the internal provider ID). With regard to our evaluation study, we powered around inpatient physician awareness of any TPAD result; the study was not designed to have enough statistical power to detect whether appropriate downstream actions were taken in response to potentially actionable TPAD results as determined by independent physician review. Additionally, we did not study the effect of our intervention for other hospital-based services (e.g., general surgery, emergency, neurology, oncology, orthopedics, etc.). These services may vary with regard to types of TPAD results, workflow, email communication practices, expectations for follow-up, etc. Finally, our method of notification will never improve awareness of TPAD results for providers within our network who do not regularly use email as part of their

daily clinical communication practices. For our study, we sent all notifications, study announcements, and study incentives to network providers via email (non-network providers received surveys and incentives via fax). For our institution, regular use of network email for clinical communications was a credible assumption given our robust culture of doing so. However, this may have important implications for other institutions interested in adopting this type of intervention but who struggle with communicating with affiliated providers via network email. Nevertheless, these institutions could leverage an automated notification strategy using other forms of communication typically used by their clinicians (e.g., internal clinical messaging within a vendor-based EMR).

Results

Of 1693 patients discharged with TPADs and identified by the notification system during the study period, 624 were excluded due to discordantly randomized physician pairs. One hundred and seventy-one patients were excluded despite having concordantly randomized physician pairs: 103 due to partial random sampling of patients with only microbiology TPAD results, 26 due to the PCP serving as the inpatient attending for the patient, and 42 due to surveys not being generated (i.e., research staff unavailable). Three-hundred and ninety-eight patients with TPADs (398/1693 or 23.5%) were not randomized: the internal provider ID necessary to randomize the PCP was missing for 109 (109/1693 or 6.4%), and research staff were unable to manually randomize the patients' physicians for 289 (289/1693 or 17.1%; most of these patients had a non-network PCP and/or were discharged prior to automation of our randomization scheme).

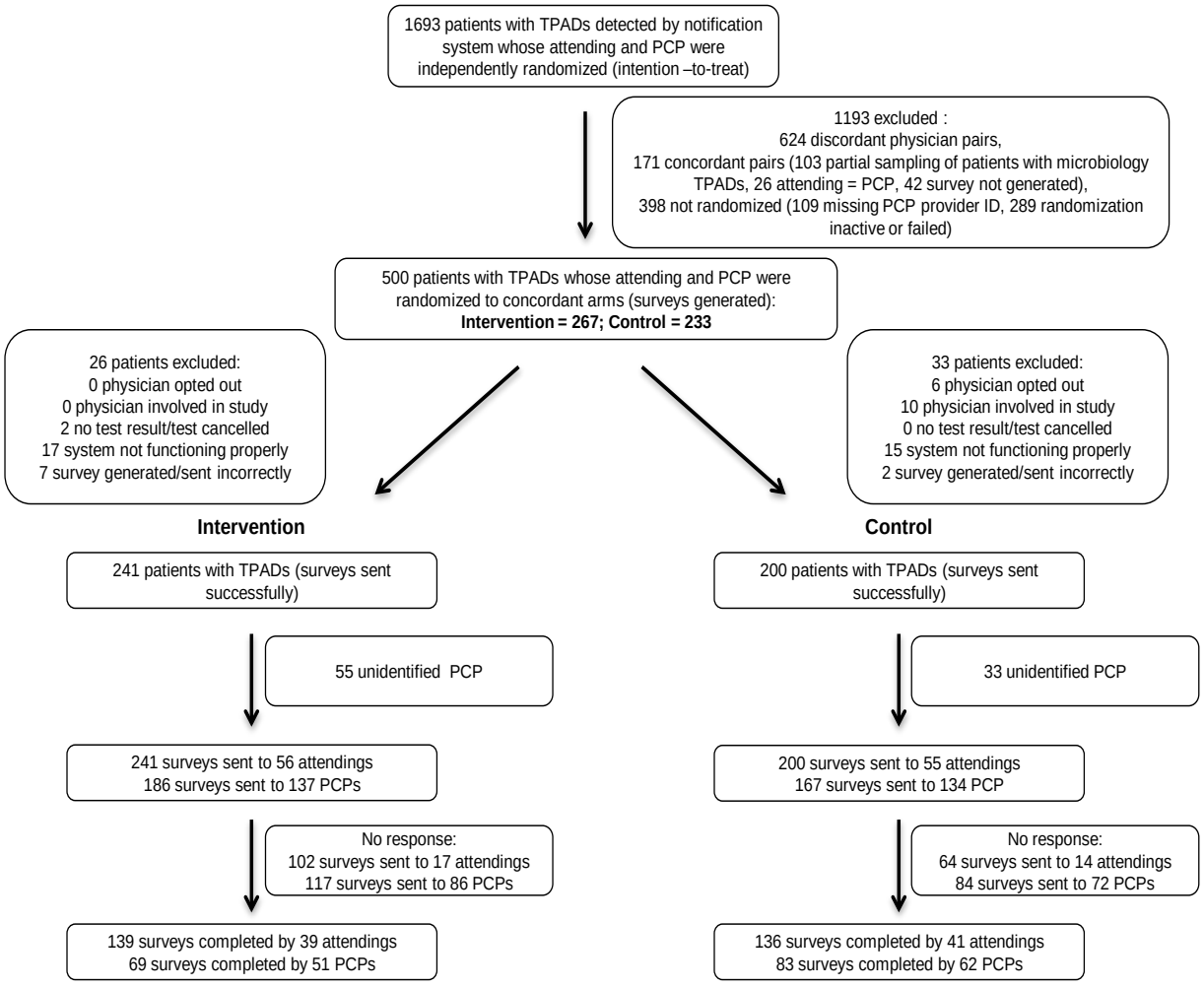
Of the remaining 500 patients whose physicians were in concordant arms, 267 were assigned to the intervention (i.e., automated email notifications to inpatient attending and PCP were sent), and 233 patients were assigned to usual care (i.e., automated email notifications to inpatient attending and PCP were suppressed). Two hundred and sixty-seven intervention and 233 control surveys were generated for the physicians caring for these patients, respectively. In the intervention arm, 26 patients were excluded: none due to the physician opting out or being involved in the study design; 2 due to the test result being cancelled post-discharge, 17 due to the system not functioning correctly during a planned update (e.g., test result not being detected, alert not triggering properly), and 7 due to surveys generated or sent incorrectly. In the control arm, 33 patients were excluded: 6 due to the physician opting out of survey (2 unique physicians), 10 due to physician being involved in study design (2 unique physicians), none due to the test result being cancelled post-discharge, 15 due to the system not functioning properly during a planned update (e.g., test result not being detected), and 2 due to surveys generated or sent incorrectly.

Two hundred and forty-one surveys were sent to 56 unique inpatient attendings caring for the 241 patients assigned to intervention. Two hundred surveys were sent to 55 unique inpatient attendings caring for the 200 patients assigned to usual care. One hundred and eighty-six surveys were sent to 137 unique PCPs caring for 186 patients assigned to intervention (55 patients did not have a PCP listed in the administrative databases and therefore no survey was generated). One hundred and sixty-seven surveys were sent to 134 unique PCPs caring for 167 patients assigned to usual care (33 patients did not have a PCP listed in the administrative databases and therefore no survey was generated). Overall, we sent a total of 441 surveys to inpatient

attendings and received 275 completed responses (inpatient attending response rate 62%). We sent a total of 353 surveys to PCPs and received 152 completed responses (PCP response rate 43%).

Baseline characteristics of inpatient attendings and patients are listed in Table 3. In general, characteristics of intervention and usual care attendings were uniform across both arms. There were slightly more intervention attendings than usual care attendings with greater than 5 years of clinical experience. Characteristics of discharged patients with TPADs appeared similar across both arms. There were more intervention than usual care patients with 2 or fewer TPADs, and there were more usual care than intervention patients with 3 or more TPADs. Although the percentage of patients with non-network PCPs was approximately equal (~30%) across both arms, this percentage was lower than expected (~40% of patients admitted to BWH have non-network PCPs). Finally, more intervention than usual care patients were readmitted within 30 days of discharge.

Figure 4. Patient Enrollment



Outcomes

The rate of inpatient attending and PCP awareness of any TPAD results for patients assigned to receive usual care was 38% and 33%, respectively. We observed a statistically significant increase in the rate of inpatient attending awareness of any TPAD results for patients assigned to the intervention compared to usual care (overall inpatient attending awareness, unadjusted analysis 76% vs 38%, p<0.0001). This effect was similar for both hospitalists and non-hospitalists. We also observed a statistically significant increase in the rate of PCP awareness of any TPAD results for patients assigned to the intervention compared to usual care (overall PCP awareness, unadjusted analysis 57% vs 33%, p=0.003). This effect was observed exclusively for patients with network PCPs. The total number of patients with non-network PCPs included in the study was small. There was a significantly increased rate of inpatient attending awareness of any actionable TPAD results (57% vs 33%, p=0.02), and a trend towards increased rate of PCP awareness of any actionable TPAD results (65% vs 48%, p=0.25) for patients assigned to the intervention compared to usual care, respectively.

Table 4. Primary outcome
Awareness of any TPAD Result(s) by Inpatient Attending

Primary Outcome	Intervention	Control	Crude OR [95% CI], p-value
% (No.) Inpt. Attendings Aware	76% (106/139)	38% (52/136)	5.19 [3.08, 8.74], p<0.0001
Hospitalist	80% (76/95)	36% (31/86)	7.10 [3.64,13.8], p<0.0001
Non-Hospitalists[¥]	72% (28/39)	43% (20/47)	3.44 [1.39, 8.50], p=0.007

[¥]Traditional internists, cardiologists, other subspecialists

Table 5. Secondary outcome(s)
Awareness of Any TPAD Result(s) by PCP

Secondary Outcomes	Intervention	Control	Crude OR [95% CI], p-value
% (No.) PCPs Aware	57% (39/69)	33% (27/83)	2.70 [1.39, 5.22], p=0.003
Network PCP	65% (35/54)	33% (24/73)	3.76 [1.79, 7.90], p=0.0004
Non-network PCP	18% (2/11)	29% (2/7)	0.56 [0.06, 5.24], p=0.61

Awareness of Actionable TPAD Result(s)

% (No.) Inpt Attendings Aware	59% (16/27)	29% (8/28)	3.64 [1.18, 11.18], p=0.02
% (No.) PCPs Aware	65% (13/20)	48% (13/27)	2.00 [0.61, 6.57], p=0.25

For patients assigned to the intervention, the majority of inpatient attendings (89%) and PCPs (70%) were satisfied with receiving automated email notifications to manage TPAD results. For patients assigned to usual care, the majority of inpatient attendings (72%) and PCPs (68%) were dissatisfied with their "standard" system of managing TPAD results. Selected comments from physician surveys are listed in Table 7.

Table 6. Satisfaction with system of managing TPAD results by treatment arm

Physician Satisfaction with Automated Email Notifications (Intervention)

Satisfaction Measures	Satisfied	Neutral	Dissatisfied
% (No.) Inpatient Attendings	89% (118)	4% (5)	7% (10)
Hospitalist	93% (88)	2% (2)	5% (5)
Non-Hospitalists¥	79% (30)	8% (3)	13% (5)
% (No.) PCPs	70% (43)	19% (12)	11% (7)
Network PCP	81% (43)	11% (6)	8% (4)
Non-network PCP (did not receive intervention)	-	67% (6)	33% (3)

Physician Satisfaction with "Standard" System (Usual Care—no automated email notifications)

% (No.) Inpatient Attendings	11% (15)	17% (23)	72% (95)
Hospitalist	7% (6)	16% (14)	77% (66)
Non-Hospitalists¥	19% (9)	19% (9)	62% (29)
% (No.) PCPs	17% (14)	15% (12)	68% (54)
Network PCP	15% (11)	16% (12)	69% (50)
Non-Network PCP	42% (3)	-	58% (4)

¥Traditional internists, cardiologists, other subspecialists

Table 7. Selected comments reported in surveys to intervention physicians

Selected Comments from Intervention Physicians
"I find this extremely useful, knowing the final results of tests, both test results that are positive as well as negative."
"Was unaware of this test even being ordered had it not been for auto-notification, would never have known about test or result. No call to PCP as test is in normal range and will not affect management."
"The concept is great. All the notifications I have received are for negative results. Might be more worthwhile for blood tests if it was only for abnormal results."
"Test was not needed and was not ordered by me."
"It is best to send these pathology results not just to the ordering physician but also the GI physician performing the biopsy."

Principal Findings

1. Awareness of TPAD results was significantly greater in the intervention arm for both inpatient attendings and PCPs.

2. Awareness of actionable TPAD results was significantly greater in the intervention arm for inpatient attendings.

3. The majority of inpatient attendings and PCPs assigned to usual care reported dissatisfaction with their current system of managing TPAD results.

4. The majority of inpatient attendings and PCPs assigned to the intervention were satisfied with automated email notifications of TPAD results.

Discussion

Most hospitals do not have a reliable system for managing TPAD results. Currently, most providers rely on documentation in the discharge summary, direct communication with the PCP (verbal or electronic correspondence), or other individual approaches. Many of these ad hoc systems are faulty for a variety of reasons, predominately because they are not failsafe. Conversely, even those healthcare systems with integrated EMRs that can place results of TPADs in the 'inbox' of designated inpatient and outpatient providers have their limitations because they do not highlight these particular tests as having increased potential for 'falling through the cracks,' do not clearly assign responsibility to a single physician the instant TPAD results are finalized, and do not give physicians a facile mechanism for communicating clinical context (including additional actions to be taken) to the provider who subsequently cares for the patient.

We designed and developed an automated email notification system that identifies and highlights the results of TPADs by alerting the responsible physician as results are finalized during a patient's transition from the inpatient to ambulatory setting. Key design features of our

system include: 1) use of electronic events which precisely and reliably capture discharge time (or a clinical status change from the inpatient to ambulatory setting) to accurately identify TPADs; 2) processes to accurately and reliably identify the responsible inpatient attending and PCP; 3) clear assignment of responsibility for TPAD results to one provider; 4) logic and configurable rules to reduce the volume of notifications to minimize risk of alert fatigue, which could be manipulated 'on-the-fly' for different physicians, services, and test types; 5) direct communication of patient identifying information as well as the test results and normal ranges within the email; and 6) language that facilitates communication between inpatient and ambulatory providers regarding clinical context, interpretation of the TPAD results, possible follow-up actions, and transfer of responsibility for these actions.

In an 8-month clustered randomized-control trial we evaluated the impact of our notification system on physician awareness of any TPAD results for patients discharged from the inpatient medicine and cardiology services at BWH. We determined that our automated email notification strategy nearly doubled the rate of awareness of TPAD results by both inpatient attendings and PCPs caring for these patients. For PCPs, this finding was observed only for network PCPs receiving email notifications, but the number of patients with non-network PCPs enrolled in our study on whom we received a completed survey was small despite our attempt at enhancing enrollment by automating randomization midway during the study period. Finally, we observed a significant increase in awareness of *actionabl*e TPAD results as determined by the surveyed physician. We attribute our findings to the prompt and timely delivery of TPAD results to the identified responsible providers involved in the patient's transition from the inpatient to ambulatory setting as this was specifically facilitated by our automated email notification system – all network physicians in both study arms had access to patients' TPAD results available within the clinical data repository, as well as the discharge summary (emailed to inpatient attendings and network PCPs within 48 hours of discharge and available within our EMR). Non-network PCPs are mailed or faxed a copy of the discharge summary within 48 hours of discharge.

Inpatient attending and PCPs in the usual care arm both reported a high rate of dissatisfaction with their usual "standard" system of managing TPAD results. Physicians typically rely on discharge documentation, reminder systems (i.e., creating individual tasks for every patient with TPADs), other ad hoc systems, or memory. As mentioned above, these "standard" systems are faulty for a variety of reasons, but mainly because they are not reliable.

Inpatient attendings and network PCPs in the intervention arm both reported a high rate of satisfaction with the strategy of receiving automated email notifications of TPAD results. We attribute this finding to physicians not having to rely on their usual "standard" system of managing TPAD results – in other words, they did not have to actively remember or create a specific task to track TPAD results when discharging patients. Nonetheless, there was variability with regard to the type of results they wished to receive (abnormal results vs. both normal and abnormal results) and to whom results should be sent (e.g., consultants). Comments from survey respondents suggest that, although physicians value the system, they desire some degree of influence over which results they receive.

Although this strategy should facilitate acknowledgement by virtue of clearly delineating lines of responsibility in the language and construct of emails (e.g., emails containing finalized results are addressed to the responsible inpatient attending and a carbon copy is sent to the PCP), we were not able to prove this hypothesis definitively. Specifically, we were not able to incorporate electronic acknowledgement functionality (i.e., read receipts) into our notification

emails due to limitations of our technology. Nevertheless, in intervention surveys, inpatient attendings comment and/or suggest that email notifications prompt subsequent communication to PCPs on certain TPAD results.

Conclusions

Automated email notification is an effective strategy for managing results of TPADs and is compatible with inpatient and ambulatory provider workflow in healthcare systems that use secure, network email for clinical communication between providers. Specifically, we demonstrated that this strategy significantly improves awareness of TPAD results by both responsible providers involved in a patient's transition from the inpatient to ambulatory settings, and is associated with overall improved satisfaction for managing TPAD results.

The intervention did not have an effect on awareness of TPAD results by non-network PCPs who by definition did not receive an email notification. While this result may have been due to small sample size, the results suggest that inpatient attendings did not contact these providers by phone with the TPAD results. Further work is required to design a system to notify non-networks providers reliably, perhaps by giving them access to select portions of the network EMR and/or notifying them directly via secure messaging services requiring user authentication.

Significance

Automated email notification is a promising strategy to improve awareness of TPAD results by inpatient and ambulatory physicians involved in a patient's transition post-hospital discharge, thereby mitigating an important patient safety concern. This strategy is practical for any healthcare network that uses secure email for clinical communication between providers, assuming accurate identification of providers involved in a patient's transition, and reliable capture of electronic triggering events (i.e., discharge time stamp).

Implications

Based on the promising findings of this study, we plan to operationalize this system at our institution, and eventually within our entire healthcare network. Additional studies are needed to assess the impact of this strategy on acknowledgement, downstream actions taken post-discharge, relative effect on network versus non-network PCPs, readmissions, and/or post-discharge health-utilization. With regard to the latter, because the intervention enhances awareness of TPAD results, it may prompt physicians to arrange more expedited follow-up, refer patients for consultation, or readmit patients with certain concerning findings. In fact, we observed that more intervention patients were readmitted within 30-days of discharge (Table 1). Finally, other HIT interventions or enhancements may be necessary to enhance communication with non-network PCPs (as described above) – an initial first step could be to improve the process of identifying non-network PCPs, and reliably providing their contact information to inpatient attendings.

Future research should also evaluate effectiveness for other clinical services, hospitals, healthcare networks, and EMR platforms. With regard to vendor-based EMR platforms, although we developed our notification system within a proprietary EMR, the strategy of highlighting and automating notification of TPAD results can be incorporated into any EMR. In fact, as our

healthcare network transitions to a new, vendor-based EMR (Epic Systems, Inc), we will need to integrate our strategy into this framework. Our experience in successfully doing this will have important implications for many other healthcare institutions and networks that have or will be adopting vendor-based EMRs.

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List of Publications and Products

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